INRTERACTIONS BETWEEN FARM EFFLUENT APPLICATION METHODS, TILLAGE PRACTICES AND SOIL NUTRIENTS

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ABSTRACT

Land disposal of liquid effluent has benefits for the environment and is economically viable. Firstly, it can reduce nutrient levels from wastes polluting waterways. Secondly, the land application of effluent has been the most common treatment method because it can provide some necessary nutrients for plant growth. In New Zealand, land application of farm liquid effluent is a common method for disposing agricultural wastes. However, there is little comparative information about nutrient recycling in soils treated with effluent using surface application or subsurface injection.

A field trial was conducted to examine the effect of tillage on the transformation of nutrient added through dairyshed effluent. Liquid effluent was either injected at 10 cm depth or broadcast on the surface at the Massey University long-term tillage experiments which include permanent pasture, and crops sown with no-till and conventional tillage as main treatments. In the first experiment, raw dairyshed liquid effluent was applied in August 1997 at the rate of 120 m^3 ha^{-1} (30 kg N ha^{-1} equivalent). This was considered as a low rate of application. In the second experiment starting in December 1997, the application was at the rate of 600 m^3 ha^{-1} (150 kg N ha^{-1}). At this rate, although the hydraulic loading was considered as a high rate, the nutrient loading was considered optimum.

Soil samples were collected before application, after one week, one month, and two months of application, at two depths: 0-10 cm and 10-20 cm and the samples were analysed for total N, total P, NO_3^-, NH_4^+, exchangeable K, available Olsen-P. Throughout the experiments, interactions between nutrient status, methods of application and different tillage practices were analysed. In the case of injection method, soil samples were taken both in the centre of the injected row and 10cm horizontally away from the centre of row.

At the low rate of application (first experiment), soil nitrogen and phosphorus status did not change significantly for up to two months after application. Soil ammonium concentration reduced immediately after one week then reduced slowly. Nitrate concentration reduced slowly during the first month and significantly reduced during the second month after application. Exchangeable K and Olsen-P were not significantly different among treatments.

At the high rate of application (second experiment), levels of soil nitrogen and phosphorus reduced slightly after two months of application. Nitrate concentration in the soil increased in the first month, but steadily reduced during the second month. On the other hand, ammonium concentration reduced gradually over a period of two months. Ammonium in injected plots was higher than that in the broadcast plots. Pasture retained more ammonium concentration compared with no-till and conventional tillage plots. Moreover, nitrate content in the injection plots was similar to that in the broadcast. This may be related to low rainfall during the experiment period that may have restricted the denitrification and reduced nitrate losses through leaching.

Generally, there was higher content of exchangeable K and available P in soil which resulted from effluent application. Method of effluent application had no effects on K and P concentrations.

Overall, there was an increase in nutrients in soil after application of liquid effluent, especially at the topsoil. There was a greater retention of nutrients in no-till soil than the conventionally tilled soil. Subsoil injection of effluent allowed higher level of nutrient retention than the surface broadcast method. This may be due to reduced nitrogen losses caused by volatilization of ammonium.

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Chapter 1

GENERAL INTRODUCTION

1. 1 Introduction

Land degradation has become a major global concern in recent years as a result of increasing demand on the land for food production and waste disposal. Moreover, the resilience of soil is finite and the degradation is not easily reserved Soil erosion represents the most complete form of land degradation. Chemical contamination of soil from excessive or improper application of fertilizers and land disposal of waste is also a serious issue.

In many parts of the world, land application of organic waste is becoming more widespread as regulatory authorities move to protect water quality by restricting waste disposal into rivers, lake and the marine environment.

For centuries, the use of farm manure has been synonymous with a successful and stable agriculture. Not only does it supply organic matter and plant nutrient to the soil but it also associates with animal agriculture and with forage crops, which generally protect and conserve soil. Moreover, the use of inorganic fertilizer alone will not always ensure adequate sustainable agricultural production levels and that land application of waste will be a necessity (Obi and Ebo, 1995).

The nutrient content in manure and slurry is highly variable. The availability of these nutrients to plants is also an important consideration and is related to crop type, soil type, timing of application, interactions with organic fertilizers, losses during storage and following application, methods of application, seasonal effects, and site management. Moreover, manure and slurry can provide other benefits including improvement in soil moisture availability, soil organic matter content and soil structure. There are two methods of application of manure and effluent in practice: broadcast and injection.

Soil injection of liquid effluent not only eliminates the ordor and the visual problems associated with surface spreading, but can also control surface runoff, pathogen transfer with potential benefits of soil loosening and improves nutrient management through the control of ammonia volatilization (Warner et al., 1988; Choudhary and Baker, 1994)

Population of farm animal in New Zealand is about 8 million cattle and 55 million sheep in 1991 (Statistic New Zealand, 1991). The waste generated from the agricultural production and processing industries sector is about 550,000 tonnes day^{-1} (CAE, 1992). This waste contains a considerable amount of nitrogen and other key nutrients for plant growth. The New Zealand Resource Management Act, (1991) encourages farmers to dispose farm effluent through land application. Land application of sewage is also being adopted in order to meet Maori cultural values that require human waste to be returned to the land rather than be allowed to pollute natural water resources (Cameron et al., 1996).

Agriculture has traditionally relied on the conventional cultivation practices to prepare soil for growing crop. Continuation of this system has resulted in serious problems of soil structure degradation and loss of crop productivity. Moreover, traditional agricultural tillage practices can cause water as well as air pollution.

Nowadays, conservation tillage practices, especially no-till, are considered desirable methods for crop establishment because they have certain advantages in enhancing soil physical, chemical and biological properties suitable for better crop production. Especially, conservation tillage can reduce the risk of soil erosion by rain or wind.

Limited information exits on the use of dairy effluent in tillage systems in cropped land, particularly when crops are grown by various tillage methods. Therefore, there is a need to investigate the effects of these tillage and cropping systems on effluent disposal and interactions with nutrient recycling.

The soil is a living filter in terms of its ability to physically, chemically and biologically treat applied effluent. The soil can physically treat effluent by filtering suspended solids, and chemically treat effluent by retaining nutrients. Biological treatment is by the action of soil micro-organisms which break down suspended solids and organic materials, and along with plants, remove inorganic nutrient (e.g. ammonium, nitrate) as part of their own requirement.

If effluent is applied correctly, it can provide fertilizer value to pasture and cropping plants. The optimum rate of application can avoid surface runoff as well as surface sealing by effluent solid. Land based application system must be considered in terms of their hydraulic and nutrient loading environment. For example, Environment Waikato (1994) demands that, nitrogen loading rate should be determined according to the following.

I. The requirement to have a nitrate concentration which meet the New Zealand drinking water standard of 50 g NO_3 per cubic metre in the site drainage water which is discharged to the receiving environment;

I. The nitrogen removal by crop uptake (either agricultural or forest);

II. The nitrogen removal by denitrification;

III. The dilution afforded by ground water before the flows enter the receiving environment, and other factors such as the form of nitrogen in the applied wastewater and seasonal changes in crop uptake rates.

Therefore, every method of effluent application must follow the rules set down by the Regional Councils. The discharge of dairy effluent to land has been categorised as a controlled activity provided that ponding, runoff and excessive leaching do not occur.

1.2 Research objective

In New Zealand, over 95% of crop establishment had been done by conventional tillage systems. Conservation tillage has a potential to increase (or at least maintain) crop yield, reduce soil and water runoff relative to conventional tillage. Also, it allows the retention of surface residues, reduces soil erosion, improves soil structure, enhances soil moisture retention, increases organic matter and nutrient levels and improves environmental quality and agricultural sustainability. This method has been widely used in North and South America and Australia. The effects of conservation tillage on soil nutrient status were well understood.

Implementation of Resource Management Act (1991) encourages farmers to dispose farm effluent through land application. However, the research about interaction of tillage systems with the application of effluent was limited. With the above background, this study was intended to evaluate the effect of tillage systems on transformation of nutrient added through the effluent application.

Specific objectives

1. To compare the effectiveness of effluent disposal with subsoil injection and surface broadcast method at high rate and low rate of application in a silt loam soil.
2. To determine the effects of effluent application on soil nutrient status that includes: total N, NH_4^+, NO_3^-, total P, Olsen P and exchangeable K.
3. To determine the effects of conventional tillage, no-tillage and permanent pasture on effluent-derived nutrient distribution in soil.
4. To recommend suitable management for applied agricultural waste on soils.

Chapter 2
LITERATURE REVIEW

Introduction

In recent years, agriculture has depended heavily upon inorganic fertilisers as primary sources of nutrients for crop production. Farmers had learned the values of organic manure and other residues in enhancing crop production centuries before scientists discovered that specific chemical elements were essential for plant growth. These organic materials are still a primary source of mineral elements, particularly among the resource-poor farmers of the developing countries. High energy costs have led to higher inorganic fertiliser prices, forcing more countries to reconsider farm waste as a source of plant nutrients.

World population growth, increasing food demand and changing of social patterns have dictated the introduction of intensive agricultural practices. The possibility that nitrogenous residues from intensive fertiliser use or animal waste disposal practices contribute to the growing problems of eutrophication of inland waters or rising nitrate concentrations in certain potable water supplies has attracted attention at international level. Another aspect of importance to developing countries is that downward leaching of soil nitrogen also implies an irreversible loss of valuable crop fertiliser. The excessive nitrate ingestion by mammals is undesirable because of possible metabolic conversion to nitrites that can cause methaemoglobinaemia especially in infants and in the presence of high amine diets or amine-derived drugs, possible hepatoxic action and formation of alkyl nitrosamines which have carcinogenic properties (Bolan, 1996).

In New Zealand, cultivation of soil under arable cropping (in a mixed cropping rotation) enhances the conversion of organic nitrogen to inorganic nitrate through the nitrification process. Nitrate being weakly retained on the soil particles, the build up in nitrate in the soil after cultivation is likely to contaminate ground water through nitrate leaching. This indicates that soil cultivation is likely to have major influence on the transformation of nitrogen and its subsequent movement in the soils.

In New Zealand, liquid effluent application on grassland is a common method to dispose waste. This method has benefits such as increasing grass yield and reducing nutrient discharging to waterway. However, only limited information is available relating to the effects of farm liquid effluent applied on cropped soil as well as on specific plants.

2. 1. Waste effluent in New Zealand

2. 1. 1 Industrial waste effluent

Effluent from industrial activities includes effluents generated in any process of industry manufacturing, trade or business and mining activities. New Zealand generated about 300000 tonnes of industrial waste annually in the late 1980's. This kind of effluent contains valuable nutrients such as N and P. However, their application on land may be limited by the presence of toxic metals, toxic organic and excessive concentrations of salt or extreme pH (Youwei, 1997). Because the chemical composition not only varies between the various wastes stream but also varies with treatment of the individual waste stream, it is difficult to apply these effluents as a source of fertilizer. Table 2.1 shows the composition of sludge or effluents from some industrial sources.

2. 1. 2 Municipal sewage effluent

Sewage effluents are major urban waste, which are produced in the treatment of domestic and industrial wastewater and sewage. Sewage sludge is the solid material obtained from the sewage treatment including contaminant from wastewater stream. The quality of treated urban sewage effluent depends on the nature of the sewage/waste streams supplied to the treatment work and the type of treatment carried out (McLaren and Smith, 1996). Annually, approximately 52000 tonnes of dry sludge are produced in New Zealand (New Zealand Department of Health 1992).

Table 2.1: Composition of sludge or effluent from a few selected waste source in New Zealand.

Parameter	Milk powder/ Butter factory^{A}	Meat processing secondary effluent^{A}	Tannery secondary effluent^{A}	Pulp and paper secondary sludges^{B}	Dairyshed effluent^{A}	Piggery effluent^{A}
Suspended Solids	----	20-100	120	-----	-----	-----
BOD_5	1500	20-100	30	-----	-----	-----
COD	------	80-400	410	-----	-----	-----
pH	10-12	-----	7.6	-----	-----	-----
Total N	70	40-200	130	32000	190	1300
Total P	35	5-30	1.6	8075	30	600
Fat	400	0-30	----	----	----	-----
Sodium	560	2700	2700	4586	50	-----
Potassium	13	----	----	2905	220	500
Calcium	8	340	340	17000	110	-----
Magnesium	1	36	36	2000	30	-----

^{A} in g m^{-3} except pH; ^{B} in mg kg^{-1} dry weight basis; ---- Not determined

Source: Hart and Speir (1992) and Carnus (1994)

2. 1. 3 Dairyshed effluent

The agricultural sector is a major part of the New Zealand economy. Farming in New Zealand occupied about 17.5 million hectares, equivalent to about 64% of the total land area (Statistics New Zealand, 1991). Beef and dairy cattle produce excreta (dung and urine)-a useful source of nutrients. With pig, the quantity of waste produced depends on several factors which makes it difficult to state an average; a cow might have weighed three times as much as a pig, yet produces about the same quantity of waste (Abbas, 1993).

Organic waste from farms is now the major source of pollution in New Zealand (Vanderholm, 1984). The amount of waste production depends on herd sizes, herd management practices, milking time, and washing practices. Due to increasing herd size, the number of dairy cows in New Zealand is increasing annually. From 2.31million cows milked in New Zealand in the 1989/90 season, it increased to 2.83 million cows in the 93/94 season (Dairy Statistics, 94/95). Table 2.2 estimated waste produced on New Zealand farms in 1987.

Table 2. 2 Estimated volume of waste produced on New Zealand farm

Animal waste	Volume of liquid effluent (*1000 tonnes day^{-1})
Dairy and beef cows	360
Pig	27
Goat and sheep	96

Source: Abbas, 1993

Dairy farming is an important facet of agriculture in New Zealand. Especially milk production is largely seasonal and extends from August to May each year for about 280 days. The dairy shed effluent is made of animal wastes or wastes produced from washing milk collection equipment. During milking, manure and urine are deposited in holding yards of milking sheds. Variable amounts of particulate (non-faecal) material were also deposited on the floor; most of them were carried on hooves of the animals. It is then cleaned up by water. With a herd of 300-330 cows, estimates of annual volumes and solids generated from milking in New Zealand are given in Table 2.3 (Macgregor et al., 1979)

Table 2. 3 Estimation of annual effluent production on an average sized of dairy farm in New Zealand

Component	Range
Volume of waste	9,000 to 10,000 m^3
Total solids	47-52 tonnes
Nitrogen	1800-2000 kg
Phosphorus	200-220 kg

Manure is a by-product of livestock production, and the properties of manure are greatly influenced by many factors such as species of livestock and method of manure handling, storage and treatment.

2. 2 Farm effluent and its effects on soil and environment

2. 2. 1 Physical effect

Waste, either solid or liquid, is a potential pollutant. Flies are nuisance in and around waste treatment facilities on farms or factories (Abbas, 1993). Effluent can change quality of waterway by changing colour, turbility or temperature (Ellwood, 1997). Loehr (1974) stated that effluent which had a yellow to brown colour may cause colour problems for downstream users. He also reported that dust resulted from feed, bedding, manures and living stock in animal production was a health hazard. Furthermore, it affects the aquatic life by reducing light penetration, affecting plant and algae photosynthesis.

2. 2. 2 Biological effects

With high nutrient in farm liquid effluent discharged in waterways, bacteria and fungi can develop very fast causing reduction in oxygen levels in water which is available for aquatic life such as fishes. When nutrients exceed the normal level, platonic alga blooms will develop. This causes discoloration of the water and reduces light penetration to plants in the water (Ellwood, 1997).

Liquid effluent contains a wide variety of pathogenic microorganisms, including bacteria, virus, protozoa helminths. If farm effluent is applied on soil, there may be a risk of disease transfer by microorganism survival on crops as well as humans.

2. 2. 3 Chemical effects

Since dairyshed include, carbon (C) bearing materials and supply nutrient (N, P and K) to soil, it can provide significant amount of nutrients for plant uptake. However, aquatic plant and animal can be affected by chemical such as pharmaceuticals and cleaning agents. Also, effluent contains some heavy metals, which can be uptaken by plants and animals causing undesirable effects for human health. High concentration of heavy metals can be phytoxic and may result in reduced plant growth and/or enhanced metal concentrations in plants, especially when the application of effluent is repeated annually.

2. 2. 4 Social and health effects

A report from the Ministry for the Environment has concluded that the quality of lowland rivers and lakes has been reduced by agricultural runoff. This was caused by increased quantities of nutrient (nitrogen and phosphorus) entering surface water from farmland and the sediment and faecal contamination from agriculture (Ministry for the Environment, 1994). When nitrate is converted into nitrite ion, it becomes toxic resulting in blue baby syndrome and stomach cancer (Hayners, 1995). Also, odour and disease can affect people around storage areas. Thus, some countries abandon the application of farm effluent on the soil surface.

2. 3 Effects of effluent application on grassland and fodder crops

Animal slurry is a mixture of faeces and urine, plus smaller amounts of other organic material such as wasted feed and bedding with varying amounts of water from various sources depending on conditions of collection. McCalla et al. (1977) suggested that the organic fraction of animal waste consists of mainly proteins that have resisted animal digestion and are more or less combined with lignin or lignin-like substances, and dead and living microbial cell from the intestinal tract.

The relative amounts of these two fractions are not known and may be expected to vary with the age and diet of the animal and possibly with storage. Usually, only about half of the N is present as ammonium, other inorganic forms generally are absent (Flowers, 1983). Nitrogen immobilisation and losses by denitrification may be encouraged by the presence of large amounts of ready-decomposible organic matter in the slurry.

The application of liquid effluent onto soil has been shown to increase the most important heterotrophic soil microorganisms (aerobic bacteria, actinomycetes, yeasts, hyphal fungi), the mineralization processes (respiration, ammonification) and biological activities (Stadelmann and Furrer, 1983)

The surface application of liquid effluent in wet soil will enhance the denitrification process because it is rich in organic carbon and is easily available for soil microorganisms and used as electron acceptor in the denitrification process by denitrification bacteria (Chaussod, 1983). Also, numbers of viable bacteria and presumptive coliforms are followed by increases in numbers of protozoa and nematodes (Opperman et al.,1989). The application of liquid effluent in soil will increase microflora growth, especially bacteria, depending on the amount of supplied sludge. Chae and Tabatabai (1986) reported that there was little mineralisation during the initial period of incubation (up to 4 weeks) of effluent with soil which increased markedly within 4-8 weeks and constantly released during the 12-24 weeks.

The addition of liquid manure into soil provides an abundant supply of organic N and a ready oxidizable C source. Water in slurry produces an anaerobic zone in soil. Because denitrification is mainly affected by aeration status, availability of C and NO_3^-, the NO_3^- created from NH_3, and the water content from effluent, effluent application to soil will create a suitable environment for denitrification process. Also, there is a rapid process of nitrification due to the presence of NH_4^+, O_2, CO_2, pH. In Chae and Tabatabai (1986) experiment, even 99 days after injection, water content in injection zone was still higher than that in the surrounding soil. In the first period of time, high water content was due to the application of liquid effluent. In the second period, the physical characteristic of the slurry was the reason for the increase of high water content. The fine, sponge-like fibrous material provided a higher water holding capacity than the surrounding soil.

The effluent application rates to agricultural lands should be such that the nutrient requirement is (e.g., nitrogen and phosphorus) met entirely, or in part of the needs of the crop. However, in addition to valuable plant nutrients, sludge containing a variety of organic and inorganic trace elements constitutes potential harm to plants and consumers. As examples, Cu, Ni, Zn and Cd are harmful to plants at relatively low concentrations, particularly plants grown on acid soils. Cadmium is of even greater concern because of its harmful effects on plants, animals and man. Toxic trace organics (e.g. polichlorobiphenyls, or PCBs) likewise may find their way into crops and subsequently through the food chain to humans. Consequently, disposal/recycling of municipal sewage sludge on agricultural lands must be carried out in a way which provides a beneficial use to the crop without developing pollution problems associated with the accumulation of trace constituents in soils.

2. 4 Effluent treatment systems

2. 4. 1 Ponds

In New Zealand, pond systems are a popular method to treat dairyshed waste. They include an anaerobic pond followed by facultative (or aerobic) pond. Hickey et al. (1992) estimated that approximately half of the 14,000 dairysheds in New Zealand used pond system to treat effluent. After being treated, liquid was discharged to streams. However, the level of treatment provided by pond system is now inadequate to safeguard the quality of many New Zealand streams and rivers. This is caused by overloading and increasing awareness of the possible adverse effects of nutrients on aquatic environment.

2. 4. 2 Alternative treatment method

Some options mentioned below have good potential for treating effluent because they have low level of complexity, application on small scale and low operation cost. These include:

1. Upgrading of present pond systems by adding a constructed wetland. This method is a simple, natural treatment system because of low construction cost and low maintenance cost.
2. Rotating biological contractors as alternative to ponds.
3. Using natural New Zealand zeolites to remove ammonium-nitrogen and phosphate-phosphorus from wastewate, or using bark filter systems for the removal of nutrients from dairy shed effluent.

2. 4. 3 Sequencing bath reactor

This method is an activated sludge process which is operated on a fill and draw sequence including commonly used fill, react (aerobic and anoxic), settle and decant treated effluent method. However, this method has not been extensively used because it needs a high level of operator skill and finance for maintenance.

2. 4. 4 Land application

Land application is a major method that is increasingly used for disposal of effluent. Land treatment permits the management and conservation of nitrogen on farms because it enables nitrogen to be recycled and reused. The adding of organic matter to soil can improve soil structure, increase the carbon/nitrogen ratio, which will increase soil moisture and nutrient retention capacity (Darkers and Kidd, 1984; Dewi, 1994).

Land treatment is defined as the controlled application of wastes to the land surface to achieve a specified degree of treatment through natural physical, chemical and biological processes within plant-soil water matrix. Land treatment systems are less energy-intensive than conventional systems such as activated sludge, trickling filters, and aerated lagoons. In land treatment, energy is needed for transportation and application of wastewater to the land. In contrast, in conventional treatment systems, energy is needed for transportation of wastewater, mixing and aeration of wastewater and sludge, and transportation of digested sludge. Moreover, land treatment requires less mechanical equipment compared with other conventional treatment processes. In addition, the land treatment system is easy to maintain and the capital cost is not high. However, selection and suitability of land treatment systems depend on soil condition, land area, and climate (Chongrak, 1989).

2. 5 Effluent as a source of nutrients

The oldest agricultural cropping system, shifting cultivation, did not depend on animal manures for crop production. In recent time, cropping systems were developed by which the supply of nutrients to arable land was generally increased by the use of animal manures. Nowadays, the value of mineral fertiliser has been proven. However, farm effluents have an intrinsic value because these have plant nutrients, other chemical constituents, water, and organic matter. With new methods of storage and application of liquid effluent the efficiency of N, P, and K is increased resulting in a higher N efficiency. For example, during increased length of storage most of the organic compounds are transformed into easily decomposable substances, or are mineralized completely (Dijk and Sturm, 1983). Therefore, farm liquid animal manure is still a valued fertiliser around the world.

Because effluent has high levels of organic matter, this helps decrease run off and sediment losses. Moreover, effluent can improve soil aggregate stability, thus it will protect soil against erosion losses (Kelling et al., 1977; Metzger and Yaron, 1987). Mbagwu and Piccolo (1990) stated that the addition of pig and cattle slurry to a sandy loam soil increased soil aggregate stability by 26% and thereby reduced the direct runoff problems.

Table 2.4 shows the typical dry matter and nutrient content of farmyard manure and slurry. These data show that the composition of manures is highly variable and depends on a number of factors such as the species and the size of the animals. In fact, these value also depends on nature of feed consumed, and the nature and amount of bedding, as well as the type of housing or confinement of the animals.

Each year, New Zealand farmers spend about $24 millions on buying fertiliser (Martyn, 1994). From a management point of view, fertilisers are easy to use. However, New Zealand has large volume of animal slurry available on dairy farms, which has significant nutrient values of fertiliser. The question arises why New Zealand has to consume a high amount of chemical fertiliser every year while they have the potential of fertiliser through effluent. If the use of dairyshed effluent is efficient, farmers can save large sum of money for themselves. Farmers do not use dairyshed effluent as a source of fertiliser because of the following constraints.

Table 2.4 Dry matter and nutrient contents of farmyard manure and slurry in the UK and USA

	DM (%)	Nitrogen(N) (kg $tonnes^{-1}$)	Phosphate (P_2O_5) (kg $tonnes^{-1}$)	Potash (K_2O) (kg $tonnes^{-1}$)
Farmyard manure				
Cattle	20-50	4-9	1-18	4-12
Pig	25	5-6	1-6	4
Poultry	68-75	17-42	18-28	13-19
Sheep	35-44	10-14	2-3	1-10
Slurry				
Cattle	1-18	2-18	1-12	2-15
Pigs	1-18	1-16	1-12	2-9
Poultry	25-46	13-17	4-21	3-15

Source: Summary of data from USA and UK sources by Dewi (1994).

It is difficult to apply the correct quantity of N, as in the form of effluent as inorganic fertiliser, because of handling and application problems. Large amount of nitrogen can be lost by the ammonium volatilisation at the time of application. In effluent, ammonium is available immediately after application, and organic N, which is only available after mineralization is variable and difficult to quantify (Powlson et al., 1989).

Sludge nutrient, unlike those in commercial fertilisers, do not provide a balanced nutrition compatible with crop requirements. Thus, applying liquid effluent based on nitrogen content may result in too much or too little of other elements. For example, when liquid effluent is applied as a nitrogen source, the phosphorus applied may exceed crop needs. Because phosphorus is an important contributor to the eutrophication of lakes and streams, in some situations, application rates could be based on the phosphorus requirement of crops, and not based on the nitrogen requirernents. Moreover, nutrient contents in effluent, vary widely depending on season, method of storage and time of application during the year. Thus at every time of application, there is a need to analyse the nutrient content in effluent. In contrast, when applying chemical this is not needed.

Excreta from housed farm animals, when mixed with water produces a slurry that is usually used as an organic fertiliser on arable or pasture land. Heavy applications of this wet, highly organic material may markedly change nitrogen cycle in the soil particularly by inducing extensive anaerobic conditions. Nitrification of the ammonium contained in the slurry may be delayed, and the soluble organic materials may induce denitrification.

The significance of denitrification in agriculture is that this process may be a major route whereby fertiliser or organic waste nitrogen is lost from the soil, diminishing the availability of inorganic nitrogen to plants. In the context of slurry disposal on land, encouragement of denitrification may provide a mechanism whereby nitrate concentration of water draining through soil into streams and aquifers is diminished. The application of slurry may reduce crop yield between 4-12% compared with fertilizer in winter wheat (Tramper, 1996). Also other studies have reported that the amount of total organic nitrogen leached was higher in the field applied with animal slurry compared with that in fields with inorganic applied by fertilizer.

It has often been shown that slurry addition markedly decreases oxygen content of gaseous phase in the soil at all the soil profile depths examined during twelve months following its application (Burford, 1976; Burford et al., 1976; Thijell and Borford, 1975). Below the applied slurry layer, the oxygen concentration at 10cm depth decreased to less than 10% within a few days of the application, and these levels remained in the following four months. With drying of the soil in summer the oxygen concentrations gradually increased to 19%. Nitrous oxide was found in the atmosphere of the slurry treated soil for a short period immediately after application, and then evolution recommenced in two months.

Large gaseous losses of nitrogen by ammonia volatilization can occur from cattle slurry applied to agricultural land (Smith and Beauchamp 1976; Beauchamp et al., 1983, Pain et al.,1989). The addition of organic material to soil can promote conditions conducive to denitrification. This is because the slurry application can increase the soluble carbon contents and create anaerobic conditions. These authors also reported more denitrification when effluent was injected than surface spread.

2. 6 Methods of effluent application

2. 6. 1 Broadcast method

2. 6. 1. 1 Benefits of broadcast

Broadcast is a common and effective method of application because of its following advantages (Abbas, 1993)

a. Application of liquid waste to land at proper rate and in combination with mineral fertilisers tends to increase dry matter yield of crops.
b. Liquid waste could easily replace farmyard manure and composted materials, particularly if it is used in combination with the retention of surface straw and might increase the yields.
c. The fertiliser effectiveness of liquid waste/manure has been found to be higher for fodder crops than for cereals.
d. Increase the physical-chemical properties of the soil and enhance the soil nutrient availability.

Following are selected types of broadcast methods currently in practice.

