THE EFFECT OF DAIRY, PIGGERY AND WOOL SCOUR EFFLUENTS ON WILLOW GROWTH AND THE SOIL CHARACTERISTICS

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The effect of dairy , piggery and wool scour effluents on willow growth and the soil characteristics

ABSTRACT

Restrictions on the disposal of agricultural effluents to the waterway means that alternative land based outlets are required in New Zealand. Willow, as a short forest rotation, represents a significant land use that could produce a high dry matter and benefit from the application of effluent irrigation. However, there has been little information on the effect of effluent irrigation on the growth of willow and the removal of nutrients.

In order to assess the effects of dairy, piggery and wool scour effluents on willow growth, a greenhouse experiment was established using the Manawatu sandy fine loam soil. A complete nutrient solution and nutrient - free tap water treatments were also included in addition to the effluent treatments. The design of the experiment was a 5 x 2 factorial combination of treatments with four replications in randomized blocks. Two factors (effluents and irrigation rates) each with 5 levels were examined, the levels of irrigation were 12.5 mm, 25 mm, 37.5 mm, 50 mm and 62.5 mm per fortnight. The plant growth, production and macro-nutrients accumulation, and the soil pH, electrical conductivity, and total N, P and cations were monitored

Irrigation with effluents affected the growth of willow cutting. The piggery and dairy effluent irrigation increased the willow growth and nutrient accumulation followed the increase in DM yield. The piggery and dairy irrigation accounted for 32% and 18% increase in total DM yield over tap water; while the wool scour effluent resulted in 17% decrease in comparison with tap water. Irrigation with dairy, piggery and wool scour effluents onto the Manawatu fine sandy loam soil, caused a significant increase in pH and EC. The significant change in pH and EC was attributed to the soluble salts in these effluents, especially K in the wool scour effluent. The recovery of N from these effluents was very small and was less than that of P and K in soil.

Chemical analysis of willow, treated with dairy, piggery and wool scour effluents up to 8 weeks, showed a relatively high concentration of N, P and K in leaf, and had a very high K and a very low Mg concentration in leaf with wool scour effluent irrigation. However, the efficiency of the N, P and K nutrient accumulated by willow was inversely related to the concentration of these effluents and the DM yield of willow cutting was positively related to the irrigation rates. It was evident that willow cutting was too young to require a large quantity of nutrients at the early growth stage and there was a risk of nutrient loss with increasing irrigation rate. The application of wool scour effluent caused a very high pH and EC, and the willow cutting growth decreased at > 37.5 mm/fortnight irrigation rates. The reasons for the detrimental effects of wool scour effluent on soil properties and willow growth need to be investigated further. The results suggested that it is possible to enhance the willow growth and adjust the soil fertility by application of dairy and piggery effluents irrigation.

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CHAPTER ONE

INTRODUCTION

1.1   BACKGROUND

There has been increasing concern about the pollution of waterways resulting from the disposal of agriculture effluents. Land application of these effluents is becoming more widespread as regulatory authorities move to protect water quality by restricting agricultural effluent into rivers, lakes and the marine environment. Substantially increased development efforts are directed toward lower technology, lower capital, and less energy intensive approaches to biological methods of these effluents recycling. However, it is not clear that soil is in fact an appropriatiate dumping ground for all agriculture effluents. In addition, there is such a wide range of agriculture effluent with different physical, chemical and biological characteristicals, so that it is inappropriate and indeed risk to transfer guidelines from one wastewater disposal system to another.

In New Zealand, dairy and piggery shed waste is often treated biologically using two pond systems. The two pond system is not designed to remove nutrients, such as nitrogen, phosphorus and potassium. These nutrients in the oxidation pond water will have a large impact on receiving waterways once discharged to stream or allowed to percolate into the ground water. With the introduction of the resource Management Act (1991), Regional Councils have focused more attention on water quality. In most regions, discharge of effluents to surface water requires a resource consent and commonly the resource consent will demand the effluent nutrient concentration to be minimized before entering the surface waters. Proposed restrictions on the disposal of agricultural effluent to the waterway means that alternative land based outlets are required.

In New Zealand, there is plenty of evidence to suggest that renovation of these effluents and other wastewater can be successfully carried out using land treatment systems. Such schemes provide plants with a useful source of nutrients. Traditionally effluent renovation

schemes have used ryegrass/clover pasture (Wells and Whitton 1966, 1970) but more consideration is now being given to other pasture plant species or using arable crops or trees.

Recently land based treatment of effluents through irrigation to short forestry rotation showed the opportunity of using the nutrients from the effluents for the production of non-polluting renewable source of energy.

Growing willow trees as a short rotation forest represent a significant land use that could produce a high dry matter and benefit from the application of irrigation with dairy effluent. There has been, however, no information on the effect of effluent irrigation on the growth of willow and the removal of nutrients. In this experiment, the willow (New Zealand 1295 *Salix kinuiyanagi*) was chosen as a tree species of short rotation forestry to examine the potential value of irrigation with three effluents, daring, piggery and wool scour effluents. The changes in the chemical properties of the soil treated with the effluents were also examined in this study.

1.2   OBJECTIVES

The objectives of the project are:

1.   To examine the growth response of willow (*Salix kinuiyanagi*, NZ 1295) to different effluents and irrigation rates.

2.   To monitor the changes in soil and plant parameters resulting from the irrigation with different effluents that affect the plant availability of nutrients.

3.   To determine the efficiency of nutrient uptake (N, P and K) by willow from effluents.

The aims achieved by the objectives include:

1.   To determine the most beneficial effluent (of three effluents) to be applied onto short forest rotation plantations (willow tree species) with respect to growth and nutrient uptake.

2.   To investigate the influence of different effluents on soil properties and plant parameters with respect to effluent chemical properties.

1.3   STRUCTURE OF THE STUDY

This thesis comprises 5 chapters. Following the introduction (Chapter 1), a general review of literature (Chapter 2) examines the treatment of effluents, and the issues and options of a wide range of effluent application practice, benefit and problems from land application of these effluents on soil, plant production and environmental quality, and possible hazards to human health. In Chapter 3, a description of the materials and the greenhouse growth experiment of willow cutting, and the detail of analytical procedures in plant, soil and effluent samples utilized in this research are given. The Results and Discussion section (Chapter 4) considers the results of the greenhouse growth experiment and the analysis of effluents, plants and soils in laboratory. A general summary and conclusion of all results of the experiments are presented in Chapter 5 with few recommendations based on the results obtained from this preliminary study.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Waste effluents contain significant concentrations of plant nutrients, particularly N and P and organic matter. Their application on land has been shown, in many cases, to result in significant increases in plant yields, improvements in soil physical conditions and chemical and biological fertility. Although the nutrient content of waste effluents makes them attractive as fertilizers, land application of waste effluents is constrained by the presence of hazardous organic chemicals, heavy metal, pathogens, salts and extreme pH values. High concentration of nitrate and phosphate derived from secondary treated effluents is also of concern for ground and surface water contamination.

This chapter provides a literature review of the beneficial effects and adverse impacts of land application of waste effluent on soil, plant production and environmental quality, and possible hazards to human health.

2.2 SOURCE OF WASTE EFFLUENTS IN NEW ZEALAND

There is a diverse range of effluents available from agricultural, industrial and municipal sewage source in New Zealand. Municipal sewage is a major contributor from larger urban centres. The main contribution from non-urban sources are dairy, poultry and pig industry wastes as well as meatworks, kiwifruit, fishing and pulp and paper industries.

2.2.1 Municipal sewage effluent

The major urban waste, sewage effluent, is produced in the treatment of domestic and industrial wastewater and sewage. The aim of sewage treatment is to remove solids, pathogens and other contaminants from wastewater streams and so to produce relatively

'clean' water that can be recycled back into the environment. The actual processes by which this is achieved vary greatly between treatment works, but usually involve a combination of physical separation and aerobic or anaerobic biological treatments. Sewage sludge is the solid material left behind when the treated water (sewage effluent) leaves the works.

In New Zealand, approximately 52000 tonnes of dry sludge solids are produced annually with 70% of this generated at three of the main population centres of Auckland, Wellington and Christchurch (New Zealand Department of Health 1992).

The quality of treated urban sewage effluent depends on the nature of the sewage/wastewater streams supplied to the treatment works and the type of treatment carried out. Treated sewage effluent differs from normal 'clean' water in the following ways (McLaren and Smith 1996):

A. Biological (BOD) and chemical oxygen demand (COD) of the effluent is higher. Treatment of the wastewater may reduce the BOD and COD demand but the level of reduction depends on the intensity of the treatment.

B. Inorganic salt concentrations are higher in wastewater, particularly sodium, chloride and bicarbonates. These ions cause an increase in the total dissolved salt content (salinity) and the sodicity (sodium content) of the wastewater and are generally not removed during treatment, except for some precipitation with bicarbonates.

C. Effluent contains higher concentrations of macronutrients, especially N and P.

D. The concentration of trace elements may also be higher as a result of the addition of industrial wastewater to the sewer. Trace elements required by plants such as boron (B), copper (Cu), manganese (Mn), molybdenum (Mo) and zinc (Zn) may be present in excessive concentrations. Other elements such as cadmium (Cd), lead (Pb), nickel (Ni) and mercury (Hg) may also contribute to the toxic hazard of the effluent.

E. Pathogenic micro-organisms (bacteria and viruses) are present, although their concentration is reduced during the treatment process. About 600000 fecal coliforms per 100 ml is found in secondary treated effluents in New Zealand. If treatment plants have effluent disinfecting facilities, then fecal coliforms will be reduced to about 8000 per 100 ml (Hauber 1995).

2.2.2 Industrial waste effluents

The definition of industrial effluents generally includes effluents generated in any process of industry, manufacturing, trade or business and mining activities. In the late 1980's, New Zealand generated about 300000 tonnes of industrial waste annually, equivalent to about 15 tonnes per $US million GDP (OECD 1991).

The composition of industrial wastes varies depending on the industrial structure of a country or region (Table 2.1). Of particular interest to land application is waste waters from factories. Most factory waste effluents are treated before disposal. However, many nutrients, metals and organic chemicals remain in significant concentrations in the treated sludges and effluents. While the nutrients contained in these wastes (e.g. N and P) make the wastes attractive as fertilizers, their application on land may be constrained by the presence of toxic metals, toxic organic, excessive concentrations of salt or extreme pH. For example, waste water from dairy, tannery and pulp and paper factories contain high concentrations of sodium ions. Tannery waste waters contain undesirable constituents, e.g. chromium, aluminium, polyphenolics and aldehydes (Carnus and Mason 1994). Effluents from pulp and paper mills contain metals and a range of toxic organic compounds. The wide range of chemical, physical and biological characteristics of these wastes makes it difficult to develop guidelines for their use. The chemical composition not only varies between the various wastes streams but also varies with treatment of the individual waste stream.

Table 2.1 Composition of sludge or effluents from a few selected waste sources in New Zealand (Carnus 1994; Hart and Speir 1992)

Parameter	Milk powder/ butter factory wastewater[A]	Meat processing secondary effluent[A]	Tannery secondary effluent[A]	Pulp and paper secondary sludges[B]	Dairy shed effluent[A]	Piggery effluent[A]
Suspended Solids	---[C]	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	50-250	2700	4586	50	---
Potassium	13	20-150	---	2905	220	500
Calcium	8	3-250	340	17000	110	---
Magnesium	1	3-10	36	2000	30	---

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

2.2.3 Agricultural waste effluents

The agricultural sector constitutes a major part of the New Zealand economy. In 1991, farming in New Zealand occupied about 17.5 million ha, equivalent to about 64% of the total land area (Statistic New Zealand 1993). The biggest proportion of the farming land is used for grazing animals which comprise about 8 million cattle and 55 million sheep in New Zealand in 1991. Large numbers of other livestock (e.g. pigs and poultry) are also raised in the country. Large quantities (about 530,000 tons in 1991 (CAE 1992)) of waste are generated from these agricultural production and processing industries sector. It is estimated that the New Zealand meat processing industry contributes a pollution load that

is equivalent to that produced by the total human population of the country (3.5 million) (Cooper and Russell 1982).

Most agricultural wastes contain valuable nutrients that could be recycled back onto the land in order to improve soil fertility and increase the sustainability of farming systems. For example, the fertilizer value of dairy shed effluent, pig slurry and poultry manure in New Zealand is estimated to be $36 million per year (Roberts *et. al.*, 1992).

Some of the more common wastes and their typical nutrient contents are shown in Table 2.2.

Table 2.2 Chemical analysis of some effluents (mg L^{-1}) (Longhust 1981; Johnson and Ryder1988)

	N	P	K	Mg	Ca
Dairy shed	190	30	220	30	110
Cheese whey	1360	440	1680	60	360
Lactic casein whey	300	880	1660	120	1070
Slaughterhouse	160	10	90	10	90
Pulp and paper	<0.1	--	11	3	4
Municipal sewage	20	7	10	3	3
Pig	1300	600	500		
Meat works	120	13	100		

2.3   TREATMENT OF WASTE EFFLUENT

2.3.1   Two pond systems

In New Zealand, the dairy and piggery shed waste is often treated biologically using two pond systems. This involves anaerobic followed by aerobic treatment of the waste and the

subsequent discharge of the effluent to land or steam (Figure 2.1). In a two pond system, the first pond is anaerobic and its waste loading is such that the oxygen in the pond is entirely consumed. The second pond, which is often termed "aerobic", is usually a "facultative" pond, with an aerobic top layer over an anaerobic base. The functions of these ponds are: (i) separation of solids; (ii) anaerobic and aerobic oxidation of dissolved organic material; and (iii) storage of digested solid residues and non-degradable solids in the bottom sludge. However, the two pond systems are not explicitly designed to remove other components which include nitrogen and phosphate. In the dairy shed, the oxidation pond water becomes pollutants when discharged to a stream.

Based on demand for increased environmental protection and enforcement of standards for the treatment of diary effluent in New Zealand, a number of approaches are being explored. These include: land application of effluents; improvements of existing pond facilities with comparatively simple modifications; and use of recyclable traps to remove nutrients (Bolan, et. al., 1996). These approaches, schematically summarized in Figure 2.2, fall into a natural hierarchy, from pond modifications (e.g. additional pond area and shallow depth ponds) to simple "add-ins" (e.g. mechanical aeration), and supplementary "add-ons" to existing pond facilities (e.g. maturation ponds, constructed wetlands and overland flow systems).

Removal of BOD, N and P is restricted by oxygen supply to the pond water, where alga growth is limited. Restricted oxygen supply also limits oxidation of ammoniac N to nitrate (nitrification) in existing dairy shed ponds in New Zealand. Various approaches have been considered to increase the efficiency of two pond systems. These include: increasing size of ponds and shallower depth; overcoming the restricted oxygenation to promote initial nitrification of wastewater by mechanical aerator; and improvement of light penetrative to enhance algal or phytoplankton growth to encourage sloughing of excess biomass and accumulated particulate.

These various pond modifications, "add-ins" and "add-ons" all require considerable research investment or demonstration by manufacturers of their treatment capabilities before they can be directly applied to dairy ponds.

Figure 1 Two pond system for Dairy & Piggery effluent treatment (Bolan *et. al.*, 1996)
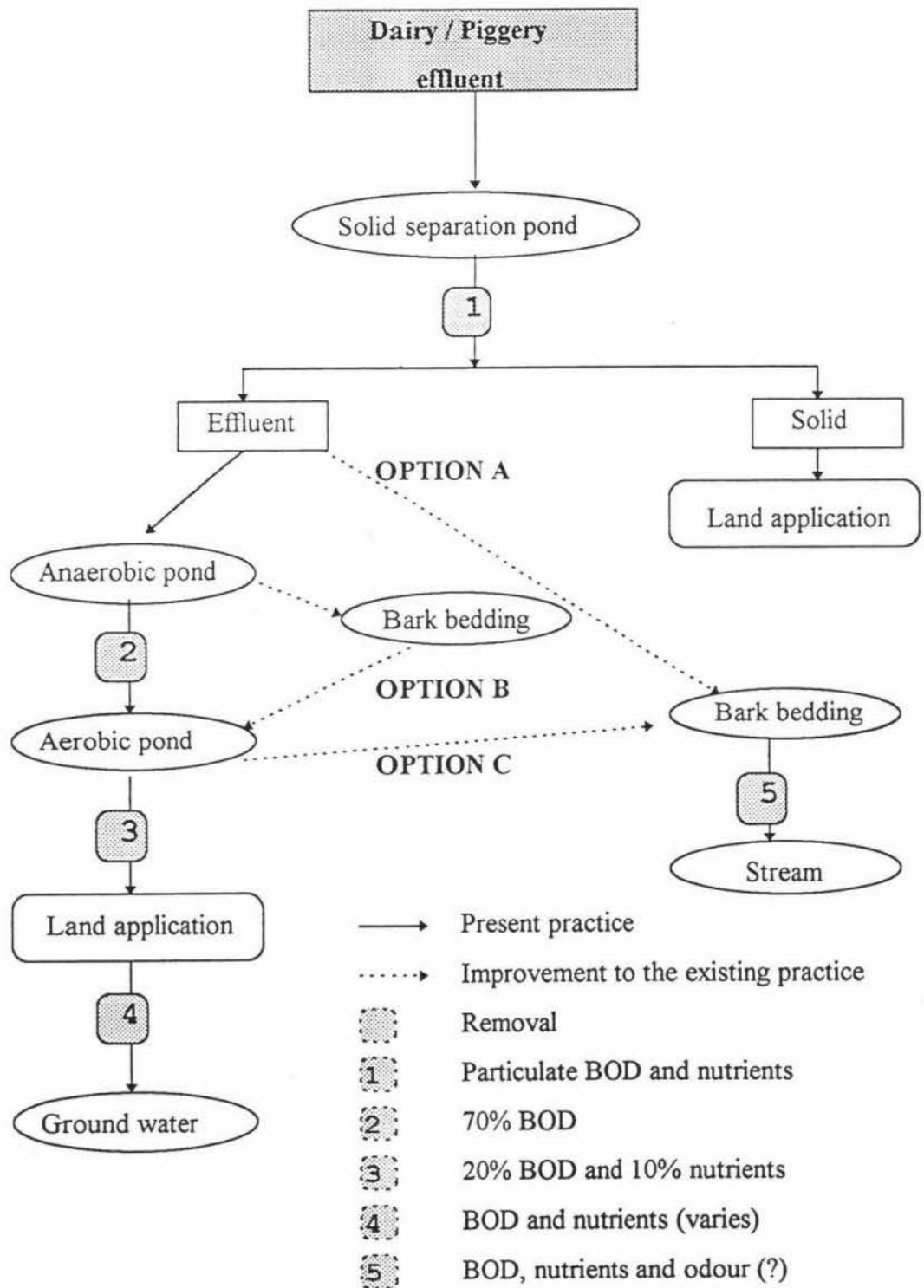
Figure 2   Schematic summary of modifications, "add-ins" and "add-ons" to existing 2-stage dairy shed wastewater treatment ponds (Sukias, J.P. 1996)

Pond modifications and "add-ins"

1. Existing 2-pond system

2. Additional or larger ponds
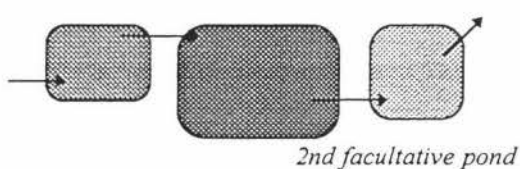
3. Shallow facultative pond
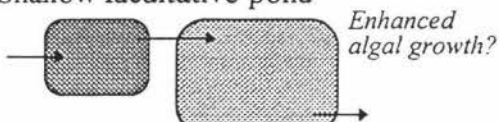
4. Mechanically aerated 2nd pond
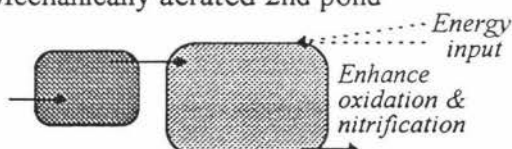
5. Aeration plus biofilm supports
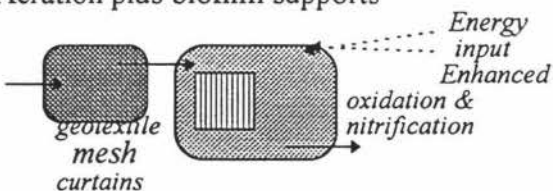
6a. Baffles fitted

6b. Multiple ponds created

Supplementary "add-ons"

7. Shallow maturation ponds
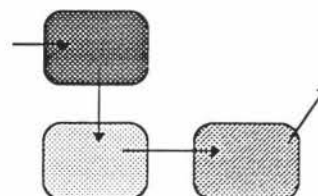
8. Rock filter

9. Overland flow beds
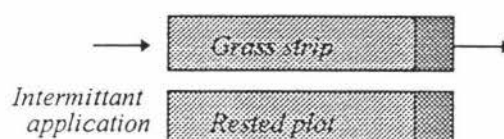
10. Constructed wetland
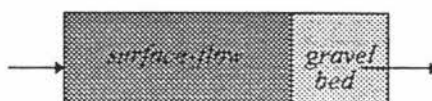
11. Rotating biological contactor
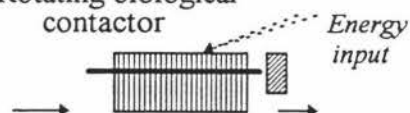
12. Land application
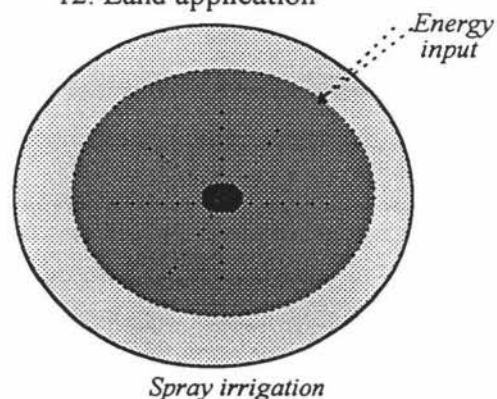
Mechanical aeration is one of the add-ins which shows the most potential for improved treatment of dairy ponds. Research is already underway on aeration, and early results appear promising, particularly for reducing ammoniacal nitrogen. Combining the use of geotextile support surfaces with aeration would provide considerable additional enhancement of nitrification.