2. 6. 1. 2 Spray irrigation

Spray irrigation is considered appropriate for the majority of New Zealand pastoral soil types during low rainfall season. The system provides reasonably uniform application of effluent. Even in the worst case of effluent irrigation, a substantial amount of Biological oxygen demand (BOD), suspended solid (SS), P, N and bacteria, is filtered by soil (Selvarajah et al., 1993). Effluent irrigation may minimise requirements for effective monitoring. However, strong wind in New Zealand can cause problems. Also odour is a big problem when this method is used. The farm wastes contain large numbers of bacteria, many of which can transmit disease to other animals or humans.

2. 6. 1. 3 Vehicle (Muck Tanker) spreading

Vehicular spreader systems commonly draw the effluent from a storage facility into a mobile tank. The effluent is then sprayed from the rear of the tank onto the land. The truck or the tractor can run up or down the paddock in strips until the application area is covered (Dairying and the Environment 1996). This method is also widely used in New Zealand. However, the weight of the vehicle and spreader can cause significant damage to the pasture and soil. Also the farm wastes contain large numbers of bacteria, many of which can transmit disease to other animals or humans. Similar to spaying, the vehicle spreading of effluent can also contaminate the treated land area.

2. 6. 1. 4 Land flooding (overland flow)

This method involves controlled effluent runoff onto pasture or to land underneath trees. The efficient surface coverage depends on the topography and it requires expensive grading in order to direct the flow. There is a high risk of polluting ground and surface water as poorly designed systems may cause the discharge to be conveyed to a stream.

2. 6. 1. 5 Risks of surface land application

When applying liquid waste onto land, the slurry, which infiltrates into the soil or remains on the surface, has been reported to depend on the nature of the slurry, the type of soil and its moisture content, and the rate of its application. Where the soil was already near field capacity, or where the rate of application of slurry was greater than the infiltration capacity of the soil, the slurry would "pond" on the surface, with the danger of surface runoff taking place. Also there is likely to be a concentration of salts in the root zone, so a balance is needed to be achieved between the salts removed by deep percolation or drainage and the salt added by the application of manures. Moreover, broadcast method can cause damage to plant, taint soil structure, create toxicity to plants and animals, cause parasite and disease transmission, effect soil fauna, and weed infestation. Also, evidence is growing that that ammonia emissions from agricultural are major contributor to forest die-back, and ammonium emission from land spreading of slurries are expected to be one of the major sources of ammonium emissions from agriculture (Phillips et al., 1991). Therefore, many countries have laws forcing farmers to manage and dispose of agricultural wastes safely.

Pagliai and Sequi (1981) stated that water pollution might occur both by the release of toxic substances and nutrients from soil to the water table and the horizontal transport of water over the land surface. In recent times, the potential for the contamination of surface water from disposal sites has greatly increased because application to the soil surface of animal slurries from intensive animal production units has become a common method of water disposal. Runoff is especially hazardous immediately after the application of liquid effluent. It also could be dangerous after slurry dewatering because of transport of slurry solids and soluble nitrogen, phosphorus and metals originating from slurry.

The intensity of runoff is related to several factors. Among them, the crop situation (including tillage systems) is very critical but can be modified by varying cultivation criteria, if necessary. In contrast, landscape and soil slope are properties peculiar to the disposal site, and climate has a geographically broader influence on a whole area or some times on a country.

2. 6. 2. Subsoil injection

Soil injection of liquid manures (particularly liquid effluent) is becoming an increasingly attractive option for both farmers and sludge disposal authorities. Whilst capital running costs tend to be higher compared to surface spreading, the agronomic benefits (reduced ammonia loss, soil loosening, pasture hygiene) and the environmental benefits (control of odour and surface runoff, compliance with regulations) are sufficient to outweigh the disadvantages. Where these benefits are important, these can result in an overall reduction in operating costs (i.e. injection if liquid undigested sludge may be a cheaper option to anaerobic digestion dewatering).

This method involves opening up the soil and forcing effluent below the soil surface. Effluent is supplied by a mobile tank. The advantages of this method include a boost to pasture growth, loose the soil, reduce the rate of nitrogen loss from volatilisation and minimise odour problem. Soil injection is common in Europe with both farmers and regulatory bodies. However, in New Zealand, this method is slowly being introduced as subsurface injection machinery becomes widely available.

With such potential advantages of injection methods, in Western Europe and North America, a number of agricultural engineers have designed and tested liquid injectors for agricultural waste disposal. In the United States, three techniques of incorporating biodegradable wastes into the soil have been established:

I. Plough-Furrow-Cover, in this system, waste was deposited into a 6 to 8 inch (15-20 cm) depth ploughed furrow immediately after deposition, and in the same operation, a plough covers the waste and opens the next furrow,

II. Sub-soil-Injection (this technique has been developed to inject slurries that would flow through a 15 cm-diameter and 60 cm long hose) and,

III. Ride and Furrow (the furrows are made on the contour, or slightly sloping to permit the water to filter into the soil and the aerobic conditions should be maintained in and at the bottom of the furrow (Safely et al. 1980).

IV. In Japan, the equipment used to apply the slurry is power-till type machine, which included a rotary harrow, so the soil clods and slurry are mixed. However, these injectors have generally not been successful in utilising the organic wastes as fertilisers (Hall, 1986).

In U.K., a design with winged tines as soil opener reduced 50% in draft force requirement compared with non-winged tines when placing slurry at 25cm depth. However when burying slurry over 25cm depth, this design adversely affected grass production through excessive pruning of grass roots and through leaching.

Tine design is important in minimising sward damage and this has been discussed by Hall et al. (1986). Warner et al. (1991) showed that on a loam soil 30 cm row spacing of injection with a 3.5 cm wide tine produced a higher yield than at 60 cm spacing with the same tine, or 75 cm spacing with 37.5 cm winged tine. However, on a sandy soil, tine spacing did not affect yields except when 3 passes were made. This is in agreement with the tine spacing trials with a 25 cm winged tine in the UK on a loamy sand. On a clay soil, optimum spacing was found to be 65 cm; the lower yield at 50 cm was due to the increased amount of sward damage (i.e. more tine passes per unit area) although it was found that under wet soil conditions, injection at 50 cm produced the most even growth response.

New Zealand has a large population of animals. However, these animals graze in pasture paddocks throughout the year and the faeces and urine are returned to pasture. Therefore animal faecal waste disposal in New Zealand is not as acute a problem as in Western Europe and North America where animals are housed during winter months. On the other hand, the runoff from these wastes is considered to be a major contributor to water pollution (Choudhary and Baker 1994).

Because of the potential benefit of injection over surface application in reducing nutrient in runoff, there is a need to use such methods for disposal of liquid effluent into soil. However, in New Zealand, injection machines have not been widely used and most of the systems for discharging wastes from dairy farms onto land are spray irrigation. Recognising the benefits of the subsoil injection, Massey University's Institute Technology and Engineering has developed an injector based on a soil opener, which creates an 'inverted-T' shaped slot. This slot shape assistes to safely dispose of slurry at shallow depths (Choudhary et al. 1988). This injector is now commercially available, and has been found to be a satisfactory alternative to broadcast methods.

2. 6. 2. 1 Benefits of subsoil injection

With the growing environmental pressures to avoid possible aerial and water pollution problems from surface spreading sewage sludge and animal slurries on farmland, subsoil injection of liquid effluent has been found favour in recent years. Compared with surface broadcast, applying animal excrement below the soil surface has following advantages:

I. The covered material does not present the unsightly appearance associated with surface spreading.
II. Odours are not emitted, as they are promptly absorbed in the soil, and fly problems associated with odours are eliminated.

III. Runoff is prevented, as the soil can be retained in a condition with a forage crop cover.

IV. The nutrient content is retained in soil for its maximum fertiliser use-efficiency (Kofored, 1981). Injection of slurry, if properly carried out, minimises the risk of nutrient runoff considerably, and at the same time gives a better effect on yield.

Subsoil injection of liquid wastes may allow land previously unutilized for agricultural use, because of proximity to housing, to be used for effluent disposal purpose (Choudhary et al., 1988). Moreover, Tunney and Molly (1986) pointed out that nitrogen efficiency of surface spread slurry is low particularly at high rates of application, and the efficiency is higher when slurry is injected. Water running from surface application sites generally contains higher concentrations of N, P, C and pathologens than water from sites where manures have been incorporated into the soil (Mueller et al. 1984). Vandemeer et al. (1987) reported that the apparent recoveries of N were higher in injected slurry compared with broadcast. These authors also concluded that the losses of N by ammonia volatilisation from surface-spread slurry was approximately 30% of the amount of slurry N applied compared with 11.5% when slurry was injected.

Soil injection of sludge and slurry improves the efficiency of nitrogen utilisation by preventing ammonia volatilisation. Hoff et al. (1981) stated that, the proportion of applied ammonium-N lost as ammonium from pig manure over a 3-5 day was 14.0, 12.2 and 11.2 % of the ammonium N applied in 90, 135 and 180 m^3 ha^{-1} surface spread, respectively. In contrast, only 2.5% were lost when 90 and 180 m^3 ha^{-1} were injected. Thomson and Pain (1989) showed that injection of pig slurry into grassland gave from 90-94% reduction in ammonium volatilisation during 73 hour compared with surface spreading. Losses N from injection by leaching and possible denitrification were higher compared with surface broadcast. However, the losses from broadcast were significantly higher than injection because of high ammonium volatilization. The environmental effects of ammonia emission into the atmosphere are widespread and can be serious. Moreover, the losses through ammonium volatilization can significantly effect crop yield because high proportion of the total N present in slurry and digested sludge is in the form of ammonia. On the other hand, the improved N efficiency through soil injection may be limited due to soil conditions and injector design, particularly on grassland where the quality of finish is important and damage to the sward surface and roots must be minimised (Godwin et al., 1985).

In the UK, interest in the injection method has increased since early 1980 primarily because it eliminated the odour problem associated with the surface spreading of unstabilised slurry. In the Netherlands, injection has become mandatory for livestock slurries largely on the basis of controlling atmospheric pollution through ammonia volatilisation. Vandemeer et al. (1987) found that there was a positive maize yield differential of 2.13 tonnes ha^{-1} when pig slurry was injected rather than surface applied. Also cattle slurry injected, both before and after sowing maize, was 60% more effective than surface application.

2. 6. 2. 2 Limitations of injection method

Compared with broadcast method, injection method needs more energy for injecting liquid into soil. It also disturbs the root zone of plant, if injected deep and in narrow spacing, during growing period. The passage of injection tines damages the sward significantly, but the damage was least on sandy soil and at low injection depth (Prins et al., 1987). However, root prunning and "die-back of pasture" was not a problem if a shallow subsurface injection at 30cm spacing was used (Abbas and Choudhary, 1995).

The injection generally required dry soil so that liquid can be easily absorbed by soil. Injection method behaved like surface broadcast disposal if soil was too wet and high volumes of effluent were disposed. Moreover, farm liquid effluent contains low level of nutrients, so machines have to run several times to get enough necessary nutrients for plant growth.

Other reason relating to limitation of injection is that it does not give a good distribution of nutrients; the area closer to the injection point there is higher concentrations of total N and nitrate N in plants (Prins et al., 1987). Compared with spreading, N losses from slurry by denitrification are larger after injection and loss depend on the time of application (Vandermer et al., 1987).

On grassland, higher yields following injection have been observed when compared to equivalent surface applications. However, the benefits of preventing ammonia volatilisation are reduced to a variable extent by damage to the sward surface and roots. Injection generally increases grass yields. However, under difficult soil conditions the yield may be significantly depressed compared to the equivalent surface application. It is clear that there is an interaction between soil type, soil moisture, and the prevailing weather conditions at the time of injection.

2. 7 NZ Resource Management Act regulations

The New Zealand Resource Management Act, 1991 (Section 5(2)), sustainable management states:

Managing the use, development, and protection of natural and physical resource in a way or at a rate, which enables people and communities to provide for their social, economic and cultural well-being and for their health and safety while:

- *Sustaining the potential of natural and physical resources to meet the reasonably for essential needs of future generations and,*
- *Safeguarding the life-supporting capacity of air, water, soil and ecosystems and*

- *Avoiding, remedying, or mitigating any adverse effects of activities on the environment.*

This Act highlights the likely trends that farmers, processors and Regional Councils must follow to ensure that effluent are disposed off in environmentally-friendly manner to comply with the regulations.

2. 8 Tillage and effluent effects on nutrient cycling

2. 8. 1 Purpose of tillage

Webster's Dictionary describes tillage "to turn or stir (as by ploughing, harrowing, or hoeing) and prepare for seed; to sow, dress, and raise crops from and to cultivate". The basic purpose of tillage is to provide a favourable soil environment for the germination and growth of a particular crop.

1. To prepare a suitable seedbed:
- To supply oxygen for plant root respiration and absorption of nutrients, especially potassium absorption is dependent on aeration.
- To supply oxygen for activity of the soil bacteria which transform organic matter into nitrates available to the plant.
- To supply oxygen for nitrogen fixation by the bacteria associating with legume roots.
- Resistance to compaction by wheels or tracks of tractors, field machines and actions of tillage tools.

2. To incorporate manures and fertiliser in soil.
4. To eliminate weeds.

2. 8.1.1 Types of tillage

Conventional tillage (CT)

This method commonly uses equipment such as mouldboard plough, disc plough, and secondary cultivation and harrows.

Conservation tillage

According to the Conservation Tillage Information Centre (CTIC), conservation tillage excludes conventional tillage operations that invert the soil and bury crop residues and includes five types of conservation tillage systems:

- Reduced or minimum tillage;
- Mulch tillage;
- Ridge till (including no-till on ridges)
- Strip or zonal tillage;
- No-tillage (NT, slot planting or direct drilling).

Tillage methods affect soil physical, chemical and biological properties. Research results have been widely reported on the effects of tillage on soil aggregation, temperature, water infiltration and retention as the main physical parameter affected. These magnitude of any change depends on soil types as well as on soil composition (Aslam, 1998).

CT causes reduction in soil aggregates more than NT and results in a change in number, shape, continuity and size distribution of pores as well as changes in the strength and stability of the soil. Furthermore, these changes modify the ability of soil to store and transmit air, water and solutes. This leads to soil degradation by soil erosion and runoff and results in the losses of nutrients affecting soil fertility and decreasing long-term sustainability of agriculture (Aslam, 1998).

No-tillage (direct drilling)

This method is an extreme form of conservation tillage, which allows removal of any tillage prior to direct sowing of seed. No-tillage is defined as specialised type of conservation tillage consisting of one-pass planting and fertiliser operation in which the soil and surface residues are minimally disturbed. The retention of surface residues in this system is very important for soil and water conservation. Projections and estimates to the year 2010 suggest that about 80% agricultural farms in the U. S will use this technique. In this method, seeds are drilled directly into uncultivated seedbeds and the remaining vegetation is suppressed or killed by herbicides, or by natural mortality.

Conservation tillage requires less energy and other inputs than conventional method. The advantages of conservation tillage have been widely studied in many countries of the world. For example, Sharma et al. (1984) suggested that there was no significant difference between the average yields when using no-tillage system or conventional system, but the energy required and cost of production in conventional system were about 1.5 times higher than those in no-tillage system. In recent experiments at Massey University suggest 38% higher yield with no-till compared with conventional tillage as shown on Table 2.5 (Hoang, 1998 unpublished data)

Table 2.5 Maize dry matter yield (tonnes ha^{-1}) as affected by two tillage treatments

Treatment	Dry matter yield (tonnes ha^{-1})
Mouldboard plough	6.5 a
No till	4.7 b

Values followed by the different letter are significant different (P<0.1).

In addition, the use of conservation tillage reduces time as well as labour input. Majid et al. (1989) pointed out that the total time requirement per hectare for rice production is about 200-300 man-hours by direct sowing, whereas, it is 500-600 man-hours by mechanical means and is 1300 man-hours by manual transplanting. Conservation tillage also contributes to improvement in soil stability, and decreases erosion of the fertile topsoil layer.

Conservation tillage affects nutrient cycling in soil in a number of ways. The effects of no-tillage on soil physical and chemical characteristics have been widely studied (Lal, 1991; Choudhary and Baker, 1994; Horne et al., 1992; Francis and Knight, 1993). Conservation tillage increases the population of earthworm as well as soil microbial activity, which make soil softer and more fertile. This method will also increase water holding capacity and moisture conservation, and reduce capital investment in machinery system. At the topsoil, concentration of organic matter, cation exchange capacity (CEC), microbiomass are higher in conservation tillage than in conventional tillage (CT) systems. Also, the immobilization of fertiliser nitrogen into soil organic matter, which is higher in conservation tillage will reduce nutrient losses by leaching. Moreover, the gaseous losses of ammonia from fertiliser, and fixation of ammonium into the clay lattices are higher in conventional tillage than in conservation tillage. However, information of effects of liquid effluent in no-tilled soil is rather limited.

2. 8. 1. 2 Tillage effects on N transformation

The effects of tillage practices on soil have been widely studied. No-till enhances mineralization process in the topsoil (Broder et. al., 1984; Rice et. al., 1986). Kingery et al. (1996) reported that the potential mineralizable N at the 0-150mm depth in no-tilled (NT) soil averaged 20-39% greater than ploughed soils. No-till also increases immobilization process. Doran (1980) pointed out that, the potential for immobilization was greater under NT because of markedly high microbial population counted in the top 7.5 cm of the soil surface. This result was confirmed by other researches such as Blevin et al. (1983) and Rice and Smith (1984).

With nitrification process, reseachers have reported conflicting results. Doran (1980) and Broder et al. (1984) concluded that nitrification rate in NT was slower than CT because of the lower NH_4^+ oxidier population under NT. In contrast, Rice and Smith (1983) and Beyrouty et al. (1986) had reported that since moisture in

NT was higher than CT, this caused higher nitrification in NT soil than tillaged soil. Staley et al. (1990) also stated that, potential nitrification activity in NT was significantly increased by 156% compared with CT.

No-tillage also increases denitrification. This is due to soil moisture content, which was consistently higher in the NT than CT (Rice and Smith, 1982; Rice et. al. 1986). Because of the higher level of denitrification in NT, gaseous N (N_2O + N_2) losses were higher in NT compared with CT (Aulakh and Rennie, 1986).

In contrast, nitrate leaching in ploughed soil was higher than that in NT (Guo et al. 1998). Because of ploughing and discing, the soil aggregates become pulverised, this physical disturbance of the soil aggregate would also eliminate the large pores creating more homogeneous systems of smaller pores. This allowed easy movement for water, allowed NO_3^- both residual and applied to move more in accordance to the piston flow concept that caused lower NO_3^- concentration in tillage soil (Drury et al., 1993; Kanwar et al., 1985).

2. 8. 2 Soil nutrient

2. 8. 2. 1 Soil nitrogen

Nitrogen is one of essential elements for plant growth. The amount of this element in available forms in the soil is small, while the quantity withdrawn annually by crop is comparatively large. In nature, biological nitrogen fixation forms the major source of N supply in legume-based pastures, and N is also added through fertilisers and manures. The nitrogen cycling in soil includes a number of processes. These includes.

I. Mineralization

II. Immobilization

III. Nitrification

IV. Ammonia volatilisation

V. Denitrification

VI. Nitrate leaching.

2. 8. 2. 2 Ammonium volatilization and nitrate leaching

As volatilization and leaching are the main reasons of nitrogen loss, it is important to describe how these processes work.

Most of the nitrogen present in ecosystems is usually in the form of organic matter. Organic N constitutes more than 90% of total N in surface soils, and the mobility and leaching of organic N is considered to be low. Ammoniacal form (NH_4^+) is the second important form of nitrogen, which is derived from the mineralization of added organic materials, soil organic N or from addition of urea and ammoniacal form of N. Ammonium (NH_4^+) is unlikely to be leached except under special field management conditions or where large amounts of NH_4^+ were added to a light textured soil. NH_4 is held in the soil by processes of cation exchange or fixation in clay lattices, and by microbial immobilization. NH_4^+ ion is easily nitrified even during its transport and also taken up by plant roots. Under certain conditions, Ammonium ions are released as NH_3 gas to the atmosphere.

Ammonium reacts quickly with hydroxyl radicals in the atmosphere to reduce NO_x contributing to the acidification of rain, and also combines with sulfur compounds, usually in the form of aqueous sulphuric acid aerosls, liberating ammonium sulphate, which contributes to soil acidification. Moreover, the deposition of ammonium on surface water impacts oligotrophic environment and contributes to the problem of eutrophication.

Moreover, volatilization of ammonium can occur whenever there is free ammonium present at soil surface. This may be due to the application of urea or ammonium fertiliser. It may also happen where urea is present in animal urine patches, or be produced from other organic sources (McLaren and Cameron, 1996). In sandy soil, alkaline or calcareous soils, the volatilization evaporation of ammonium is significant (Brady, 1984). The volatilization losses of NH_3 are usually highest when the soil temperature is high. In New Zealand, N losses through volatilization from fertilisers such as urea, animal urine patches are significant (McLaren and Cameron, 1996). Similarly, other studies have shown that surface application of animal manures may lead to losses of N though NH_3 volatilization during the first 5 to 10 days after application (Thompson et al., 1990; Cabrera et al., 1993).

Nitrate (NO_3^-) is created from ammonium through the process of nitrification, which is a process mediated by specialist soil bacteria which oxidise NH_4^+ to form NO_3^-. Nitrification normally proceeds rapidly so that only low level of ammonium is usually present in soils (Haynes, 1995). Once being formed, NO_3^- does not readily go into the continuous immobilization/mineralization process except via plant uptake. The possibility of its reduction to NH_4^+ by its direct contact with a highly reduced soil layer is remote in nature. That factor, combined with the high mobility of NO_3^- in soil and the limited capacity of any well-leached soil to retain salts, result in the transport of nitrate with the percolating water. The order of easy leaching of N forms in the soil is: $NO_3^- = NO_2^- >>> NH_4^+ >>>$ organic N.

Khanna (1981) explained that nitrate ions are weakly adsorbed onto soil (non-specific adsorption) and are liable for leaching, either before or after undergoing biological cycling. For a defined ecosystem, transfer of nitrogen out of the plant rooting zone by percolating water may be considered as leaching loss. In certain cases, it may still present little environmental hazard because of denitrification in deeper layers. In many situations, however, the leaching of nitrogen is of concern to the aquatic as well as to the terrestrial environment, adversely affecting human and animal health. The amount and depth to which nitrate is leached is controlled by such factors as rainfall, soil moisture retention, site quality index and the type and succession stage of vegetation.

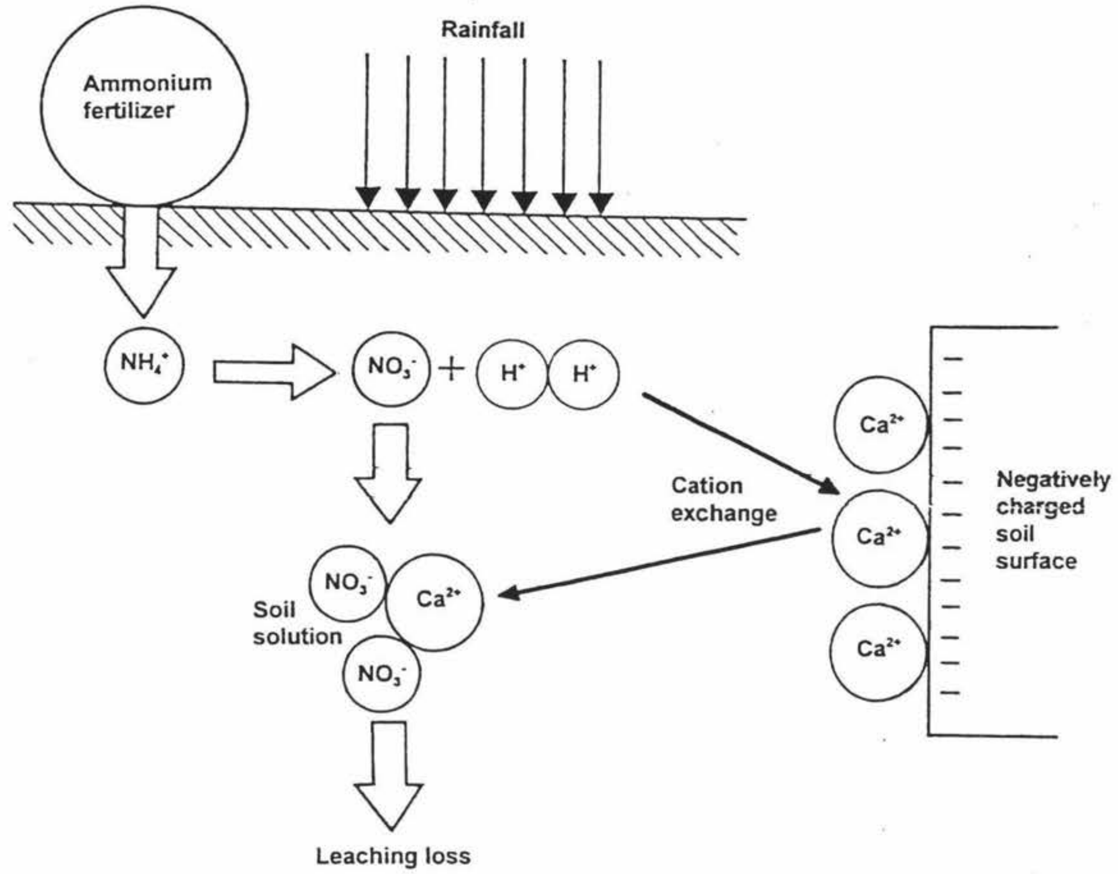


Fig. 2.1 A schematic diagram of the process involved in acidification and nitrate leaching following nitrification of ammonium fertiliser (Haynes, 1995)

With the combined forms of nitrogen contained in soil or added as fertiliser, nitrate ion always leaches out in appreciable amounts by water passing through the soil profile. The reason is that, apart from some acid soils in the tropics, there is no significant absorption of nitrate onto soil surfaces, and there are no common insoluble nitrates. Hence, nitrate in soil solution is displaced downwards by rainfall or irrigation water and it can be carried beyond the root zone and eventually into groundwater, if water is added. The nitrate movement in the field is a complex process and depends on factors such as: fertilisation, soil texture, land use, crop rotation and cultivation.

Nitrate is not directly toxic to human until it is converted into the nitrite ion (NO_2^-). Two potential problems, "blue baby" syndrome and stomach cancer, are often associated with high nitrate levels. Moreover, excess nitrate is one of the reasons resulting in eutrophication, which undesirably changes the overall ecological balance of the river or lake and water quality.

2. 8. 2. 3 Nitrogen recycling

When liquid effluent is applied to soil, there is likely an increase in N content in soil. It also influences the N leaching loss. The leaching loss of N depends on the rate of application and the method of disposal of effluent. Nitrate leaching losses are small when effluent is applied at low rate, but it is relatively higher at greater rate of application. Thus the amount of application which matches the demands of growing plant will not cause adverse impact on groundwater quality. The increase in denitrification by application of liquid effluent can reduce the leaching losses but it may also enhance emissions of NO, N_2O, and N_2 gases and cause the environmental impacts.

Because fertiliser N is available immediately after application, little of applied N typically remains for potential leaching after crops are harvested. In contrast, liquid effluent continues to mineralize after crop harvest causing the release of nitrate, which is the source of nutrient leaching (Haynes, 1995). This author also reported that the concentration of nitrate is lower under NT in comparison with conventional tillage. This difference was slight at low rate of application but significantly high at very high application rates. He suggested that high moisture in no till associated with the increase in water infiltration might enhance denitrification. One of the reasons for lower nitrate content in effluent irrigated is that most nitrogen in liquid effluent is in ammonium form and easy to be volatilized into atmosphere while the application of fertiliser have lower potential of ammonium evaporation.

Sommer and Ersboll (1994) concluded that, losses from injected slurry directly into harrowed soil are about one-third of the losses from a soil left unworked. Kanwar (1993) reported that lower NO_3^- concentrations in the subsurface drainage water were observed under the no-tillage system in comparison with the chisel ploughing. This author also suggested that lower application of N would result in lower NO_3^- concentration in the surface drainage water in comparison with higher N application rate of 135 kg ha^{-1}. This suggested that better N management would improve the water quality.

Because the utilisation of slurry as fertiliser for grassland and arable soils is low with variable recoveries of N, slurry is often treated as a waste product rather than a fertiliser resource. Ammonia volatilisation from surface applied liquid effluent has long been recognised as an important factor leading to poor recovery of N. Moreover, the losses of N may occur through the denitrification and leaching depending on soil conditions and time of application.

In conclusion, the application of liquid effluent either on the surface or subsurface injection makes changes to nitrogen cycle in soil, especially nitrate and ammonium. It improves the nutrient content in soil and also enhances the denitrification process in soil. The extent of these changes depends on soil, temperature, and climate conditions.