"Add-ons", by their very nature, provide buffering against excursion to poor effluent quality, as well as providing additional treatment. Add-ons are frequently designed to achieve types of treatment for which the existing ponds are not designed. For example constructed wetlands and rotation biological contactor (RBC's) provide nutrient and suspended solid removal, and maturation ponds remove high amounts of pathogens and faecal indicator bacteria.

Although the improvements to pond system can bring those effluents under control, the secondary effluents still need to be disposed off onto land according to a requirement to fulfil obligations under the Treaty of Waitangi with respect to Maori spiritual values, which generally require wastes to be purified by earth (Sukias,1996).

2.3.2 Land application

In general, irrigation with effluents should consider the influence on groundwater quality; quantity and time of application to crop production; climate factors such as rainfall and potential evapotranspiration; crop factors such as crop cover and root extent; and soil factors such as soil water availability, initial soil water content, infiltration, and drainage.

Irrigation with secondary-effluents has been as the most common land treatment method, which give more emphasis on nutrient cycling. this has been applied in a number of experiments based on a key feature of the terrestrial plant systems for specialized use such as agriculture (pastures, vine growing, vegetable etc.), forestry (cutting, standpost and short rotation forest (SRF)), and landscape (golf courses, parks and gardens). In New Zealand, land application of sludge is not as yet a commonly practised means of waste

management. However, there has been increasing interest in the utilization of sewage effluents on the irrigation of forestry land (Cameron *et. al.*, 1996).

The objective of land application of secondary treated effluents is to utilize the chemical, physical and biological properties of the soil/plant system to assimilate the waste components without adversely affecting soil quality or causing contaminants to be released onto water or the atmosphere. Plant growth on the land treatment site is a key feature of the system as it removes nutrients and water from the waste-treated soil as well as protecting the soil from damage during waste application (Cameron *et. al.*, 1996).

Land treatment of secondary treated effluent may involve either disposal or reuse. Some systems are designed to simply dispose of wastewater after more or less intensive purification. This procedure might be useful in the case of communities far from receiving water. Other systems are designed to recharge the groundwater with wastewater after its final purification through the soil, such as 'cypress dome' ecosystem.

Secondary effluents also can be utilized to irrigate farm land with surface or subsurface flooding or by spraying to improve the fertility of the soil and increase the crop yield.

Most of the incidents of reuse of irrigation with secondary effluents for pasture growing are for disposal rather than planned resource use. Usually there is no charge to the farmer for the water, the prime concern of the authority is to get rid of it with minimum cost and environment effects. However, undoubtedly greater numbers of sheep and cattle can be raised in this way and thus the source is not wasted. But animal activities, like grazing, need to be synchronized with the effluent application.

The value of irrigation with secondary effluent for landscape is seen in several ways: 1) enabling conservation of good quality town supply water; and 2) increasing the amenity of outback towns where water is scarce and simply could not be used for recreation.

Irrigation with secondary effluents for forestry can be permitted a variable effluent quality, there is no fear of health problems and in most case a useful and perhaps profitable crop

can be achieved. Irrigation with secondary-treated effluent is more likely to increase growth in young trees, either planted or natural, than in pole-size or larger trees. Because a major determinant in growth rate is nutrient uptake and assimilation, young trees will benefit more than old trees to the treatment (Fitzpatrick *et. al.*, 1989).

The Wool Supply Research Group has established trials of mainly willows and poplars at 11 sites across UK, representing different climatic and soil conditions. These are tested for yield, disease and frost resistance, growth habit etc. Possibly due to the use of unrooted cuttings as planting stock, water has been found to be as important as fertilizers during the early years, which would favour the use of wasters with high water content (Raph.E.H. et.al., 1992). Denmark has recently estimated they would required 30,000ha of coppice willows to dispose of all their sewage sludge production (Nielsen, 1990).

A drip irrigation system showed a coppice willow plantation on sandy soil capable of utilizing 150 kg N/year with no leak to groundwater (Christersson, 1987). Studies on evapotranspiration rate have demonstrated willow plantations capable of using > 500 mm /yr.(Hansen, 1988).

Fibre shortage have led to an increased awareness of many possible benefits of short rotation coppice crops in UK. With stricter regulations on river disposal, and enforceable penalties for pollution, there appears to be great potential for land treatment of range of waster (Raph.E.H. *et.al.*, 1992).

Several factors impose limitations on the use of effluent in terrestrial agriculture. The most important are: 1) the seasonal demand for irrigation water while the effluents supply is more or less constant, 2) the limitation to crops or methods of application because of the concentration of the nutrients, trace and toxic elements, residual pathogenic organism; and 3) insufficient agricultural area to utilize the supply of the effluents (e.g. municipal wastewater).

2.4   SECONDARY-TREATED EFFLUENT DISCHARGE TO WATER

Discharge of sewage waters, sludges and other wastes (e.g. dredged spoils, hazardous wastes) into the marine environment (rivers, lakes and sea) is practised in many countries (UNEP 1993). In New Zealand, about 60% of sewage is discharged to coastal waters after secondary treatment. However, the treated effluents still retain high concentrations of organic matter, suspended solids, nutrients (particularly N and P) and other contaminants (Hauber 1995). Similarly it is estimated that Australia produces about 100000 tons of N and 10000 tons of P in sewage effluent annually and much of this is discharged to coastal waters (Bridue 1995).

Discharging sewage and other nutrient-rich wastes to waterways can result in depletion of dissolved oxygen, eutrophication, chemical toxicity and salinity. Eutrophication and salinity are considered to be the two major water quality problems in Australia (Sumner and McLaughlan 1996).

Eutrophication is produced by an excess concentration of nutrients in the water leading to accelerated plant growth and changes in plant species composition. The critical nutrients responsible for eutrophication are N and P, although other nutrients, e.g. iron, molybdenum, manganese and silicon, may also contribute to the process. The critical nutrient concentration above which eutrophication may occur depends upon the specific aquatic systems; however, eutrophication may become visually evident when the concentration of total N reaches around 400 - 600 μgL^{-1} and /or when total P reaches 40 - 60 μgL^{-1} (AEC 1987). Eutrophication can have a dramatic impact on the coastal or inland aquatic ecosystems, including blooms of phytoplankton (algal bloms) and loss of seagrass. Some of these algae are toxic and sometimes cause death of fish and livestock.

In New Zealand, serious eutrophication problems are becoming more common. For example, in January and February 1993, there were wide spread incidences of algal blooms and shellfish poisoning around New Zealand's coastlines which resulted in the temporary shut down of the entire coastline from shellfishing, and the temporary cessation of shellfish exports. The direct economic consequences and redemption costs of eutrophication are

very high, it is estimated that eutrophication may cost Australia $A 10 - 50 million per year (Cullen, 1996).

2.5   WASTE EFFLUENT UTILIZATION IN AQUACULTURE

There have been many successful report on the benefits of effluents treated in aquaculture, such as 'polishing' water for reuse by water hyacinth. In these systems fish is used as a sentinel organism. For example, Hepher and Schroedr, (1974) reported the presence of fish improved the treatment potential of the pond with and without organic wastes (Table 2.3).

Table 2.3   Some effects of stocking fish in waste treatment ponds

Pond type	No fish; Manured*	Fish;** manured	Fish; no manure
Bacteria(1000/ml)	17-27	1.6-6.7	0.7-4.3
pH(0900hrs)	7.9-8.3	8.3-8. 9	8.6-8.7
DO (ppm)[1]	0.7-9.5	9.0-15.9	10.0-13.8
Temperature	9-15	9-15	9-15

(^{0}C, 0900hrs)

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*   Fluid cow manure, 10 to 13 percent dry matter; added at rates up to 800 kg BOD_5 (20 ^{0}C) and 5600 kg solid per hectare every two weeks.

**   Fish stocked: common carp, bottom feeder; and silver carp, a filter feed.

1:    Dissolved organics.

2.6   EFFECTS OF LAND APPLICATION OF WASTE EFFLUENTS ON PLANT

Global, regional and national organizations have imposed, or are imposing, increasingly strict regulations on the discharge of wastes to the sea. The 1972 London Dumping Convention specifies the ban of sea dumping of certain hazardous wastes unless it is proven that the hazardous substance is in trace amounts and would be made harmless in the sea (UYNEP, 1993). In the EU, discharge is required to be secondary treated, and in areas sensitive to eutrophication, the sewage is required to be tertiary treated, and wherever possible the sewage should be reused.

It is now unacceptable to pump liquid wastes directly into a stream or out to sea, land disposal of such effluent is becoming the preferred option. However, we need to know what happens to the effluent in soil, and how the disposal process can be managed to minimize effects harmful to the environment. Waste prevention, minimization, recovery and recycling are strongly encouraged, and alternative ways and new technologies are sought for the disposal of waste effluents.

2.6.1 Production

There are many reports of the beneficial effects on plant growth of applying secondary treated effluents to land. Land application of dairyshed effluent has been shown to be very effective in stimulating pasture growth (MacGregor *et. al.*, 1979; Goold, 1980; Cameron *et al.*, 1996). Yeates (1978) reported that pasture growth was increased from 12000 kg DM ha^{-1} y^{-1} to 16000 kg DM ha^{-1} y^{-1} with the application of dairy effluent. Goold (1980) recorded a 27% increase in pasture production with 6 mm of dairy shed effluent applied every 21 days (representing 156 kg N, 46 kg P and 348 kg K ha^{-1} y^{-1}) and a 43% increase with 12 mm application to a clay soil in Northland, New Zealand. The effluent effects are particularly significant in spring, summer and autumn (Figure 2.3)

Figure 2.3 Effect of dairy shed effluent and water on seasonal pasture production (mean of four year data) (Robaerts _et al.,1992_).
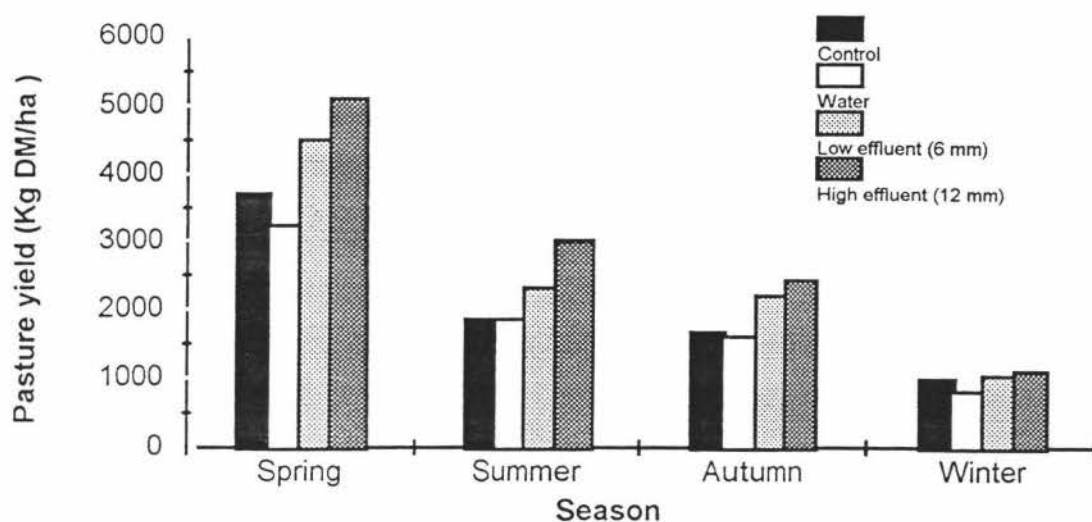
Land application of sewage effluent has also been reported to cause significant pasture yield increases. In a New Zealand study, Quin and Woods (1978) showed that pasture response to the nutrients applied through sewage effluent (equivalent to 116 kg N, 34 kg P, and 68 kg S ha^{-1} y^{-1}) was greatest in summer and autumn. Phillips and Grant (1994) have described the possible benefits from recycling waste water from Melbourne to irrigate crops.

In New Zealand, Cameron _et. al._, (1995) measured a 70% increase in pasture production from both a low and a high rate of application of pig slurry (200 and 600 kg N ha^{-1} y^{-1}). However, there was a lower N use efficiency (8 kg and 15 kg DM per kg N applied at 600 and 200 kg N rates, respectively) and a greater leaching loss of N at the higher rate of application.

2.6.2 Physiological and ecological response of plant

Neilsen _et. al._ (1989) reported that yields of tomato, sweet pepper, onion, bush bean and melon with municipal wastewater effluent irrigation were greater than or similar to yields obtained with well water. Effluent irrigation resulted in decreased Zn and increased P in plant tissues. Corn irrigated with sewage effluent has been shown to accumulate lead in

the stem and leaves, but not in the grain. It can be used as grain but not silage. Johns *et. al.* (1994) reported that irrigation with secondary treated sewage effluent resulted in a 100% increase in leaf lamina vitamin B concentration in banana over irrigation with tap water.

High concentration of N in crops also can reduce the sugar content of crops, which may affect flavour and quality. In addition, high levels of N may induce vegetative growth and delay flowering and fruiting. Changes in plant species composition and plant density, however, can occur with continued waste application (Benckiser and Simarata 1994). Legumes species are generally not encouraged with continuous irrigation with N rich effluent.

Crop-interplant and agroforestry are more efficient than along cropping system and forest on recycling nutrients and improving the productivity.

Regarding the effect of irrigation with effluents on plants, most reports on damage to vegetation from applied wastewater have emphasized the role of salts or overfertilization (Baier and Fryer, 1973), particularly when the water is derived from agricultural and food industry wastes (Morisot and Gras, 1974). Neary *et. al.* (1975) found evidence of boron toxicity to red pine needles in a plantation irrigated with 2.5, 5 and 8.8 cm of wastewater/wk. Other authors have reported tree death due to ice damage (Sopper and Kardos, 1972).

Relatively few papers in the field of wastewater irrigation discuss plant disease. In one study, unidentified root rot complex (Marten *et al.*, 1979) was involved in a severe decline of alfalfa in wastewater irrigated plots at 6 and 10 cm/wk applications. Zeiders (1975) Zeiders and Sherwood (1977) found significantly more tawny blotch (caused by *Stagonospora foliicola*) on reed canarygrass irrigated with 5 cm municipal wastewater than on non-irrigated plants. Therefore, land application effects need to be carefully monitored so that the plant/soil system is not damaged.

2.7 EFFECTS OF LAND APPLICATION OF WASTE EFFLUENTS ON SOILS AND THE ENVIRONMENT

2.7.1 Soil chemistry

Many studies have shown that soil fertility is increased after land application of wastes (e.g. Keeley and Quin, 1979; Hart and Speir, 1992). A study of the effects of over eighty years of application of meatworks effluent to Lismore stony silt loam soil in Canterbury, New Zealand, has shown that considerable increases in soil N, P, K, S, Ca, Mg, organic carbon, pH and base saturation can occur (Table 2.4).

Table 2.4   Nutrient status of soil (0 - 15 cm) after 80 years of meatworks effluent application (Keeley and Quin 1979).

	Disposal area	Control (non-irrigated)
pH	6.4	6.1
Organic C (%)	4.45	3.88
N (%)	0.46	0.36
C/N	9.7	10.8
Total P (mg/kg)	1500	630
Available P (mg/kg)	270	30
Extractable SO_4-S (mg/kg)	27	3
Cation ($cmol_c$ kg^{-1})		
Ca	15.4	9.4
Mg	1.0	1.0
Na	1.2	0.5
K	1.4	0.5
Base saturation (%)	87	66

In short-term studies, for example, Tungcul *et. al.* (1996) have also shown trend of increasing soil nitrate, pH, and exchangeable K, Ca, Mg with dairy farm-pond effluents

irrigation during growing season for one year old willow (N.Z.1295) and Eucalyptus tree at 7.5 mm, 15 mm and 30 mm of irrigation rates in Plamerston North.

The annual rate of organic matter input in effluent treatment systems is generally regarded as being too low to cause a significant increase in soil organic carbon content. However, application of untreated meat processing effluent since 1899 has been reported to cause an increase in soil organic C from 5.6 to 6.8%, and increases in microbial biomass, soil respiration, mineralicable N, available P and enzyme activities (Ross et. al., 1982). Although this may be seen as beneficial to soil fertility and plant growth it can also result in substantial amounts of nutrients being leached from the soil (Keeley and Quin 1979). Not all wastes lead to an increase in soil organic matter. Land application of industrial wastes with a high pH (pH 10 - 13) is likely to dissolve soil organic carbon (Lieffering and McLay 1996), which in turn may lead to the development of soil structural problems.

2.7.2 Nitrogen

The rate of waste application has a considerable influence on the N leaching loss and excessive application rates can pose a significant threat to water quality. Keeley and Quin (1979) calculated that over 40% of applied N was leached below the rooting zone in Lismore stony silt loam pasture soils that received meatworks effluent at a rate of over 900 kg N $ha^{-1} y^{-1}$. Lysimeter studies have confirmed that nitrate leaching losses are small when wastes are applied at relatively low rates but that leaching losses are considerably greater at higher rates of application (Canerib et. al., 1995). Results from the Wagga Wagga Effluent Plantation Project (Polglase et. al., 1994) also show that irrigation of treated sewage effluent at twice the rate of water use by gum trees (*Eucalyptus grandis*) and pine trees (*Pinus radiata*) can result in increased nitrate leaching losses (Bond et. al., 1996). Application of effluent at a rate that matched plant water use did not result in an adverse impact on groundwater quality.

The method of disposal of effluent also affects the of N leaching. For example, nitrate concentrations as high as 224 mg L^{-1} were observed at a depth of 5.5 m below a septic

tank well in a Karrakatta sand on the Swan Coastal Plain in Western Australia (Whelan and Barrow 1984), whilst surface applications generally result in lower leaching losses.