2. 8. 2. 4 Soil phosphorus

Phosphorus is a major nutrient required by plants and is found in low concentration in soil and water. It is dispersed into the environment through a variety of mechanisms including municipal and industrial discharge, the spreading of commercial fertilisers, animal manures and sewage sludge and soil erosion. Total P in soil ranges from 0.02 to 0.15% P. This amount of P depends on the parent material from which the soil has developed, and the condition of weathering and leaching. The native P in soils, originates mainly from primary P minerals as apatits, in which P is present essentially as tricalcium phosphate, $Ca_3(PO_4)_2$. There are primary, secondary or tertiary orthophosphate ions in soil.

The phosphorus concentration in wastes always varies, and its retention mechanisms in most soil in New Zealand and Australia makes it difficult for P leaching (White and Sharpley, 1996). However, the extensive leaching can occur where disposal rates are excessive and soils are coarse textured and contain low hydrous oxides.

It is now well established that phosphorus most commonly limits the yield in freshwater phytoplankton communities (Thomas et al., 1980). Substantial addition of phosphorus to a body of water usually results in increased algae production and increased decomposition of organic matter, which causes depletion of oxygen. These changes are often referred to collectively as eutrophication. When liquid effluent is applied to soil in qualities that far exceeded the requirement for efficient plant production, there may be a risk of P leaching to groundwater and to surface water where it contributes to the eutrophication (Riemsdijk et al., 1987).

Part of phosphate taken up by the pasture is in fact returned to the soil as plant residues such as roots or uneaten litter. Above-ground losses of phosphate from the cycle, about 20-30 % of the phosphate taken up by the pasture, are mainly in the form of animal products and dung distributed to unproductive areas such as farm races and yards. A larger proportion of the phosphate in both dung and plant residues (70-80%) is water soluble. The remainder of the phosphate in these materials is organic in nature and enters the soil organic P pool (Fig. 2.2). This phosphorus in soil is separated into three fractions, biomass P, labile organic P and inert organic P. Such of soil organic-P is considered to be very stable. However, recent studies suggest that the phosphate in the soil solution is closely linked to a labile fraction of the soil organic P by means of a rapid cycling of phosphate through the soil biomass. Phosphate released by enzymatic breakdown from decaying organisms (mineralization) may be either reimmobilized back into the biomass or be taken up by plant roots.

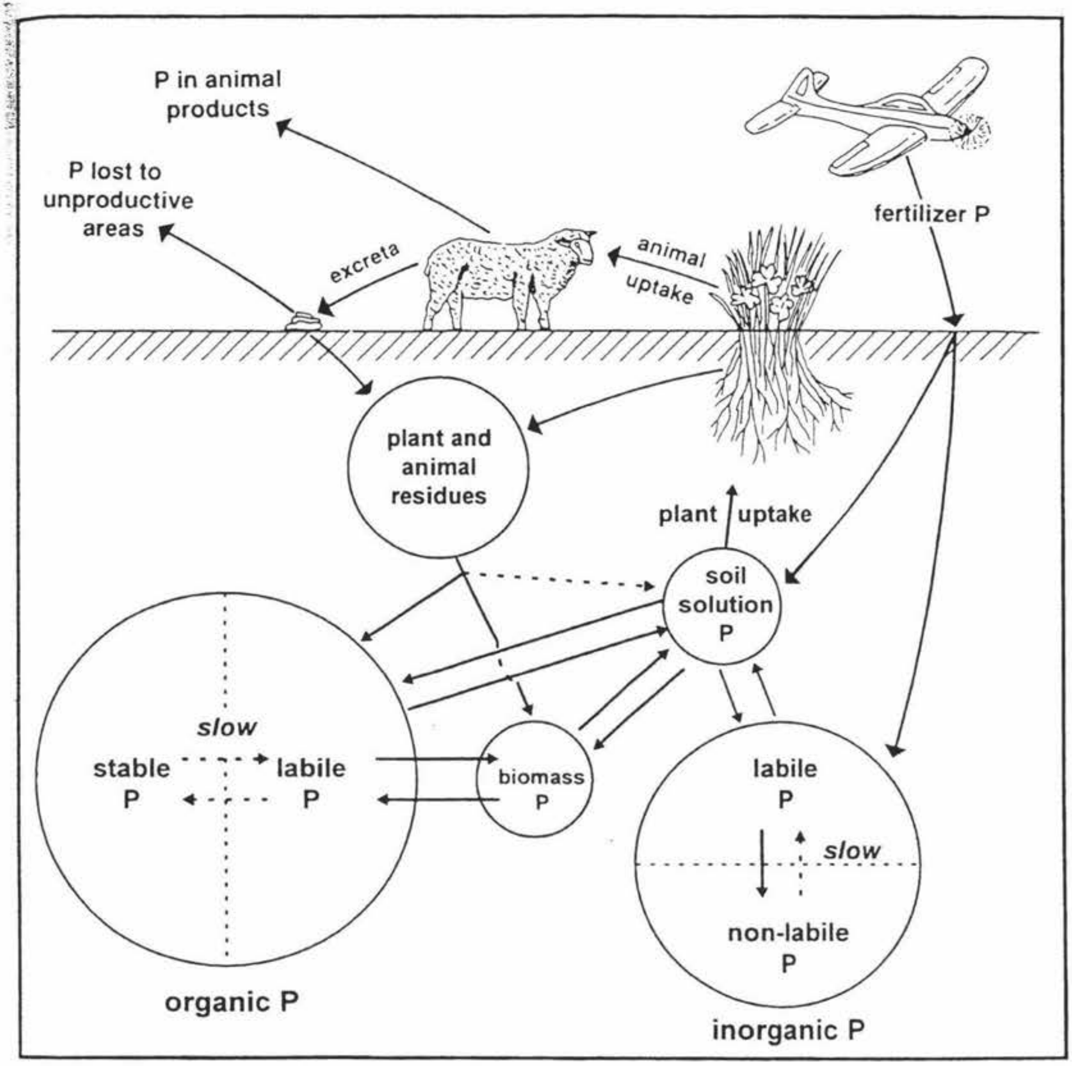


Fig. 2.2 The phosphorus cycle in a grazed pasture system

Almost all soil tests for P are used to determine the amount of labile inorganic phosphate in soil, i.e. that fraction of the soil P that can readily move into the soil solution, which is called available P.

2. 8. 2. 5 Phosphorus recycling

Phosphate in animal slurries is mainly present as solid-phase inorganic P (Riemsdijk et al., 1987). The fraction present in the solid fraction may differ for different slurries. This variability may be described partly by the variation in dry matter content of slurries but also due to the composition of the animal feed, where the mineral is often added. Some researchers reported that about half of total P in cattle slurry is present in the solid fraction. Both in the solid phase as well as in the liquid phase P is mainly present as inorganic P (80%), the remainder being organic P. Only a small fraction of the total P, which is present in solution of slurry, is present as dissolved organic P (1-2%). The inorganic P solids in slurry are relatively soluble. When slurries are applied on soil, the minerals gradually dissolved in the water percolating through the soil. The dissolved inorganic P then starts to react with soil components and/or with other ions in the soil solution. This leads to the formation of adsorbed P containing solids (where the largest part of the P is not in direct contact with the soil solution). This fraction is also referred to by the term precipitated P. The organic P fraction in the slurry is subject to mineralization to inorganic P when slurry is applied to soil.

Vetter and Steffens (1988) have suggested that high slurry dressing might cause considerable phosphorus displacement into deeper soil layers. In their experiment, with P dressings between 175 and 600kg P ha^{-1}, 8-13% of the added phosphorus moved into a soil depth of 60-90cm. They also observed a faster downward displacement of phosphorus with slurry phosphorus than with mineral P fertilisers. If soil is acid, the downward displacement of P is high. Excessive levels of P may be present in farming systems dominated by animal-based agriculture (Sims, 1995 and Provin et al., 1995).

However, with lower rate of application of slurry, for example, 10 times grass requirements, may result in little or no increase in phosphorus leaching or of translation below 30 cm in the profile. Very high rates of application of poultry manure to a sandy soil had not resulted in any extra leaching of phosphorus after

7 years (Unwin, 1980). This result was similar to that of Gerritse (1981), in which only with high rate of application, the fraction of organic phosphorus amount appeared in mobile form. Under normal rate and average rainfall, the leaching of P was not significant. Destain (1980) also reported that, with heavy quantities of P in slurry, there was a considerable accumulation of organic P in the surface but only a gradual increase in the amount of exchangeable P in soil. McAllister and Steven (1980) also reported that the application of slurry did not result in increased P level and concluded that, because of more intensive and fragment crop, harvesting might further improve P removal rate.

It can be concluded that at adequate application rates of farm effluent do not always seriously effect the recycling of P in soil as well as its leaching to waterways. However, when over-application occurs, the potential for P leaching can also increase.

2. 8. 2. 6 Soil potassium

Potassium is an essential element considered as the third major nutrient for plant growth after nitrogen and phosphorus. Potassium exists in inorganic form in plant cells where it functions in several physiological processes including the maintenance of electrical balance at membranes, enzyme activation, carbohydrate production and transport, and stomatal activity. The amount of K in the plant compartment, which comprises the K in the herbage and in the roots, is a function of the dry matter (DM) yield and the tissue K concentration (Williams, 1988). Plant requirement for this element is quite high. Potassium deficiencies greatly reduce crop yields and decrease resistance to certain plant diseases. Williams (1988) reported that, fertiliser with K stimulated increases in nitrogen fixation by legumes and improved nitrate uptake by grass species. In soil, total potassium is about 0.1-4 % on weight basis and it consists of following four distinct forms (McLaren and Cameron, 1996):

- Mineral potassium (90-98% of total K) which is completely unavailable for plant uptake.

- Fixed potassium- slowly available
- Exchangeable potassium and in soil solution potassium

In major dairy farming soils of New Zealand, exchangeable K levels account for between 1 and 5% of the total soil K content (Williams, 1988).

Only a small percentage of the total soil potassium is present in soil solution. This kind of potassium is readily available for plant uptake. Also the K^+ in soil solution is easy to leach by water draining through the profile. Soils with high clay and organic matter content have a high cation exchange capacity and are effective in retaining potassium against leaching.

2. 8. 2. 7 Potassium recycling

Tillage has an important role in potassium recycling. Some researchers have concluded that reduced tillage system can lower K uptake by plants. Schulte (1979) reported that reduced tillage might cause yield loss but improve yields under reduce tillage relative to conventional tillage in situations where cool soils restrict root growth and K uptake. Because reduce tillage can control soil erosion, it also conserves nutrients in soil (Table 2.6).

Table 2.6 Tillage system effects on residue cover, soil erosion, P and K losses with fall-applied P and K in the USA.

Tillage system	June residue cover (%)	Soil loss (tons ha^{-1})	Nutrient loss (kg ha^{-1})	
			P	K
Fall-ploughed	3	51.5	38	18.6
Fall-chiseled	35	9.9	8	7.8
Spring-chiseled	35	9.4	8	8.9
No-till	80	1.1	3	8.9

Source: Laflen (1982)

Crop removal of K varies from 20 kg ha^{-1} for grain crops to 600 kg h^{-1} for a forage crop cut several times per year. The amount of K applied to K deficient soils is usually larger than the amount removed, especially when only the grain is harvested. Since most of the K in effluent is in a soluble inorganic form, it reacts similarly to fertilizer K when it is applied to the soil. The effect on the level of available K in the soil will be determined by the balance between the amounts applied, the amount absorbed in an unavailable form, and the amount that may be leached from the soil (Olsen and Barber, 1977).

The application of liquid effluent can lead to hypomagnesemia in cattle if there is excessive amount of K percent in the effluent. Potassium is retained well by heavier soils and to a lesser extent by sandy soils so that residual K will be available to succeeding crop. If K application exceeds the availability of soil, it will cause leaching and pollute water supplies from sandy soils.

Overall, K use-efficiency is higher with adequate rate of K fertiliser application. Also, application of effluent can stabilise crop yields at a higher level than mineral fertilizing, giving higher content and yield of protein and increased Mg, Ca, K, P concentration in cultivated plants (Koc, 1996).

2. 9 Summary

This chapter reviewed the current methods for disposing liquid effluent and its effects on soil nutrient status in New Zealand and elsewhere. Also, the interactions between land preparation methods and nutrient recycling in soil were highlighted. Farmers often consider the liquid effluent as waste or fertiliser depending on how they are able to dispose of the amount produced without noticeable damage to the land productivity or the quality of its production (Gasser, 1987).

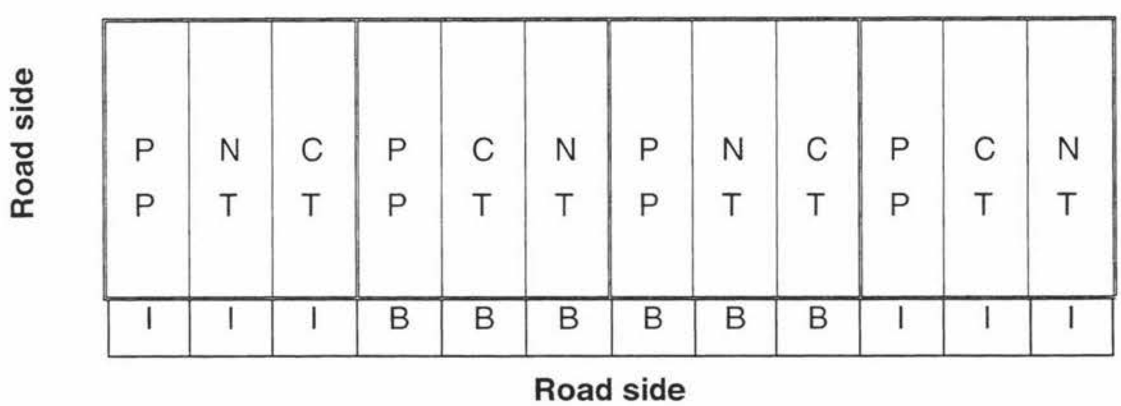
Ponds are normal treatment system in New Zealand before discharging treated effluent as a waste to rivers or lakes. Spray irrigation and surface application are the two methods that are commonly used in New Zealand. With the application of farm effluent onto soil, there is an increase in nutrient status in soil and higher pasture yield is achieved. However, New Zealand land area is highly sloping causing the loss of nutrients by runoff if liquid effluent was applied by broadcast method. Injection method has more advantages compared with broadcast to reduce nutrient losses. Moreover, there is only limited detailed research data available on the interactions between subsurface injection of effluent and tillage system. Therefore, this study focused on comparing effects of liquid effluent disposal method, and their interactions with different tillage system and primary nutrient status in soil.

Chapter 3

MATERIALS AND METHODS

3.1 Experimental layout

The experiments were conducted on the Massey University long-term tillage experiments which included comparison of conventional tillage (CT), no tillage (NT) and permanent pasture (PP) (Choudhary, 1996). In these experiments, permanent pasture was converted to a double-crop rotation (Summer maize - *Zea may L.* and Winter oats *Avena sativa,* L.cv. *awapuni*) using conventional and no-tillage in 1995. Soil type was Ohakea silt loam with poor natural drainage with 5% slope. The experimental design included three tillage treatments, two application methods with two replicates and were arranged in a randomised complete block (RCB) design, as shown in Fig. 3.1



** PP: Permanent pasture; NT: No tillage and CT: Conventional tillage;*

** I: Injection method; B: Broadcast method*

Fig. 3.1: Field experimental layout

3. 2 Description of subsoil injection

The Massey designed injector machine was used to inject effluent into soil (Choudhary, 1988). This machine used the inverted-T opener originally designed for no-till technology (Baker, 1976). The opener created soil grooves, which allowed large volume of liquid application and retention of in-groove moisture. The groove shape helps to reduce the loss of ammonium from the effluent. To obtain an even lateral distribution of nutrients, the openers were spaced in 30 cm row spacing. The depth of application was 10 cm. This allowed the nutrients to be close to the root zone for immediate uptake.

The injection machine included a wavy pre-disc ahead of the opener, which assisted in cutting surface residue. Following the opener were twin rubber tyred wheels to close the grooves without exerting excessive pressure, which may force out the slurry. It also help to reduce the death of grass along the edge of the injection slits when the soil is too dry (Vandermeer et al., 1987). The depth of opener in soil was adjusted mechanically by raising or lowering the shank relative to the wheels. With this construction, the machine can inject a volume of approximately 120 m^3 ha^{-1}.

3. 3 Application of liquid effluent

3.3.1 Field preparation for the experiment

Growing zone of corn root is concentrated at 10cm depth. Shallow injection has been shown to be superior to deep placement as the latter method requires a heavy tractor and damages the injected pasture through excessive root pruning particularly when it is used during spring and summer (Choudhary et al., 1988). Also, the shallow and narrow grooves allow the deposition of organic waste closed to the pasture root mass for immediate uptake of nutrients. This depth also helps to reduce the nutrient leaching and root disruption of pasture or crop. Thus in this experiment, liquid effluent was injected at 10 cm depth.

Fig. 3.2: Massey University designed Inverted-T injector used in the experiments.

The first experiment followed a winter oats (*Avena sativa,* L.cv. awapuni) and summer maize crop (*Zea may L.*) rotation. The crops are sown either with no-tillage technique or with conventional tillage. Permanent pasture is regularly mowed and treated with fertilizer as required. Details this experiment is described in the section 3.5.3.

In the second experiment, two weeks before sowing corn seed, weeds in no-tillage treatment were controlled by herbicide spray with a mixture of 4 litres ha^{-1}

of Roudup and 1 litres ha^{-1} of Versatill. Conventional tillage was ploughed by mouldboard plow at the depth of 20 cm followed by two passes of a power harrow (Fig. 3.3). Corn seed rate of 65 kg ha^{-1} was sown on no-till and conventional tillage. Fertilizer (Nitrophoska containing 12% N, 10% P, 10 % K and 1% S) was also drilled at the rate of 120 kg ha^{-1}. Seed drilling was done using the Aitchison seed drill model Seedamatic 1112. The progress of the second experiment is shown in the section 3.5.4

Fig. 3.3: Land preparation for the cultivated treatment for the second experiment

3. 3. 2 Collection of liquid effluent

Effluent was collected from Dairy Farm No. 3. soon after cows were brought to the dairyshed for milking. The raw effluent collected from a sump after solids from the feed pad was scraped into a stockpile. It also includes the effluent from other cowshed activities such as vat and milking machine washing, spilt milk and cow bail cleaning. Effluent was analyzed to determine the nutrient status to find out the necessary volume of effluent required for the experiment. The reason of selecting yard washdown water was that because the yard washing practices are similar among farmers, these results could be applied widely. Furthermore, it was also easy to collect effluent with simple equipment. The nutrient in raw effluent was higher compared with that collected from dairy pond. Table 3.2 shows the nutrient contents both in the first and the second sampling.

Because the amount of phosphorus was low in the effluent, the application rates of effluent were calculated on the N content basis.

Table 3. 1: Nutrient content in liquid effluent at two times of application

	First experiment ($\mu g\ l^{-1}$)	Second experiment ($\mu g\ l^{-1}$)
Total N	230	250
Total P	20	19

3.3.3 Experiment 1: Low rate of application during spring

One of the objectives of this experiment was to evaluate the effects of low rates of effluent application on the amount of downward movement of nutrient in soil profile, which may affect aquatic life and water quality. Moreover, this may increase nutrient levels in soil for plant growth. Also, during the spring and early summer months, pasture growth is often rapid and there would be a sink effect on plant N uptake. So leaching events are minimal or absent. Thus, the NO_3 can stay in the soil until it is absorbed by plant, and/or immobilised into soil organic forms or lost in gaseous form (Haynes 1995).

Moreover, even though the amount of this nutrient in liquid effluent was small, it would still help farmers to reduce additional nitrogen requirement for the next crop. However, during spring time, often wet soil limits a high rate of application of liquid effluent, and high rate if applied at this time, can cause nutrient losses through runoff. Thus, in the first experiment, liquid effluent was applied at the rate of 120 $m^3 ha^{-1}$ (30 kg N ha^{-1} equivalently) soon after harvesting oats in June 1997. At this low rate of application, it was considered as a safe method of disposal of liquid effluent on soil.

Oats were harvested by sheep grazing on 14th June 1997. At this time, soil was generally wet. Prior to starting the slurry application, the injector was tested using water to set the required tractor speed and volume necessary to get enough nutrients for the experiment. On 23th, July 1997, fresh liquid effluent was collected from Dairy Farm No. 3, and stored in a tanker overnight. Liquid effluent was applied next day by either subsoil injection or broadcast on the surface by the injector covering an area of 300 cm long and 120 cm wide (Fig. 3.4).

Fig 3.4: The field application of liquid effluent on the experimental plots

3.3.4 Experiment 2: High rate of effluent application in summer

Nitrogen loading rates referred to the Regional Councils rules, guidelines and resource consent conditions range from 100 to 600 kg N ha^{-1} $year^{-1}$. The amount of N applied in the effluent has considerable influence on N leaching losses. The most common maximum loading rates for permitted or controlled activities used in rules under transitional, proposed or operative in Manawatu-Wanganui Regional Council plans are either 150 or 200 kg N $ha^{-1}yr^{-1}$. If effluent is applied at a rate that equates plant N requirements, groundwater N concentrations are not likely to be seriously affected.

Also, during summer, soil has higher ability to intake liquid effluent. Thus, in the second experiment, the liquid effluent was applied at the rate of 600 m^3 ha^{-1} (an equivalent rate of 150 kg N ha^{-1}). At this rate, the leaching of nitrate was expected to be limited but would likely to improve the use-efficiency of liquid effluent. At this rate, effluent was considered as a source of fertilizer. Here the application rate of effluent was considered as a fertilizer source of nitrogen although the phosphorus amount in effluent was still low.

Liquid effluent was then "injected" or broadcast covering 70 cm long and 100 cm wide plots. Because of the fact that the tillage experiment has major long-term objectives to test soil physical and bio-chemical effects of tillage intensity and cropping regime, it was not possible to use whole plots for this experiment. Therefore, because of the small area used for the present study, injection and broadcast of effluent were done manually. To obtain a rate of application of 150 kg N ha^{-1}, an equivalent volume of 43 litres per $0.7m^2$ was used.

At the end of the experiment, the corn crop was harvested at maturity for dry matter yield before grazing with sheep.

3.4 Collection of soil samples

Nutrient status in soil often varied even in the small area, therefore the method of soil sampling and number of samples are important for any experiment. This was more important when sampling for nutrients that were highly mobile, e.g. nitrate. Thus in this experiment, to reflect clearly the interaction among treatments, a large number of samples were taken. The plots were segregated from nearby areas by using aluminum barries as shown in Fig. 3.5. Soil samples taken from outside the treated area were considered as a control treatment.

Fig. 3.5 Rectangular core used for sampling

The determination of fate of nitrogen and other soil nutrient was an important objective of the experiment. Especially in the injection method, the equal distribution of nutrient within the centre of the groove and between rows is important. Therefore, it was considered necessary to collect appropriate soil samples from the soil profile. Soil samples were collected either in the centre of grooves or 10 cm horizontally apart to determine the distribution of nutrient in the injected plots. Soil samples were collected from two depths: 0-10 cm and 10-20 cm in this experiment. Depth of 20 cm was chosen to correspond with ploughing depth.

The spacing used was an important factor to determine efficiency of injection method. Too wide spacing was likely to result in a non-uniform crop response as well as low overall distribution. Too narrow a spacing was likely to damage to root zone of crop and consume more energy. Godwin et al. (1985) suggested that under silty clay loam, 50 cm of spacing caused unequal distribution of grass yield. Kofoed (1981) pointed out that, injector used with 30 cm spacing between the tines resulted in yield higher than 60 cm spacing with the same injector. With the Massey University injector which was set at 30 cm, Abbas (1993) found that there was only 10.8% difference in total N between the centre of the groove and 10 cm horizontally away from the groove when animal blood was injected at 11.5 cm. However, with dairyshed effluent which had low solid percentage than in blood, more even horizontal distribution was expected. Three sampling situations were compared: in the centre of groove, 10 cm away in the injected plots and broadcast.

Four likely scenarios were expected:

1. If nutrients were higher both in the groove center and 10 cm away compared with broadcast, this would mean injection method was superior than the broadcast.
2. If nutrients in the centre of the groove were higher compared with broadcast

but not different from 10 cm away, injection method is still better than broadcast at both low rate and high rate of application.

3. In comparison with broadcast, if nutrients in the centre of groove were higher, but lower than at 10 cm distance from the centre, the nutrients were not spreading out and that row spacing was too wide.

4. If nutrients levels were lower both in the centre of the groove and 10 cm apart compared with broadcast method, we can conclude that broadcast method was better than injection method.

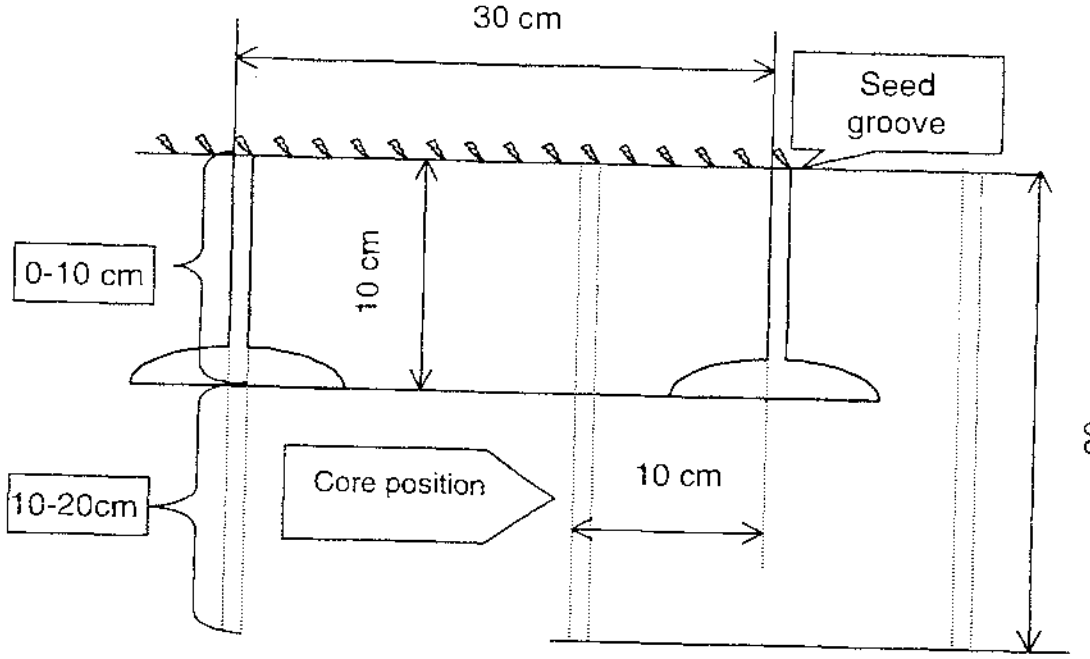


Fig. 3.6: Field sample collection profile for soil nutrient measurement

During the experiment, soil samples were collected four times: before application (no application), after one week, after one month, and two months of application for analyzing ammonium, nitrate, Olsen P and exchangeable K. One-month interval was considered enough to achieve a transformation of nutrients. Because nitrogen and phosphorus are stable in soil, they were only analyzed before application, after one week and after two months. Fig. 3.6 shows the profile of collection of soil sampling.

Soil samples were collected, as in the first experiment, at two positions in injection plots: one was in the centre of grooves and one was 10 cm away from centre. These samples were taken in each plot and bulked. In the broadcast plots, soil samples were collected randomly at three positions. In this way, at every sampling date, 96 samples were collected. After collection, samples were brought to the dry room in Soil Science Laboratory.

3.5 Method of analysis of soil and effluent

3.5.1 Total nitrogen and phosphorus measurement

In this experiment, the modified method of Kieldahl Digestion (McKenzie and Wallace, 1954) was used to determine the total N and P content in soil. One gram of finely ground dry soil was digested with 4-ml mixture acid solution including potassium sulphate, selenium and sulphuric acid. Then it was heated at 350^0C in an aluminum heating box for 6 hours. The solution was cooled and diluted to 50ml with dionised water by a vortex mixer. The solution was stored overnight for settling solid. An autoanalyzer was used to analysis the diluted sample. Total N and P contents were read directly from the graph recorded from the autoanalyzer.

For analysing the effluent, $10cm^3$ of liquid effluent was added to 4 ml of acid digestion mixture. The solution was heated at 120°C for 3 hours, then at 300°C for 5 hours. The remaining steps were similar to the analysis of soil sample.