Soil conditions at effluent irrigation sites are generally favourable for denitrification. During an effluent irrigation event the soil temporarily becomes anaerobic and this, combined with the high concentrations of nitrate and organic carbon supplied by the effluent, is ideal for denitrification reactions to occur. Organic carbon concentrations in meat-processing effluents are usually in the range of 300 - 1000 g m^{-3}, of which 60% is water soluble (Cooper $et.$ $al.$, 1979). Russell $et.$ $al.$ (1993) reported peak rates of N_2O emission of 379 g N_2O-N ha^{-1} h^{-1} from primary treated meat processing wastes applied to a pasture soil and a lower emission rate of 62g N_2O-N ha^{-1} h^{-1} from anaerobic treated effluent. Since anaerobic treatment removes about 80% of the organic matter (Russell and Cooper 1983), the differences in N_2O emission rates were attributed to the lower concentrations of organic carbon in the anaerobic treated effluent.

Enhanced denitrification has been proposed by some workers as a means of reducing the nitrate leaching loss (Barkle $et.$ $al.$, 1993). However, enhanced emissions of N_2O gas may cause other environmental impacts, such as ozone depletion and global warming. Complete denitrification in the presence of excessive amount of soluble carbon results in the release of N_2 gas which is considered safe. Soil temperature has an important influence on dinitrification rate and some workers believe that at temperatures below 12 ^{0}C denitrification is not a viable nitrate removal mechanism anyway (Russell $et.$ $al.$, 1993)

2.7.3   Phosphorus

Phosphorus retention mechanisms in most pasture soils in New Zealand and Australia are considered to result in a low risk of P leaching (White and Sharpley 1996). For example, the depth of leaching was reported to be less than 0.025 m after 2.5 years of application of treated sewage effluent in the 'Flushing Meadows' scheme at Wagga NSW (Falkiner and Polglase 1996). However, P leaching is a concern in some sandy soils.

The P concentration of individual wastes frequently varies, for example, septic tank effluent varies from 11 to 31 mg P L^{-1}, with a mean of 16 mg P L^{-1} (Reneay et. al., 1989). This makes it difficult to control P inputs and limit leaching loss. Although most studies indicate that P contamination from septic tank effluent is limited to shallow groundwater adjacent to disposal sites, extensive leaching can occur where disposal rates are excessive and soils are coarse textured with low concentrations of hydrous oxides (Reneay et. al., 1988).

Calcareous soils have been promoted as particularly suitable for effluent disposal because of their ability to sorb P and thus reduce the risk of leaching into water (e.g. Lance 1977). However, recent studies (Whelan 1988) have indicated that they can in fact have a limited capacity to store phosphate. Their suitability for waste disposal may be limited by acid production during nitrification of waste derived NH$_4^+$ which may in turn result in the dissolution of soil carbonate and consequently the release of previously sorbed P (Wheelan 1988).

2.7.4   Soil pH

Sodium hydroxide is often used as a cleaning agent in many industrial and food processing plants. The wastes from these plants are alkaline with pH values often above 10 (Lieffering and McLay 1995). Land application of these alkaline wastes can therefore increase soil pH. Keeley and Quin (1979) and Barnett and Parkin (1985) have reported significant increases in soil pH following the application of fellmongery effluent and dairy factory wastewater, respectively. Campbell et. al. (1980) also reported an increase in soil pH following the application of wool scour effluent to a Waimakariri sandy loam in Canterbury.

2.7.5   Exchangeable cation

Keeley and Quin (1979) reported a significant increase in base saturation and exchangeable K$^+$ following application of wool scour effluent.

A high concentration of sodium in soil is of concern because it can cause a reduction in soil aggregate stability. This can cause a decrease in infiltration rate and an increase in the risk of run-off. High salt concentrations in soil solution can also reduce the soil osmotic water potential and thus decrease the amount of water that is readily available for plant uptake.

An annual application of 1000 mm of effluent irrigation with a concentration of 100 mg L^{-1} of total dissolved salts would apply 10000 kg of salt per hectare. Sodicity can be developed when effluent with a high sodium adsorption ratio (SAR) is applied (Sumner and McComchie 1996). The application of secondary treated dilute sewage effluent to soil growing bananas at Woolgoola, NSW, was reported to increase the soil sodium concentration from 0.11 cmol (+) kg^{-1} to 0.31 cmol (+) kg^{-1} (Johns and McConchie 1994). Despite the low electrical conductivity of the effluent (0.44 dS m^{-1}) the soil exchangeable sodium percentage (ESP) values reached 4% during the trial. Land application of treated sewage effluent in the 'Flushing Meadows' plantation near Wagga Wagga, NSW, has also been found to have significantly increased soil salinity (Smith *et. al.*, 1996).

The application of effluent from a pulp and paper mill in New Zealand was reported to have caused an increase in SAR from 2 to 16 and an increase in sodium concentration in groundwater (Johnson and Ryder 1988).

2.7.6 Soil biology

Yeates (1995) reported that 7 years of spray irrigation of sewage effluent into a 17 year old *Pinus radiata* plantation on dune sands caused an increase in earthworm and nematode populations and a decrease in the populations of some groups of litter arthropods (spiders, aphids and adult diphtheria). The effluent irrigation also appeared to increase the rate of litter breakdown.

There are concerns about the health of animals grazing effluent irrigated pastures, particularly where sewage sludges and effluents have been used. The New Zealand Department of Health recommends a withholding period of up to 6 months before the

animals can be allowed to graze depending on the treatment that the waste has received (New Zealand Department of Health 1992). Knowledge regarding pathogen survival from other wastes, such as poultry manure, is limited (Edwards and Saniel 1992).

2.7.7 Heavy metals

Although metal concentrations in plants can be increased by additions of metals to soils, the uptake of most elements tends to be somewhat limited, such that humans, livestock and wildlife are not at any chronic risk from metal in the soil (Chaney and Oliver 1996). Further phytotoxicity of some of the heavy metals protects the food-chain from being contaminated by the heavy metal.

Three heavy metals (Cu, Ni and Zn) out of 4 (including Cd) that are of concern in a number of waste materials such as tannery effluent, pulp and paper sludges and piggery wastes are essential for humans.

It is Cd that has received the most attention regarding its potential passage into the food chain. However, even with Cd, it is only in areas where flood irrigated rice is the staple food in the diet that major human health problems are likely (Chaney and Oliver 1996).

Plant uptake is not the only possible pathway for metals to enter the food chain. Contaminated soil can be ingested directly by grazing animals. A 500 kg dairy cow may ingest about 900 g soil per day, equivalent to about 6% of dry matter intake. In some cases soil could constitute up to 14% of the total dry matter intake (Healy 1968). The soil ingestion was recognized by the USEPA as one of the pathways for risk assessment for potential transfer to humans and livestock of contaminants in sewage sludge-treated soils (Chaney and Oliver 1996).

2.7.7.1 Metal leaching

In general, metals added to soil in wastes, particularly sewage sludge, accumulate in the surface layers of the soil. There appears to be little movement of heavy metals below the

zone of incorporation of the sewage sludge (Emmerich *et. al.*, 1984). However, if wastes contain significant quantities of metals in the form of simple inorganic salts, leaching to groundwater is more likely to be a potential problem. For example, McLaren *et.al.* (1994) showed that substantial amounts of chromium (as dichromate $Cr_2O_7^{2-}$) and arsenic (as arsenate H_2AsO^{4-}) from timber treatment solutions could be leached through structured soils. This study also showed that preferential flow of metals (peak leaching prior to 1 pore volume of leachate) could be of particular importance in terms of speeding up their movement down through the soil towards groundwater.

2.7.7.2   Effects of metals on soil biological activity

There has been controversy on effects of metals on soil biological activity, particularly when the metals are present in sewage sludge (Smith 1991). In particular we need to understand any changes in metal bioavailability which take place over long periods of time following waste application to the soil. Berrow and Burridge (1980) have hypothesised that when the organic matter added in wastes breaks down, the metals held by it will be released and become more mobile and bioavailable. However, it has also been suggested that with time, metals added to the soil will react with the soil and revert to less mobile and bioavailable forms (Lewin and Beckett 1980). The most conservative approach to minimize the impact of metals in soil should be to minimize metal inputs to the soil wherever possible (McLaren and Smith 1996).

2.7.8   Organics

Muszkat *et. al.* (1993) studied the migration of organics in a soil which had received sewage effluent for about 20 years, and found that many of the organic compounds had migrated through 20 m depth. These organic compounds include aliphatic hydrocarbons, pesticides (e.g. prometon, a triazine herbicide), solvents (toluene), organic acids and esters, and plasticizers (e.g. diisooctyl phthalate). The apparent mobility and deep penetration of the compounds were attributed to the enhancement of aqueous solubility of the organics by surface active surfactants and dissolved humic and fulvic acids present in the effluents.

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2.7.9   Soil structural properties

Land application of wastes is reported to have a variable effect on the infiltration rate and hydraulic conductivity of the soil. Magesan *et. al.* (1996) reported that the application of secondary treated sewage effluent increased the macroporosity of a sandy loam from 11 to 19% and the saturated hydraulic conductivity from 39 to 57 mm h^{-1}. However, reductions in infiltration rate have also been reported following the application of some wastewater, for example sewage (Reneau *et. al.*, 1989) and fellmongery effluent (Balks and McLay 1996). McAuliffe (1984) found that soil permeability was reduced by 95% within two days of applying wool scour effluent. Reductions in infiltration rate are attributed to the formation of a biological mat or crust (Bouma *et. al.*, 1972; Krisitiansen 1981), the accumulation of solids filtered from the effluent (DeVries 1972), and/or the collapse of soil structure due to organic matter dissolution (Lieffering and McLay 1996). A reduction in infiltration rate can cause ponding of effluent to occur and this can increase the smell from the effluent disposal area. There is also an increased risk of surface runoff occurring which may cause contamination of adjacent rivers and lakes. If these problems become serious they can threaten the viability of the effluent disposal operation.

Land application of waste effluents can have a variety of beneficial or detrimental effects on soil physical conditions, depending on the characteristics of the waste effluent and the soil. Research and monitoring programmes are therefore necessary to ensure that waste application systems are sustainable and that they do not damage soil quality (Cameron 1996).

2.8   CONCLUSIONS AND FUTURE RESEARCH NEEDS

This review has found:

1.   Many waste effluents contain significant concentrations of nutrients and, if used properly, can indeed serve as valuable nutrient source for agricultural, horticultural and forestry production without causing significant adverse effects on the soil or the

wider environment. Recycling nutrients in these wastes effluents can improve the sustainability of farming systems but excessive rates of application have been shown to cause N and P pollution of surface or groundwater.

2.   Some waste effluents also contain undesirable and often toxic elements or compounds, (e.g. heavy metals, trace organic, salts and pathogens) and some have extremely low or high pH. While many negative impacts of land application of these wastes on soil quality, and animal and human health have been reported, these impacts may be minimised by sound management systems, such as alternative plant species, constructed wetland, forestry and SRF,ect.

3.   In most past practices of agricultural effluents disposal by direct landfilling nitrogen was the key element in terms of both as a nutrient source and a pollution of groundwater or surface runoff. The secondary effluents were more regarded as an irrigation source than as a fertilizer, the long-term fate of some compounds or elements in those effluents are not yet well understood and needs continued investigation, especially for the agricultural secondary effluents.

4.   Willow, presenting as a SRF species, is thought to be ideal for land treatment with secondary effluent irrigation due to their fibrous root systems and ability to utilise large quantities of water and nutrients, the interest in biomass production in association with land disposal of secondary effluent is merited.

5.   Assessment of the nutrient removal ability of SRF crops is the key important point to determine the potential of waste effluent application in the system, the data of different effluents and their rates will be needed for specific soil conditions.

CHAPTER THREE

MATERIALS AND METHODS

3.1   MATERIALS

3.1.1   Soil

Manawatu fine sandy loam soil (Tropic Dystrochrept) (0 - 10 cm depth) was collected from No 4 Dairy Farm, Massey University for the growth experiment. The soil was air-dried, thoroughly mixed and sieved to < 5mm. One kg of the air-dried soil was weighed into free draining pots.

3.1.2   Plant

Willow (*Salix kinuiyanagi*) cuttings (shrub willow 1295 New Zealand) were obtained in the end of May 1996 from the nursery of Hort Research Unit, Palmerston North. Cuttings with 80 mm length and 6 - 8 mm top-end diameter and with 2 buds were stored in air-tight polyethylene bags in a cold store room (5 ^{0}C) for one month before planting in the pots. Willow was chosen for this study because it produced a high biomass with irrigation and has been shown to be a good tree species for short rotation forestry under New Zealand conditions.

3.1.3   Effluents

Wool scour effluent, dairy farm-pond effluent and piggy effluent were collected from Feltex Wool Process Company (Marton), Massey University No 4 Dairy shed and New Zealand Pig Breeding Farm, respectively. The effluents have been primary treated to remove large solids, and secondary treated under alternate aerobic and anaerobic cycles in an extended aeration pond to oxidize organic matter, reduce nitrogen content, and separate clear effluent from sludge. Effluent samples were stored in iron holding tank

(250 L, totally enclosed to inhibit algal growth) in a cold room at 5 ^{0}C throughout the experiment period. A complete nutrient solution and tap water were used for comparison and these are also included as 'effluents' in the Results and Discussion Chapter.

3.2 METHODS

3.2.1 Experimental design

The potential for effluents to increase soil quality and productivity is determined by changes in the physical and chemical properties of rooting zone that affect the plant availability of water, nutrients and toxic compounds. Effluent application also has the potential to reduce plant growth due to salinity build up, toxic ion effects (Israeli, 1986), and low soil oxygen levels (Abruna, 1980).

In this experiment, it was assumed that the Manawata sandy loam soil (3 - 10 cm) contained insufficient amounts of N and P to sustain the normal growth of willow cutting. A complete nutrient solution and nutrient-free tap water treatments were also included in addition to the effluent (wool scour, dairy and piggery) treatments. The trial with effluent irrigation was carried out in pots in the greenhouse. Four electrical bulbs (1000 watt each) were used to supply 12 hours light for day time during July to September and the temperature was controlled at 25 ^{0}C for day time and at 15 ^{0}C for night by an automatically heating system. The design of the experiment was a 5 x 2 factorial combination of treatments with four replicating in randomized blocks. 1 kg soil was weighed into pots and one willow cutting was planted in each pot. 100 pots (5^2 x 4) were located on 4 trailers (2.5 x 1 m^2), the positions of the trailers were changed each week for maintaining the same amount of light intercepted during the experiment.

Two factors each with 5 levels were examined; the factors included effluents and irrigation. The levels of irrigation: 12.5 mm, 25 mm, 37.5 mm, 50 mm and 62.5 mm per fortnight; and effluents: wool scour effluent, dairy farm-pond effluent, piggy effluent, nutrient solution and tap water.

The effluent application rates were based on the soil surface area of 12 cm diameter pot. The levels were equivalent to 16.1, 32.2, 48.3, 64.4, 80.5 ml per day. Each application is based on the field capacity of soil to avoid excess drying of soil in pots or flooding. All pots were provided with bottom -end cover to collect any free draining leaching and the leachate was added back into the pot. The plants were grown up to 70 - 80 cm height shoots during first 4 weeks before irrigation treatments started. Irrigation by hand using a marked container commenced on 30 June 1996 (every day) and ended on 25 September 1996. Weed growth on all pots was controlled by hand-clearing.

3.2.2 Collection of soil and plant samples

3.2.2.1 Soil sampling

Soil samples were collected after harvesting from 50 pots representing, two replications per treatment. The remaining pots were used for collecting the root samples. The soil samples were air-dried, the soil aggregates were crushed using a porcelain motar and pestle and then sieved to < 2 mm. The soil samples were used for N, P, K, Na, Ca, Mg, pH and electrical conductivity measurements.

3.2.2.2 Plant sampling

The main cutting used for planting was not included in the calculation of dry matter. Only the branching shoots were used for dry matter measurements. Stem and leaves were collected from each pot and biomass weight was recorded separately for leaves and shoots. Plant samples were dried at 85 ^{0}C in a force draught oven for 10 minutes firstly then at 65 ^{0}C for 48 hours. After oven drying, the samples were weighed by using a 3 decimal place balance and recorded.

50 root biomass samples (two replications per treatment) were collected and their weights recorded. Root biomass was collected by putting the pots first into a bucket (25 L) with water to separate the soil from root, then washed with an automatic root washer that use a jet of water to remove soil particles adhering to root. The fresh roots were then dried at

70 ^{0}C in a forced draught air oven for 36 hours and weighed for each pot separately. An average value of the 2 replications was calculated and recorded as the root biomass.

All plant dry samples were ground separately using Cyclotec 1093 sample mill, and kept in air tight polyethylene bags for chemical analysis.

3.2.3   The measurement of shoot growth and root length

3.2.3.1 Shoot length

The length of the shoot was recorded three times before harvesting. The height of shoot growth was measured from the base of the main cutting to the top of the stem.

3.2.3.2 Root length

During the harvesting, the length of 25 root samples (one sample per treatment) was measured using a Comair Root Scanner. A relationship was obtained between the length and the weight of the root mass. This relationship was used to calculate the length of root from the other replication and the average root length of each treatment was calculated.

3.2.4   Soil and plant for chemical analysis

3.2.4.1   pH

Soil pH was measured in water and the effluent pH was measured directly in the effluents.

The pH of the dried and ground soil samples from each pot was analyzed in duplicate and in random order to avoid systematic errors; whenever the results of duplicate analyses differed by > 5% and the analysis of an additional subsample did not produce results agreeing to within 5%, the results for the three analyses were averaged.

Five g of soil material were mixed in a bottle with 12.5 ml of distilled water (solid: solution ratio 1 : 5). The mixtures were shaken vigorously in closed bottles and left over night before a pH reading was made. For each effluent three subsamples were used for pH measurement and the mean value was used.

3.2.4.2   Electrical conductivity

A 1 : 5 solid: water extraction procedure was used to measure conductivity (Bower and wilocox, 1965). A five g air-dried sample (< 2 mm sieved) was added to 25 ml of deionised water and stirred well. It was shaken in an end-over-end shaker for 30 minutes and filtered through No. 1 filter paper. A conductivity cell connected to a self adjusting conductivity meter was calibrated in a 0.01 M KCl solution to 1.14 mmho/cm at 25 ^{0}C. The temperature and the conductivity of the extracted solutions were measured. The cell constant was arrived at by dividing the theoretical value for 0.01 M KCl by the measured value. The soil conductivity was corrected to standard temperature 25 ^{0}C using standard temperature factors (Massey University Soil Science laboratory methods, unpublished). Sample conductivity was then calculated using Equation

Conductivity = $a*b*c$

where: a = measured conductivity

b = cell constant

c = temperature factor

3.2.4.3   Soil exchangeable K, Na, Ca and Mg cations

Ammonium acetate (1M) was used to extract exchangeable K, Na, Ca and Mg by leaching 1 g air dried soil with 50 ml NH_4OAc solution at pH 7.0 for 1 hour.

Triplicate samples of 1 g (air dry < 2 mm) soil from each pot were mixed with 2 g acid washed silica sand and packed into a leaching tube (pipette tip) which had a macerated filter paper plug (Whatman # 41 filter paper). The columns were leached with 50 ml of 1M ammonium acetate and the leachate collected in 50 ml volumetric flasks which were made up to volume with ammonium acetate. The blank was 2 g of washed silica sand.

Soil exchangeable K, Na, Ca and Mg cations were determined using standard flame atomic absorption spectrophotometer methods and the 'GBC 903' instrument.

3.2.4.4 Soil and plant for total N and P

The Kieldahl Digestion method (McKenzie and Wallace, 1954) was used to determine the total N and P content of soils and plants in this experiment. The Kjeldahl digestion method involves digesting 1 g soil and 0.1 g plant material with 4 ml of a digest mixture containing possum sulphate, selenium and sulphuric acid. The digests were heated in aluminium blocks at 350 ^{0}C for four hours and cooled over night. They were then diluted with deionised water, thoroughly mixed in a vortex mixer and analyzed using the auto analyser. Dilutions were made as necessary with deionised water to achieve levels of N that were within the linear range for the auto analyser. Two blanks were run with every set of 30 tubes.

During the Kieldahahl digestion N is recovered in ammoniacal form. This form of N was measured using an auto analyser by following Berthelot's indophenol blue reaction method (Markus *et. al.*, 1985). The phosphorus in the plant sample was measured by vanadomolybdate yellow method.

3.2.4.5 K, Ca and Mg in plants

The content of K, Ca and Mg in plants was determined by nitric acid digestion method. 0.1 g plant sample (oven dried at 70 ^{0}C) was weighed using a 4 decimal place balance (< 0.103 g) into digest tubes. Two Wageningen standard herbage samples (obtained from Wageningen) and a blank sample were measured with each digestion set. In a fume cupboard 4 ml concentration nitric acid (69%) were added to each tube and a small glass funnel was placed on top, digested at 150 ^{0}C until brown fuming stops. The tubes were then wrapped in aluminum foil and the temperature was increased in small steps up to 200 ^{0}C to evaporate to dryness at least for 4 hours. The tubes were removed from block while still warm, 5 ml of 2M HCl were added and made up in deionised water. After two hours, 1 ml of solution containing 25,000 ppm Sr, Cs solution was added and made up to 25 ml

with deionised water. Using Vortex mixer the digest solution was thoroughly mixed. The digest was then stored in storage tubes for chemical analysis.

The concentration of Na, K, Ca and Mg in the plant digests was determined using standard flame atomic absorption spechrophohmetric methods and a 'GBC 903' instrument. Lower limits of detection (2σ) in the samples, for the instrument conditions and dilutions used, correspond to 0.2 mg/L for Na, and 0.05 mg/L for Mg, K and Ca.

3.2.5   N, P, K, Na, Ca and Mg in effluents

The N and P contents of the effluents were determined by Kjeldahl digestion and automated analyser method. 5 g of accurately weighed piggery, dairy and wool scour effluents with were digested with 4 ml of a mixture containing potassium sulfate, selenium and sulfuric acid. The digests were heated in aluminum blocks at 350 ^{0}C for four hours and cooled over night. They were then diluted with deionised water upto 50 ml , thoroughly mixed in a vortex mixer and analyzed using the auto analyser for total N and P. Two blanks were run for contr.

The Na, K, Ca and Mg cation in piggery, dairy and wool scour effluents were determined by nitric acid digestion method. 5 g of each effluent with three replications were weighed with a 3 decimal place balance into digest tubes. Two blank sample were used as a control. In the fume cupboard 4 ml concentrated nitric acid (69%) were added to each tube and a small glass funnel was placed on top, digested at 150 ^{0}C until brown fuming stops. The tubes were then wrapped in aluminum foil and the temperature was increased in small steps up to 200 ^{0}C to evaporate to dryness at least for 4 hours. The tubes were removed from block while still warm, 5 ml of 2M HCl were added and made up in deionised water. After two hours, 1 ml of solution containing 25,000 ppm Sr, Cs solution was added and made up to 25 ml with deionised water. Using Vortex mixer the digest solution was thoroughly mixed. The extractant was then stored in storage tubes for Na, K, Ca and Mg cation analysis.

3.2.6 Statistical analyses and curve fitting procedures

Analysis of variance using a General Liner Model procedure was used for analysis of the experimental data. The computer programme used for the statistical analyses was SAS (Statistical Analysis System) on the computer network system available at Massey University. The results were analyzed as a randomized complete block design.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Firstly, the effect of different effluents on willow cutting will be discussed based upon willow growth, production and nutrient assimilation performance. Subsequently, the effect of effluents on soil characteristics will be discussed based on the chemical values of the effluents and the soil.

4.1 GROWTH RESPONSE OF WILLOW CUTTING TO EFFLUENT IRRIGATION

4.1.1 Effect of effluent on shoot growth

The effects of effluent treatments on shoot growth were different at different stage of willow growth. The effect of effluents on the mean net shoot growth for these periods is summarised in Table 4.1

4.1.1.1 At two weeks after irrigation

At first two weeks after irrigation, there was a significant difference in net shoot growth between the piggery effluent treatment and the tap water, while there was no significant difference among nutrient solution, dairy and wool scour effluents (Table 4.1).

The mean shoot growth values for the piggery and tap water treatment were 54.7, 75.3, 89, 98.7 and 105.7 mm, and 25, 56, 67.7, 95 and 94 mm at 12.5, 25, 37.5, 50 and 62.5 mm/fortnight irrigation rate, respectively. The large difference in the mean net shoot growth between the piggery and tap water treatment was obtained at the irrigation rates ≤ 37.5 mm/fortnight where the mean net shoot growth in piggery treatment was over 32% greater than tap water treatment. In contrast, the mean net shoot growth in piggery was

only 4% and 11% greater than tap water treatment at the irrigation rates of 50 mm and 62.5 mm/fortnight (Figure 4.1a).

Table 4.1 The mean net shoot growth (mm) at 2, 5 and 8 weeks after effluent treatments. Values followed by the same letter are not significantly different at 0.05 probability level

Irrigation rate	Mean net shoot growth		
(mm/fortnight)	(mm)		
	August 15	September 5	September 25
	2 weeks	5 weeks	8 weeks
12.5	47.3d	39.3e	10.7e
25	64.9c	61.5d	25.7d
37.5	78.1b	88.5c	45.3c
50	97.1a	146.5b	69.5b
62.5	100.6a	171.3a	84.3a
	Analysis of variance		
Effluents	**	***	***
Irrigation rates	***	***	***
Effluent x rate	N.S	***	***

**: $p > 0.005$ *** : $p > 0.0001$; N.S: Not significant.

There was a significant response to shoot growth of willow with increasing levels of irrigation rate. The mean net shoot growth of willow cutting at 12.5 mm, 25 mm, 37.5 mm, 50 mm and 62.5 mm fortnight rates was 47.3 mm, 64.9 mm, 78.1 mm, 97.1 mm and 100.6 mm respectively (Table 4.1). The mean net shoot growth at 62.5 mm showed significantly higher than that of the rest, except at 50 mm level. The difference in mean net shoot growth was also significant among the irrigation rates of 12.5 mm, 25 mm and 37.5 mm.

The results show that a) the net shoot growth of the willow was affected by both irrigation rates and different effluent irrigation at this stage. However, the effect of irrigation rate on the net shoot growth was more than that of the effluents. b) the irrigation of 50 mm/fortnight was the most economical irrigation rate at this growth stage, because the 62.5 mm/fortnight application did not significantly increase the shoot growth more when compared to that at 50 mm/fortnight application.

4.1.1.2   At five weeks after irrigation

At five weeks after continuing irrigation treatment, there was a very significant effect on net shoot growth of both different types of effluents and irrigation rates ($p = 0.0001$); the interaction of the effluent treatments and irrigation rates also was very significant ($p = 0.0001$).

It was observed that the mean shoot growth showed significant difference among all effluents treatment at this stage, except between tap water and wool scour effluent treatment, and between the nutrient solution and dairy effluent treatment. The mean net shoot growth was significantly different at each irrigation rate for all effluents at this growth stage of willow cutting. The mean net shoot growth at different irrigation rates for all effluent treatments was 171.3 mm at 62.5 mm/fortnight, 146.5 mm at 50 mm/fortnight, 88.5 mm at 37.5 mm/fortnight, 61.5 mm at 25 mm/fortnight and 39.5 mm at 12.5 mm/fortnight (Table 4.1).

Figure 4.1b shows the mean net shoot growth in different effluent treatments combined with each irrigation rate. The large difference in mean net shoot growth among different effluent treatments was obtained at 37.5 mm, 50 mm and 62.5 mm/fortnight irrigation levels for each effluent where the mean net shoot growth was 177, 199 and 225 for piggery, 111.3, 176.7 and 198 mm for nutrient solution, 81, 166.7 and 198.3 mm for dairy effluent, 67, 95.3 and 105.7 mm for tap water, 65.7, 95 and 120 mm for wool scour effluent, respectively. The mean net shoot growth of piggery treatment at there irrigation rates was 72% and 78%, 108% and 109%, 113% and 86% greater than that of tap water and wool scour effluent treatment, respectively.

For all effluents, the highest and the lowest mean shoot growth always appeared at the highest and the lowest irrigation rates, respectively. The highest mean shoot growth was 312%, 415%, 360%, 215% and 359% greater than that of the lowest for piggery, nutrient solution, dairy, tap water and wool scour effluent treatment, respectively.

4.1.1.3   At eight weeks after irrigation (Plate 1)

At eight weeks after irrigation treatment, there was still a very significant effect of effluents and irrigation rates on willow shoot growth (p = 0.0001). The interaction of the effluent treatments and irrigation rates was also very significant (p = 0.0001).

The difference in mean net shoot growth rate was significant only for the tap water, nutrient solution and dairy effluent (Table 4.1). At this stage, the mean net shoot growth for different irrigation rates was 74.8 mm in piggery treatment, 60.7 mm in dairy treatment, 52 mm in nutrient treatment, 31.5 mm in tap water treatment and 17 mm in wool scour effluent treatment. The mean net shoot growth for different irrigation level was 84.3 mm, 69.5 mm, 45.3 mm, 25.7 mm and 10.7 mm at 62.5, 50, 37.5, 25 and 12.5 mm/fortnight irrigation levels, respectively.

Figure 4.1c shows the mean shoot growth in different effluent treatment combined with each irrigation rate. The piggery effluent produced the highest mean net shoot growth for each irrigation rate except at the 25 mm/fortnight irrigation level, the piggery irrigation showed a significant increase of 4.4, 2.37, 1.43 and 1.24 times more than wool scour effluent, tap water, dairy and nutrient solution irrigation, respectively. Although the difference in the mean net shoot growth between tap water and wool scour effluent was significant and the mean net shoot growth for the wool scour effluent was the lowest (Table 4.1). The lowest mean net shoot growth of wool scour irrigation only was at the irrigation level ≥ 50 mm/fortnight (Figure 4.1c). On the other hand, the irrigation of 62.5 mm/fortnight always produced the highest mean for each effluent treatment except the

wool scour effluent. The mean net shoot growth of wool scour effluent treatment was same at 62.5 and at 50 mm/ fortnight irrigation levels.

Figure 4.1 The effect of different effluents and irrigation rates on net shoot growth

b. Five weeks

c. Eight weeks

Legend:
- Tap water
- Wool scour effluent
- Nutrient solutioin
- Dairy effluent
- Piggery effluent

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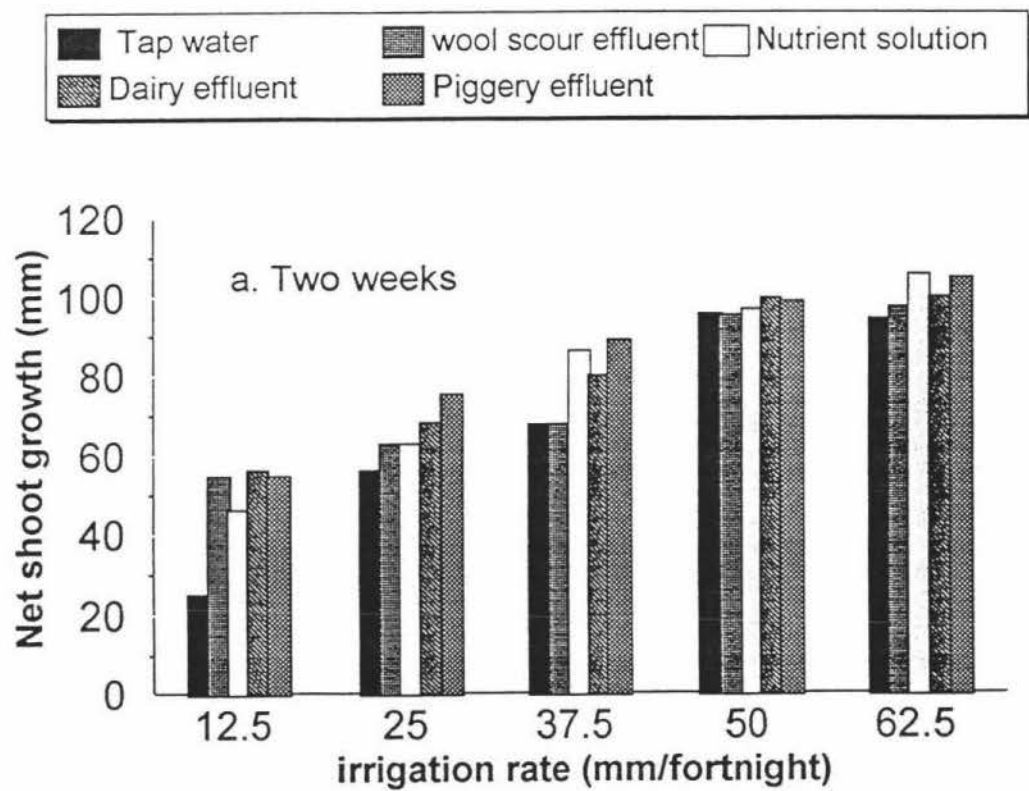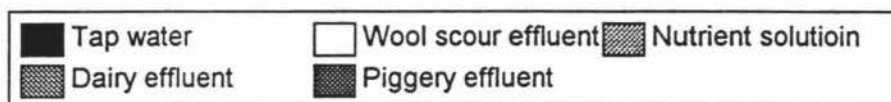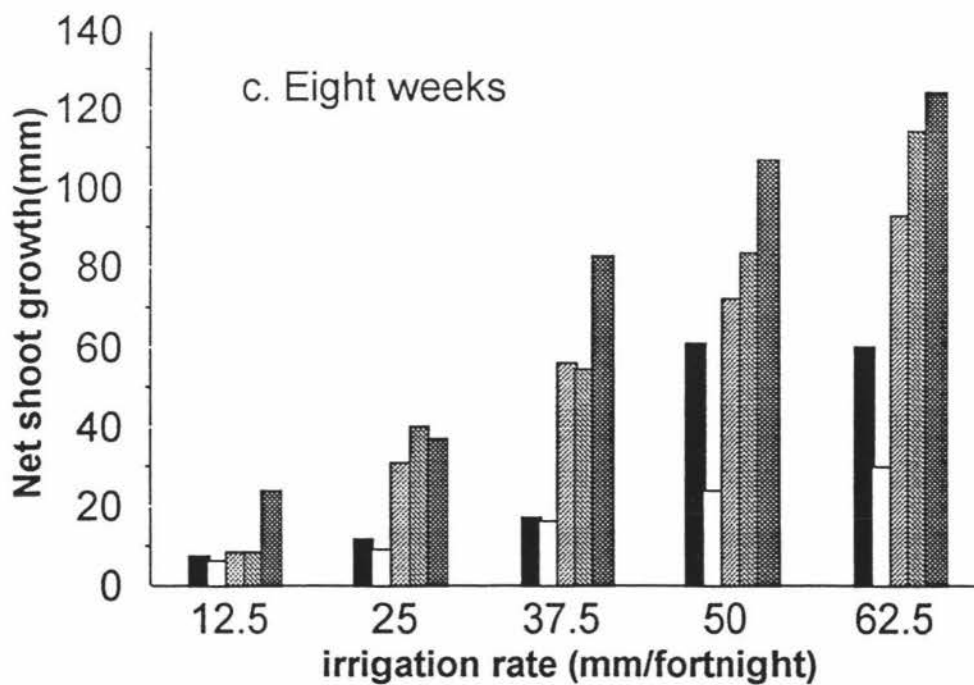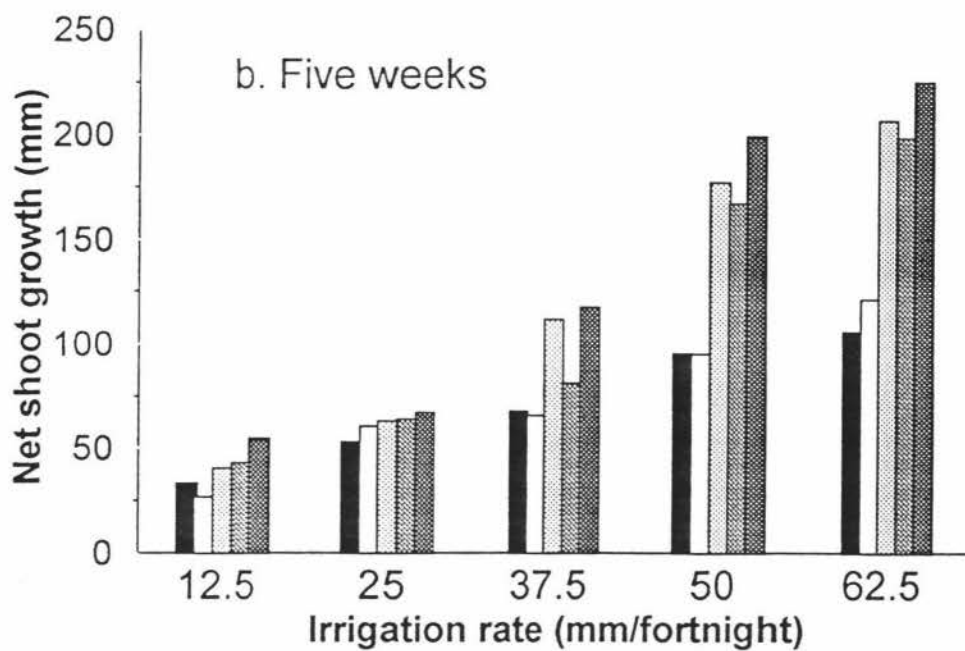
4.1.1.4   Explanation of effect of different effluents on willow shoot growth

It was observed that willow shoot growth showed different performance with different effluents and irrigation rates during different growth stages. At the two weeks irrigation, the effect of different effluents on shoot growth was very small, which increased with time. In contract, the effect of different effluents on shoot growth was more pronounced at < 37.5 mm rate than at > 50 mm rate at the first 2 weeks irrigation (Figure 4.1a). After five weeks irrigation, the effect of different effluents on shoot growth was pronounced at > 37 mm/fortnight (Figures 4.3 - 4.7). This is attributed to the difference in water and nutrients requirements of the willow cutting at different growing periods. This result may suggest that willow cutting needed very less nutrients at early stage, and nutrient solution, dairy, piggery and wool scour effluents supply more nutrients at 50 mm/fortnight irrigation rates than that required by the plants. On the other hand, during the period of 20 days (from the September 5 to September 25), the net shoot growth decreased for all irrigation rate treatments (Figures 4.3 - 4.7) in comparison with the earlier period (from August 25 to September 5). This appeared to be caused by water insufficiency, because no nutrient deficient symptoms were observed at 62.5 mm/fortnight for nutrient solution treatment at this stage.

These results showed that the shoot growth of the willow can be used as a monitoring criteria to investigate the response of different effluent application to willow growth, especially for irrigation rates. However, the sensitivity of the monitoring criteria changes with time. Tree height growth has been widely used as a monitoring criteria to investigate the tree response to irrigation with effluents in many studies (Brockway, 1982; Cooly, 1979 and 1980;). Einspahr *et.al.* (1972) have demonstrated that in some woody plants, height growth is stimulated primarily by applied water and diameter growth is increased by added nutrients. The present study also confirmed that the willow shoot growth showed response mainly to water supplement, because the difference in of the net shoot growth for the same irrigation rate between different effluents was obviously smaller than that of the same effluent treatment between different irrigation rates.

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The pervious researchers found that the sensitivity of tree growth response depends on tree species. Brochway (1982) reported that the optimum growth response to wastewater irrigation was exhibited by lowland hardwood species of the genera Populus and Fraxinus. Moderate growth response was seen in mesic-site upland hardwoods and poor response were measured in dry-site pines and oaks. The data in the present experiment showed that there was a net shoot growth response to different effluents. Tungcul, *et. al.* (1996) also confirmed that willow cutting had a growth response to irrigation with dairy effluent.