3.5.2 Ammonium and nitrate measurement

Ammonium and nitrate were measured by the automated phenate method as described in standard method and has been modified by the Lime and Fertilizer Research Laboratory, Massey University, New Zealand. Three grams of dried soil (<2mm) was extracted by 30 ml of 2M KCl. The liquid extract was filtered through Whatman No.41. Ammonium and nitrate content in the extracted solution were analyzed by an autoanalyse machine at 720 nm.

3.5.3 Available phosphorus measurement

Plant available P was determined by Olsen Test. Air-dried soil was weighted and placed into centrifuge tube followed by extraction by 10ml of 0.5M $NaHCO_3$ (pH=8.3) solution for 30 minutes. Samples were shaken in a centrifuge for 2 minutes at a speed of 4,000 rpm. Then the solution was filtered by Whatmen paper and 4 ml of this solution was put into 50ml flank. Then 10 ml of solution containing ammonium molyblate and ascorbic acid was added and the volume was made to 50 ml with deniosed water. The solution was shaken and the intensity of the blue colour was measured after 30 minutes at a wave length of 712 nm using spectrophotometer.

3.5.4 Exchangeable potassium measurement

Exchangeable K content in soil was determined by leaching 1 gram dried soil with 50 ml ammonium acetate (1M) at pH 7 for one hour. One gram of soil (air dried< 2mm) was mixed well with 3 gram acid washed silica and put into a leaching tube (pipette tip) which had a macerated filter paper plug (Whatman # 41 filter paper). Then the tube was leached with 50ml of 1M ammonium acetate for one hour. The solution collected was made up to 50 ml in volumetric flask. The Standard Flame Atomic Absorption Spectrophotometer model "GBC FS3000" was used to determine the soil exchangeable K.

3.6 Data analysis

All statistical analyses were performed using the Statistical Analysis System (SAS, 1989). The data were analyses for determining the variances.

Chapter 4
RESULTS AND DISCUSSION

4.1 Experiment 1: Low rate of application (in winter)

4.1.1 Effects of method of effluent application on nutrient contents

Low rate of effluent application (120 m^3 ha) resulted in a nutrient loading of 30 kg N, 2.4 kg P per hectare. One month after application of effluent, ponding of effluent on the soil surface could be seen in the conventional tillage plots. On the other hand, no liquid effluent was visible on the surface of the PP and NT plots both in the injection and broadcast plots. This suggested that even in winter, the NT and PP have higher infiltration rates than the CT. The existence of effluent on the surface of conventional tillage indicated that tillage intensity is a major factor affecting the soil absorption capacity.

Fig. 4.1 Effluent ponding visible on the surface of CT plots after application

Because conventional tillage removes crop residue and damages soil structure from soil surfaces, the infiltration is reduced and surface runoff is increased compared to no-tillage (Azooz and Arshad, 1996; Choudhary et al., 1997; Guo et al., 1998). Because of low absorption capacity, conventional tillage would cause a higher flow of liquid effluent to waterways and contaminate the aquatic environment.

4.1.1.1 Total nitrogen

To compare the effects of placement methods on main treatments (i.e. NT, PP and CT), total nitrogen was compared between the injection (centre of groove, 10 cm away) and broadcast at one week as well as two months after application. Also, effects of two depths: topsoil (0-10 cm) and subsoil (10-20) cm were compared.

At both depths, levels of nitrogen did not change after two months of application (Table 4.1a). When considering the depth of placement method, there was a significantly higher total N content at the surface (0-10cm) soil (3.35 g kg^{-1} soil) as compared to that in the (10-20cm) subsoil (2.41 g kg^{-1}) both after one week and two months after application of effluent (Table 4.1a). Similar results were obtained for the NT and CT (Tables 4.1b and 4.1c). Also, there was no significant difference in total N content between placement methods (Table 4.2). This was true for both 0-10 cm as well as 10-20cm depths.

Soil receives N from the application of nitrogenous fertilizers, fixation of atmospheric N_2 by legumes and animal manures (including waste material). Losses of soil N occur due to volatilization, denitrification and leaching. Other factors that affect the nitrogen were the uptake by crop. With the application of liquid effluent, the release of gaseous ammonium into atmosphere is the main reason for nitrogen losses. Volatilization may occur when NH_4^+ was present at the soil surface.

The possible reason for no reduction in total N was that there was no crop growing during this experiment, so the nitrogen losses through plant uptake were low. Moreover, the application of liquid effluent can increase the immobilization process, create more organic matter resulting in low nitrogen loss by leaching and run-off (Flowers and Arnold, 1983). Similarly, Trehan (1994) reported that about 50% of N through cattle slurry application on soil was converted to an organic form in 9 days. Also, during winter, low temperature limited the losses of ammonium by volatilization (McLaren and Cameron, 1996). The higher nitrogen level in topsoil was not due to the application of liquid effluent, which had only small amount of N, but because of the natural higher fertility of the soil and the biological N_2 fixation in the root nodules of legumious plants. Also, in the arable system, crop residues are returned to the soil surface where they decompose and release N resulting in a higher total nitrogen in the topsoil (Haynes, 1995).

Table 4.1 Effects of tillage systems and time lapse after effluent application on total N at two soil depths (g kg^{-1} soil)

(a)PP			
Soil depth	**Time of application**		
(cm)	One week	Two months	$LSD_{(0.05)}$
0-10	3.35	3.34	0.09
10-20	2.41	2.41	0.07
$LSD_{(0.05)}$	0.07	0.08	
(b)NT			
0-10	3.19	3.17	0.08
10-20	2.43	2.42	0.08
$LSD_{(0.05)}$	0.1	0.09	
(c)CT			
0-10	3.03	3.01	0.1
10-20	2.46	2.45	0.09
$LSD_{(0.05)}$	0.156	0.111	

Table 4.2: Effects of method of effluent application on nitrogen

Depth (cm)	Time after application	Total nitrogen (g kg^{-1} soil)			
		Injection	10cm away	Broadcast	No application
0-10	one week	3.21 a	3.18 a	3.2 a	3.18 a
	two months	3.19 a	3.17 a	3.16a	3.15 a
10-20	one week	2.45 a	2.44 a	2.41 a	2.43 a
	Two months	2.45 a	2.43 a	2.41 a	2.42 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.1.1.2 Ammonium

Permanent pasture and no-till

There was a significant reduction in ammonium after one month compared with one week after application at the topsoil (Table 4.3a). Then it remained at the same level during the second month. Level of ammonium was only higher in the centre of injected groove in the topsoil after one week of application compared with no application (Fig. 4.2). On the other hand, no difference was found among injection, 10 cm away and broadcast during the experiment. The difference in ammonium between the topsoil and subsoil was significant during the experiment. Similar trends were found in the NT (Fig. 4.3).

Conventional tillage

Within one week of application, there was a significantly higher level of NH_4^+ in the centre of groove in injection plots compared with no application at 0-10 cm, but not in 10 cm away and broadcast (Fig. 4.4). In addition, NH_4^+ content in injection was not significantly higher than that in 10cm away and broadcast. This difference existed until the end of the first month and then disappeared during the second month. Also there was a significant reduction in the mean value of ammonium at the end of experiment compared with that at the beginning of the application at the topsoil (Table 4.3c). On the other hand, no difference was found in the subsoil among placement methods.

Table 4.3: Effects of tillage systems and time lapse after effluent application on ammonium at two soil depths (mg kg^{-1} soil)

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0–10	18.8	13.4	12	3.7
10 – 20	9.06	6.4	5.23	3.3
$LSD_{(0.05)}$	2.3	3.7	2.9	
(b)NT				
0 –10	12.53	9.9	8.5	3.2
10 –20	6.4	5.96	5.46	2.7
$LSD_{(0.05)}$	2.3	2.9	2.7	
(c)CT				
0 –10	9.9	6.95	6.02	2.7
10 –20	5.87	4	3.96	2.2
$LSD_{(0.05)}$	2.9	2.2	2.9	

Ammonium was formed by the conversion of organic form of N through soil microbial activities called mineralization (ammonification) process. In liquid effluent, the main component of N may be in the ammonium form. The proportion can be about 50% of total nitrogen contained in the effluent. Volatilization of ammonium was the main reason for the losses of nitrogen in soil.

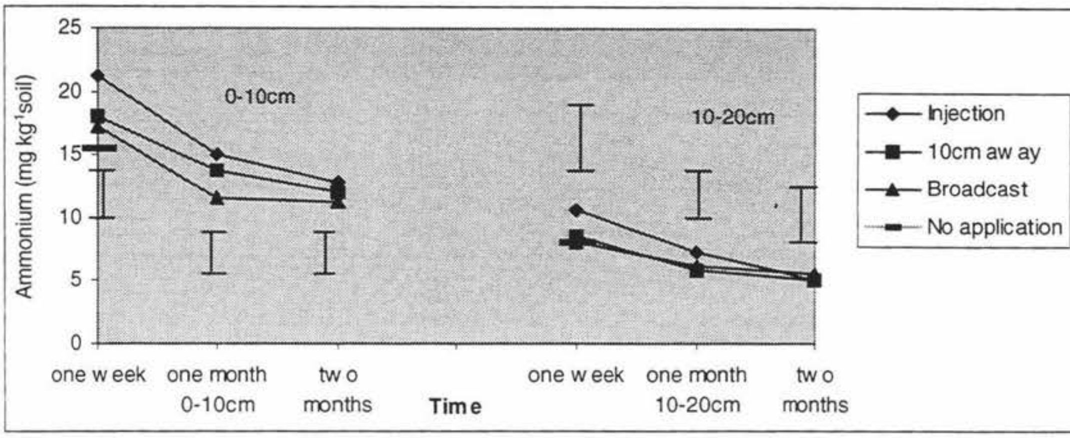


Fig.4.2: Effects of method of effluent application on ammonium in permanent pasture (Vertical bars show LSD at P=0.05)

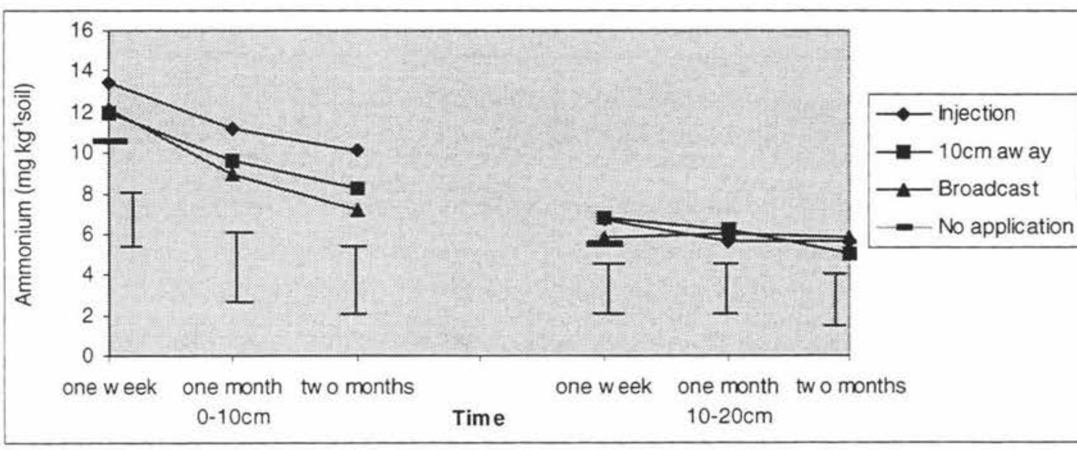


Fig.4.3: Effects of method of effluent application on ammonium in no-till (Vertical bars show LSD at P=0.05)

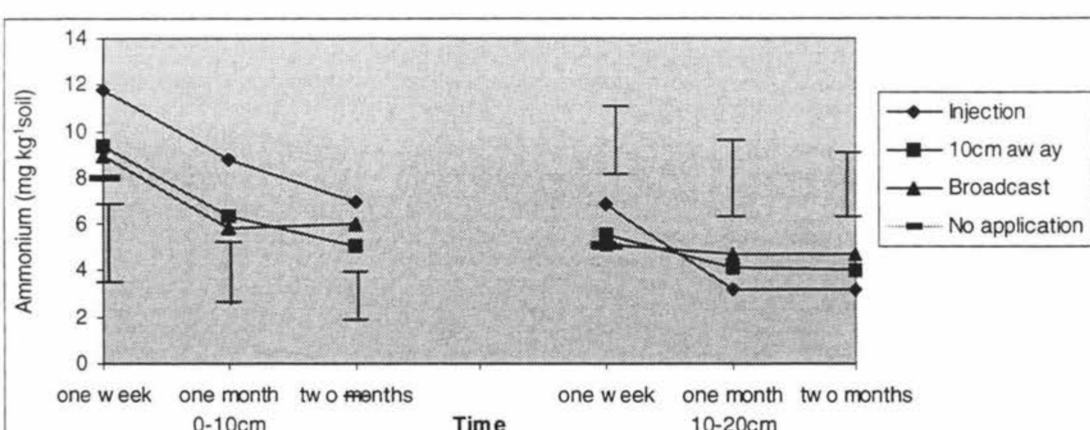


Fig.4.4: Effects of method of effluent application on ammonium in conventional tillage (Vertical bars show LSD at P=0.05)

No liquid effluent existed on the surface due to higher infiltration rate in the NT and PP after one week of application. This may reduce the losses of ammonium by runoff in these systems during winter. Therefore, no significant difference between placements was observed between the NT and PP. The higher level of ammonium in the groove centre compared with 10 cm away and broadcast method in CT during the first month indicated that ammonium was kept in the grooves such that it prevented losses through either volatilization or runoff. In contrast, effluent was still on the top of soil surface in CT resulting in ammonium losses by runoff. Level of ammonium in the subsoil, in both injection and broadcast method, did not change after effluent application because its movement in soil profile was slow. Beauchamp et al. (1983) had found that, in spite of rainfalls during their experimental period, only a small amount of ammonium applied on the surface was moved into 0-2 cm soil layer.

4.1.1.3 Nitrate

Permanent pasture

Nitrate content did not reduce after first month of application, then it significantly reduced during the second month of the experiment (Table 4.4a). Nitrate contents were similar in all placement methods irrespective of the depth (Fig. 4.5). Also nitrate levels in subsoil reduced slightly during the experiment but this reduction was not significant. On the other hand, there was a significantly lower level of nitrate in the subsoil compared with that in the topsoil.

No-till and conventional tillage

Nitrate decreased steadily over two months of application (Tables. 4.4b and 4.4c). However, no difference was found among placement methods. The data indicated that there was a higher level of nitrate in the topsoil compared with that in the subsoil during the experiment (Tables 4.4b and 4.4c). The same patterns were found in CT (Fig 4.7).

Table 4.4: Effects of tillage systems and time lapse after effluent application on nitrate at two soil depths (mg kg^{-1} soil)

Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
(a)PP				
0–10	2.2	2	1.37	0.27
10–20	1.41	0.97	0.74	0.23
$LSD_{(0.05)}$	0.32	0.34	0.41	
(b)NT				
0–10	2.3	2	1.51	0.25
10–20	1.5	1.13	0.86	0.28
$LSD_{(0.05)}$	0.27	0.14	0.29	
(c)CT				
0–10	2.1	1.78	1.3	0.22
10–20	1.3	1.1	0.6	0.21
$LSD_{(0.05)}$	0.36	0.36	0.29	

Nitrate was created from the nitrification process, in that ammonia was enzymatically oxidised by certain microorganisms in the soil. Under ideal temperature, soil and moisture conditions, nitrification occurs at a very rapid rate, especially where adequate ammonium ion are available and the nitrifying organism can supply nitrates at a rate that is more than the requirements of crop plants and may result in excess nitrates. Under normal condition, it takes two weeks for nitrate in effluent to appear in the soil. Among the mineral N species, nitrate has greater leaching potential than ammonium because it is very mobile in soil and can be leached during high rain or irrigation. The leaching increases when nitrate is generated in soil in excess of the amount required by plants (Selvarajah, 1996).

Organic carbon is essential substrate for denitrification. Organic matter improves water retention in soil, so any increase in added organic matter, and hence carbon, may promote denitrification. However, adding organic material also improves soil structure, increases the porosity of heavier textured soils, and reduces the tendency for a soil to become anaerobic and denitrify.

In injection plots, nitrate conversion from ammonium was possibly reduced by leaching. On the other hand, it was likely that nitrate lost in broadcast method was by runoff. Moreover, the low apparent recoveries of N may suggest denitrification losses (Smith and Unwin, 1983). Thus, there was no differences in nitrate level in injection and broadcast. The application of liquid effluent in wet soil would increase the denitrification process because rich organic carbon would be easily available for soil microorganisms and could be used as an electron acceptor in the denitrification process by denitrification bacteria (Chaussod, 1983). This causes the losses of nitrate and enhanced volatilization of nitrous oxide and nitrogen gas (N_2O and N_2) (McLaren and Cameron, 1996). This process readily occurs in poorly drained soils (Singleton and Barkle, 1995).

The present results were not similar to other studies. Other researchers have reported that, nitrate content in soil increased about one month after application of liquid effluent. In the present experiment, amount of ammonium was low due to low rate of effluent application resulting in low nitrate content in soil. Low level of ammonium in the second month resulted in low nitrate which was released from the nitrification process. Therefore, nitrate in soil significantly reduced by leaching or runoff during the second month. Moreover, losses of nitrate by runoff and leaching are high when soils have low permeability or they are saturated with water during winter (Steenvoorden, 1981). Low ammonium level and reduced microbial activities were the main reasons for the low level of nitrate content in the subsoil.

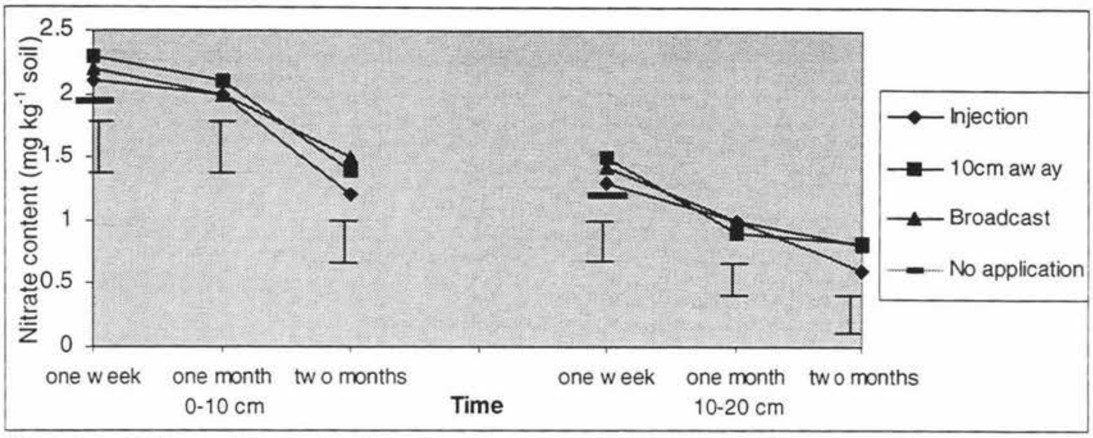


Fig. 4.5: Effects of methods of effluent application on nitrate in permanent pasture (Vertical bars show LSD at P=0.05)

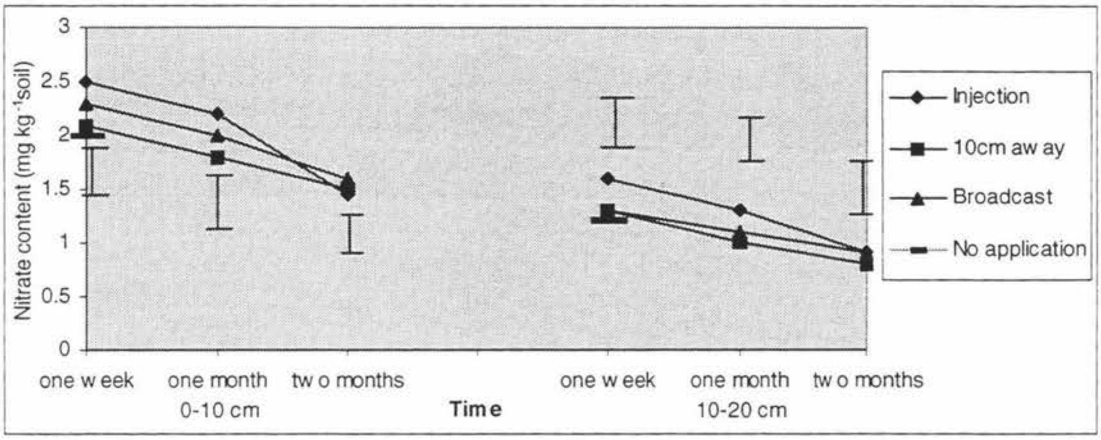


Fig. 4.6: Effects of methods of effluent application on nitrate on no till (Vertical bars show LSD at P=0.05)

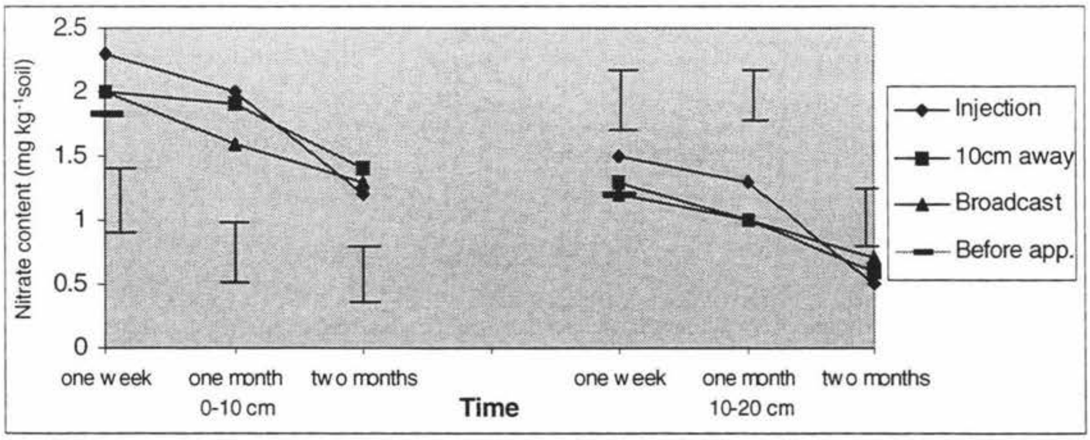


Fig. 4.7: Effects of method of effluent application on nitrate in conventional tillage (Vertical bars show LSD at P=0.05)

4.1.1.4 Total phosphorus

Permanent pasture

Total phosphorus did not change two months after application both in the topsoil and subsoil (Table 4.5a). Also, there were no significant differences among placement methods (Table 4.6). There was significantly higher total P content in the surface soil than that in the subsoil.

No-till and conventional tillage

Similar patterns were found in NT and CT (Tables 4.5b and 4.5c). Total P did not change 2 months after application in both topsoil and subsoil irrespective of placement method (Tables 4.6). There was a significantly higher level of total P in the topsoil compared with that in the subsoil both in the NT and CT during the experiment (Tables 4.5b and 4.5c).

Total P in all soil treatments did not significantly change during the experiment suggesting that in long term phosphorus levels remained stable long term in soil. Baker et al. (1975) stated that it was widely recognized that phosphorus was strongly held by most soil, and the losses in subsoil and groundwater runoff were insignificant. Also leaching of P is generally low due to sorption of P by P-deficient sub-soils. Moreover, because there was no crop growing in winter so the total P lost through plant uptake was small. In addition, phosphorus in effluent existed in organic form and so its losses by runoff or leaching was small. Also, the leaching of phosphorus was normally low under silt loam soil (White and Sharpley, 1996). In addition, the losses of P were only high when soils were fertilized with relatively high rates of P to maintain optimal production.

The movement of phosphorus from the topsoil to subsoil is a slow process. Therefore phosphorus accumulation in the topsoil was significantly higher than that in the subsoil of NT and PP.

Table 4.5 Effects of tillage systems and time lapse after effluent application on total phosphorus at two soil depths (g kg^{-1} soil)

Soil depth (cm)	Time of application		
	One week	Two months	$LSD_{(0.05)}$
(a)PP			
0-10	0.70	0.7	0.02
10-20	0.55	0.54	0.03
$LSD_{(0.05)}$	0.04	0.03	
(b)NT			
0-10	0.69	0.67	0.03
10-20	0.56	0.56	0.04
$LSD_{(0.05)}$	0.04	0.04	
(c)CT			
0-10	0.64	0.63	0.04
10-20	0.58	0.58	0.03
$LSD_{(0.05)}$	0.03	0.04	

Table 4.6: Effects of methods of effluent application on phosphorus in permanent pasture

Depth (cm)	Time After application	Total phosphorus (g kg^{-1} soil)			
		Injection	10cm away	Broadcast	No application
0-10	One week	0.67 a	0.66 a	0.67 a	0.66 a
	Two months	0.65 a	0.65 a	0.66 a	0.65 a
10-20	one week	0.56 a	0.57 a	0.56 a	0.56 a
	Two months	0.56 a	0.56 a	0.56 a	0.55 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.1.1.5 Available phosphorus (Olsen P)

Permanent pasture and no-till

Levels of Olsen P in soil did not change in both the topsoil and subsoil during the experiment (Tables 4.7a and 4.7b). After application of effluent, the amount of Olsen P concentration in both injection and broadcast plots increased but not significantly (Fig. 4.8). However, placement methods had no effect on Olsen P levels in soil. The data also suggested that there was a higher level of Olsen P in the topsoil compared with that in the subsoil. Similar results were obtained in no-till (Fig. 4.9).

Table 4.7: Effects of tillage systems and time lapse after effluent application on Olsen P (mg kg^{-1} soil) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0 – 10	24.1	23.1	22.2	2.6
10 – 20	14.5	13.4	13.2	1.9
$LSD_{(0.05)}$	2.1	2.7	2.6	
(b)NT				
0 –10	24.1	22.21	22.1	2.6
10 –20	13.8	12.4	13	2.3
$LSD_{(0.05)}$	2.3	2.8	2.1	
(c)CT				
0 –10	21.03	19.9	20.06	2.1
10 –20	15.06	14.9	14.6	2.2
$LSD_{(0.05)}$	2.5	2.1	2.9	

Conventional tillage

Data showed that placement method did not have any effect on the amount of Olsen P in soil (Fig. 4.10). Also, level of Olsen P in soil did not change after two months of application both in the topsoil or subsoil (Table 4.7). Similar to NT and PP, a higher level of Olsen P was found in the topsoil compared with subsoil during the experiment.

It is likely that, if broadcast method caused losses of available P by runoff, injection plots caused losses by leaching resulted in the same amount of Olsen P losses in two treatments. Phosphorus concentration and losses in natural subsurface flow were higher than that in tile drainage because the contact time of water flow with subsoil was longer for natural subsurface than for tile drainage (Culley et al., 1983). On the other hand, high moisture content and more rain during the winter months created larger amount of Olsen P losses when broadcast. Moreover, low infiltration rate in CT caused high amount of Olsen P loss though runoff. Gracey (1984) reported that the reason for the reduction in Olsen P when applying effluent was that P in the effluent did not have intimate contact with soil causing losses of Olsen P by runoff. However, low rate of effluent application made it difficult for any change of Olsen P to occur in soil.

The significantly higher level of Olsen P in the topsoil compared with that in the subsoil was possibly due to higher bioactivities in the surface soil and the application of annual fertilizer, which released more available P in the topsoil. Also phosphorus is strongly retained in the subsoil resulting in low level of Olsen P.