Figure 4.2 The effect of different effluents on willow length combined with different time
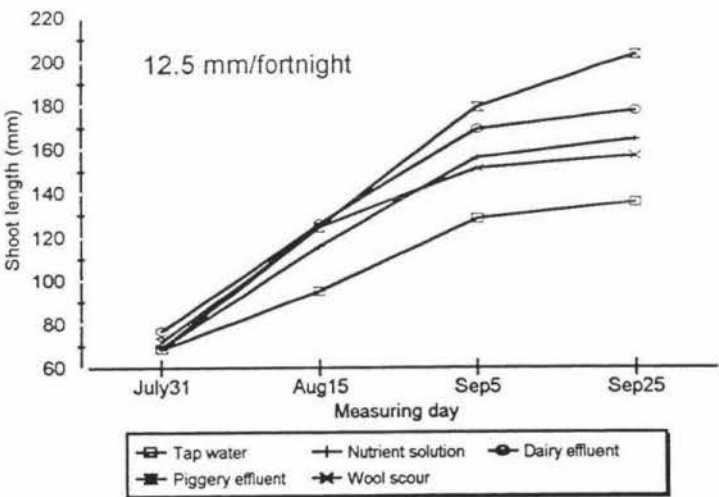
Figure 4.3 The effect of different effluents on willow length combined with different
time
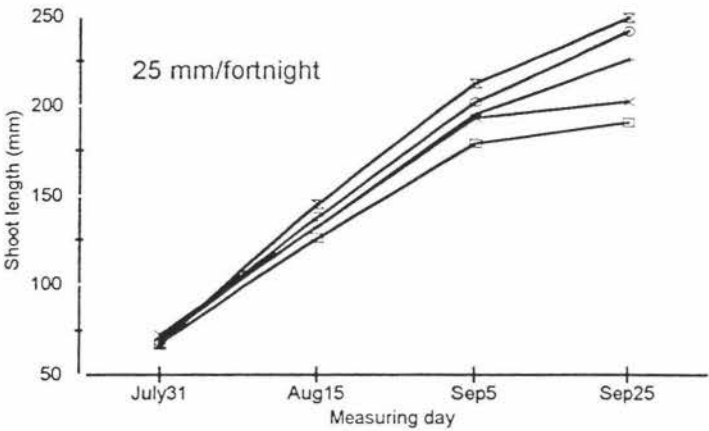
Figure 4.4 The effect of different effluents on willow length combined with different
time
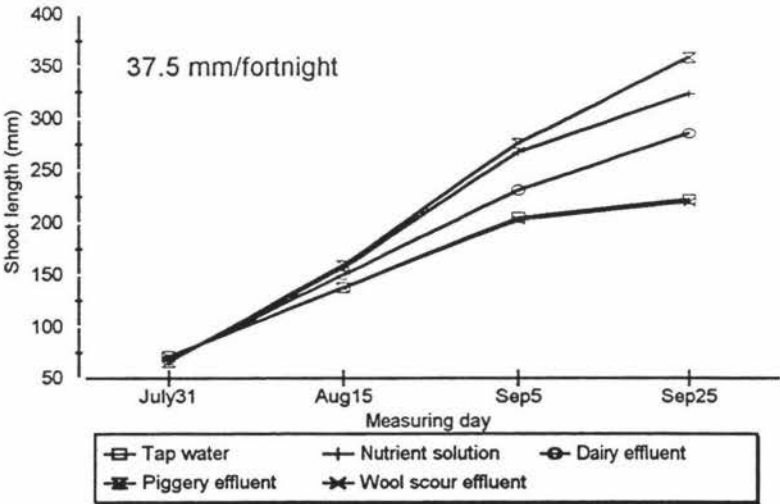
Figure 4.5 The effect of different effluents on willow length combined with different
time
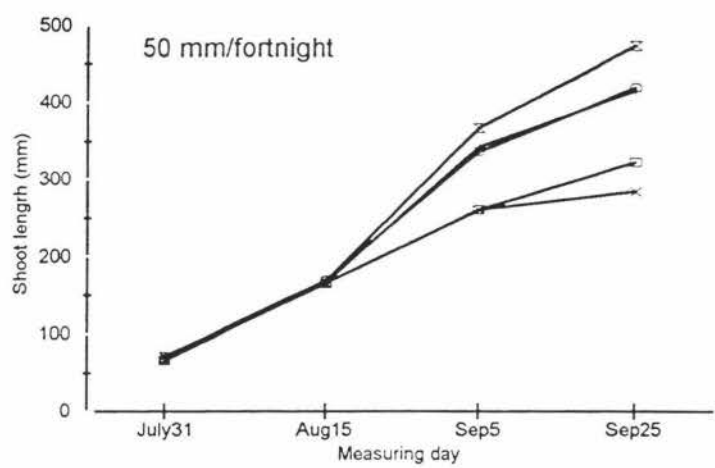
Figure 4.6   The effect of different effluents on willow length combined with
different time
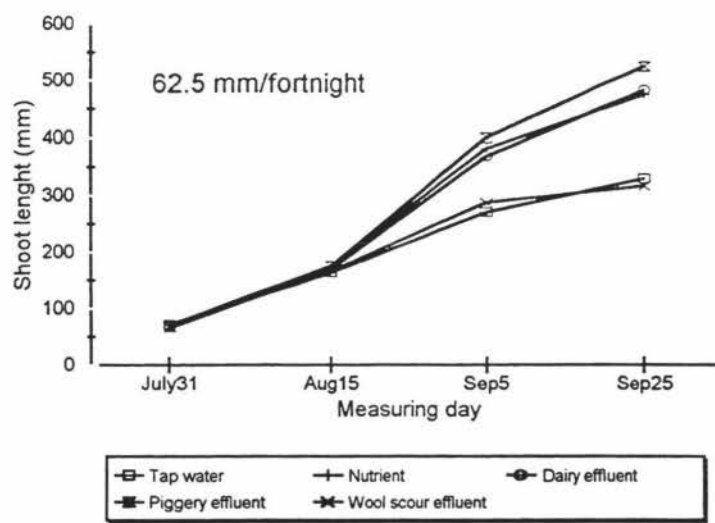
4.1.2   The effect of effluents on diameter of willow cutting

There was significant difference in the diameter growth of willow between different effluent treatments and irrigation rates (p = 0.0001). The interaction of different effluents and irrigation rates on shoot diameter was also significant (p = 0.0012). The highest mean diameter was obtained in piggery effluent treatment, which was significantly different from the plants grown in the rest of other effluent treatments for all irrigation rate except at 12.5 mm/fortnight. The mean diameter for the willow cutting ranged from the highest of 4.92 mm in piggery effluent to the lowest of 4.35 mm in the wool scour effluent treatment. There was no significant difference in the mean diameter between nutrient solution and the dairy effluent treatments. There was also no significant difference in the mean diameter between the tap water and wool scour effluent treatment.

The mean diameter values were 5.72, 5.24, 4.63, 4.10 and 3.38 mm at 62.5 mm, 50 mm, 37.5 mm, 25 mm and 12.5 mm/fortnight irrigation levels for all effluent treatments, respectively. The mean diameter showed a significant increase with increasing levels of irrigation rate for all effluent treatments (Table 4.2).

Table 4.2   The mean diameter of willow cutting at each effluent treatment for all irrigation levels, and at each irrigation level for all effluent treatments. Values followed by the same letter are not significantly different at 0.05 probability level

Effluent	Diameter (mm)	Irrigation (mm/fortnight)	Diameter (mm)
Piggery	4.92a	62.5	5.72a
Nutrient solution	4.63b	50	5.24b
Dairy	4.67b	37.5	4.63c
Water	4.39c	25	4.10d
Wool scour	4.36c	12.5	3.28e

The effect of effluents combined with irrigation rates on shoot diameter is shown in Figure 4.7, the effect of irrigation rate on diameter growth greater was than the effluents.

Figure 4.7 The effect of the different effluents on the diameter of willow cutting with combination of irrigation rates
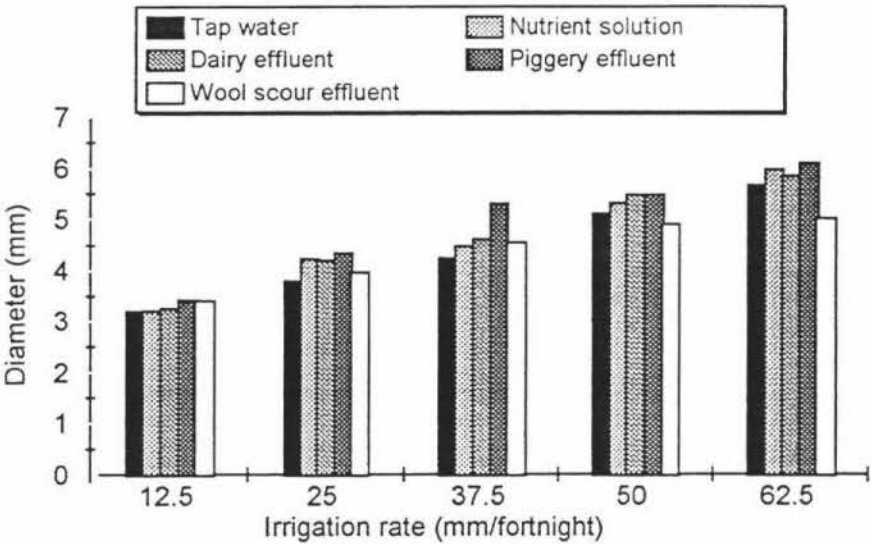
Plat 1 Effect of effluents on willow shoot growth

Plat 1 (continue) Effect of effluents on willow shoot growth

The results showed that there was no consistent response to effluent irrigation when the diameter and the shoot growth of willow were used as monitoring criteria to investigate the effect of the effluents on willow growth. The results of the shoot growth for willow cutting showed that the wool scour effluent caused a decrease in the shoot growth at the end of 8 weeks irrigation when compared to the tap water as a source of irrigation. However, the result of diameter growth showed that there was no significant difference between wool scour and tap water treatments (Table 4.2).

Fitzpatrick,G.E. (1986) reported that sewage effluent irrigation on container-grown tree, accelerated growth only in 4 out of 20 tree species when it was compared to tap water. The tree height growth was used as a monitoring criteria in his experiment.

The effect of the effluents on plants growth is attributed to their many functions, such as a source of water, nutrient supplement or toxic element and physiological active substance (function was similar to growth hormone). On the other hand, different plant species have their own biological characteristics. Therefore, evaluation of effluents function on plant, especially for tree was complex and many studies in depth are required. Although the study could not explain the disparity between the height and diameter with these effluents, the data suggested that both shoot growth and diameter growth of willow responded to the effluents, which could be used as monitoring criteria when we examine the willow response to effluents.

4.1.3   Root mass and length

The fine root lengths vary with different effluent and irrigation rate treatments (Appendix 4.2). The mass of root, however, (diameter > 0.1mm) increased with increasing irrigation rates among all types effluent treatments (see Plate 2). The nutrient solution treatment had a significantly less amount of root (diameter > 0.1 mm) than the other treatments except the wool scour effluent treatment. The colour of the fresh root was obviously different (Plate 2) between wool scour effluent treatment and the rest of other treatments. The colour of root was darker in wool scour treatment than in the other treatments.

Plat 2 Effect of effluents on willow root growth

4.1.4   Effect of effluent on dry matter yield

The dry matter yields of aboveground, underground and total for willow in each effluent treatment and irrigation rate are given in appendix 4.1.

4.1.4.1   Aboveground DM yield of willow cutting

There were significant differences in the mean shoot dry yields and total DM yield between different effluent treatments and irrigation rates. However, the significant difference of root DM yields with different effluent treatment showed that there was no significant difference among nutrient solution, piggery and dairy effluent treatments.

The mean aboveground DM yield for piggery (5.62 g/pot) was significantly higher than the mean aboveground dry matter yield recorded in the rest of the treatments. There was a significantly difference in aboveground DM yield among all effluent treatments except between nutrient solution and dairy effluent (Table 4.3).

Table 4.3   The mean DM yield of willow (g/pot) at each effluent treatment for all irrigation levels. Values followed by the same letter are not significantly different at the 0.05 probability level

Treatment	Mean aboveground DM	Mean root DM	Mean total DM
Piggery	5.62a	1.15a	6.83a
Nutrient solution	5.02b	1.07ba	6.14b
Dairy	4.08cb	1.00ba	5.89b
Water	4.27c	0.849b	5.15c
Wool scour	3.53d	0.507c	4.14d
Analysis of variance			
Effluents	***	***	***
Rates	***	***	***
Effluent x rate	***	***	***

*** : $p > 0.0001$.

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Figure 4.8 showed the mean DM for all treatment combinations. The highest mean aboveground dry matter yield of willow was produced at the 62.5 mm/fortnight for all effluent treatment, which ranged from the highest of 9.65 g/pot in piggery effluent treatment to the lowest of 5.17 g/pot in wool scour effluent treatment. The order of the mean DM yield at 62.5 mm/fortnight was: piggery (9.65 g/pot) > nutrient solution (8.58 g/pot) > dairy (7.65 g/pot) > tap water (7.16 g/pot) > wool scour effluent (5.17 g/pot).

Figure 4.8 The effect of different effluents and irrigation rates on aboveground DM yield
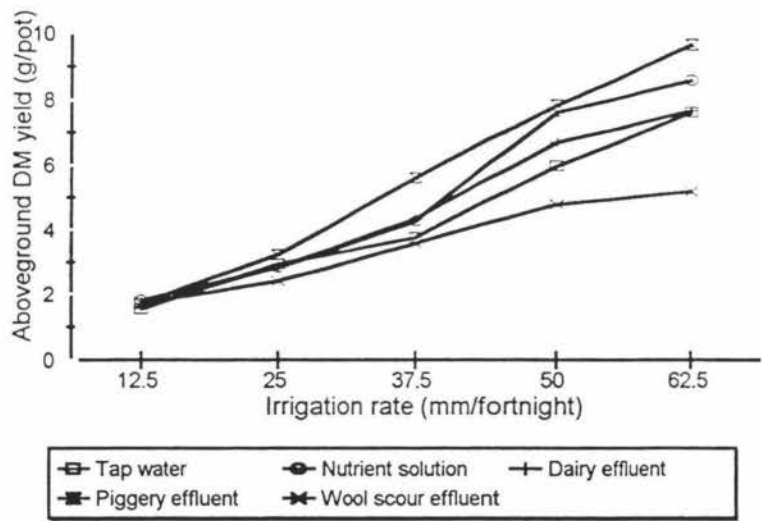
The results indicated that the mean aboveground DM yield showed different responses between the piggery, dairy and wool scour effluents. This suggested that the aboveground DM yield could be used as a monitoring criteria to investigate the effect of these effluents on willow growth under this experiment condition. However, there was no significant difference of aboveground DM yield between dairy effluent treatment and tap water control in this experiment.

The results also suggested that piggery and dairy effluents can be used as a source of irrigation for willow growth, while the wool scour effluent was not a good source of

irrigation for the willow, because the aboveground DM yield of willow had a significant decrease when irrigated with wool scour effluent compared to irrigation with tap water.

4.1.4.2   Root DM yield

The mean root DM yield in piggery treatment was significantly higher than that recorded in water treatment while there was no significant difference between piggery and nutrient solution treatments. On the other hand, the average of mean root DM yield significantly increased with a increasing irrigation rates for all effluent treatments (Table 4.3).

Figure 4.9 showed the factorial and the overall mean root DM all treatment combinations.

The highest mean root DM yields of willow was at 62.5 mm/fortnight irrigation level for all effluent treatments where the mean DM yield ranged 2.04 g/pot in piggery to 0.68 g/pot in wool scour treatment. The highest mean root DM yield of piggery treatment was 3 times more than that of the wool scour effluent treatment at the end of this experiment.

Figure 4.9 The effect of different effluents and irrigation rates on willow cutting root DM yield
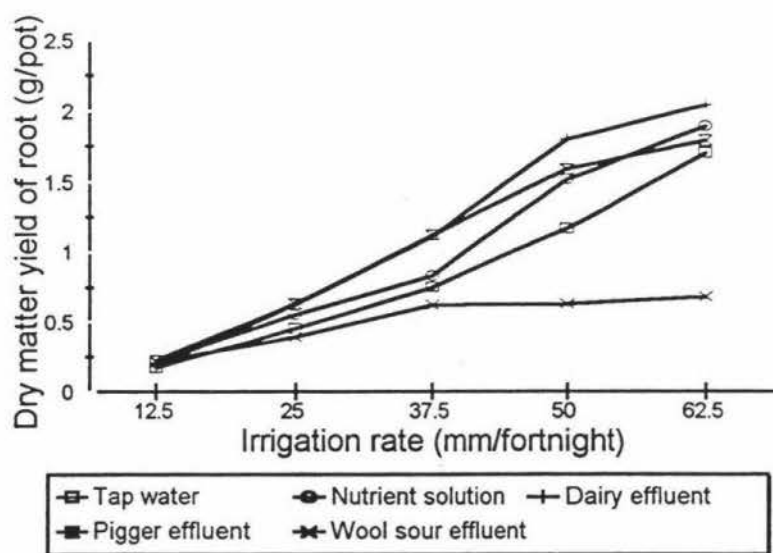
4.1.4.3   Total DM yield of willow cutting

The mean total DM yield for each irrigation rates was significantly higher in piggery treatment than that recorded in the rest of other effluent treatments. However, there was no significant difference in the total DM yield between nutrient solution and dairy treatments. On the other hand the mean total DM yield was significantly increased with increasing irrigation rates for all effluents, the mean total DM yield increased by 341%, 285%, 151%, and 69% for 62.5 mm, 50 mm, 37.5 mm, 25 mm/fortnight respectively, when irrigation raised from 12.5 mm/fortnight to 62.5 mm/fortnight (Table 4.3 and 4.4).

Figure 4.10 showed the overall means of all treatment combinations.

It could be observed from the different effluent treatments that the mean total dry matter yield increases with increasing rates of irrigation for all effluent treatments except wool scour effluent. The highest mean total DM yield was obtained at the irrigation rate of 62.5 mm/fortnight for all effluent treatment, the order of the mean total DM yield followed: piggery treatment (11.2 g/pot) > nutrient solution (10.7 g/pot) > dairy (9.7 g/pot) > tap water (9.1 g/pot) > wool scour effluent (5.41 g/pot).

Figure 4.10 The effect of different effluents and irrigation rates on willow cutting total DM yield
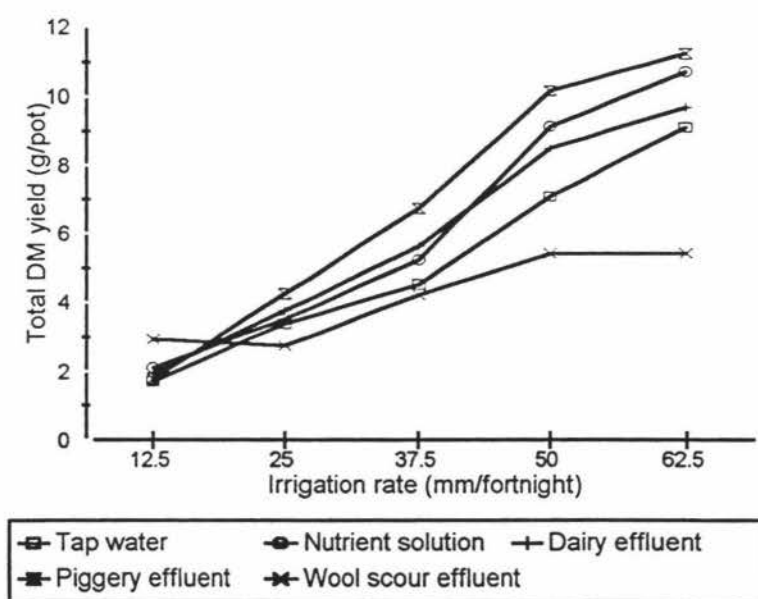
It was observed that there was a disparity between the total DM yield and aboveground DM yield when they were used as monitoring criteria to identify the effect of different effluent treatments on willow growth. There was significant difference in total DM yield when the piggery, dairy and wool scour effluents were compared with tap water. While there was significant difference in aboveground DM between only dairy and tap water treatments (Table 4.3). The result implied that there was difference in the effect of dairy effluent on the aboveground and root accumulation for the willow cutting.

Table 4.4   The mean DM yield of willow (g/pot) at each irrigation rate level for all effluent treatments.   Values followed by the same letter are not significantly different at the 0.05 probability level

	Different effluent treatments		
Irrigation rates	Mean aboveground DM	Mean root DM	Mean total DM
12.5mm/fortnight	1.69e	0.12.5e	2.09e
25mm/fortnight	2.87d	0.53d	3.53d
37.5mm/fortnight	4.31c	0.89c	5.25c
50mm/fortnight	6.58b	1.34b	8.05b
62.5mm/fortnight	7.64a	1.62a	9.23a
	Analysis of variance		
Effluents	***	***	***
Rates	***	***	***
Effluent x rate	***	***	***

*** : $p > 0.0001$.

The results showed that the interaction effect between effluents and irrigation rates was very significant for DM yield of aboveground, root and total ($p = 0.0001$). However, the effect of different effluents on the total DM yield of willow cutting was less than that of irrigation rates (Figure 4.8 - 4.10).