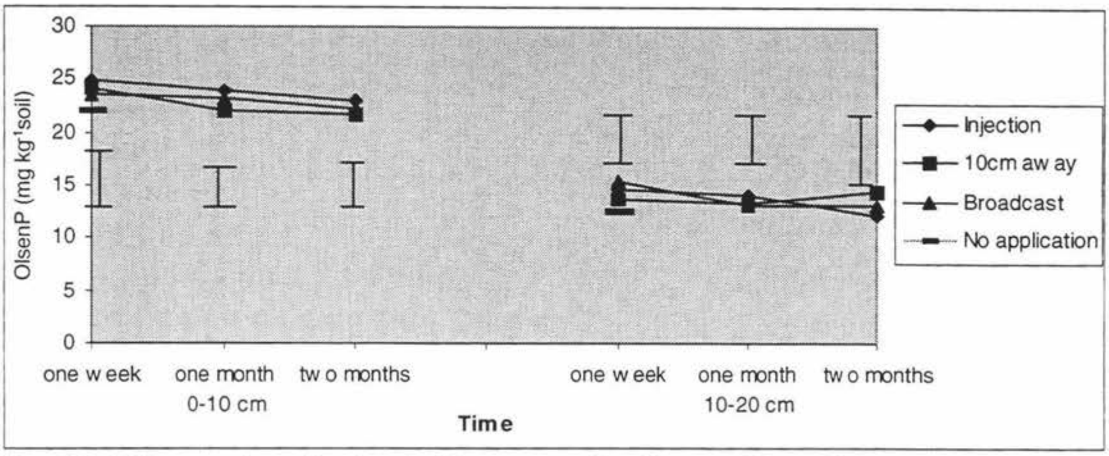


Fig. 4.8: Effects of methods of effluent application on Olsen P in permanent pasture (Vertical bars show LSD at P=0.05)

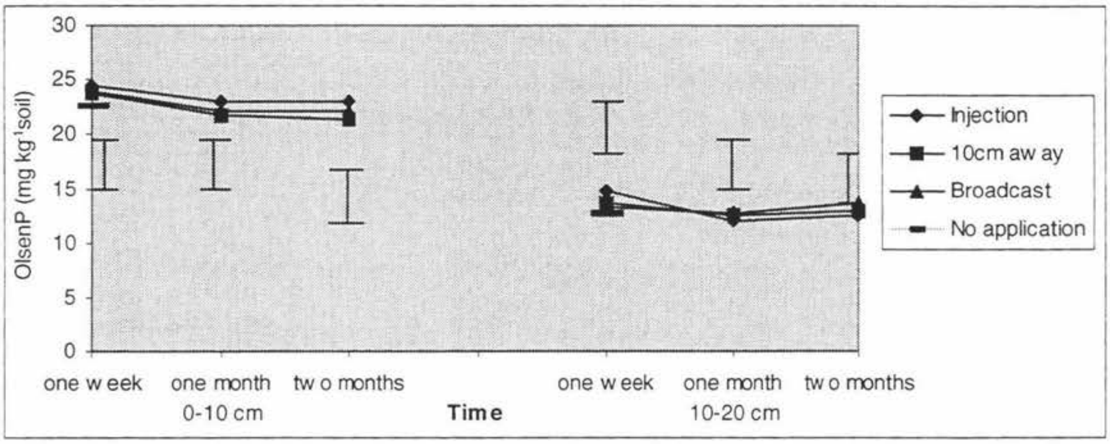


Fig. 4.9: Effects of methods of effluent application on Olsen P in no-till (Vertical bars show LSD at P=0.05)

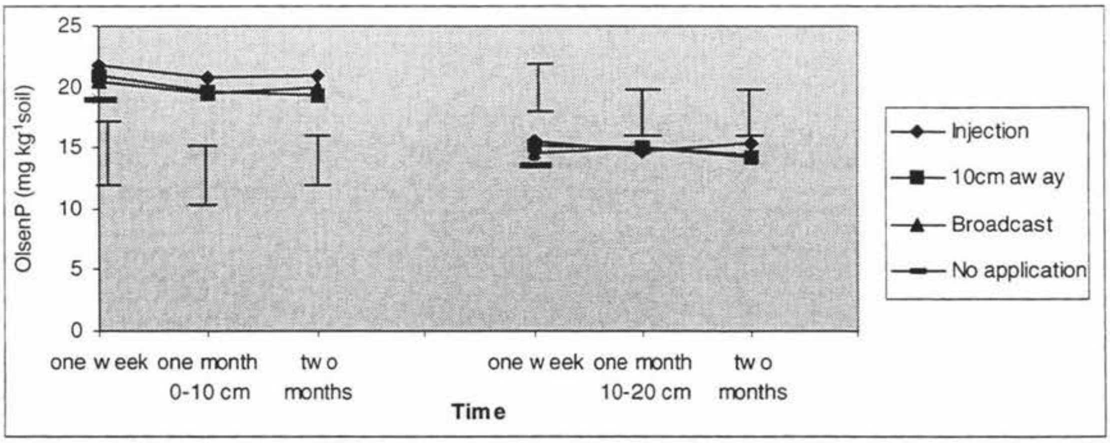


Fig. 4.10: Effects of methods of effluent application on Olsen P in conventional tillage (Vertical bars show LSD at P=0.05)

4.1.1.6 Exchangeable potassium (K^+)

Permanent pasture

After two months of effluent application, exchangeable K did not significantly reduce in both depths (Table 4.8a). Data obtained also indicates that after application of liquid effluent, exchangeable K in the surface soil of the centre of injection plots (0-10 cm depth) slightly increased compared with no application (Fig. 4.11). However, difference of K^+ among methods of effluent application was not significant. Also the topsoil had a higher level of exchangeable K than the subsoil.

Table 4.8: Effects of tillage systems and time lapse after effluent application on exchangeable K (mg kg^{-1} soil) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0–10	186	181.6	179	12
10 – 20	89.26	85	79	15.3
$LSD_{(0.05)}$	16.1	15.6	18.5	
(b)NT				
0 –10	191.1	186.6	185	14.2
10 –20	92.72	84.81	87.1	17.6
$LSD_{(0.05)}$	13.1	15.4	16.2	
(c)CT				
0 –10	173.3	170	167	12.8
10 –20	98.37	91.41	93.3	11.3
$LSD_{(0.05)}$	14.2	13.7	11.7	

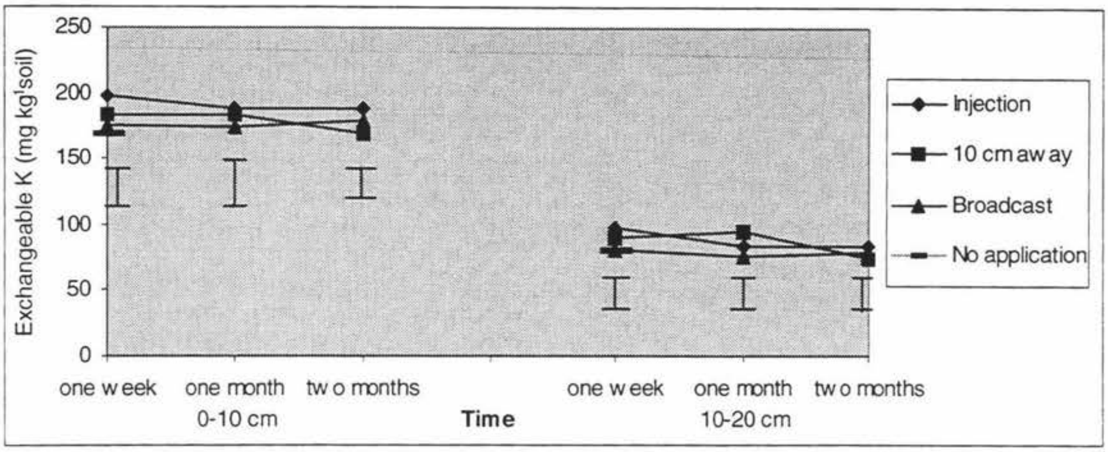


Fig. 4.11: Effects of methods of effluent application on exchangeable K in permanent pasture (Vertical bars show LSD at P=0.05)

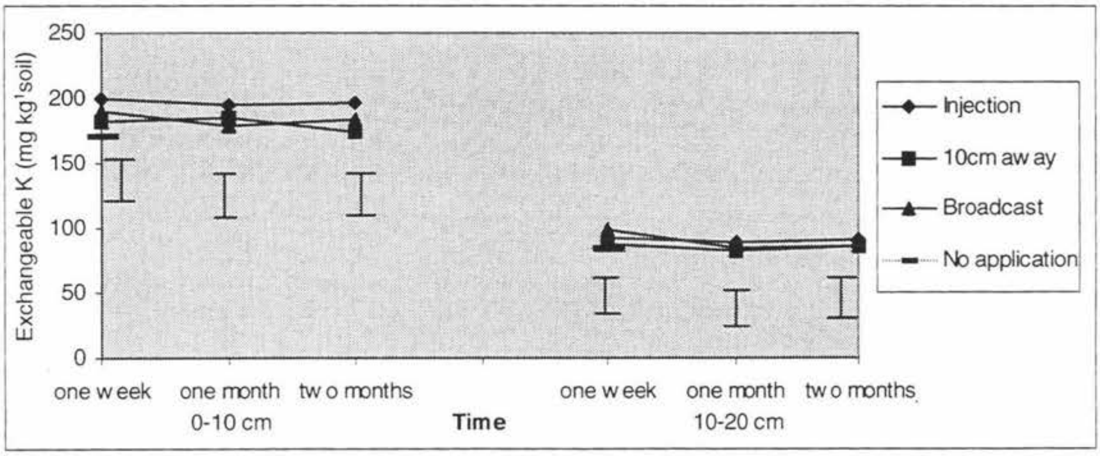


Fig. 4.12: Effects of methods of effluent application on exchangeable K in no-till (Vertical bars show LSD at P=0.05)

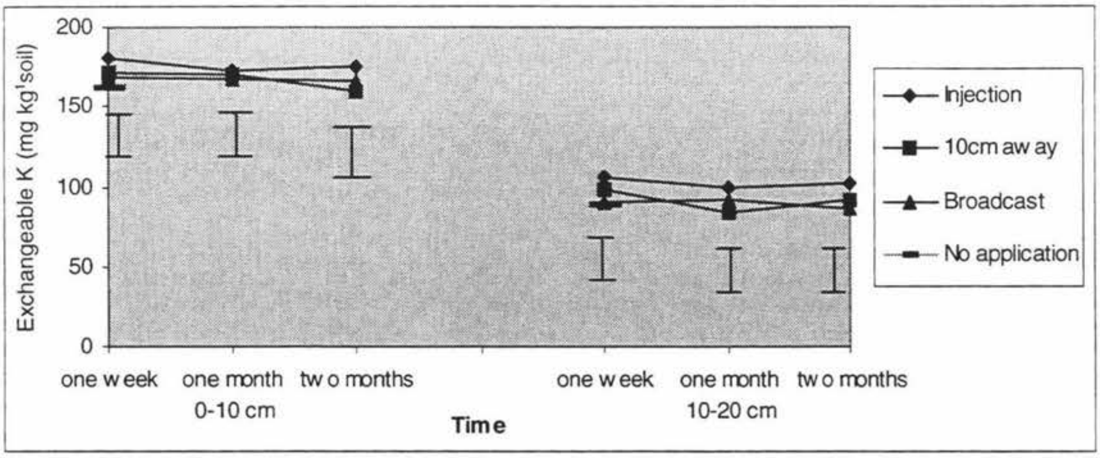


Fig. 4.13: Effects of methods of effluent application on exchangeable K in conventional tillage (Vertical bars show LSD at P=0.05)

No-till and conventional tillage

Similar results were achieved in the NT and CT as that in the PP. No difference was found between placement methods (Figs. 4.12 and 4.13). Also the topsoil retained more K^+ than the subsoil (Tables 4.13b and 4.13c). In addition, changes in K^+ content in the soil were not significant after two months of effluent application.

Water soluble and exchangeable K in soil together comprise the readily plant available K. Exchangeable K is readily replaced by other cations such as Ca, Mn, Mg, so it is readily available for plant uptake. The main reason for K^+ reduction was due to plant uptake and leaching. Leaching losses of K^+ vary according to soil type, soil chemical properties (Williams, 1988).

Because effluent has a considerable amount of K^+, it slightly increased in the soil in the centre of the groove after application. The application of liquid effluent can increase the soil pH (Youwei, 1997). When pH increased, there was new charge from the constant potential surface colloids. Thus greater retention is created and caused in a concomitant increase in K^+ adsorption resulting in low amount of K^+ lost by leaching. Also at higher pH, the K^+ ions can get the sites from Ca and H_3O^+ (Munson, 1985) resulting in the reduction of K^+ in soil solution. Moreover, when the soil pH is increased in the absence of Ca^{++}, the increased CEC can increase the amount of K^+ adsorbed from the soil solution and reduce K^+ leaching (Bolan et al., 1988). In addition, K^+ lost by plant uptake was small because there was no crop during this time. Therefore, exchangeable K did not significantly reduce two months after of application.

Higher level of crop residue in the topsoil was a possible reason for the higher release of exchangeable K in the soil surface compared with the subsoil in all treatments.

4.1.2 Effects of land preparation on soil nutrient contents

4.1.2.1 Total nitrogen

There were no significant differences between methods of effluent disposal, therefore these data were pooled. Data obtained shows a higher total N in the PP compared with that in the NT which was higher than the CT, both after one week and two months after the application in the topsoil. Also, total P in the NT was higher than in the CT. However, no difference was found in the subsoil (Table 4.9).

The significantly higher levels of total N in the PP and NT compared with that in CT was due to the higher initial levels of nitrogen content in the PP and NT in no application (3.36, 3.17, 3.02 g kg^{-1} soil in PP, NT and CT respectively). The higher level of nitrogen in the PP and NT compared with CT has been reported by many researchers (Dick, 1983; Follet and Peterson, 1988; Lal et al., 1990; Horne et al., 1992; Karlen et al., 1994). Aslam (1998) concluded that CT cropping caused marked decline in soil surface organic matter, which reflected in low total N content. Moreover, nitrogen applied by effluent was converted to organic N or easily incorporated into microbial biomass N, and created net immobilization which reduced the losses of N by leaching and runoff in the PP and NT (Trehan, 1994).

In the NT and PP, no soil disturbance resulted in fertilizer accumulation in the soil surface. Thus the higher level of total N in the PP and NT compared with that in CT was only observed in topsoil. Whereas, fertiliser in CT was mixed in soil profile causing a slightly higher level of N in the subsoil of CT although this difference also was not significant.

Table 4.9: Tillage method effects on total soil nitrogen

Depth	Time	**Total nitrogen (g kg^{-1} soil)**		
(cm)	after application	PP	NT	CT
0-10	one week	3.37 a	3.20 b	3.03 c
	two months	3.35 a	3.17 b	3.01 c
10-20	one week	2.42 a	2.43 a	2.46 a
	two months	2.42 a	2.43 a	2.45 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.1.2.2 Ammonium

Injection method

Land application methods have a significant effect on ammonium content. The highest level of NH_4^+ was found in the PP. The ammonium concentration was in the order of: PP>NT=CT. These patterns were similar whether measured in the middle of the groove or 10 cm distance. However, the level of NH_4^+ in the subsoil was not significant between application methods. (Figs. 4.14 and 4.15).

Broadcast method

The highest level of ammonium was found in the PP than in the NT and CT in the topsoil. Also amount of ammonium concentration in soil steadily reduced over period of two months of the application (Fig. 4.16). In addition, placement did not have effect on ammonium content in the subsoil even there was a slightly higher amount of ammonium in the PP plots compared with NT and CT after one week of application.

It is likely that the absence of cover (fallow crop) in CT causes more ammonium losses than the PP due to leaching and runoff. Other researches have suggested that the rate of ammonium leaching on fallow soil more than from grassland because of the absence of cover on the soil surface. The cover crops can reduce erosion and NH_4^+ leaching by incorporating the N into biomass. Therefore, ammonium in the PP was higher than that in the CT. In addition, the reduction in ammonium during the time of application suggests that a part of ammonium in effluent was converted to nitrate by the nitrification process.

Topsoil can hold more ammonium content than subsoil. The reason for this was that in the topsoil there is a high amount of nitrogen and more microbial activities, which can create net mineralization (McLaren and Cameron, 1996) causing higher ammonium content in the topsoil.

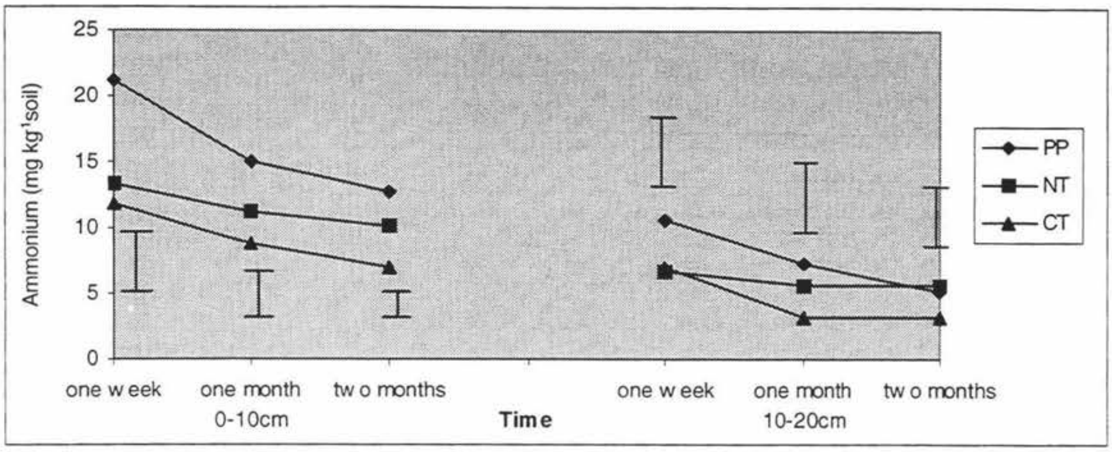


Fig. 4.14: Interaction between tillage systems and effluent application by injection method on ammonium (at the centre of the groove). Vertical bars show LSD at P=0.05

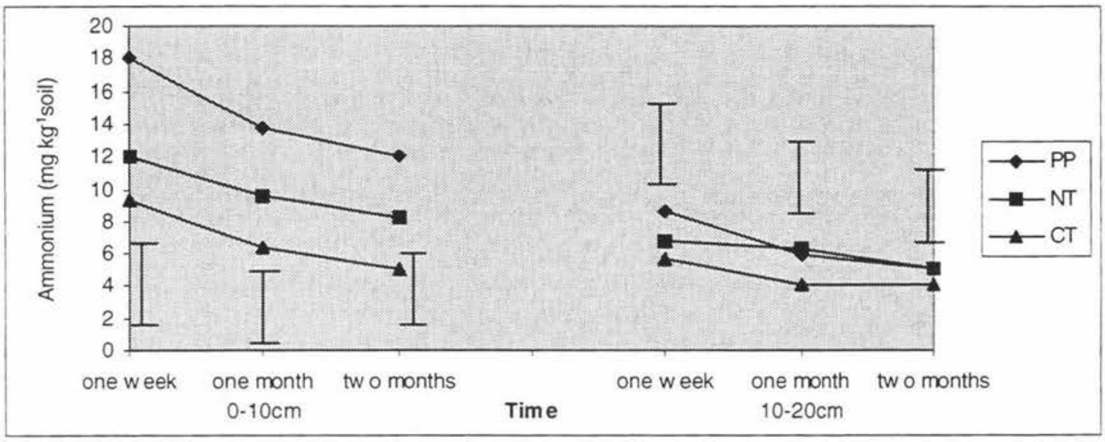


Fig. 4.15: Interaction between tillage systems and effluent application by injection method on ammonium (10 cm away from the groove). Vertical bars show LSD at P=0.05

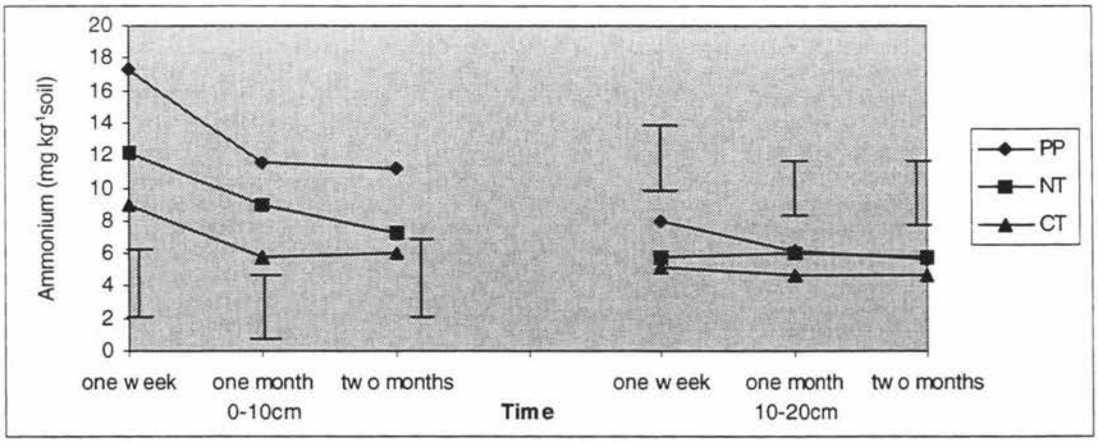


Fig. 4.16: Interaction between tillage systems and effluent application by broadcast method on ammonium (Vertical bars show LSD at P=0.05)

4.1.2.3 Nitrate

Injection method

No difference in nitrate content was found among tillage systems during the experiment both in the centre and 10 cm away from the groove (Fig. 4.17). Level of nitrate concentration slightly reduced during the first month of application, and then significantly decreased during the second month. In the subsoil (10-20 cm depth), reduction in nitrate was observed after two months of application. Similar trends were observed in NO_3^- concentration of 10 cm away from the groove (Fig. 4.18).

Broadcast method

There was a slightly higher level of nitrate in the PP and NT compared with that in the CT although it was not significant during all the time of the experiment (Fig. 4.19). Also the changes in nitrate in the subsoil were not significant with all tillage systems.

Many studies have reported that nitrate content under the PP and NT was lower than that in CT due to leaching during winter (Rice and Smith, 1982; Broder et al., 1984; Lamb et al., 1985). This was probably caused by higher macropres in the NT and PP compared with the CT and resulted in more nitrate lost by leaching. However, in this experiment, nitrate level under different tillage systems was similar. These results were similar to Angle et al. (1993). They suggested that the lack of winter crop on CT plots affected the soil N content in root zone and the subsequent increasing rate of N leaching. Earlier, Groffman (1985) also reported that because of the high soil moisture, there was no difference in nitrification activities between CT and NT during winter season. The cover crops reduced erosion and NO_3^- leaching by incorporating the N into biomass. Moreover, grass provides a permanent cover and generally absorbs N whenever mineralization is occurring such that grassland is potentially a less "leaky" system than arable farming. In addition, the amount of nitrate losses in this time was low because low rate of application did not cross the "break-point" rate of application to soil. Only over that point, nitrogen will accumulate in the soil and be a potential risk for leaching by winter rainfall.

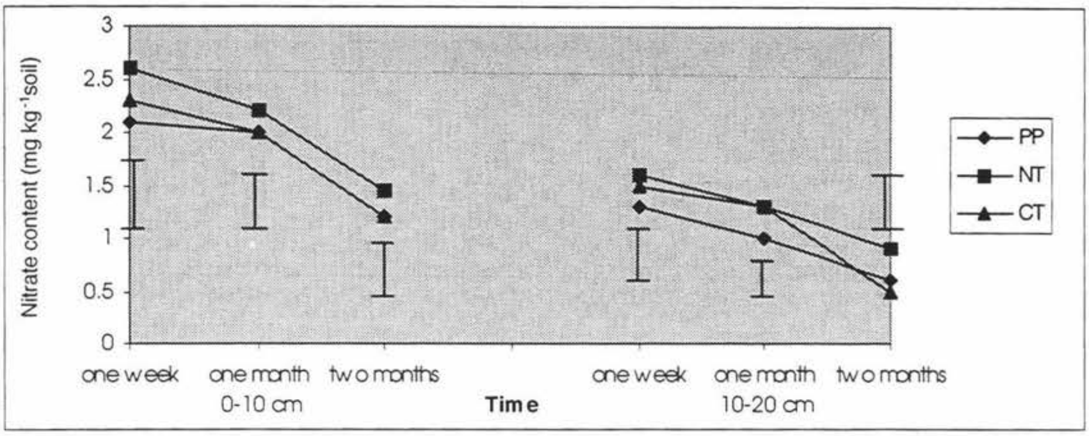


Fig. 4.17: Interaction between tillage systems and effluent application by injection method on nitrate (at the centre of the groove). Vertical bars show LSD at P=0.05

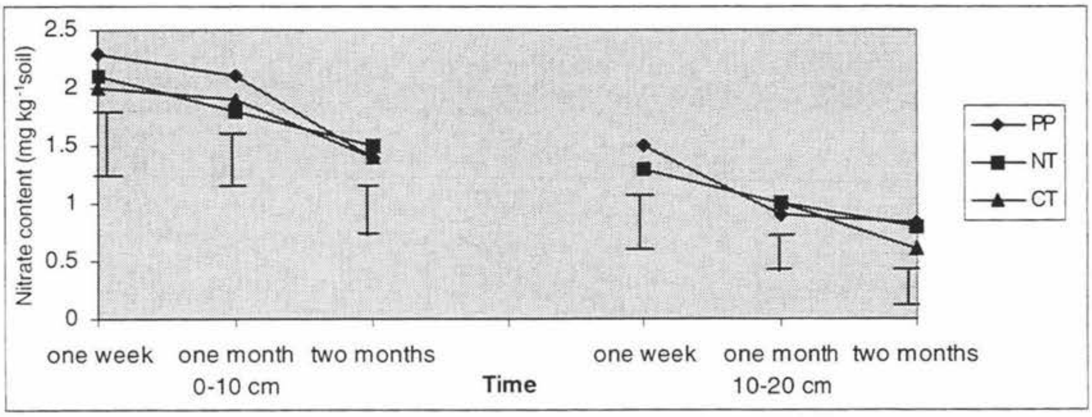


Fig. 4.18: Interaction between tillage systems and effluent application by injection method on nitrate content (10 cm away from the groove). Vertical bars show LSD at P=0.05

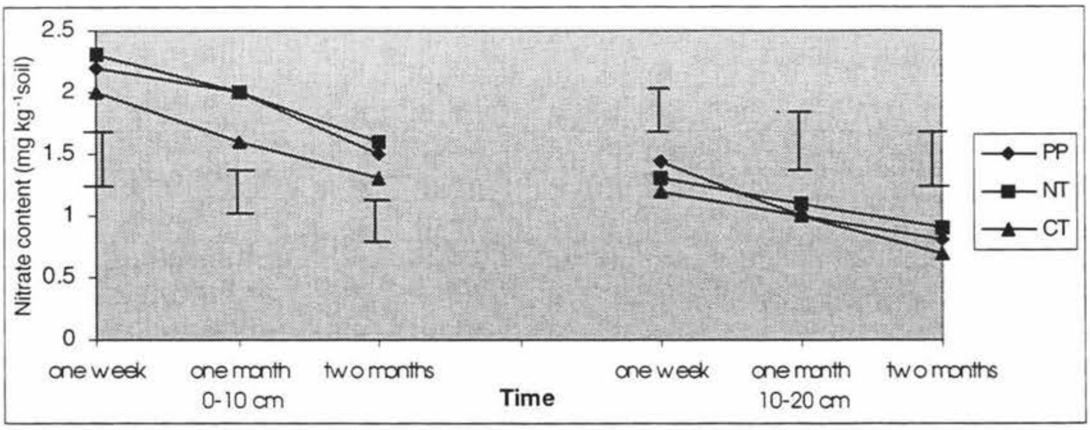


Fig. 4.19: Interaction between tillage systems and effluent application by broadcast method on nitrate content (Vertical bars show LSD at P=0.05)

The level of NO_3^- concentration in the PP was similar to the NT and CT, but nitrate in the PP was likely to be taken up by growing grass. In contrast, nitrate in NT and CT would leach into waterways and affect water quality. Thus application of effluent in pasture during winter would have advantages compared with the discharge of effluent to fallow soils both under the NT and CT.

4.1.2.4 Total phosphorus

Injection method

There were no significant differences in total P between disposal methods hence these data were pooled together. Similar to the nitrogen, there was a significant effect of tillage systems on the phosphorus content (Table 4.10). The PP and NT had higher phosphorus content than CT during two months of the experiment. On the other hand, there were no differences in total P between cultivation methods in the subsoil. In addition, the total P content was not significantly reduced after two months of application in all treatments.

Table 4.10: Tillage method effects on soil total phosphorus

Depth	Time	**Total phosphorus (g kg^{-1} soil)**		
(cm)	after application	PP	NT	CT
0-10	One week	0.70 a	0.69 a	0.60 b
	two months	0.69 a	0.68 a	0.59 b
10-20	one week	0.55 a	0.56 a	0.58 a
	two months	0.54 a	0.56 a	0.58 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

The significantly higher level of total phosphorus in the PP compared with the CT was partly due to higher level of P in the PP before application (0.69, 0.68 and 0.59 g kg^{-1} soil in the PP, NT and CT respectively). Phosphorus is lost from land in runoff and through leachate. Because of its strong affinity for soil, most phosphorus is lost in the form of sediment-bound P in runoff and leaching of P is usually inconsequential (Logan, 1980; Nelson and Logan, 1983; Logan et al., 1991). Because runoff in CT was higher than in the NT and PP (Guo, 1997) the loss in total P in the surface of the CT was higher than the NT and PP resulting in lower of total P in the CT soil.