4.1.5   Effect of effluents on macro-nutrient uptake by willow cuttings

4.1.5.1   Nutrient concentration in leaf

The concentrations of N, P and K in willow leaf varied with both the effluents and the irrigation rates. There was an increase in the average concentration of N, P and K in leaf irrigated with nutrient solution, dairy and piggery effluents when compared to tap water.

The average concentration of N, P and K in leaf of the nutrient solution treatment was 1.4, 1.34 and 1.32 times greater than that for tap water treatment respectively; the average concentration of N, P and K in leaf of dairy effluent treatment was 1.32, 1.22 and 1.35 times greater than that for tap water treatment respectively; and the average concentration of N, P and K was 1.28, 1.47 and 1.25 times greater in piggery effluent treatment than that for tap water treatment. The average concentration of Ca and Mg in leaf of dairy and piggery effluent treatment was less than tap water treatment and nutrient solution (Table 4.5). On the other hand, the average concentration of macro-nutrients in leaf of the wool scour effluent treatment was the lowest for N, P, Ca and Mg, and the highest for K when it was compared with other effluent treatments.

There was no significant difference in nutrient concentration in leaf between different irrigation rates. This result was consistent with the report by Rebecc *et. al.* (1996) who noticed that there was no significant difference in nutrient concentration in leaf among different irrigation rates for one year older willow cutting when it was irrigated with dairy effluent treatment. However, in the present experiment, there was an increase in N, P and K concentration for the nutrient solution, dairy and piggery effluent treatment. This may indicate that where willow plants are suffering from nutritional stress, they are likely to respond to nutrient input though effluents. The willow cuttings had a significant increase in DM yield when they were irrigated with dairy and piggery effluent when compared to tap water. Therefore, nutrient dilution in leaf from increasing irrigation rate may result from increased growth. Furthermore, these results implied that the two types effluents

(dairy and piggery) not only acted as a source of water for willow, but also supplied some nutrients.

The average concentration of the highest K and the lowest N, P, Ca and Mg recorded in leaf for the wool scour effluent treatment, which was caused by a higher K concentration in wool scour effluent (Table 4.6). The concentration of K was nine times more in wool scour effluent than in dairy and piggery effluents, which would depress the uptake of other nutrient by willow cutting.

Table 4.5   The average nutrient concentration of the willow leaf with different effluent treatments

Treatment	% N	% P	% K	% Ca	% Mg
Tap water	2.44	0.12	0.75	1.45	0.27
Nutrient solution	3.42	0.16	0.99	1.83	0.24
Dairy effluent	3.06	0.14	1.01	1.34	0.21
Piggery effluent	3.12	0.17	0.94	1.25	0.22
Wool scour	2.35	0.09	2.03	0.98	0.15

Table 4.6   The concentration of macro-nutrients in effluents

Source	N (mg/L)	P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)
Dairy effluent	212.5	26.3	284	88	43
Wool effluent	373	19.5	2968	93	34
Piggery effluent	655	98.2	262	84	27
Nutrient solution	174	59.0	155	--	--

Leaf nutrient concentrations were normally used as criteria to investigate the plant growth response to nutrient input. Ferrier (1996) reported that in a field trial, the foliage nutrient

concentrations were significantly higher in sewage effluent treatment than in control for scots pine.

The response of plant growth to effluents treatment varied with effluents composition, soil chemical and physical properties and plant species. The parameters of biomass and nutrient concentration in this experiment implied that irrigation with piggery and dairy effluents had the potential to increase willow cutting growth through decreased water stress, and improved nutrient supply.

4.1.5.2   Nutrient uptake

The amount of nutrients take up by willow cutting in each effluent treatment was calculated (Table 4.5) from the whole plant DM yields and their nutrient concentration. There was a trend that the N, P and K uptake increased with increasing input in effluents except wool scour effluent, while there was no obvious relationship between Ca and Mg input and uptake. The wool scour effluent treatment had the lowest amounts of nutrient uptake except K.

The total amount of N uptake by willow cutting was 1.85, 1.46 and 1.94 times more in nutrient solution, diary and piggery irrigation treatment than in tap water treatments, respectively; the total amount of P was 1.8, 1.3 and 1.9 times more in these three treatments than in tap water treatment respectively; the total value of K uptake was 1.56, 1.44 and 1.54 time greater in nutrient solution, dairy and piggery effluent treatments than tap water treatment. While there was no obvious difference in Ca and Mg between the various effluent treatments except a lower value of Ca in dairy effluent treatment.

In order to investigate the effect of the amount of N, P and K in effluents on N, P and K uptake by willow cutting, an alternative method of analysis that permits a distinction to be made between the response of willow uptake to increased N, P and K application, and the response of willow to increased uptake, is therefore useful. The relation between N, P and K uptake by willow cutting and N, P and K added by different effluents was shown Figure

4.12, 4.13 and 4.14. The nutrient solution had the highest efficiency on N and K uptake by willow cutting; while the dairy effluent had the highest efficiency on P uptake. It is interesting to note that the nutrient solution had a lowest concentration of N and K and the dairy effluent had the lowest concentration of P. On the other hand , the highest N and P concentration in piggery effluent accounted for the lowest efficiency of N and P, while the highest K concentration in wool scour effluent accounted for the lowest efficiency of K. For example, 0.2 g nitrogen uptake by the willow cutting under the Manawata soil condition was observed from the N input of 0.3 g nitrogen in the nutrient solution, 0.6 g in the dairy effluent , and 1.5 g N in the piggery effluent (Figure 4.12).

The results showed that effluents with high concentration of N, P and K will supply more nutrients than that required by the willow plant. In other words, effluents with high concentration of N, P and K could cause more N, P and K loss than those with low concentration of N, P and K.

Bernal *et. al.* (1993) reported in a greenhouse experiment that N, available P and K recovered in plant decreased with increasing irrigation rate of pig slurry application. Results from the Wagga Wagga Effluent Plantation Project (Ploglase *et. al.*, 1994) also showed that irrigation of treated sewage effluent at twice the rate of water use by gum trees (*Eucalyptus prandis*) and pine trees (*Pinus radiata*) can result in increased nitrate leaching losses (Bond *et. al.*, 1996).

We can not judge the efficiency of nutrient uptake from the wool scour effluent, because the line deviates from the linear and some growth factor other than nitrogen availability is yield-determining (Figure 4.12).

There was no significant difference in N, P and K concentration in leaf for different irrigation rates in any of the effluent. However, there was significant difference in mean DM yield among different irrigation rates for all treatments. Furthermore, there was a close positive correlation between irrigation rate and DM yield for all effluents treatment, with R^2 values of 0.978 in tap water, 0.952 in nutrient solution, 0.976 in dairy effluent, 0.961 in piggery effluent and 0.68 in wool scour effluent. The results from the regression

relationship between irrigation rate and DM yield indicated that the irrigation rate resulted in the accumulation of DM yield rather than increasing the nutrient concentration in leaf. That was confirmed from the results that there was a greater difference in DM yield between the irrigation rates than between the effluents.

The wool scour effluent treatment showed a poor correlation between irrigation rate and DM yield of the willow cutting, the result was caused by reduction of DM yield when irrigation rate rose over 37.5 mm/fortnight. That was attributed to the detrimental side effects of wool scour effluent on plant growth.

Figure 4.11
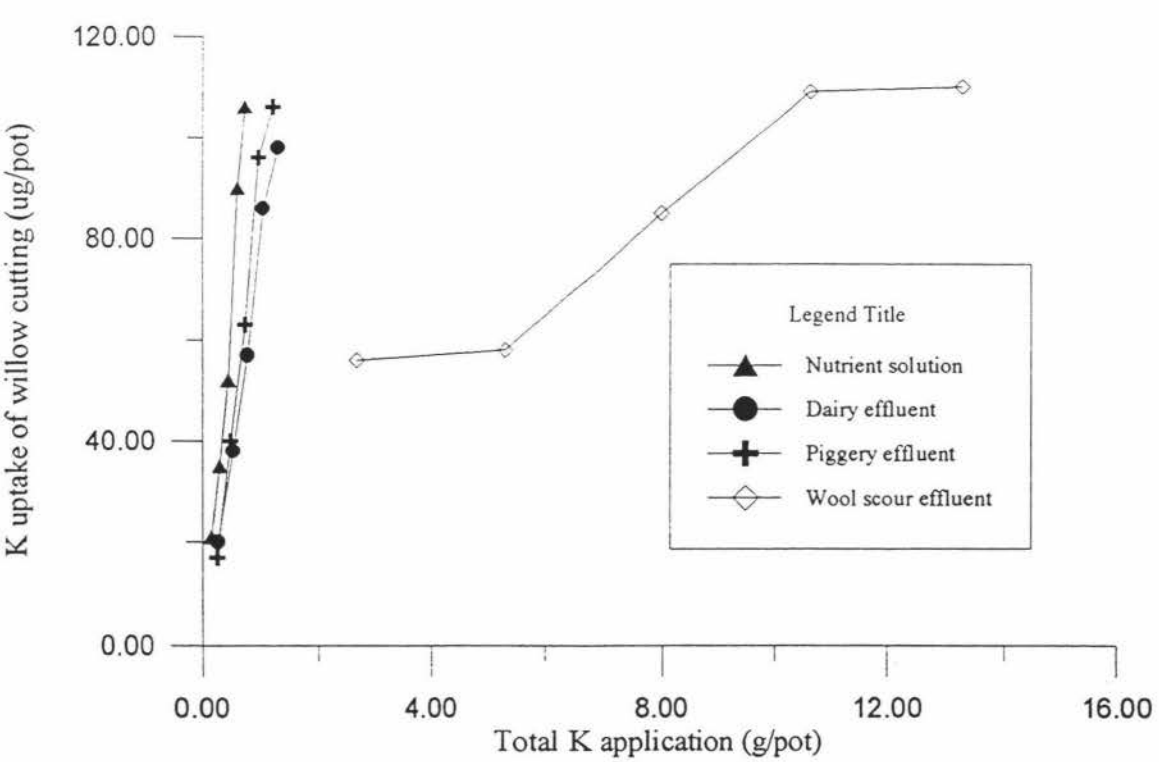
Figure 4.12
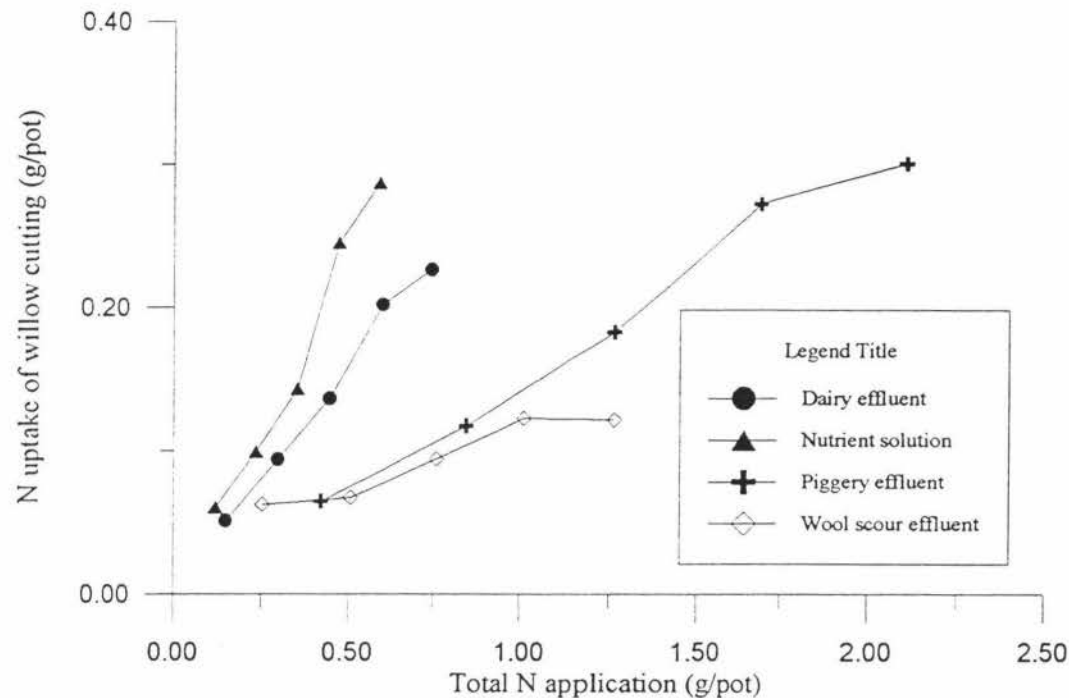
Figure 4.13
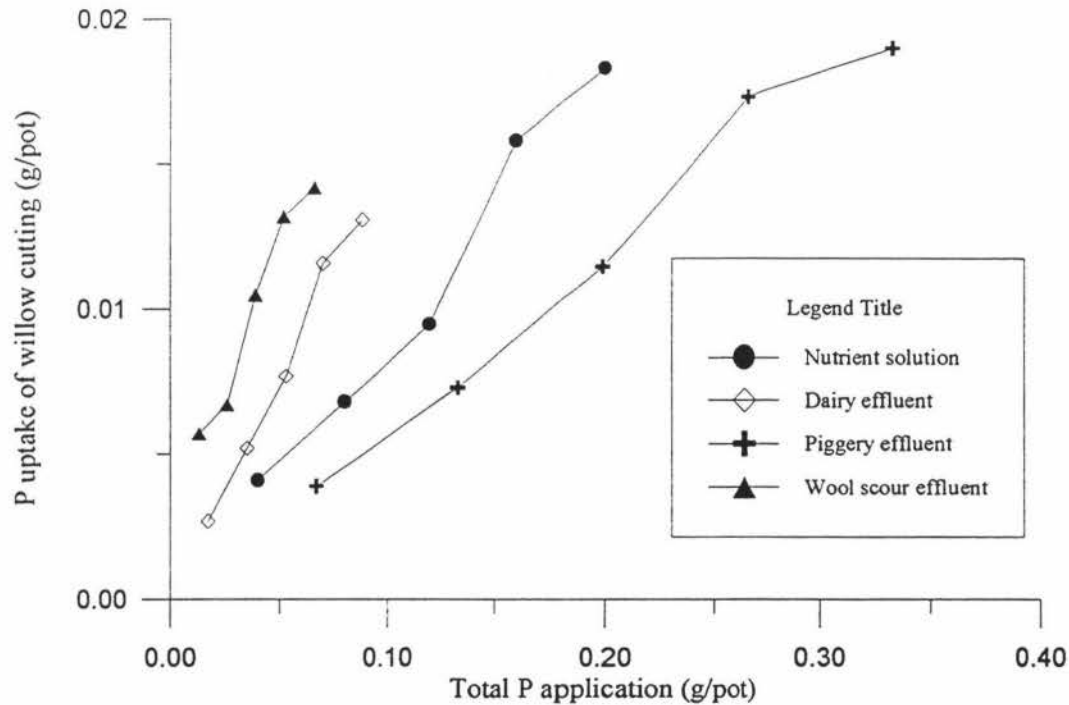
Table 4.7 Nutrients uptake (g/pot) by willow cutting with different effluent treatment

Treatments	N added	N uptake	P added	P uptake	K added	K uptake	Ca added	Ca uptake	Mg added	Mg uptake
Tap water	ND	0.155	ND	0.010	ND	0.068	ND	0.132	ND	0.025
Nutrient solution	0.58	0.286	0.12.5	0.018	0.53	0.106	ND	0.196	ND	0.026
Dairy effluent	0.75	0.227	0.09	0.013	1.93	0.098	0.59	0.59	0.291	0.012
Piggery effluent	2.11	0.301	0.33	0.019	1.78	0.105	0.57	0.141	0.186	0.025
Wool scour effluent	1.27	0.122	0.07	0.014	12.5.10	0.109	0.63	0.053	0.227	0.008

ND: Not deferent

4.2   SOIL CHARACTERISATION

4.2.1   pH

4.2.1.1   pH of the effluents

The pH of the original effluent samples and the pH of the soil samples irrigated with the effluent at the conclusion of the experiment are presented in Table 4.8. The pH of tap water and nutrient solution are close to neutral and the pH values of the other effluent are high. The pH of wool scour effluent was alkaline indicating the presence of high K and Na concentration.

Table 4.8   The pH of the original effluents and the soil treated with the effluent. Value followed by the same letter are not significant at 0.05 probability level.

Effluent	Effluent pH	Soil pH
Tap water	7.18	4.94c
Nutrient solution	7.00	4.96c
Dairy effluent	7.65	5.48b
Piggery effluent	7.48	5.51b
Wool scour effluent	8.08	7.26a

4.2.1.2   Effect of effluent irrigation on soil pH

There was a significant difference in pH values of the soil samples between different effluents and irrigation rates (p = 0.001). The interaction of different effluent and irrigation rate on pH was also significant (p = 0.001).

There was a significant difference in soil pH value between wool scour effluent and other effluents. There was no significant difference in soil pH value between nutrient solution and tap water irrigation, and between piggery and dairy effluent irrigation. The wool scour effluent had the highest pH value of both the original effluent and the soil treated

with the effluent. The pH value of the original wool scour was about o.5 unit higher than the rest of other effluents, but the average pH value of the soil treated with wool scour was 1.7 units higher than that of the dairy and piggery, and 2.3 unit higher than that of nutrient solution and tap water. The pH values of piggery and dairy effluents were 0.6 and 0.3, and 0.3 and 0.57 unit higher than nutrient solution and tap water, respectively. But the mean pH for the soil treated with these effluents was about 0.55 and 0.46 unit higher than that of nutrient solution and tap water. The mean pH values for different irrigation rates were 5.95, 5.79, 5.59, 5.45 and 5.25 at 62.5 mm, 50 mm, 37.5 mm, 25 mm and 12.5 mm/fortnight irrigation levels. The mean pH value significantly increased with increasing irrigation rate for all effluent treatment. In other words, the greater the irrigation rate, the higher the pH value of the soil.

4.2.1.3   Explanation for effect of effluent irrigation on soil pH

The pH value of all effluents ranged from 7.00 to 8.08. The maximum difference was about 1 pH unit in effluents, but the maximum difference in pH of the soil irrigated with the effluents was 2.3 pH units. The significant difference in soil was caused by the soluble salts in these effluents.

Campbell *et. al.* (1980) showed that the concentration of total soluble salts at two sites that received effluent were significantly higher than at untreated site, mainly because of increases in K concentration. Johns *et. al.* (1994) demonstrated the highly significant effect of Na on pH when the soil was irrigated with secondary treated sewage effluent.

The concentration of K was high both in the wool scour effluent and the soil samples treated with this effluent, which was consistent with the report by Campbell *et. al.* (1980). The present experiment showed that there was no significant difference in K concentration in soil between tap water and dairy and piggery effluents. However, there was a significant difference in Na concentration in soil between these effluents. This suggests that the difference in pH value for dairy and piggery effluents soil was caused by exchangeable Na in the soil.

Shipper *et. al.* (1996) observed that the pH value was higher in soil treated with meat effluent treatment than with tap water. Therefore, the rise in pH value in soil is most likely related to altered nutrient cycling in the effluent-irrigated plots, and may be caused by both hydroxyl ion produced and exported during denitrification.

4.2.1.4   Implication of the effluent irrigation on soil pH

The pH value of a soil is a complex phenomenon and if unexpected shifts in pH occur, then it is likely that other changes may be occurring in the medium. Similarly, if pH remains stable, many other soil characteristics are also relatively stable (Tucker *et. al.*, 1987). pH value here is discussed with respect to the exchangeable cations that have been measured in this experiment.

The dairy, piggery and wool scour effluents increased the pH value when irrigated in acidic pH soil condition, that will provide a favourable medium for plant growth. On the other hand, when it irrigated in alkaline soils with a higher pH value, that may lead to an unfavourable medium for plant growth. The wool scour effluent with a high concentration of K, which will not only lead an imbalance of nutrients in soil but cause pH value to raise rapidly when it is irrigated onto soil. Therefore, wool scour effluent was restricted as a water source for willow growth under Manawatu fine sandy loam soil condition. Alternatively, dairy and piggery effluents are not only good water source for willow growth under this soil condition, but can improve the pH value of the soil to a favourable condition.