4.1.2.5 Available phosphorus

Injection method

Both in the centre of groove and 10 cm away, there was no significant reduction in Olsen P after two months of application compared with that at the beginning of the experiment (Figs. 4.20 and 4.21). Also, there was slightly higher Olsen P in the PP and NT compared with that in the CT but this difference was not significant. Similar patterns were obtained in the subsoil.

Broadcast method

Similar to injection, tillage systems did not have any effect on Olsen P content in soil during the experiment even though there was a slightly higher Olsen P content in the PP and NT compared with that in the CT (Fig. 4.22). Also, the levels of Olsen P in the subsoil were not significantly different under different tillage systems.

Because soil under the NT and PP has more residues than the CT, this can reduces soil sediment losses resulting in low Olsen P loss through runoff. However, soil under the NT and PP has more macropores than the CT and may cause higher Olsen P losse by leaching. In addition, lower microbial activities as well as lower absorption of liquid effluent in the CT resulted in low incorporation of available P in effluent with soil caused Olsen P loss through runoff in winter. All these factors resulted in no difference occuring Olsen P contents among tillage systems. Also, the application rate was low so the reduction of Olsen P in soil was not significant.

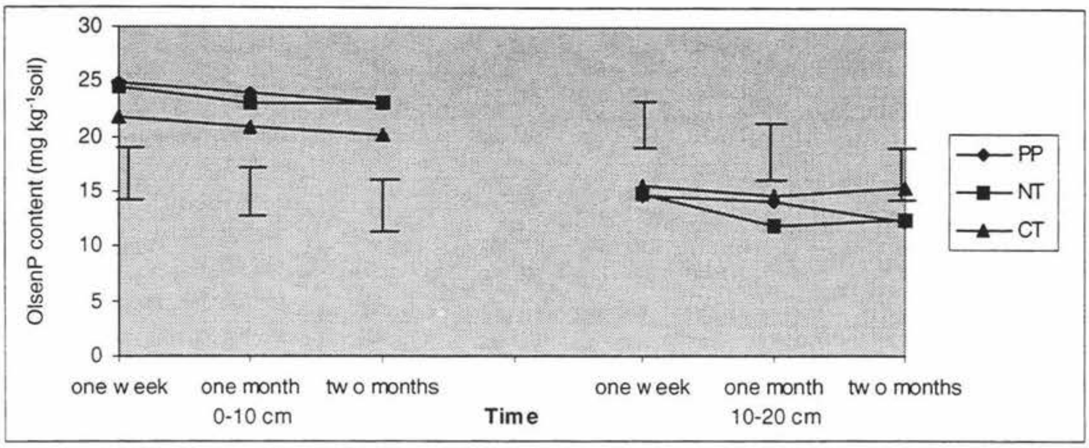


Fig. 4.20: Interactions between the tillage systems and effluent application by injection method on Olsen P (at the centre of the groove). Vertical bars show LSD at P=0.05

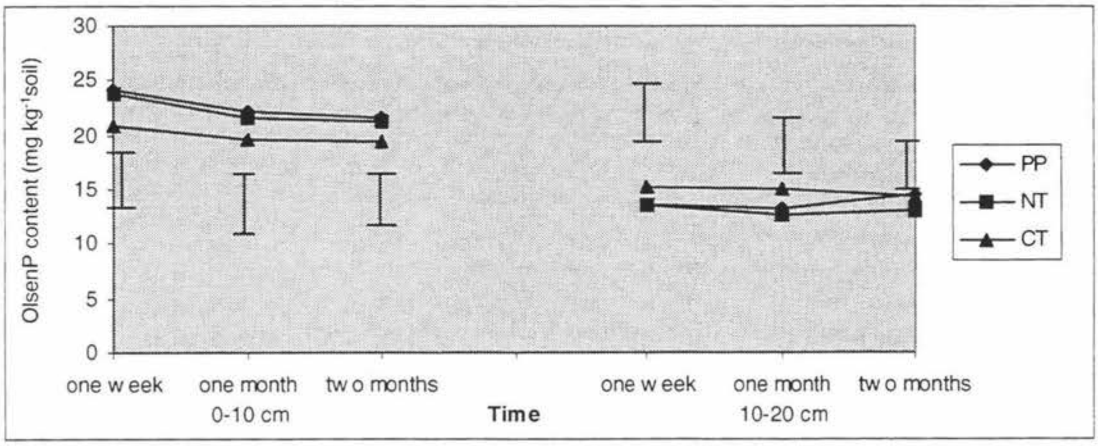


Fig. 4.21: Interactions between the tillage systems and effluent application by injection method on Olsen P (at 10 cm away from the groove). Vertical bars show LSD at P=0.05

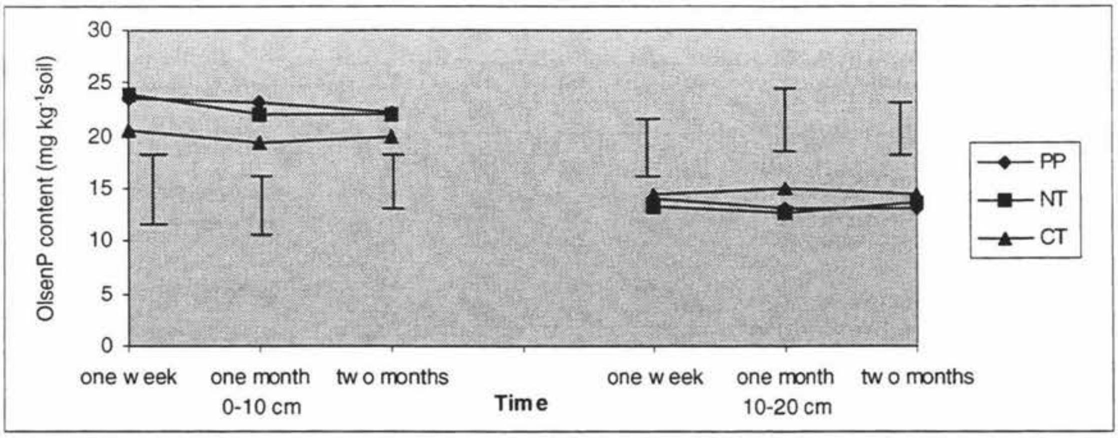


Fig. 4.22: Interactions between the tillage systems and effluent application by broadcast method on Olsen P (Vertical bars show LSD at P=0.05)

4.1.2.6 Exchangeable potassium

There were no significant differences in exchangeable potassium among the three tillage treatments during the experiment both in the topsoil and subsoil (Figs. 4.23, 4.24 and 4.25). Also, K^+ levels found in broadcast plots was similar to those in the injection method (Fig. 4.25).

Low rate of application is the likely reason for no difference occurring in K^+ content. Under normal condition, exchangeable K is lost in combination by both runoff and leaching. Residues left on the surface of the NT and PP soil may in long run increase preferential movement of exchangeable K through the soil profile causing significant losses of K^+. On the other hand, the CT did not indicate much movement of K^+ through soil profile (Munson and Nelson, 1963). However, higher losses of K^+ in the CT would likely to occur through runoff compared with the NT and PP. Because available K is held as exchangeable K on the colloid removed so the losses of K^+ are much larger with sediment in runoff (Olsen and Barber, 1977). Therefore, when effects of leaching and runoff in all tillage treatments were combined, K^+ content was similar among treatments. Even if there was same amount of K^+ lost in all tillage practices, the loss in the PP was mainly due to grass uptake. Thus, during winter, grassland did not limit the losses of nutrient but increased the efficiency of effluent.

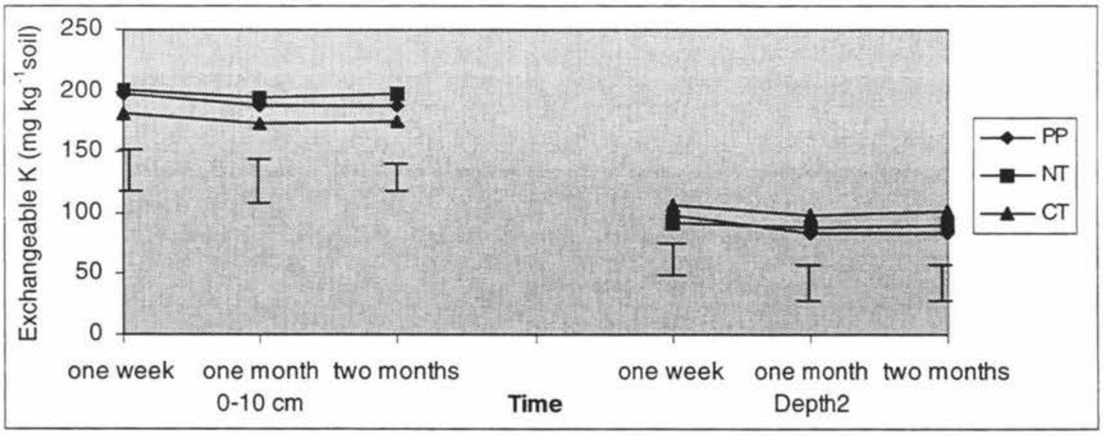


Fig. 4.23: Interactions between tillage systems and effluent application by injection method on exchangeable K content (at the centre of the groove). Vertical bars show LSD at P=0.05

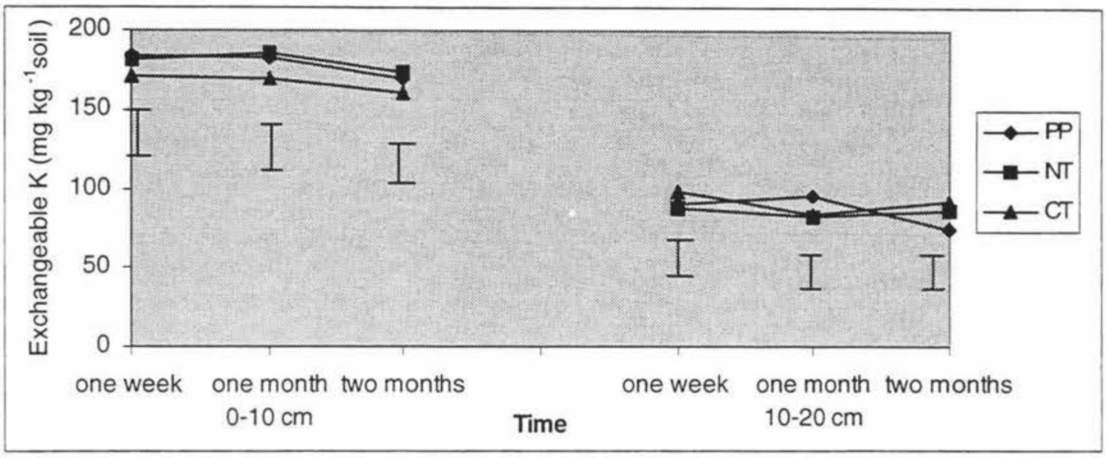


Fig. 4.24: Interactions between tillage systems and effluent application by injection method on exchangeable K (10 cm away from the groove). Vertical bars show LSD at P=0.05

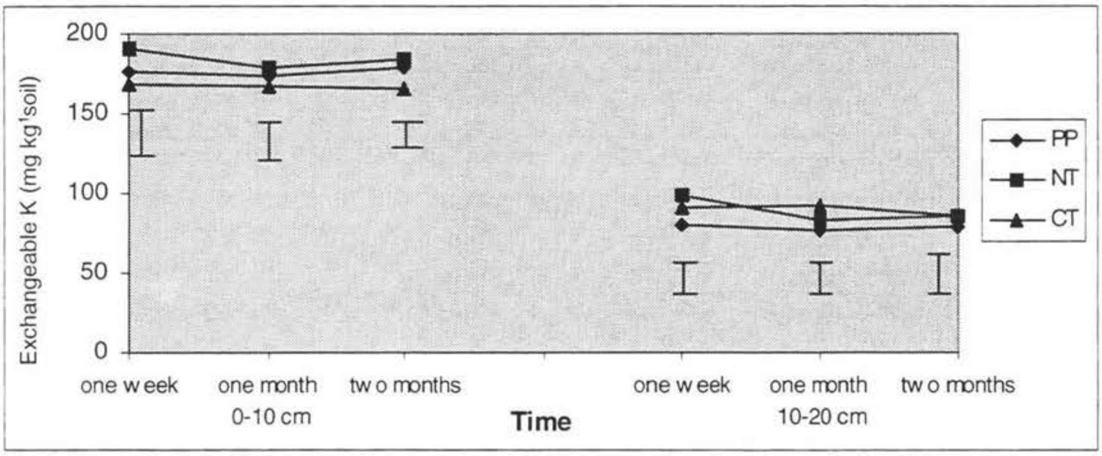


Fig. 4.25: Interaction between tillage systems and effluent application by broadcast method on exchangeable K (Vertical bars show LSD at P=0.05)

4.1.3 Summary

At the low rate of liquid effluent application, the following conclusions could be drawn.

1. Some nutrient concentration such as ammonium increased at the topsoil soon after one week of application.
2. During winter, effluent should not be surface-applied in CT because wet soil

condition limit absorption ability. The low infiltration is likely to cause "ponding" on the surface and the danger of nutrient losses through surface runoff.

3. Nutrients at the soil surface were, as expected, higher than that in the subsoil irrespective of whether effluent was injected or broadcast.
4. Almost nutrients were higher in the topsoil of the PP and NT as compared to the CT. However, there were no such differences at the 10-20 cm depth.
5. Concentration of NH_4^+, NO_3^-, reduced over a period of two months of measurement. Such losses of nutrient under fallow land could have been caused by leaching, volatilization or runoff, but these were not determined.

4.2 Experiment 2: High rate of effluent application (in summer)

In this experiment the effluent rate of application was $600m^3\ ha^{-1}$. This resulted in a nutrient loading of 150 kg N, 114 kg P per hectare. To ensure that there was no runoff from the treated plots, effluent was applied at a small dose for a number of times. In the PP and NT plots, soil absorbed all effluents after two applications over a day both by broadcast or injection. In the conventional tillage, it took 5 applications (over 2 and a half days). This is because the PP and NT have higher infiltration rate compared with that in the CT. Earthworm populations and plant roots are usually greater under the NT and PP than under the CT (Francis and Knight, 1993; Guo, 1997 and Aslam, 1998) and result in a greater number of earthworm and dead root channels in the NT and PP. Consequently, water infiltration rate in the PP and NT is higher compared with the CT.

Tillage that provides water stable aggregates at the surface and soil pores open to the surface is effective for achieving favourable infiltration. However, those aggregates often are unstable and soil dispersion and surface sealing may occur rapidly, thus causing a rapid decline in infiltration rate in the CT. This has a major impact on the efficiency of application system as this will reduce the number of passes if machines are used to applied effluent on the PP and NT. This will help to reduce effluent volatilization to ambient condition, and reduce soil compaction.

4.2.1 Placement method effects on nutrient content

4.2.1.1 Total nitrogen

Permanent pasture

Nitrogen level in the PP reduced after two months of application (Table 4.11a). After one week of application, there was a significant increase in total N in the injected plots compared with control (Table 4.12). However, the increase in total N at 10 cm away and broadcast was not significant compared with control and there was no difference between lateral spread at 10cm distance and broadcast. In contrast to the topsoil, the increase in the subsoil N was not significant and it did not change during the experiment. The data also suggested that total N content in the topsoil was significantly higher than that in the subsoil.

No-tillage and conventional tillage

Similar to the PP, there was a significantly higher level of total N in the centre of the injected grooves compared with that in control plots after one week of application. However, this difference disappeared at the end of the experiment. Total N in the topsoil reduced significantly after two months of application. Compared with topsoil, total N was lower in the subsoil in both injection and broadcast. Also, the method of effluent application did not affect nitrogen content in subsoil. Similar patterns were observed in the CT treatment (Table 4.11c).

Due to an adequate amount of N applied by liquid effluent (150 kg N ha^{-1}) there was an increase in total nitrogen in the centre of the injected groove. The main reason for reduced amount of total N in the topsoil between one week and two months of the experiment was due to nitrogen uptake by maize crop. With the maize dry matter yield of about 6 tonnes ha^{-1}, total nitrogen uptaken by corn was 60-100 kg ha^{-1} causing reduction in soil nitrogen. The volatilization of ammonium was likely another reason for reduced nitrogen in soil.

Table 4.11 Effects of tillage systems and time lapse after effluent application on total N at two soil depths (g kg^{-1} soil)

(a)PP			
Soil depth	**Time of application**		
(cm)	One week	Two months	$LSD_{(0.05)}$
0-10	3.42	3.33	0.09
10-20	2.25	2.23	0.06
$LSD_{(0.05)}$	0.1	0.12	
(b)NT			
0-10	3.32	3.27	0.05
10-20	2.23	2.21	0.06
$LSD_{(0.05)}$	0.09	0.11	
(c)CT			
1-10	3.08	3.01	0.06
10-20	2.36	2.34	0.05
$LSD_{(0.05)}$	0.05	0.06	

Table 4.12: Effects of method of effluent application on soil nitrogen

Depth	Time	**Total nitrogen (g kg^{-1} soil)**			
(cm)	After application	Injection	10cm away	Broadcast	Control
0-10	One week	3.32 a	3.28 ab	3.29 ab	3.19 b
	Two months	3.24 a	3.23 ab	3.19 ab	3.14b
10-20	One week	2.32 a	2.27 a	2.27 a	2.25 a
	Two months	2.30 a	2.25 a	2.24 a	2.26 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.2.1.2 Ammonium

Permanent pasture and no-till

Concentrations of ammonium significantly reduced after effluent application (Table 4.13a). One week after application of effluent, there was a significant increase in soil ammonium compared with that in the control plots and it was in the following order of: centre groove>10cm away=broadcast>control (Fig. 4.26). At the end of first month, ammonium content was higher than control only in the centre of injection plots but these differences disappeared at the end of experiment. In the subsoil, there was a significant increase in NH_4^+ after one week in injection plots compared with the control but these differences disappeared during the following months (Table 4.25a). Also, ammonium in the topsoil was significantly higher than that in the subsoil. There were similar trends in the NT (Fig. 4.27).

Table 4.13: Effects of tillage systems and time lapse after effluent application on NH_4^+ (mg kg^{-1} soil) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0 – 10	20.28	15.65	10.62	2.3
10 – 20	10.75	6.95	6.28	1.8
$LSD_{(0.05)}$	3.8	3.3	2.3	
(b)NT				
0 – 10	13.5	10.03	9.65	2.8
10 –20	8.53	7.15	7.03	2.6
$LSD_{(0.05)}$	2.6	2.3	2.1	
(c)CT				
0 –10	11.5	7.15	6.03	2.3
10 –20	7.2	4.05	3.35	2.1
$LSD_{(0.05)}$	3.1	2.8	2.1	

Conventional tillage

Amount of ammonium in the CT significantly reduced during the experiment (Table 4.13c). There was a significantly higher level of ammonium in all treatment plots compared with that in the control. However, this difference disappeared in all placement methods during following two months. Similar trends as those in the PP and NT were observed in the subsoil of the CT.

Surface-applied ammonium accumulation is quickly volatilized and this loss happens within several days after application of effluent (Thompson et al., 1987 and Vandermeer et al., 1987), especially under high temperature during summer. However, as expected, ammonium loss was significantly reduced in the groove of injection plots. This result is similar to those of Hoff et al. (1981) and Sutton et al. (1982), Hoff et al. has reported that 10 to 14% of applied ammonium was lost in broadcast application compared with a 2.5 % loss in injection plots.

In this experiments, during the second month, as ammonium was converted to nitrate, or was takenup by plants likely causing equal amount of ammonium remaining at the end of the experiment among placement methods (Fig. 4.28). Moreover, there might have been a decrease in ammonium due to immobilization. Manure or slurries are known to increase N immobilization as they contain easily decomposable C compounds with low N contents (Chapman and Heath, 1987).

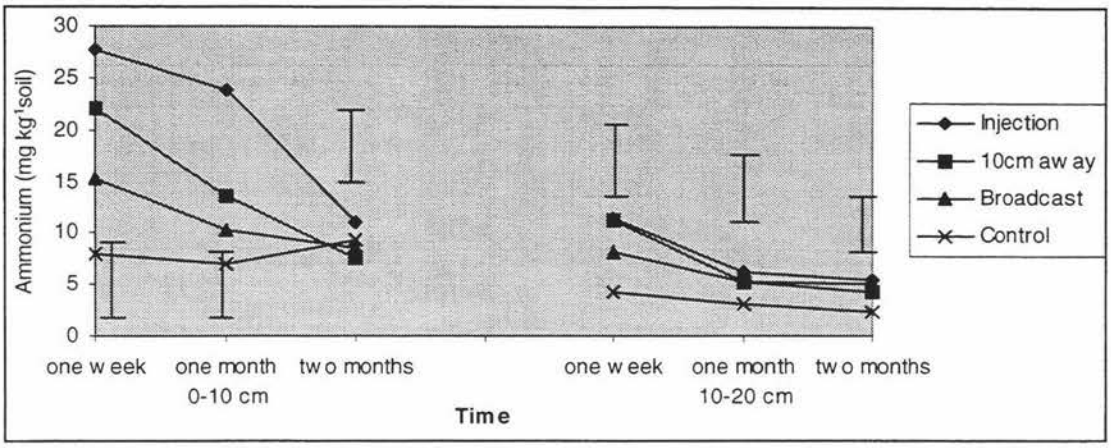


Fig. 4.26: Effects of methods of effluent application on ammonium in permanent pasture (Vertical bars show LSD at P=0.05)

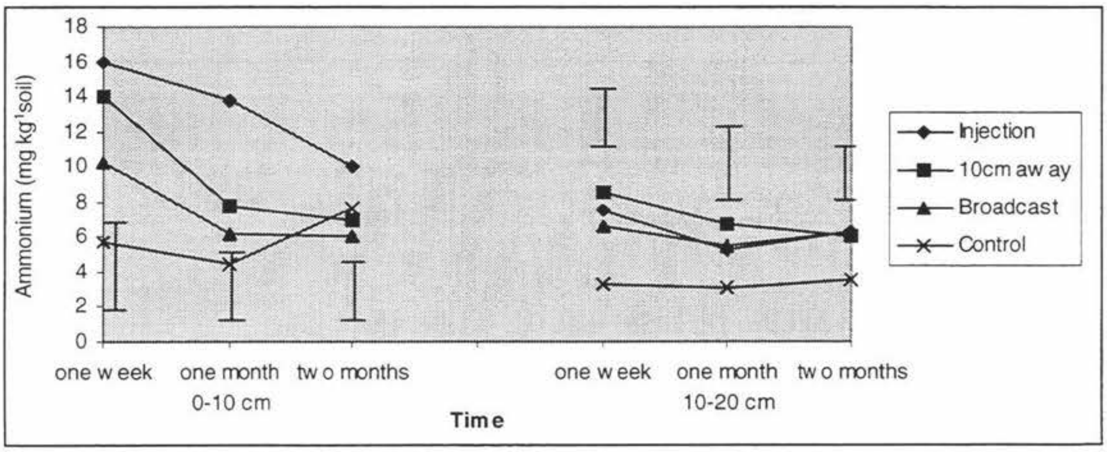


Fig. 4.27: Effects of methods of effluent application on ammonium in no-till (Vertical bars show LSD at P=0.05)

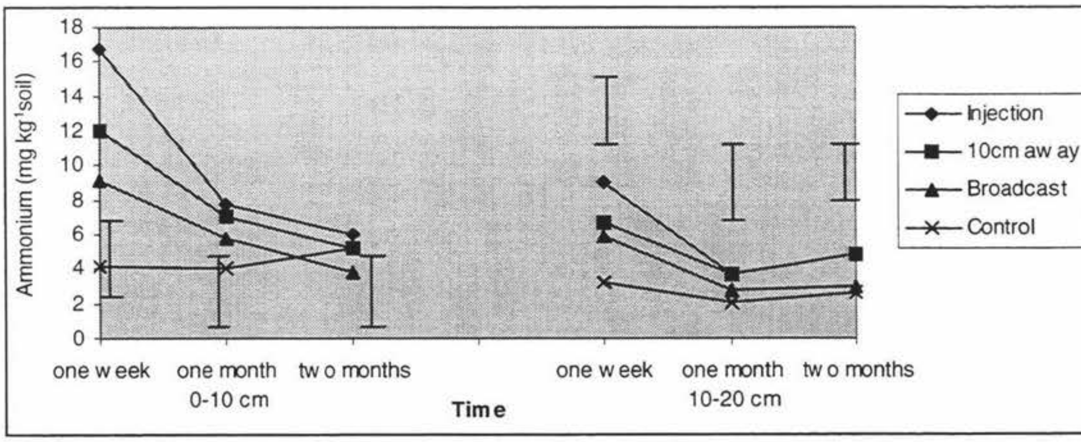


Fig. 4.28: Effects of methods of effluent application on ammonium in conventional tillage (Vertical bars show LSD at P=0.05)

4.2.1.3 Nitrate

Permanent pasture

Within one week of application, all treatments had similar amount of nitrate (Fig. 4.29). Nitrate levels significantly increased in treatment plots compared with that in the control at the end of first month after application and were in the following order: Broadcast>injection=10 cm apart>control. Then these levels significantly reduced during the second month of application. In the subsoil, nitrate level increased after one month of application both in the injection and broadcast. Then NO_3^+ value reduced during the second month of effluent application (Table 4.26a). Moreover, nitrate in the topsoil was significant higher than that in the subsoil during the first month but no differences was found at the end of the experiment (Table 4.26a)

No-till

Similar trends were found in no-till (Table 4.26b). There was an increase in nitrate concentration at the end of the first month of application effluent compared with control. However, no significant difference was found among different placement methods (Fig. 4.30). Also, nitrate levels increased during the second month in all treatments in the subsoil. However, no difference was found between the topsoil and the subsoil at the end of the experiment (Table 4.26b).

Conventional tillage

Nitrate content in the CT increased during the first month after liquid effluent application and then it reduced during the second month (Table 4.14c). Compared with control, there was a significantly higher level of nitrate content but no differences among treatments appeared (Fig. 4.31). In the subsoil, the level of nitrate content also increased after the first month of application. At the end of the first month, nitrate content in soil was higher in the injection plots compared with the broadcast plots. This situation existed until the end of the experiment.

Table 4.14: Effects of tillage systems and time lapse after effluent application on nitrate (mg kg^{-1} soil) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0–10	2.93	3.63	1.06	0.54
10–20	1.49	2.22	1.1	0.48
$LSD_{(0.05)}$	0.76	0.87	0.41	
(b)NT				
0 –10	3.78	4.96	2.87	0.45
10 –20	2.2	3.56	2.46	0.41
LSD	0.42	0.44	0.5	
(c)CT				
0 –10	3.97	5.1	3.68	0.42
10 –20	2.28	3.23	2.42	0.34
$LSD_{(0.05)}$	0.47	0.43	0.49	

The application of animal manures or slurries to soil are known to enhance losses of N through denitrification process due to the addition of easily decomposable organic compound (Paul and Beauchamp, 1989). Also, aerobic decomposition of these compounds causes a fast depletion of oxygen in the soil atmosphere, which favors development of anoxic microsites adequate for denitrification (Rice et al., 1988).

The considerably larger losses of nitrate from the injected slurry compared to that from surface applied slurry may be due to the presence in the soil of a larger quantity of inorganic N together with a large amount of added organic matter in a zone of more restricted aeration in injection plots (Thompson et al., 1989). However, losses through denitrifcation are usually lower than those through NH_3 volatilization. Comfort et al., (1990) reported that the losses of denitrification of injection of dairy effluent into soil ranged between 2.5-3.2 % of the slurry's NH_4^+ or 1.0-1.3 % of total applied N.

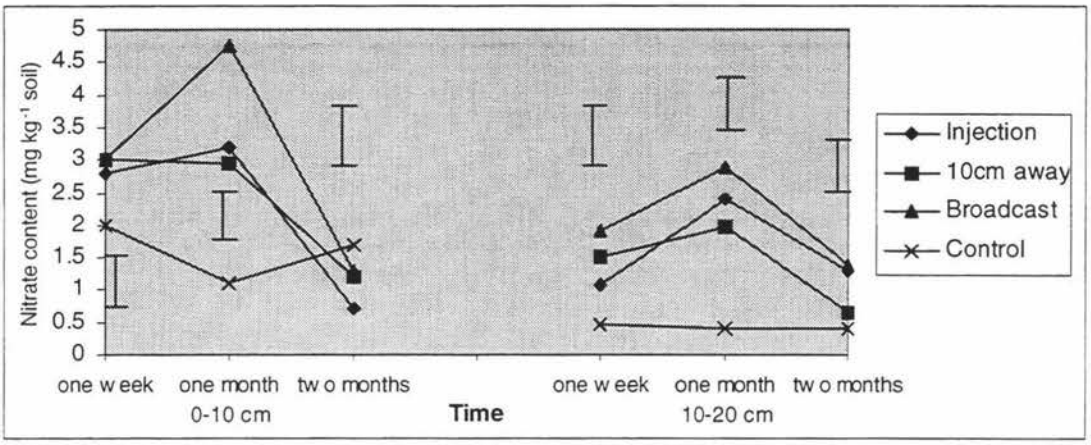


Fig. 4.29 Effects of methods of effluent application on nitrate in permanent pasture (Vertical bars show LSD at P=0.05)

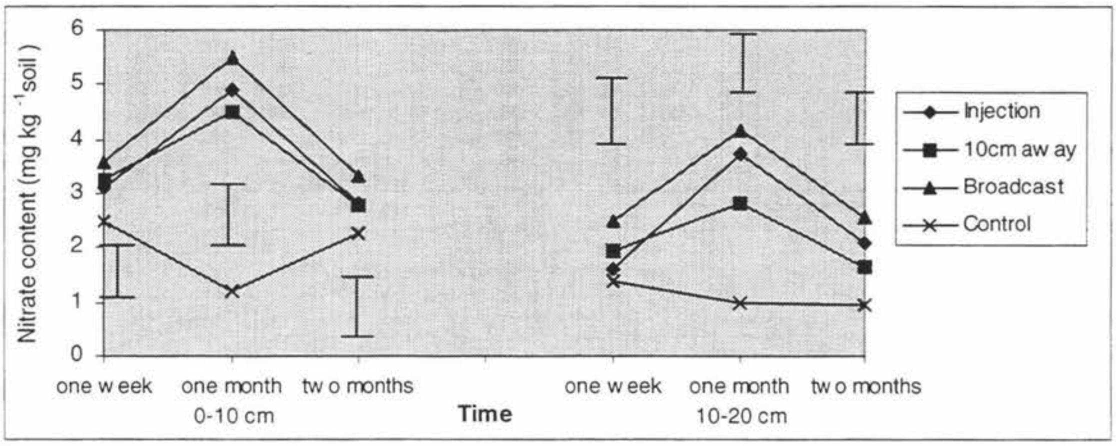


Fig. 4.30: Effects of method of effluent application on nitrate on no till (Vertical bars show LSD at P=0.05)

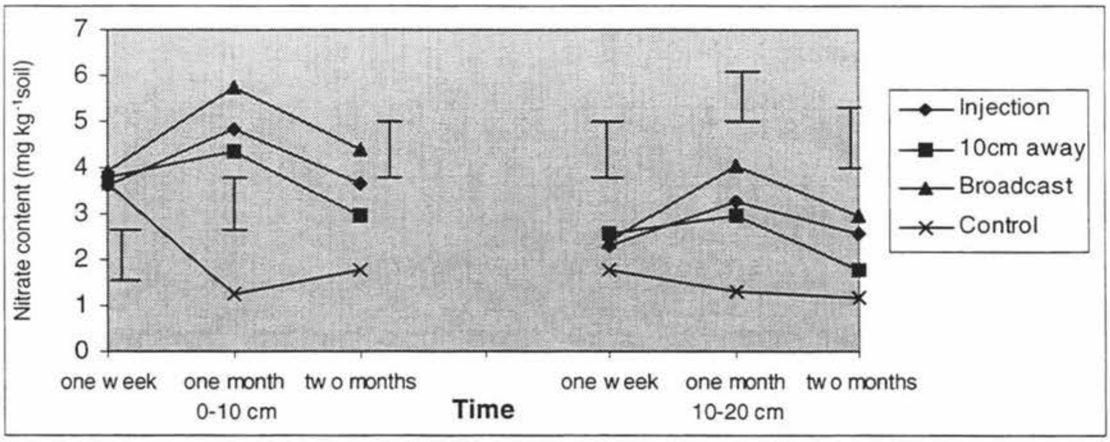


Fig. 3.31: Effects of methods of effluent application on nitrate in conventional tillage (Vertical bars show LSD at P=0.05)

During the second month, the amount of nitrate in all placements significantly reduced. This reduction was likely due to losses by plant uptake or by the denitrification process, in which nitrate converted to gaseous form and lost. It is apparent that the placement methods did not affect nitrate content in the NT and CT although injection method may potentially lead to increased N leaching (Steenwoorden, 1989).

It was also likely that since the depth of injection was only 10 cm it resulted in low nitrate leaching. This is not an unrealistic result. Shallow placement of liquid effluent in grass and arable crop is likely to benefit the uptake and retention of N by putting the effluent in close proximity to crop roots as well as leading to better utilization of applied N and smaller leaching losses (Choudhary, 1989). Similar results were obtained by Sneath and Phillips (1992) and Smith and Powlesland, (1990).

Because of high mobility of nitrate, there were downward movements of nitrate to the subsoil causing nitrate levels in subsoil layer similar to the topsoil at the end of the second month in the NT and CT plots.

4.2.1.4 Total phosphorus

There were no changes in phosphorus concentration at the end of the experiment compared with that at the beginning of the experiment in the PP (Table 4.14a). Data obtained indicated that, total phosphorus after 2 months did not significantly change compared with that in control treatment. Also total P in the topsoil (0-10 cm) was significantly higher than in the subsoil. At the subsoil, there was no effect of placement method on total P. Also the reduction in total P after two months of application was not significant (Table 4.15).

In New Zealand, soils generally have low available P status, and P fertilizer is usually applied at the time of planting crops. One of the important reactions of P with soil is that P movement is very slow in soil. Thus, there is very little phosphorus leached out of soil in water drainage or runoff (Sharpley, 1977; Sharpley et al., 1986). However, phosphorus in liquid effluent was reported to be much more mobile than in normal condition (Johnston, 1981; Furrer and Gupta, 1985). In addition, surface runoff and soil erosional losses of P applied fertilizers, animal manure and sewage sludge have potential risk of environmental pollution due to the contamination of surface water with phosphate.

Table 4.15 Effects of tillage systems and time lapse after effluent application on total phosphorus (g kg^{-1} soil) at two soil depths

(a)PP			
Soil depth	**Time of application**		
(cm)	One week	Two months	$LSD_{(0.05)}$
0-10	0.71	0.70	0.02
10-20	0.56	0.56	0.02
$LSD_{(0.05)}$	0.03	0.03	
(b)NT			
0-10	0.68	0.67	0.02
10-20	0.58	0.58	0.02
$LSD_{(0.05)}$	0.03	0.02	
(c)CT			
0-10	0.63	0.62	0.03
10-20	0.59	0.59	0.02
$LSD_{(0.05)}$	0.03	0.03	

However, the amount of application was low in these experiments (about 15kg of total P equivalent) so it was not unexpected to observe any changes in total P in these experiments. Moreover, during this season, low rainfall and dry soil also reduced the losses of phosphorus by runoff. These results were similar to those obtained by White and Sharpley (1996), who indicated that losses of manurial P happened only in the case of high rainfall immediately following application, or in circumstances of sandy soils or very acid peaty soils receiving high inputs of P.

Table 4.16: Effects of method of effluent application on total phosphorus ($g\ kg^{-1}$ soil)

Depth	Time	Total phosphorus			
(cm)	after application	Injection	10cm away	Broadcast	Control
0-10	one week	0.68 a	0.67 a	0.67 a	0.66 a
	Two months	0.67 a	0.66 a	0.66 a	0.65a
10-20	one week	0.58 a	0.58 a	0.58 a	0.57 a
	Two months	0.58a	0.58 a	0.57a	0.57 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.2.1.5 Available phosphorus (Olsen P)

Permanent pasture and no-till

Level of Olsen P in soil did not change during the experiment both in the topsoil and the subsoil (Table 4.16a). In both PP and NT, there was significantly higher level of Olsen P in application plots as compared to control during the second month of application and the Olsen P level was in the following order: injection>control and injection=broadcast=10 cm away (Figs. 4.32 and 4.33). In contrast, the difference between treatments in the subsoil was not significant. Also, Olsen P did not change over a two months period and the level of Olsen P in the topsoil was higher than that in the subsoil.

Conventional tillage

Similar to the PP and NT, there was a significantly higher amount of Olsen P in the application plots irrespective of placement methods (Fig. 4.34). In addition, there was a significant reduction in Olsen P after one month of the experiment

(Table 4.16c). No difference was found among treatment in the subsoil.

Table 4.17: Effects of tillage systems and time lapse after effluent application on Olsen P (mg kg^{-1}) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0 – 10	28.5	27.3	29.2	2.1
10 – 20	16.25	14.6	14.74	2.5
$LSD_{(0.05)}$	1.7	1.9	2.03	
(b)NT				
0 –10	27.7	26.28	27.58	1.9
10 –20	15.7	14.3	14.58	1.7
$LSD_{(0.05)}$	1.3	1.4	1.45	
(c)CT				
0 –10	25.1	21.3	22.6	2.3
10 –20	17.66	16.67	16.6	1.5
$LSD_{(0.05)}$	1.38	1.63	1.89	

Most of the P in effluent is inorganic P. Therefore, there was an increase in Olsen P in all placement methods during the first and the second month of effluent application as compared to control. Even after taking into account Olsen P by uptake by plants, Olsen P was released from biomass P and organic P, so its level did not reduce even after two months of application in the PP and NT plots. The reduction in Olsen P in the CT may result from the losses of Olsen P in runoff in the second month. Sharpley (1977) suggested that the major loss of P in surface runoff is associated with sediment, due to the high sorption capacity of soil material for P. Natural fertility and the application of fertilizer in previous crops resulted in the accumulation of available P in the topsoil in the NT and PP plots. On the other hand, fertiliser was mixed by ploughing before growing maize resulting in equal distribution of Olsen P in the topsoil and subsoil in CT plots.

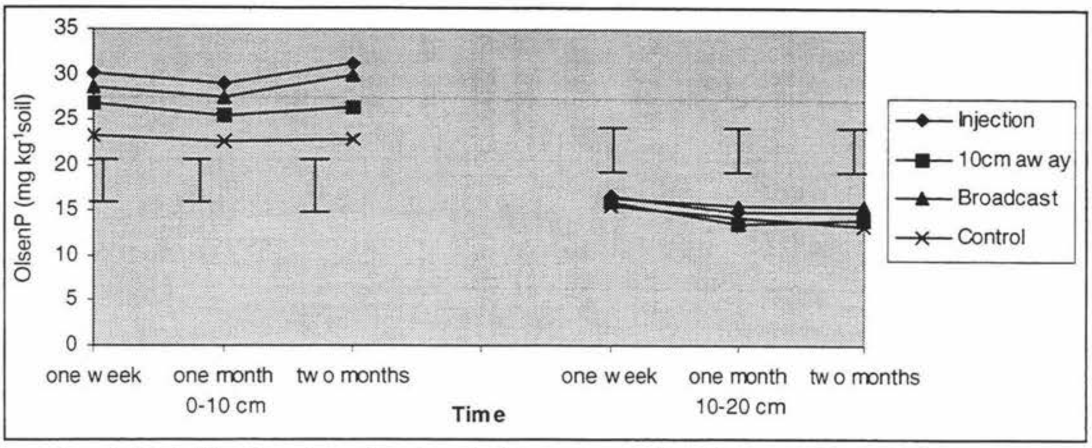


Fig. 4.32: Effects of methods of effluent application on Olsen P in permanent pasture (Vertical bars show LSD at P=0.05)

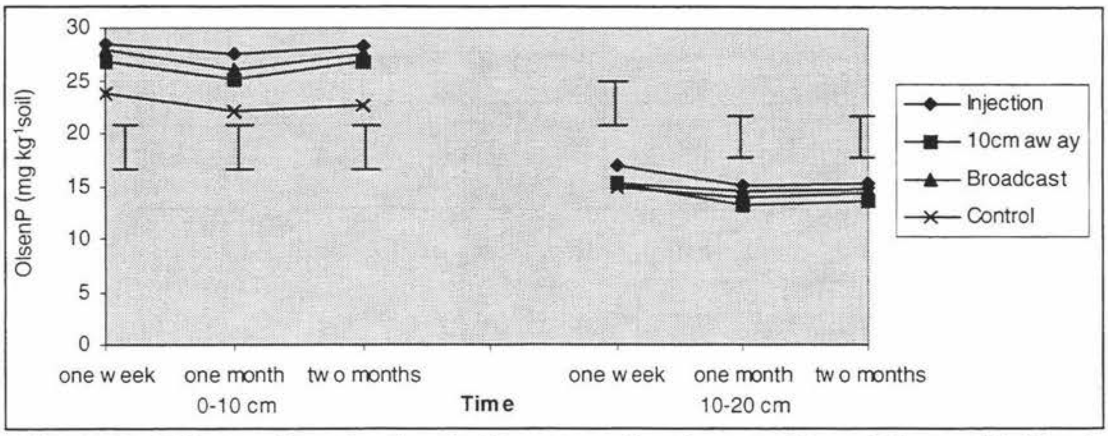


Fig. 4.33: Effects of methods of effluent application on Olsen P in no till (Vertical bars show LSD at P=0.05)

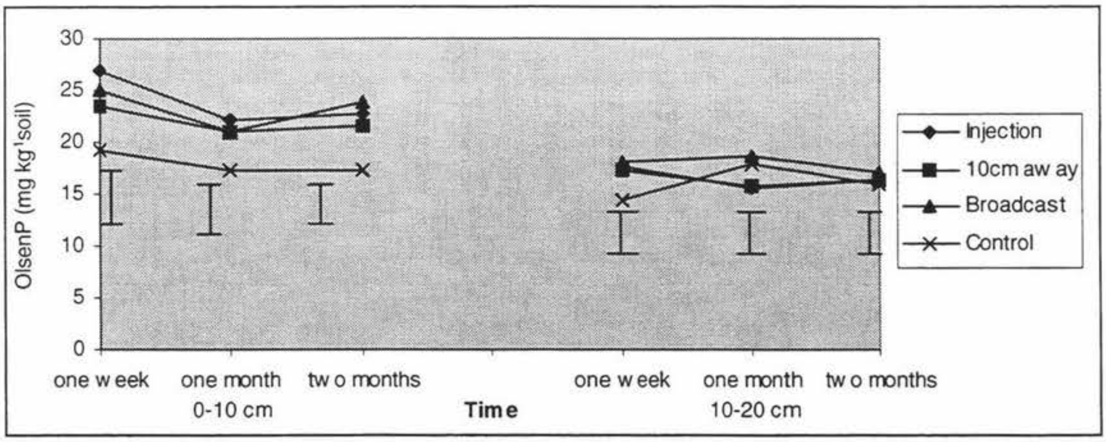


Fig. 4.34: Effects of methods of effluent application on Olsen P in conventional tillage (Vertical bars show LSD at P=0.05)

4.2.1.6 Exchangeable K

Permanent pasture and no-till

The data obtained shows that K^+ content in soil reduced significantly after one month of application. However, only a slightly reduction in K^+ during the second month (Table 4.31ab). After one week, there was a significant increase of exchangeable K compared with control (Fig. 4.35 and 4.36). In the centre of the injection plots, the exchangeable K values was highest but this was not significantly different form the values in the broadcast and 10 cm away. Also, there were similar trends in the subsoil.

Table 4.18: Effects of tillage systems and time lapse after effluent application on exchangeable K (mg kg^{-1} soil) at two soil depths

(a)PP				
Soil depth (cm)	Time after application			$LSD_{(0.05)}$
	One week	One month	Two months	
0 – 10	226.7	195.6	197.7	21.4
10 – 20	123.3	84.1	82.5	19.6
$LSD_{(0.05)}$	13.4	15.6	14.7	
(b)NT				
0 –10	228.45	195.6	192.6	11.3
10 –20	119.6	90.8	89	12.9
$LSD_{(0.05)}$	13.7	11.6	12.8	
(c)CT				
0 –10	208	148.2	147	14.5
10 –20	142.3	122	120	11.2
$LSD_{(0.05)}$	11.8	10.6	12.2	

Conventional tillage

Similar to the PP and CT, a significantly higher level of K^+ was founded in broadcast as compared to control during the first month of application (Fig. 4.37). Also, level of K^+ reduced after one month of application in the subsoil (Table 4.17c) and placement did not have any effects on K^+ at both depths.

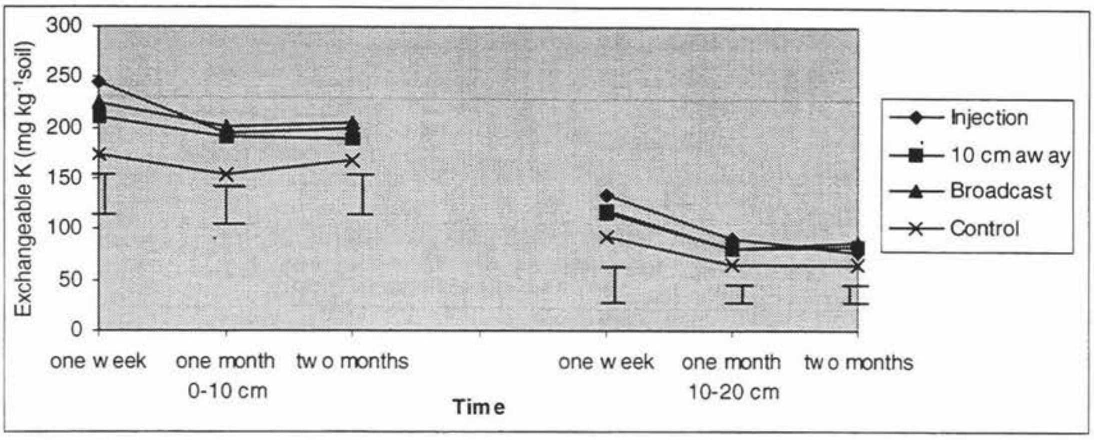


Fig. 4.35: Effects of methods of effluent application on exchangeable K in permanent pasture (Vertical bars show LSD at P=0.05)

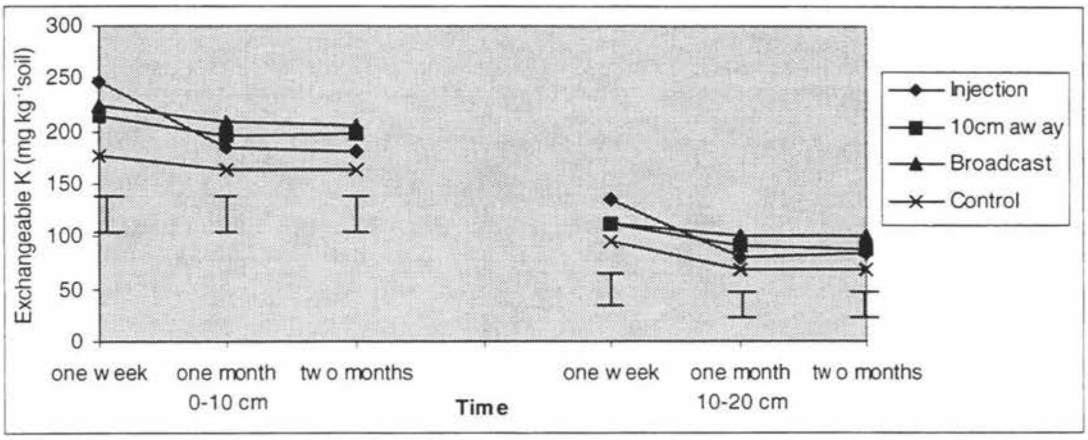


Fig. 4.36: Effects of methods of effluent application on exchangeable K in no till (Vertical bars show LSD at P=0.05)

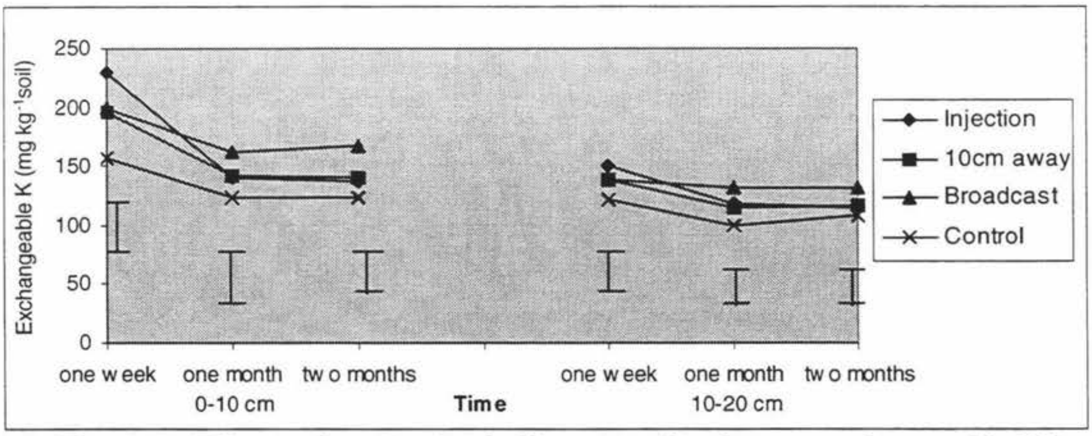


Fig. 4.37: Effects of methods of effluent application on exchangeable K in conventional tillage (Vertical bars show LSD at P=0.05)

Exchangeable K is elcetrostatically bound to the surface negative charges on clays and organic matter. The amount of exchangeable K present in a soil will partly depend upon the quantity of soil surface negative charge.

It is likely that when effluent was applied on soil, exchangeable K increased. McLaren and Cameron (1996) stated that most of the demand for potassium is in the vegetable growth stage. For example, more than 50% of the total plant potassium is absorbed during the first third of the growth period. Therefore, the uptake by maize crop resulted in the significant reduction in K^+ during the first month of application.

Existing undisturbed residue on the soil surface undisturbed in the NT and PP resulted in higher K^+ accumulation at soil surface. In contrast, ploughing made a relatively equal distribution of exchangeable K at both depths in the CT.

4.2.2 Effects of land preparation on soil nutrient content

4.2.2.1 Total nitrogen

Total N in the PP and NT was higher than the CT (Table 4.19). When considering the changes of total N in different tillage systems, there was significant reduction from 3.10 to 3.03 g kg^{-1}soil total N after two months in CT. On the other hand, there were no change in total in NT and PP. No difference was found in the subsoil (10-20 cm) among tillage systems.

The significantly higher total N in the NT and PP as compared to the CT was possibly due to the higher level of initial N content in the soil before application of liquid effluent (Doran 1980; Carter, 1986; Carter, 1991; Angle et al., 1993; Costantini et al., 1996). The present study suggests that the application of liquid effluent did not affect the advantage of the NT compared with the CT. The lower total N in the CT is probably caused by increased oxidation, release organic compounds to the soluble form and lower return of crop residues compared with the NT and PP (Edward et al., 1992). Moreover, nitrogen immobilization is enhanced and nitrification is diminished under the NT and PP resulting in higher total nitrogen in the topsoil of the NT compared that in CT. Also, the lower water infiltration rates in the CT compared with the NT and PP is the possible reason for significantly higher losses of total N through volatilization of ammonium. The data also indicated that nitrogen content in the subsoil of the PP was slightly lower compared with conventional tillage. The reason for such differences was perhaps related to the through mixing of soil in the CT treatment.

Table 4.19: Tillage method effects on total nitrogen

Depth	Time	**Total nitrogen (g kg^{-1} soil)**		
(cm)	after application	PP	NT	CT
0-10	one week	3.46 a	3.89 a	3.12 b
	two months	3.39 a	3.32 a	3.03 b
10-20	one week	2.30 a	2.29 a	2.41 a
	Two months	2.28 a	2.28 a	2.38 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

4.2.2.2 Ammonium

Injection method

There was a significant increase in ammonium content within a week after application of effluent. NH_4^+ in the PP was significant higher than that in the NT and CT (Fig. 4.38). Such differences remained up to one month but disappeared at the end of the second months. On the other hand, no difference was observed between the NT and CT. Ammonium contents in subsoil were not different among tillage methods. Overall, ammonium content in all treatments reduced significantly during the experiment over a period of two months. On the other hand, at the 10-20 cm depth, no changes in NH_4^+ contents were found due to tillage treatment over two months of effluent application.

10cm away from the groove and broadcast

Generally, there was a significant reduction in ammonium content during the experiment. Similar to the injection method, the level of ammonium contents in the PP was significantly higher than that in the NT and CT after one month of application.

The grass on the PP surface might reduce the losses of ammonium in soil during the first month. In contrast, only little cover in the surface of NT and no cover in CT (at that time corn crop was small), caused the losses of ammonium during first month. In addition, pH in the PP and NT is slightly lower than CT (Choudhary et al., 1997). Therefore, nitrification is reduced in the NT and PP because nitrification is limited under acid condition. That difference gradually disappeared in the following month due to the uptake by corn crop. Also, the lower level of ammonium in CT and NT may be due to the higher nitrification rate in the NT and CT than that in the PP and resulted in the losses of ammonium.

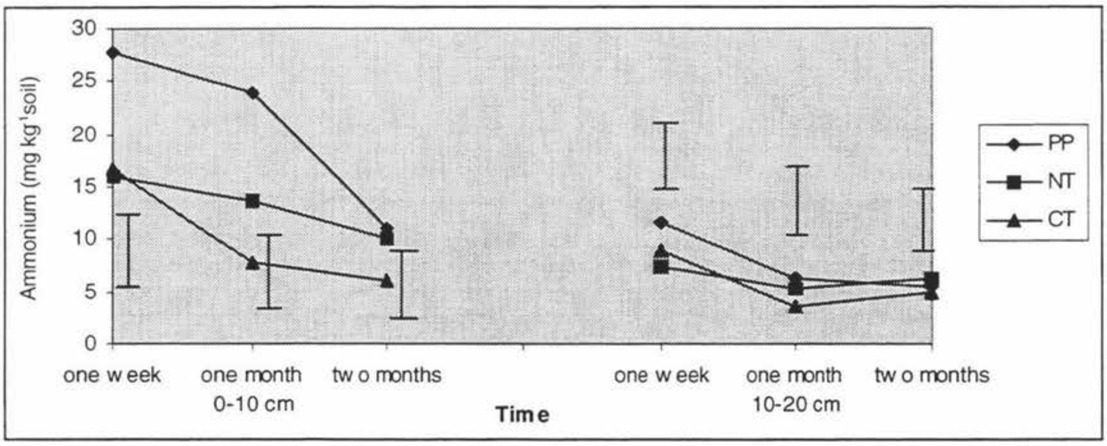


Fig. 4.38: Interactions between the tillage systems and effluent application by injection method on ammonium (at the centre of the groove). Vertical bars show LSD at P=0.05

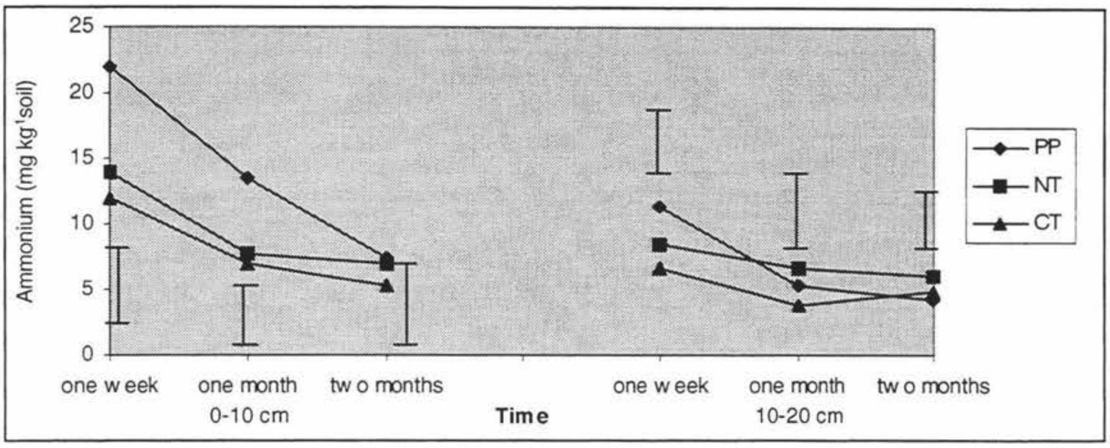


Fig. 4.39: Interactions between the tillage systems and effluent application by injection method on ammonium (at 10 cm away from the groove). Vertical bars show LSD at P=0.05

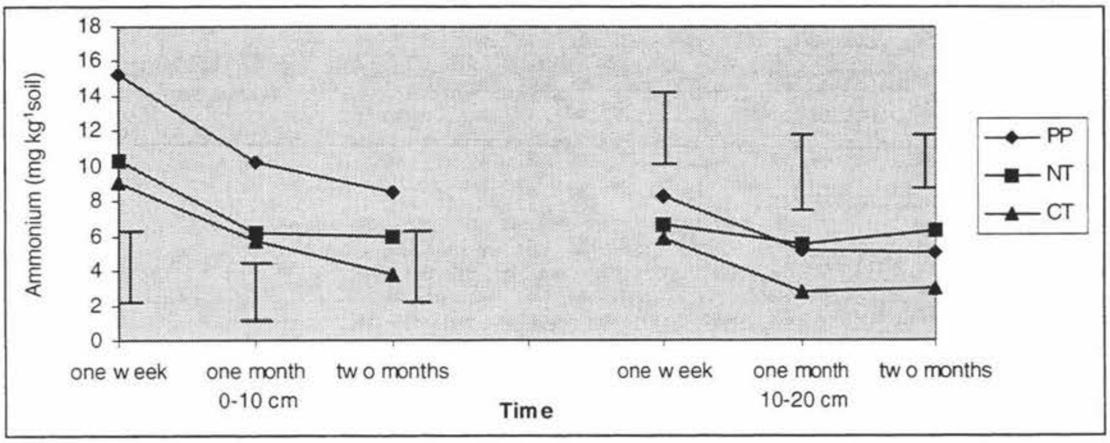


Fig. 4.40: Interactions between the tillage systems and effluent application by broadcast method on ammonium (Vertical bars show LSD at P=0.05)

4.2.2.3 Nitrate

Injection method

Nitrate contents increased during the first month of application, then significantly decreased during the second month of application (Fig. 4.41). However, there were no differences in nitrate content between the CT and NT treatments but this was higher than that in the PP. Similar trends were found at the 10-20 cm depth.