In addition, tree species lead to soil acidification and forest land acidic phenomenon has been reported (Dan Binkley, 1994). Common expectation included greater acidification of soils under conifers than under hardwoods. These views were derived from comparisons where pre-existing differences in soils were attributed to the current species (Stone, 1975). Therefore, irrigation with dairy and piggery effluent for short rotation forest may have some potential in preventing acidification.

4.2.2 Electrical conductivity

4.2.2.1 Electrical conductivity of the original effluents

The New Zealand Soil Bureau use the following ratings for the electrical conductivity (EC) of New Zealand soil (Blakemore *et. al.*, 1987):

> 2000 μS/cm	Very high
800 - 2000	High
400 - 800	Medium
150 - 400	Low
< 150	Very low

Table 4.9 EC of the original effluent samples and soils treated with the effluents. Values followed by the different letter are significant at 0.05 probability level.

Source	Electrical conductivity (μS/cm)	
	Original effluent	Soil treated with the effluents
Tap water	240	252e
Nutrient solution	—	438d
Diary effluent	1580	486c
Piggery effluent	2970	748b
Wool scour effluent	6050	1069a

Based on Soil Bureau ratings, wool scour and piggery effluents had a very high EC value, dairy effluent had a high EC value and tap water had a low EC value. Although dairy, piggery and wool scour effluent had a high EC value, it did not lead to a high EC value in soil when irrigated with dairy and piggery effluent (Table 4.9). The exchange complex and clay mineralogy of the soil probably play important roles in the control of the EC value.

4.2.2.2   Electrical conductivity of the soils

There was a significant difference in EC value of the soil samples irrigated with different effluents at different irrigation rates (p = 0.001). The interaction of different effluent and irrigation rate on EC was also significantly (p = 0.001).

The mean EC value was 1069, 748, 486, 438 and 252 μS/cm in soil when irrigated with wool scour, piggery, dairy, nutrient solution and tap water, respectively (Table 4.9). The wool scour effluent had the highest EC value in both effluent and the soil treated with the effluents. The mean EC value of the soil irrigated with wool scour was 1.42, 2.19, 2.43 and 4.24 times greater than that irrigated with piggery, dairy, nutrient solution and tap water, respectively. The EC value of wool scour effluent was 2.32, 3.82 and 25.2 times more than that of piggery, dairy effluent and tap water. There was significant difference in the average of mean EC values between the different irrigation rates. The EC value of different irrigation rates significantly increased with increasing irrigation rates for all treatments. The mean soil EC value of irrigation rate was 762, 685, 598, 504 and 445 μS/cm in soil after irrigation with 62.5, 50, 37.5, 25 and 12.5 mm/fortnight. The highest mean EC value was obtained for the 62.5 mm/fortnight rate, which was 1.11, 1.27, 1.51 and 1.71 times more than that of the irrigation levels at 50 mm, 37.5 mm, 25 mm and 12.5 mm/fortnight. The effect of different effluents on soil EC value was more than that of irrigation rates.

4.2.2.3   Explanation of the effect of the effluent irrigation on the soil electrical conductivity

The increase in EC value of the soil after effluent irrigation was influenced by two factors: the addition of salts in the effluent and the retention of salts (Bernal, 1992). The EC value of soil irrigated with tap water also increased with increasing irrigation rates during the experiment, because of small accumulation of salts added in tap water. K and Na in effluent made significant contribution to the increases of EC value in different effluents and treated-soil.

The results of this experiment were in good agreement with those of Benal *et. al.* (1992), Stadelman and Furrer (1985) and Campbell *et. al.* (1980). These researchers found that when the waste effluent contains significant quantities of exchangeable base cations then the base saturation of the soil may also be increased. Keeley and Quin (1979) reported a significant increase in base saturation and exchangeable K^+ following application of wool scour effluent. The results of irrigation with wool scour effluent in this study were similar to the results of Keeley and Quin (1979).

4.2.2.4 Implication of the effect of the effluent irrigation on soil electrical conductivity

The detrimental effect of the irrigation with waste effluents on soil is that it often leads to soil salinity. An annual application of 1000 mm of effluent irrigation with a concentration of 100 mg L^{-1} of total dissolved salts would supply 10000 kg of salt per hectare. Salinity can be developed when effluent with a high sodium absorption ratio (SAR) is applied (Sumner and McComchie 1996). The application of secondary treated dilute sewage effluent to soil growing bananas at Woolgoola, NSW, was reported to increase the soil sodium concentration from 0.11 cmol (+) kg^{-1} to 0.31 cmol (+) kg^{-1} (Johns and McConchie, 1994). Despite the low electrical conductivity of the effluent (0.44 $\mu S\ m^{-1}$) the soil exchangeable sodium percentage (ESP) values reached 4% during the trial. Land application of treated sewage effluent in the 'Flushing Meadows' plantation near Wagga Wagga, NSW, has also been found to have significantly increased soil salinity (Smith *et. al.*, 1996).

The application of effluent from a pulp and paper mill in New Zealand was reported to have caused an increase in SAR from 2 to 16 and an increase in sodium concentration in groundwater (Johnson and Ryder, 1988).

High salt concentrations in soil solution can also reduce the soil osmotic water potential and thus decrease the amount of water that is readily available for plant uptake.

This experiment showed that there is no risk of soluble salt accumulation in soil following dairy and piggery secondary effluent in Manawatu fine sandy loam soil under greenhouse condition when the EC values compared with the EC values of the New Zealand Soil Bureau in rating, although the risk is greater for repeated high irrigation rates. Therefore, irrigation with dairy and piggery as irrigation source to Manawatu sand fine loam soil area is considered safe. In addition, the soil can be reclaimed by leaching with rain under field condition. On the other hand, the risk of salinity is more heavier with wool scour effluent than with dairy and piggery effluents. The irrigation rate should be restricted to a maximum amount of 25 mm/fortnight to prevent soil salinity. When large rates are used, soil may need to be reclaimed by leaching with fresh water.

4.2.3   Total N and P

4.2.3.1   Total N and P content of the effluent

Piggery effluent had the highest total N value, followed by wool scour effluent and dairy effluent (Table 4.10). The values reported here for total nitrogen and phosphorus in effluents were similar to those reported by Carnus (1994) and Hart and Speir (1992).

Table 4.10 **Total nitrogen and phosphorus content of the effluent and soil treated with the effluents. Value followed by the same letter are not significant at 0.05 probability level**

Source	Content of the effluent		Total N and P in soil	
	N (mg/L)	P (mg/kg)	N (mg/kg)	P (mg/kg)
Tap water	ND	ND	189c	107c
Nutrient solution	174	59	219a	124ab
Dairy effluent	220	26	208b	123b
Piggery effluent	655	98	221a	128a
Wool scour effluent	373	20	207b	111c

ND: Not determined

Discharging these effluents and other nutrient-rich wastes to waterways can result in depletion of dissolved oxygen, eutrophication, chemical toxicity and salinity. Eutrophication is produced by an excess concentration of nutrients in the water leading to accelerated plant growth and changes in plant species composition. The critical nutrients responsible for eutrophication are N and P, although other nutrients, e.g. iron, molybdenum, manganese and silicon, may also contribute to the process. Eutrophication may become visually evident when the concentration of total N reaches around 400 - 600µg L^{-1} and/or when total P reaches 40 - 60µg L^{-1} (AEC 1987). Eutrophication can have a dramatic impact on the coastal or inland aquatic ecosystems, including blooms of phytoplankton (algal bloms) and loss of seagrass. Some of these algae are toxic and sometimes cause death of fish and livestock (Cameron *et. al.*,1996).

Eutrophication and salinity are considered to be the two major water quality problems in Australia (Sumner and McLaughlan, 1996). In New Zealand, serious eutrophication problems are becoming more common. For example, in January and February 1993, there were wide spread incidences of algal blooms and shellfish poisoning around New Zealand's coastlines which resulted in the temporary shut down of the entire coastline from shellfishing, and the temporary cessation of shellfish exports. The direct economic consequences and redemption costs of eutrophication are very high (Cullen, 1996). Therefore, a major consideration in the potential of these effluents discharge or use by land as irrigation source or fertilizers is their nutrient or water balance.

Various studies (e.g. Phillips 1973, Yeates 1978, Goold 1980) have shown that dairy shed effluent is a valuable fertilliser capable of stimulating pasture growth. Goold (1980) measured a 27% increase in pasture production when 6 mm of effluent was applied every 21 days on Northland clay soil. Cameron (1995) measured a 70% increase in pasture production from both a low and a high rate of application of pig slurry (200 and 600 kg N $ha^{-1}Y^{-1}$). In the present experiment, wool scour effluent decreased the willow cutting growth and DM yield at application rates $\geq$ 50 mm/fortnight, although it had a higher N value than dairy effluents. The concentration of N and P in willow leaf irrigated with wool scour effluent was lower than that of tap water treatment. This suggests that the poor

growth due to wool scour effluent irrigation is related to physiological problems rather than nutrient deficiencies.

The availability of nutrients to plants will also depend on the type of effluent, irrigation rates and type of plant cover. Traditionally effluent renovation schemes have used ryegrass/clover pasture (Wells and Whitton 1966 and 1970), but several factors impose limitations on the use of effluent in terrestrial agriculture. The most important are: 1) the seasonal demand for irrigation water while the effluents supply is more or less constant, 2) the limitation to crops or methods of application because of the concentration of the nutrients, trace and toxic elements, residual pathogenic organism. Therefore more consideration is now being given to other pasture plant species or using arable crops or trees, particularly short rotation plantations (Sims *et. al.*, 1990).

Effluent application on land has been shown, in many cases, to result in significant increases in plant yields, improvements in soil physical conditions and chemical and biological fertility. Land application of waste effluents is constrained by the presence of hazardous organic chemicals, heavy metal, pathogens, salts and extreme pH values.

Comparing tap water treatment, the dairy and piggery effluents treatment resulted in higher N and P concentration in soil. The results will be interpreted in section 4.2.4.4.

4.2.3.2   Effect of different effluents on the N content of the soil

There was significant difference in total N in soil between different effluent treatments and the different irrigation rate treatments. The interaction of different effluents and irrigation rates on N content was also significant.

It was observed that there was a significantly small increase in soil total N in dairy, nutrient solution, piggery and wool scour effluent treatment, when compared to tap water. However, there was no significant difference in total N between the first four effluent treatments. The order of the mean total N concentration in soil was: the piggery > dairy > wool scour effluent (Table 4.10).

The total N in soil decreased with increasing irrigation rates, the mean total N content was more under 50 mm/fortnight than over 50 mm/fortnight. This may be attributed to N loss by volatilization, denitrification and leaching.

Schipper *et. al.* (1996) reported in a field trial of irrigation with domestic effluent for radiata pine that no changes were observed in total N. Ferrier *et. al.* (1996) indicated that the majority of total N was associated with the solid in effluent and nitrate, characteristically only present in the liquid phase, contributed little to the nitrogen loading.

The experiment results reported in the present experiment are similar to the greenhouse results of Beranal *et. al.* (1993) who observed significant increase in soil N, and P. Eight months after application of pig slurry at a range of rates to a calcareous soil in Spain.

4.2.3.3   Effect of effluent on total P content of the soil

There was a significant increase in total P in soil treated with nutrient solution, piggery, and dairy effluents when compared to the wool scour effluent treatment or tap water. There was no significant difference in total P in soil among piggery, nutrient solution and dairy treated soils. The total soil P content increased with increasing irrigation rates except tap water. The highest P content was obtained for 62.5 mm/fortnight, which was significantly higher than the rest of other irrigation rates. There was a significant difference in total P content between below 25 mm/fortnight and over 37.5 mm/fortnight treatments. The high value of total P in soil resulted from P input by effluents.

4.2.3.4   Explanation of the effect of the effluents on soil total N and P content

The results shown that the nutrient solution, piggery and dairy effluents provided larger amount of phosphorus than that required by the willow cutting, so that most phosphorus in these effluents was recovered in the soil. The content of P in soils treated with effluents was influenced by various processes: removal by the willow cutting; the assimilation or release of inorganic phosphate from the pool of these effluents; and equilibration with

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calcium phosphates and with phosphate adsorption sites. The increase in P uptake by the willow cutting with the application of nutrient solution, dairy and piggery effluent resulted from the available phosphate in these effluents. On the other hand, the increase in soil total P may result from adsorption and precipitation of phosphorus as an insoluble fraction, such as calcium phosphate (Vivekanandan and Fixen, 1990).

The dominant form of N in effluents is ammonium. Ammonium in soil can be taken up by plants, adsorbed at the surface of clay and or humus, fixed in the crystalline structure of clay minerals, immobilized by micro-organisms. The content of total N in soil was higher in dairy and piggery effluent treatment than in tap water, the increase in total N of the soil may result from the input of N and organic matter in these secondary effluents. Generally, there was a small proportion of inorganic-N and organic matter in piggery, dairy and wool scour secondary effluent, which was recovered by soil after it is irrigated into soil. The nutrient solution showed a small increase in total N concentration that may be attributed to the N-released from the organically-N pool in the willow-soil system.

4.2.3.5   Implications for soil N and P of effluent irrigation

Since N in the effluents is in both mineral and organic forms (with long-term and short-term mineralisable N) it is an ideal nutrient source for land application. Unlike its mineral counterpart (fertiliser-N), the effluent is believed to release N slowly depending on the demand for mineral N in soil.

A measure of total P in soil is not very revealing as to the likelihood of plants establishing on the soil. In most soils the amount of the total P that is an available form is very low, seldom exceeding 0.01% of total P (Brady, 1984). Additionally, when soluble fertilizer salts of P are supplied to soils, the P is often rendered insoluble or unavailable to high plants (Brady,1985). Irrigation with these effluents treatments have led to a increase in total P concentration in soil. Therefore, the experiment showed that P can be stored in soil after irrigation without considerable risk of loss by leaching. Comparing the total N and P input by effluents and the N and P content in soil after irrigation, the P covered by soil was more than that of N as P content in soil increased with increasing irrigation rate,

while N content in soil showed no significant increase with increasing irrigation rate. The results implied that the N loss from irrigation with these effluent was considerably more than P.

4.4 THE EFFECT OF DIFFERENT EFFLUENT AND IRRIGATION RATE ON THE BASIC CATIONS

4.4.1 Potassium

The higher the concentration of K in effluent, the higher exchangeable K in soil treated with the effluents. However, there was no significant difference of exchangeable K in soil among the effluents except wool scour effluent treatment.

Table 4.11 The exchangeable K of original effluent and the soil treated with the effluents. Value followed by the same letter are not significant at 0.005 probability level

Effluent	Effluent total K (mg/L)	Soil exchangeable K (me/100g)
Tap water	--	4.36b
Nutrient solution	155	5.03b
Dairy effluent	283	5.90b
Piggery effluent	262	5.74b
Wool scour effluent	2968	44.5a

Based on the New Zealand Soil Bureau rating, the content of the exchangeable K in the Manawatu fine sandy loam soil is very high (Table 4.11, 12).

Soil exchangeable K is the fraction sorbed at exchange site, mainly on clays and humic colloids. Usually the contribution of exchangeable K to the total K content of soils is below 2% i.e., between 10 and 400 ppm (Schroeder, 1974). In the major dairy farming

soils of New Zealand exchangeable K levels (measured by the NH_4OAc method) account for between 1 and 5% of the total soil K content (Williams, 1988).

The neutral molar NH_4OAc method of assessing K release is widely used as an index of K release for predicting the supply of soils. However, many workers (Willians *et. al.*, 1986; Jackson, 1985) found that a measure of both exchangeable K and noexchangeable K forms better predict the K supply than the NH_4OAc method alone.

There was a significant difference in exchangeable K content between irrigation with wool scour effluent and irrigation with other effluents. The mean exchangeable K content in soil was 44.5 me/100 g after eight weeks irrigation with wool scour effluent, which was 10.1 times greater than that of the tap water. There was no significant difference of exchangeable K content in soil for irrigation with nutrient solution, dairy and piggery with tap water. On the other hand, the mean exchangeable K content in soil increased with increasing irrigation rates except tap water. The mean exchangeable K content of 17.1 me/100 g in soil for all effluents was obtained at 62.5 mm/fortnight irrigation level, which was 1.2, 1.6 and 2.1 times more than that of irrigation rates at 32.5, 25 and 12.5 mm/fortnight level. While there was no significant difference in exchangeable K content in soil between at 62.5 mm/fortnight and at 50 mm/fortnight. The effect of different effluent on exchangeable K in soil was greater than that of the irrigation rate.

The experiment showed that the high exchangeable K content in soil was caused by the amount of the K input, which was reflected by both the K concentration in effluent and irrigation rate. For example, the K concentration of wool scour effluent was 11.3 times greater than that of dairy effluent, the mean K content of soil treated with wool scour effluent was 7.5 times more than that of the soil treated with dairy effluent. The K content of the soil irrigated with tap water decreased with increasing irrigation rate, which may be attributed the plant uptake and leaching.

Potassium is an essential plant nutrient. It is essential for photosynthesis, for starch formation and for the translation of sugars and it increases crop resistance to certain diseases. However, many authors have shown that high exchangeable K concentration

suppress uptake of Mg by plant (Metson 1974). Horvath and Todd (1968) suggested that the exchangeable Mg/K ratio should be at least 2.0 for good plant growth. In this experiment, the Mg/K ratio was 0.28, 0.31, 0.26, 0.25 and 0.035 for soil treated with tap water, nutrient solution, dairy, piggery and wool scour effluent, respectively (Table 4.13). The willow leaf appeared yellow after irrigation with wool scour effluent for 6 weeks, which may be partly related to the Mg/K ratio.

4.4.2 Exchangeable Na

Based on the ratings for New Zealand Soils (Blakemore *et. al.*, 1987), the exchangeable Na content of the soil irrigated with tap water and nutrient solution was medium. However, the values of exchangeable Na was high in soil when it was irrigated with dairy, piggery and wool scour effluents (Table 4.12, 4.13). There was significant difference in Na content in soil irrigated with different effluents and irrigation rates. The mean Na content in soil was 1.68, 1.05, 0.81, 0.54 and 0.45 me/100g for wool scour effluent, Piggery, dairy, nutrient solution and tap water treatment, respectively. The mean Na content in soil irrigated with wool scour effluent was 1.6, 2.1, 3.2 and 3.5 times greater than that of piggery, dairy, nutrient solution and tap water, respectively. On the other hand, the Na content in soil significantly increased with increasing irrigation rate for all treatments. The mean Na content in soil was 0.55, 0.74, 0.92, 1.23 and 1.29 me/100g at the irrigation rate of 12.5 mm, 25 mm, 37.5 mm, 50 mm and 62.5 mm/fortnight, respectively. The highest Na content was obtained at the irrigation level of 62.5 mm/fortnight for all effluents, which was 1.3, 1.4, 1.8 and 2.3 times greater than that of irrigation rate at 50 mm, 37.5 mm, 25 mm and 12.5 mm respectively. The effect of different effluents on Na content was more than that of irrigation rate.

It was observed that irrigation with dairy, piggery and wool scour effluents lead to an increase in exchangeable Na content in soil, which may be attributed to the amount of Na in effluent (the Na in effluent was not measured). However, the high Na content with dairy, piggery and wool scour effluent in soil should be decreased by leaching in field condition because it is easily leached. The Na concentration in plant was not measured because sodium (Na) is not considered an essential element for all plants (Brady, 1984).

However, in plants, potassium (K) and Na are the two principle monovalent metallic cations and an increase in one generally results in a reduction in the other (Black, 1968).

4.4.3 Calcium

Calcium (Ca) is an essential plant nutrient (Brady, 1984). It has a strong influence on percentage base saturation, pH and other related properties that depend on the acid/base balance in the soil; it has a buffering effect on pH (Cresser *et. al.*, 1993; Bellamy *et. al.*, 1995). High values of exchangeable Ca in soils are favoured by high levels of Ca in parent materials, high CEC, and high % base saturation (Miller, 1968).