10 cm away from the centre

No difference of nitrate content was found in different tillage systems after one week of application. On the other hand there was an increase of nitrate content in all treatment during the first month then significantly reduced in the second month of application (Fig. 4.42). There was a significant reduction in nitrate concentrations during the second month of application. In the subsoil, the CT and NT had a significantly higher level of nitrate content compared with the PP during the experiment

Broadcast method

There was a significant increase in nitrate content in all tillage systems at the end of the first month but no difference was found among tillage systems. Nitrate content reduced significantly during the second month of application. At the end of the experiment, nitrate contents were in the following order: CT=NT>PP. On the other hand, levels of nitrate content increased in the subsoil. Similar patterns were found in the subsoil in the following order: CT=NT>PP (Fig. 4.43).

Earlier research has suggested that, no-till caused high amount of nitrate lost by leaching. Earthworm from NT could create more macropores that would enhance leaching losses of surface-applied N (Clement, 1982). However, low rainfall during this season limited nitrate leaching and resulted in no differences between the CT and NT. In contrast, cover of grass in the soil surface and the higher level of moisture content in the PP compared with the CT and NT (Gauer et al., 1982; Blevins et al., 1983) can cause higher denitrification process and increase release of nitrogen in gaseous form into atmophere. Moreover, the cover of grass which reduces the soil temperature of the PP soil may have significantl influence on nitrifier numbers. Broder et al., (1984) reported that only $2^{0}C$ lower temperature can significantly reduce nitrification process in soil and results in lower nitrate released. In addition, a higher water content in the PP (Guo, 1997) which reduced aerobic nitrifier activity and increased denitrification and resulted in lower soil NO_3^-

in the PP compared with CT and NT. Bijay-Singh et al. (1989) reported that, the soil (0-10cm) of the grassland had a denitrification potential five times greater than that of the arable soil. In addition, there is rapid immobilization of NH_4^+ in the rhizosphere leaving a small amount of NO_3^- in the soil profile for leaching (Huntjens and Albers, 1978) and resulting in highest amount of total N in the PP compared with the NT and CT. It was likely that, there was not much NO_3^- leaching in this dry summer but higher level of NO_3^- was lost by suitable condition of denitrification in PP. The significantly higher levels of nitrate in the CT compared with the PP under subsoil were likely due to more water infiltration rate in the PP which might cause some of nitrates simply flushed beyond a depth of 20 cm (Blevins et al., 1983).

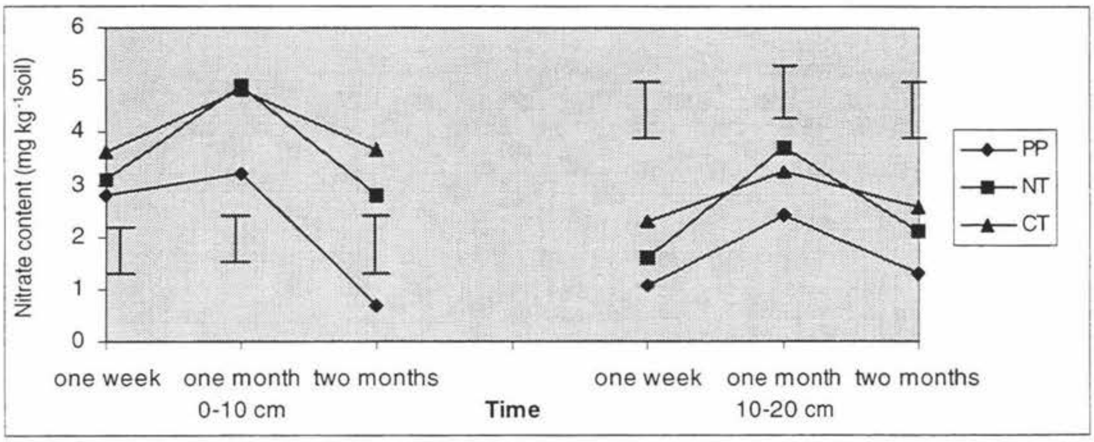


Fig. 4.41: Interactions between tillage systems and effluent application by injection method on nitrate (at the centre of the groove). Vertical bars show LSD at P=0.05

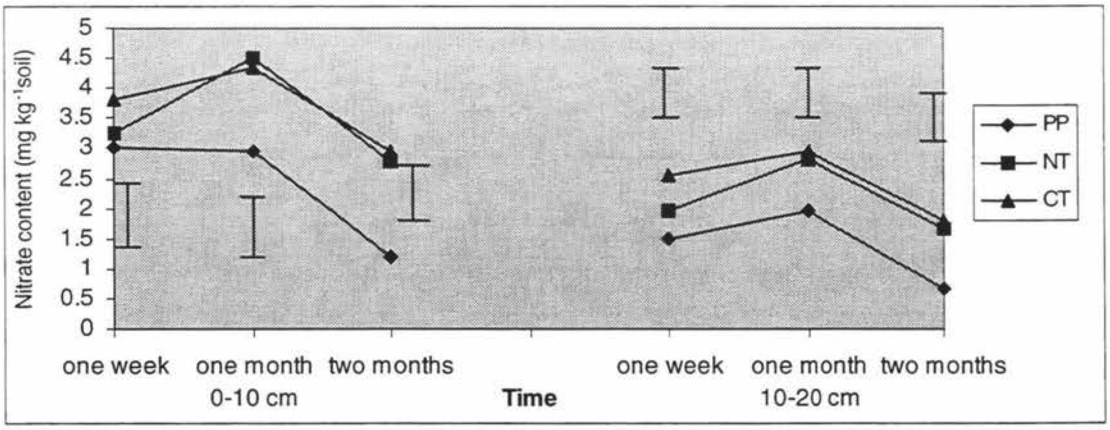


Fig. 4.42: Interaction between tillage systems and effluent application by injection method on nitrate (10cm away from the groove). Vertical bars show LSD at P=0.05

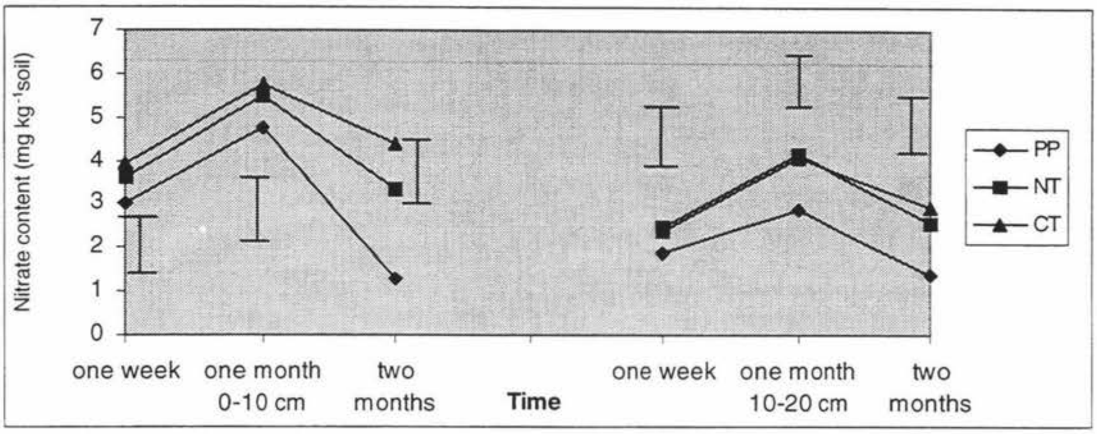


Fig. 4.43: Interactions between tillage systems and effluent application by broadcast method on nitrate content (Vertical bars show LSD at P=0.05)

4.2.2.4 Total phosphorus

As the first experiment, tillage method had a significant effect on phosphorus content in the topsoil. There was significantly higher level of total P in the PP and NT compared with the CT (Table 4.19). These differences remained until the end of the experiment. There were no changes in total P after two months of application both in the topsoil and subsoil.

In addition, P contents were significantly higher at the 0-10 cm depth than the 10-20 cm depth.

Table 4.20: Tillage method effects on total phosphorus

Depth	Time	**Total phosphorus (g kg^{-1} soil)**		
		PP	NT	CT
0-10	one week	0.72 a	0.69 a	0.62 b
	two months	0.71 a	0.69 a	0.62 b
10-20	one week	0.57 a	0.58 a	0.59 a
	two months	0.56 a	0.58 a	0.59 a

Values followed by the same letter in each row did not differ at the 0.05 level of significance

The higher level of P in the PP and NT was due to higher level of total P before the application (0.7, 0.68 and 0.61 g kg^{-1} soil in the PP, NT and CT respectively-Tables 4.28, 4.29 and 4.30). Because the soil surface under the NT and PP was not disturbed, total P would accumulate at the soil surface and this element moved slowly into soil profile (Dick, 1983; Dick and Daniel, 1987).

4.2.2.5 Available phosphorus (Olsen P)

Fig. 4.44 shows that Olsen P concentration at the surface soil (0-10 cm) was lower in the CT treatment than in the NT and PP. Also level of Olsen P in all tillage systems did not significantly change during the experiment. On the other hand, Olsen P contents in the subsoil was similar irrespective of the tillage systems. Furthermore, there was a higher level of Olsen P in the topsoil compared with subsoil. Similar results were observed at 10 cm horizontally away from the groove centre and in the broadcast treatment (Figs. 4.45 and 4.46).

The relatively higher level of Olsen P in the PP and NT was probably related to higher amount of Olsen P at the beginning of the experiment (i.e. 28.5, 27.7, 25.1 mg kg^{-1} in the PP, NT and CT treatments respectively at the centre of injected row-Table 4.31). Furthermore, even after the application of liquid effluent the NT and PP still contained higher levels of Olsen P than CT. There was incomplete reaction of soil components in the unmixed surface layer in no-till soils which thereby contributed a greater portion of desorpable P per unit of available P than in the conventional tillage soils (Oloya and Logan, 1983). Bioactivities of soil surface enhance the mineralization which releases Olsen P available for plant uptake, thus may result in significantly higher Olsen P in the topsoil as compared with the subsoil. In addition, low rainfall during the experiment resulted in no significant difference of Olsen P losses by leaching or runoff.

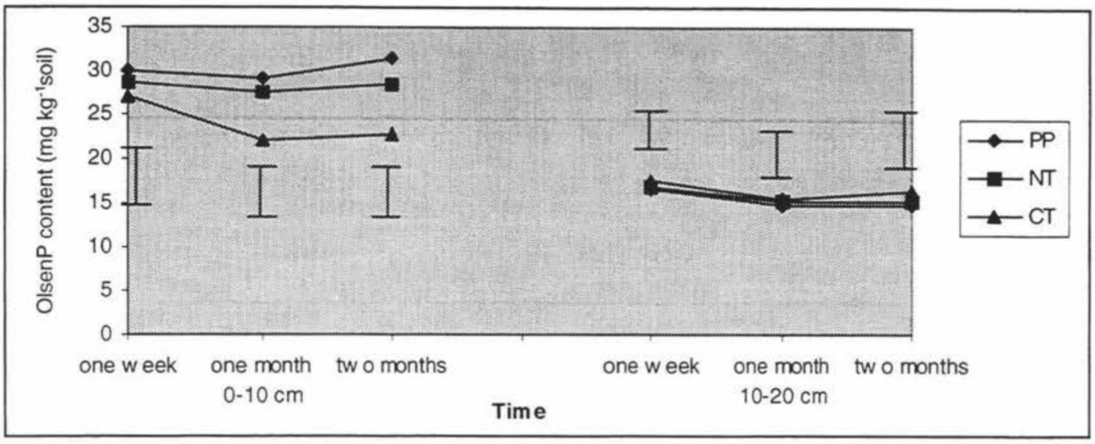


Fig. 4.44: Interactions between tillage systems and effluent application by injection method on Olsen P (at the centre of the groove). Vertical bars show LSD at P=0.05

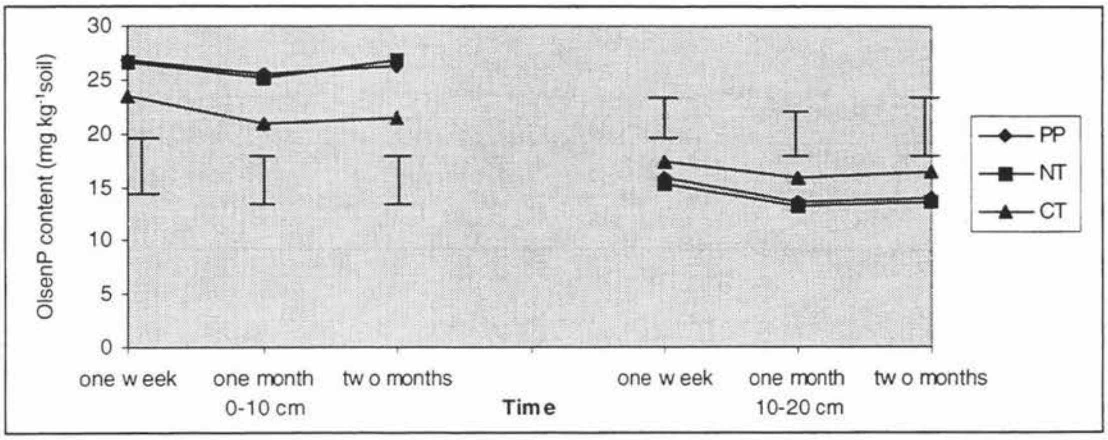


Fig. 4.45: Interactions between tillage systems and effluent application by injection method on Olsen P (10 cm away from the groove). Vertical bars show LSD at P=0.05

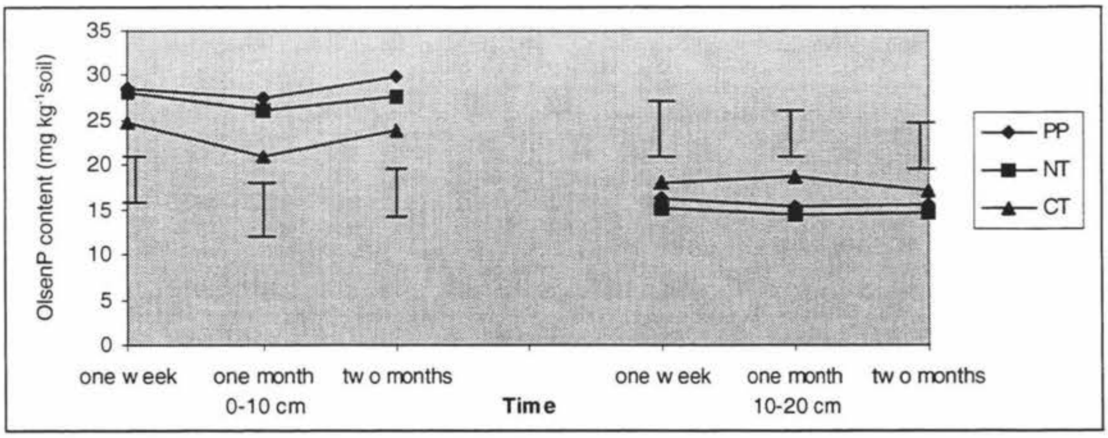


Fig. 4.46: Interaction between tillage systems and effluent application by broadcast method on Olsen P (Vertical bars show LSD at P=0.05)

4.2.2.6 Exchangeable potassium

Tillage methods had significant effects on exchangeable K in soil. At the beginning of the experiment, K^+ content was similar among three treatments. One week, one month, and two months after application, exchangeable K in the CT was lower than that in the PP and NT (Fig. 4.47). In contrast, K^+ in the subsoil of the CT was slightly higher than that in the NT and PP although this was not significant. Similar patterns were found at 10 cm far from centre and in the broadcast treatment (Figs. 4.48 and 4.49)

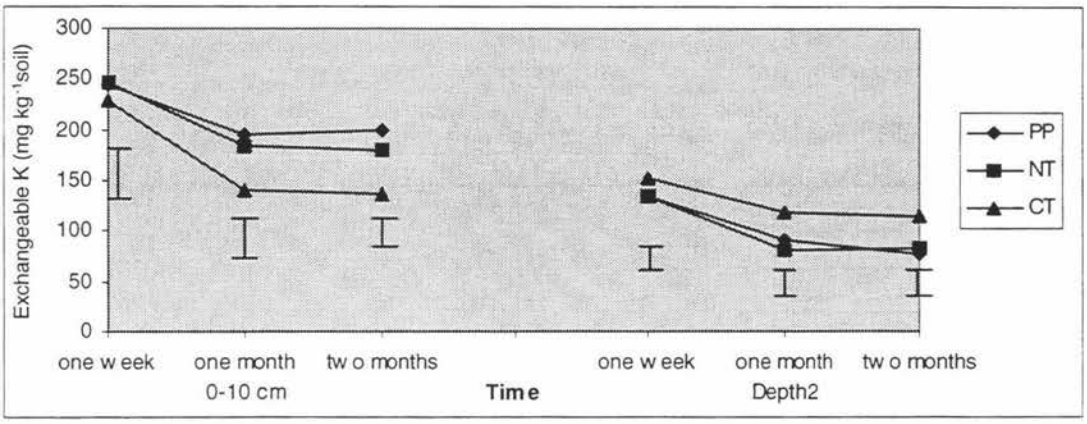


Fig. 4.47: Interactions between tillage systems and effluent application by injection method on exchangeable K (at the centre of the groove). Vertical bars show LSD at P=0.05

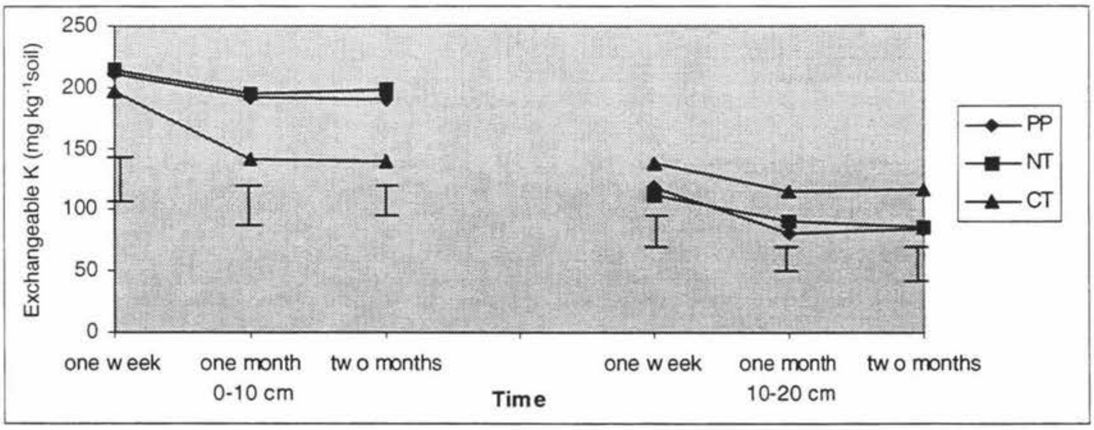


Fig. 4.48: Interaction between tillage systems and effluent application by injection method on exchangeable K (10 cm away from the groove). Vertical bars show LSD P=0.05

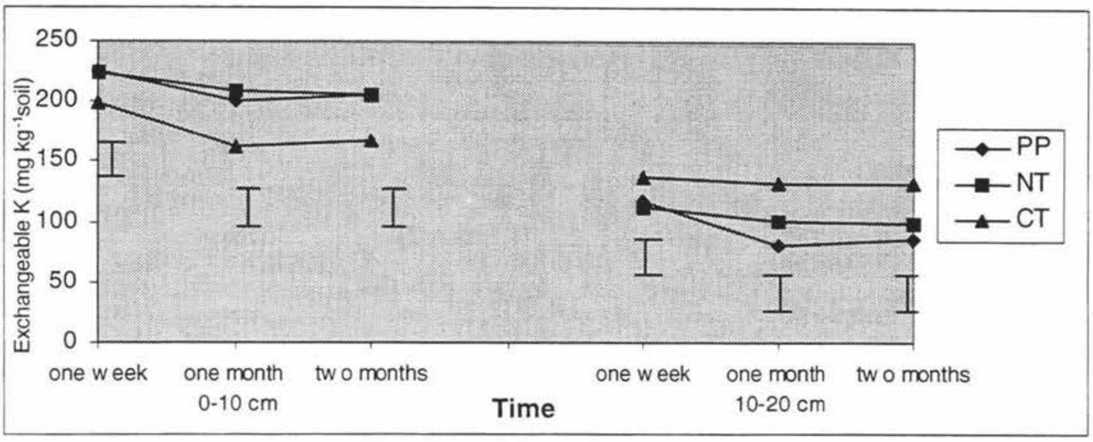


Fig. 4.49: Interactions between tillage systems and effluent application by broadcast method on exchangeable K (Vertical bars show LSD at P=0.05)

It is possible that in the NT and PP, more K^+ is released to available forms through mineral weathering (Johnston et al., 1992). Also more concentration of K^+ in the surface layer of the NT and PP soil is apparently due to the return of crop and grass residue on the soil surface (Follett and Peterson, 1988 and Lal et al., 1991). In addition, because of the accumulation of organic matter in the surface, there was higher operationally defined high-affinity K^+ sites in the NT and PP compared with the CT. This would also serve well in storing and protecting the added K^+ from leaching (Evangelou and Blevins, 1985). Slightly higher level of exchangeable K in the CT in the subsoil compared with the NT and PP suggested that K^+ in the topsoil was mixed with subsoil when it was ploughed. In ploughed plots, crop residues were incorporated to 20 cm depth but remained at the surface in the unploughed plots. This probably explains the subsoil in the CT system having greater extractable K content (Comia et al., 1994).

4.2.3 Summary

Following are key conclusions obtained from the high rate of the application of liquid effluent (150kg N ha^{-1}) onto soil.

- There was a significant increase in soil nutrient irrespective of mode of application of effluent i.e. broadcast or injection.

- There were generally higher nutrients in the centre of the groove than 10 cm away and broadcast. This could result in the efficient use of nutrient when using the injection method. In the case of nitrate, lower concentration was observed in the centre of the groove compared with that in the broadcast.
- The PP and NT treatments retained higher amount of nutrient than the CT. In the case of nitrate, the PP had lower concentration content compared with that in the CT and NT.
- Olsen P and Exchangeable did not change during the experiment even there was the uptaken by plant.

Chapter 5

GENERAL CONCLUSION AND RECOMMENDATIONS

From the results obtained from the two experiments, which utilized application of effluent in the NT, PP and CT with injection and broadcast methods, following general conclusions can be drawn.

Land application of liquid effluent can produce significant increase in soil nutrients. This would, however, require high volume of application. At the low rate of 30kg ha^{-1} (120 m^{-3} litres ha^{-1}), the increases in total nitrogen, phosphorus, and potassium were not significant.

Generally, total nitrogen significantly reduced after 2 months of application in the CT. This reduction in nitrogen was possibility due to plant uptake, leaching of inorganic nitrogen or volatilization of ammonium. The lowest reduction in nitrogen was observed in the injection plots. This implied that the subsoil injection of effluent maintains more nutrients compared with the surface application. However, at the subsoil (10-20 cm depth), the effects of placements were not clear, suggesting that most of the nutrients added remained in the topsoil.

Pasture plots generally retained more nitrogen in the topsoil suggesting that pasture had access to high levels of nutrients.

When effluent was applied in the centre of groove, higher ammonium levels were observed compared with broadcast method with the PP and NT after one week and one month of application. However, at the end of the second month, ammonium contents at all placement methods were found to be similar.

The application of liquid effluent did not affect available P and K contents at low or high rates of application. Also, the placement method had no effects on P level.

The PP and NT can retain nutrients better than CT, these nutrients include nitrogen, ammonium, phosphorus, Olsen P and Exchangeable K.

The results from the two experiments also indicated that with all three tillage treatments, PP, NT, CT, almost all nutrients measured in the centre of the groove were higher than the broadcast method. These results were not clear at low rate of application, but were obvious at high rate of application. Also, the result suggested that even when there was an unequal distribution of nutrients in the injection method, nutrients accumulated in the injection method was higher than those in broadcast.

5.1 Specific conclusions

1. Application of liquid effluent can improve nutrient content in soil under fallow in winter or in maize crop in summer.
2. Injection method can improve the efficiency of liquid effluent in soil because it retained more nutrients available for plant uptake.
3. In all treatments, nutrient accumulation in topsoil was higher than that in the subsoil both in the broadcast and injection method of effluent disposal.
4. Higher effluent volume can be applied on the PP and NT treatment because these have higher infiltration rates than the CT as well as maintained high levels of nutrient for plant uptake.

5.2 Recommendations for future work

The nutrient cycling in soil under the application of liquid effluent is a dynamic process, especially when comparing different tillage practices. That process not only depends on soil characteristics, crop condition but also on variations in climate. In New Zealand condition, most leaching of nutrient occurs from late autumn to early spring when plant uptake is low and rainfall exceeds evaporation. It also occurs when soil is wet and there is heavy rainfall. Therefore, there is a need to further investigate the effect of climatic conditions on nutrient cycling in soil.

Total benefits from dairyshed effluent are sometimes not apparent from crop yields during the first or even second or third year following application. A portion of the nutrients and organic matter in manure is broken down and released during the first one or two years. Sometimes it is held in humus-like compounds subject to very slow decomposition. Thus the element nutrients are released very slowly. Also, the components of manure that are converted to humus will have continuing effects on soils years after their application. Moreover, the use of no-till in an arable cropping has both immediate and long term soil chemistry changes. Thus, it is necessary to continue the experiments over a longer time and with different crop rotation.

Injection method has more advantages compared with broadcast method. For example, total N, ammonium, and Olsen P, which are available for plant uptake are higher than that in broadcast. Interestingly, however, exchangeable K in soil reduces compared with broadcast. This suggests that if high level of exchangeable K was required, then additional K amendments would be recommended.

Although nutrient content under injection method was higher than that under broadcast method, research about the efficiency of injection method should be carried out to include effects on crop production. The reasons for the differences in nutrient levels among the tillage methods need to be elucidated. This should involve measurements of other components of nutrient cycling such as volatilization, denitrification, leaching and surface runoff.

The interactions of liquid effluent by injection and broadcast methods with the alternation of different tillage systems are complicated processes. Thus models, which combine all the effects, which directly or indirectly affects nutrient recycling, such as temperature, slope, moisture content, crop rotation, residue management and impact on ground water contamination, especially runoff, should be developed.

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