There was a significant difference in Ca content in soils irrigated with wool scour, piggery and dairy effluent when compared to nutrient solution and tap water. There was no significant difference in Ca content among different irrigation rate except at 62.5 mm/fortnight. The mean Ca content in soil was 6.5, 6.4, 6.3, 6.1 and 5.6 me/100g for wool scour, piggery, dairy, nutrient solution and tap water, respectively. Based on the ratings for New Zealand Soils (Blakemore *et. al.*, 1987), the exchangeable Ca value of Manawatu fine sandy loam soil is considered to be medium after 8 weeks of continuous irrigation with diary, piggery and wool scour effluent. The results showed that the exchangeable Ca in these effluents are too low to cause significant change in the exchangeable Ca of the soil.

4.2.4   Magnesium

There was significant difference in Mg content in soils irrigated with wool scour, piggery, dairy and nutrient solution when compared to tap water. The mean exchangeable Mg content was 1.56, 1.55, 1.54 , 1.47 and 1.22 me/100g in soil treated with wool scour, piggery, dairy, nutrient solution and tap water respectively, after 8 weeks irrigation. The small increase in exchangeable Mg in the soil resulted from the Mg input by effluent. However, no significant difference in Mg content in soil was found among different irrigation rates.

Magnesium is an essential plant nutrient used in relatively large amounts and derived purely from soil solids (Brady, 1984). It has a function in the chlorophyll molecule and several other physiological functions in plants (Metson, 1968). Based on the New Zealand Soil Bureau ratings for Mg in New Zealand soils, the values of exchangeable Mg are in medium after irrigation with these effluents. Except wool scour effluent treatment, willow was not found to be deficient in Mg for the other effluent treatments. The experiment showed that there was a relatively low Mg concentration in leaf when willow irrigated with wool scour effluent and the willow leaf had a deficiency symptom. Although no information has been available about the Mg concentration in willow leaf, the data of this study showed that an induced deficiency may occur when level of exchangeable K is very high resulting in low Mg/K ratios depressing the uptake of Mg by willow (Table 4.10). Therefore, when wool scour effluent is used as a irrigation source for short forest rotation crop, there may be a risk of Mg deficiency. However, it depend upon the soil and tree species.

Table 4.12 The Soil Bureau of New Zealand uses the following rating for Ca, Na, K and Mg ontent of new Zealand soils (Blakemore *et. al.*, 1987)

Exchangeable Ca Content of soil	Exchangeable Na Content of soil	Exchangeable K Content of soil	Exchangeable Mg Content of soil	Assessment
> 20 me/100g	> 2 me/100g	> 1.2 me./100g	> 7 me./100g	Very high
10 - 20	0.7 - 2	0.8 - 1.2	3 - 7	High
5 - 10	0.3 - 0.7	0.5 - 0.8	1 - 3	Medium
2 - 5	0.1 - 0.3	0.3 - 0.5	0.5 - 1	Low
< 2	< 0.1	< 0.3	< 0.5	Very low

Table 4.13 The mean exchangeable K, Ca, Mg and Na in soil treated with different effluent irrigation for 8 weeks. Values with the same letter are not significantly different at the 0.05 probability level.

Treatment	Exchangeable Ca	Exchangeable Na	Exchangeable K	Exchangeable Mg
Tap water	5.65b	0.45e	4.36b	1.22b
Nutrient solution	6.06 ab	0.54d	5.03b	1.55a
Dairy effluent	6.35 a	0.81c	5.90b	1.55a
Piggery effluent	6.38 a	1.05b	5.74b	1.47a
Wool scour effluent	6.53 a	1.68a	44.48a	1.56a

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

REVIEW OF LITERATURE

From the review of literature, the following conclusions can be drawn:

1. Many waste effluents contain significant concentrations of nutrients and, if used properly, can indeed serve as valuable nutrient source for agricultural, horticultural and forestry production without causing significant adverse effects on the soil or the wider environment. Recycling nutrients in these wastes effluents can improve the sustainability of farming systems but excessive rates of application have been shown to cause N and P pollution of surface or groundwater.

2. Some waste effluents also contain undesirable and often toxic elements or compounds, (e.g. heavy metals, trace organic, salts and pathogens) and some have extremely low or high pH. While many negative impacts of land application of these wastes on soil quality, and animal and human health have been reported, these impacts may be minimized by sound management systems, such as alternative plant species, constructed wetland, forestry and short rotation forestry (SRF).

3. In most past practices of agricultural effluents disposal by direct land application nitrogen was the key element in terms of both the nutrient source and the pollution of groundwater or surface runoff. The secondary effluents were more regarded as an irrigation source than as a fertilizer, the long-term fate of some compounds or elements in those effluents are not yet well understood and needs continued investigation, especially for the agricultural secondary effluents.

4. Willow, presenting as a SRF species, is thought to be ideal for land treatment with secondary effluent irrigation due to their fibrous root systems and ability to utilise large quantities of water and nutrients, the interest in biomass production in association with land disposal of secondary effluent is merited.

5. Assessment of the nutrient removal ability of SRF crops is the key important point to determine the potential of waste effluent application in the system, the data of different effluents and their rates will be needed for specific soil conditions.

EFFLUENT IRRIGATION

From the research project, the following conclusion can be drawn:

1. The results of greenhouse growth experiment showed that the willow shoot growth, diameter, root growth and dry matter yield can be used as monitoring criteria to investigate the response of different effluent application to willow performance. However, the sensitivity of these monitoring criteria changes with different effluents and irrigation rates. The response of willow to these effluents and irrigation rate depend mainly on the willow species' ecological requirements in terms of water and nutrients.

2. The willow with dairy and piggery effluent irrigation at all levels (12.5 mm, 25 mm, 37.5 mm 50 mm and 62.5 mm/fortnight) resulted in a significantly higher shoot growth and DM yield than those with tap water. The willow with wool scour effluent over 37.5 mm/fortnight irrigation resulted in a significantly lower shoot growth and DM yield than those with tap water. The order of all mean total DM yield with different effluent irrigation was piggery (5.62 g/pot) > nutrient solution (5.06 g/pot) > dairy (4.64 g/pot) > tap water (4.27 g/pot) > wool scour effluent (3.53 g/pot). The mean DM yield of willow for irrigation with dairy and piggery effluent was 18% and 32% more than that of tap water respectively, while the mean DM yield of irrigation with wool scour effluent was 17% less than that of tap water.

3. In comparison with the concentration of N (2.44%), P (0.12%) and K (0.75%) in willow leaf with tap water irrigation for 8 weeks, the dairy and piggery irrigation resulted in a high concentration of N (3.06% and 3.12%), P (0.14% and 0.17%), and K (1.01% and 0.94%) in leaf, while the wool scour effluent irrigation lead to a decrease in N, P, Ca and Mg concentration except a very high K (2.03%) concentration in leaf. The high N, P and K concentration in willow leaf from dairy and piggery effluent irrigation was caused by input of these nutrient in the effluents, which may lead to the changes in the available form of these nutrient in the soil.

4. The efficiency of N, P and K accumulation by willow was inversely related to their concentration in the effluent, the higher the N, P and K concentration in the effluent, the lower the efficiency of accumulation. There was an indication that the willow had assimilated the nutrients in different effluents through the DM yield accumulation. The DM yield of willow increased with irrigation rates. There was a linear relationship between the irrigation rates and DM of willow with R^2 values of 0.952 for dairy effluent, 0.961 for piggery and 0.68 for wool scour effluent.

5. When irrigated with dairy, piggery and wool scour effluent onto the Manawatu sandy fine loam soil-willow system, there was no significant difference in the N content of the soil between the irrigation rates whereas the P content of the soil increased with increasing irrigation rates. This indicates that there was a loss of N from the soil and the willow cutting was too young to remove large quantity of nutrients.

6. The pH and EC values increased with increasing the irrigation rates for these effluents. The order of pH and EC values in soil was wool scour effluent (7.26 and 1069 μS/cm), piggery effluent (5.15 and 748 μS/cm) and dairy shed effluent (5.48 and 486 μS/cm). The changes in pH and EC in soil with dairy, piggery and wool scour effluent irrigation were caused by the addition of salts in these effluents and the retention of the salts in soil. To investigate which cations were making the most significant contribution to pH and EC increase, the potassium, sodium, calcium and magnesium were determined in the experiment.

7.   Preliminary results of this study suggest that piggery effluent was the best irrigation source for willow in respect with the plant growth, production and the changes in the soil properties after using these effluent irrigation for 8 weeks period. Dairy effluent also was a good irrigation source to enhance the willow growth and production. They not only improved the soil fertility and enhanced the N, P and K assimilation, but also changed the soil pH into a favourable level without causing significant others adverse effects on the soil. The wool scour effluent is not a good source for willow growth. It not only led to the DM yield decrease, but also caused a very high pH and EC values in the soil. The high K concentration in wool scour effluent affected the soil pH and EC values and the assimilation of other nutrients, especially magnesium. Willow irrigated with wool scour may cause the Mg deficiency problem as the Mg symptom in leaf was seen and a very small ratio of Mg/K (0.035) was found.

RECOMMENDATIONS FOR FUTURE WORK

1.   Further study on the effect of dairy and piggery effluent on willow should be established under field conditions for the long term investigation, as the ability of the nutrient removal by willow changes with time and also the leaching of nutrients in field will be different from greenhouse. The willow irrigated with dairy and piggery effluents under the field conditions increases the proportion of nutrient renovation, as the root system develop and more fully occupy the short rotation forestry sites.

2.   In this project the beneficial effect of dairy and, piggery effluents on willow cutting growth, nutrient uptake and soil chemical properties was obtained. However, the amount of nutrient lost is unknown, which will be required to be assessed for using these effluents to irrigate onto short rotation forestry based on the concerning of the environmental management.

3. There was an evidence for decline in willow growth at high rates of irrigation with wool scour effluents (37.5 mm/fortnight). The reasons for the detrimental effects of wool scour effluent on soil properties and willow growth need to be investigated further.

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The aboveground DM Yield of willow cutting with different effluents and irrigation rates(g/pot)

Treatments	Irrigation rate (12.5,25, 37.5, 50 and 62.5 mm/fortnight)				
	Mean	Mean	Mean	Mean	Mean
Tap water	1.54	2.93	3.76	5.98	7.61
Nutrient solution	1.81	2.83	4.27	7.62	8.58
Dairy	1.63	2.84	4.34	6.68	7.65
Piggery	1.72	3.23	5.6	7.83	9.65
Wool scour	1.73	2.4	3.58	4.78	5.17

The root DM yield of willow cutting with different effluents and irrigation rate (g/pot)

Treatments	Irrigation rate (12.5,25, 37.5, 50 and 62.5 mm/fortnight)				
	Mean	Mean	Mean	Mean	Mean
Tap water	0.17	0.45	0.75	1.17	1.7
Nutrient solution	0.22	0.55	0.83	1.52	1.89
Dairy	0.18	0.63	1.11	1.8	2.04
Piggery	0.22	0.63	1.12	1.59	1.79
Wool scour	0.21	0.39	0.62	0.63	0.68

The MD yield of willow cutting with different effluents and irrigation rates (g/pot)

Treatments	Irrigation rate (12.5,25, 37.5, 50 and 62.5 mm/fortnight)				
	Mean	Mean	Mean	Mean	Mean
Tap water	1.71	3.38	4.51	7.07	9.1
Nutrient solution	2.1	3.52	5.22	9.13	10.72
Dairy	1.95	3.76	5.61	8.49	9.69
Piggery	1.78	4.25	6.72	10.17	11.23
Wool scour	2.93	2.75	4.21	5.41	5.41

The application amount of N, P and K by different effluents for 8 weeks period

Treatment	Application rate(mm)	Effluent-added(ml)	Total n(g/kg)	Total p(g/kg)	Total k (g/kg)
Dairy	12.5	896	0.197	0.024	0.254
	25	1792	0.394	0.048	0.508
	37.5	2688	0.591	0.072	0.762
	50	3584	0.788	0.096	1.016
	62.5	4480	0.985	0.12	1.27
Piggery	12.5	896	0.586	0.088	0.235
	25	1792	1.173	0.176	0.47
	37.5	2688	1.758	0.264	0.705
	50	3584	2.347	0.352	0.94
	62.5	4480	2.93	0.44	1.175
Wool scour	12.5	896	0.381	0.017	2.659
	25	1792	0.762	0.034	5.318
	37.5	2688	1.143	0.051	7.977
	50	3584	1.524	0.068	10.64
	62.5	4480	1.905	0.085	13.295
Nutrient solution	12.5	896	0.156	0.053	0.139
	25	1792	0.312	0.106	0.278
	37.5	2688	0.468	0.159	0.417
	50	3584	0.624	0.212	0.556
	62.5	4480	0.78	0.265	0.695

The Data of root dry weight and length for different effluent treatment

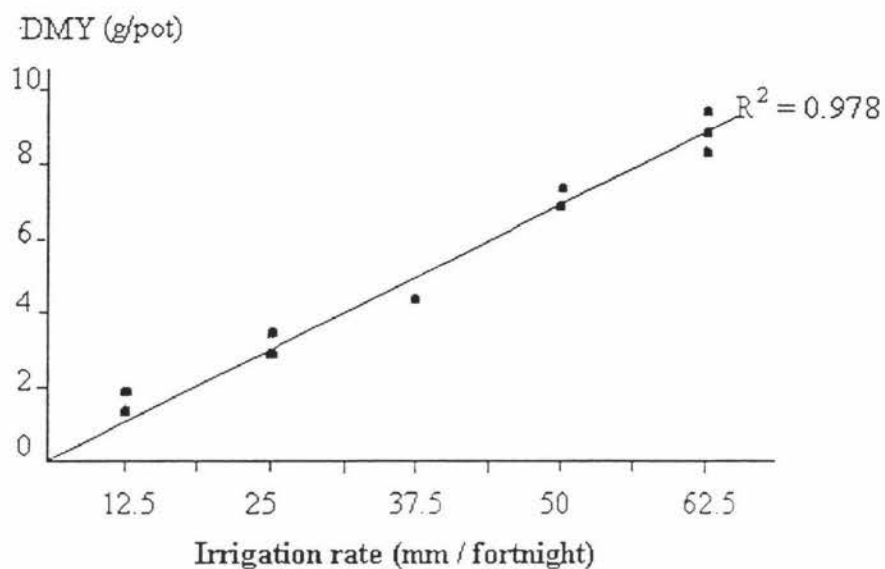| Treatment	Weight(g)	Length(m)	Treatment	Weigh(g)	Length(m)
Tap water	0.14	11.9	Nutrient solution	0.19	21.4
	0.24	20.4		0.5	29.7
	0.4	33.7		0.62	44.4
	1.27	170.9		1.62	129.7
	1.58	129.4		2.02	187.2
Dairy	0.28	23.7	Wool scour effluent	0.19	22.4
	0.75	45.2		0.41	30.2
	1.64	82.5		0.71	52.9
	1.66	114		0.99	64.5
	1.98	190		1.02	71.2
Piggery	0.19	12.1			
	0.85	72.5			
	1.38	107			
	1.54	114			
	197	127			

Figure 21. The relationship of the DM yields (g/pot) with irrigation rate
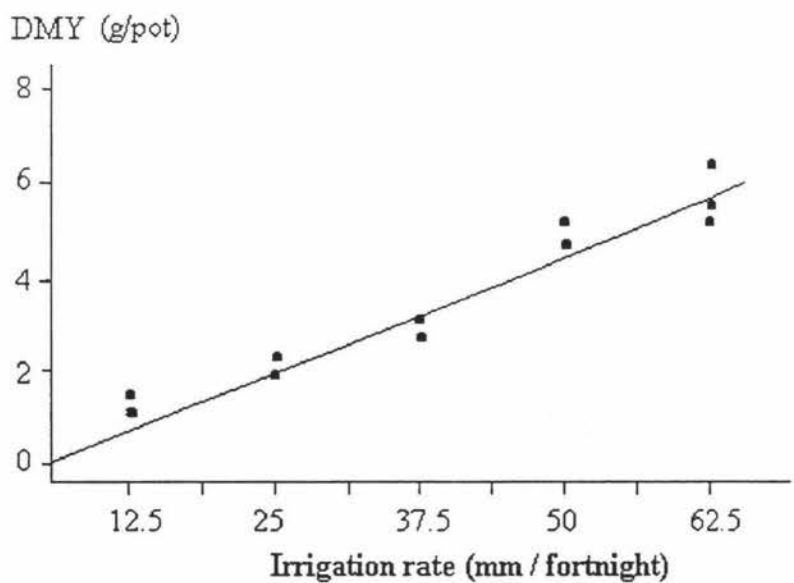
(Tap water treatment)

Figure 22. The relationship of the DM yields (g/pot) with irrigation rate

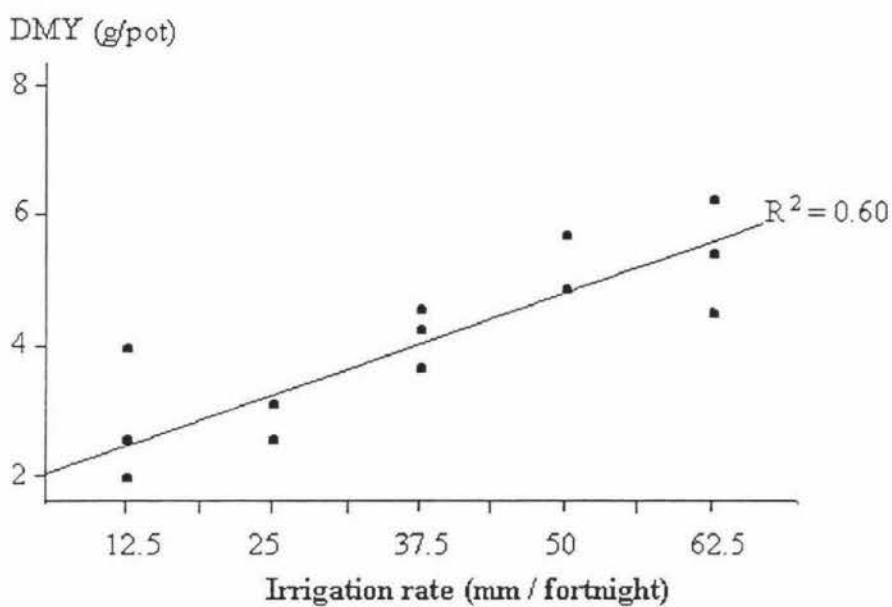**(Nutrient solution treatment)**

**Figure 23. The relationship of the DM yields (g/pot) with irrigation rate
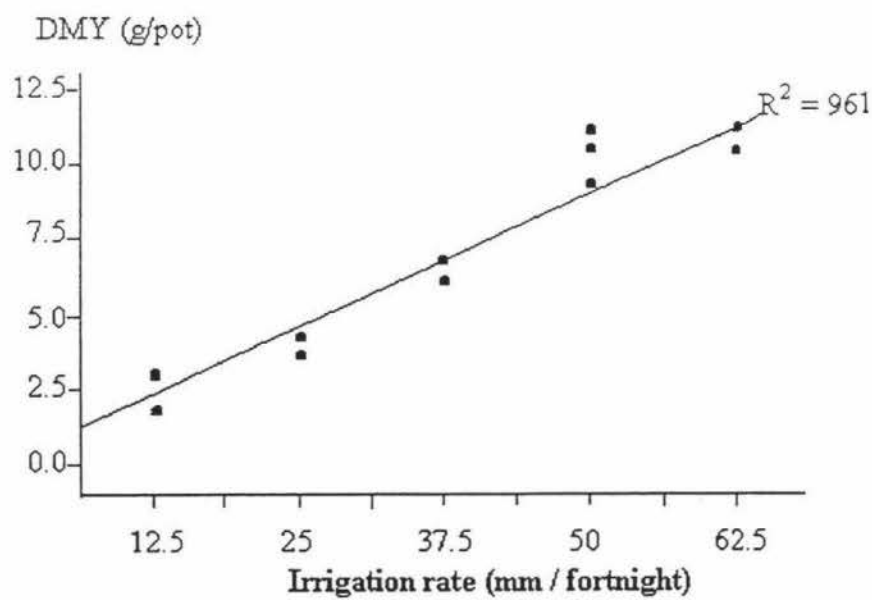(Wool scour effluent treatment)**

**Figure 24. The relationship of the DM yields (g/pot) with irrigation rate
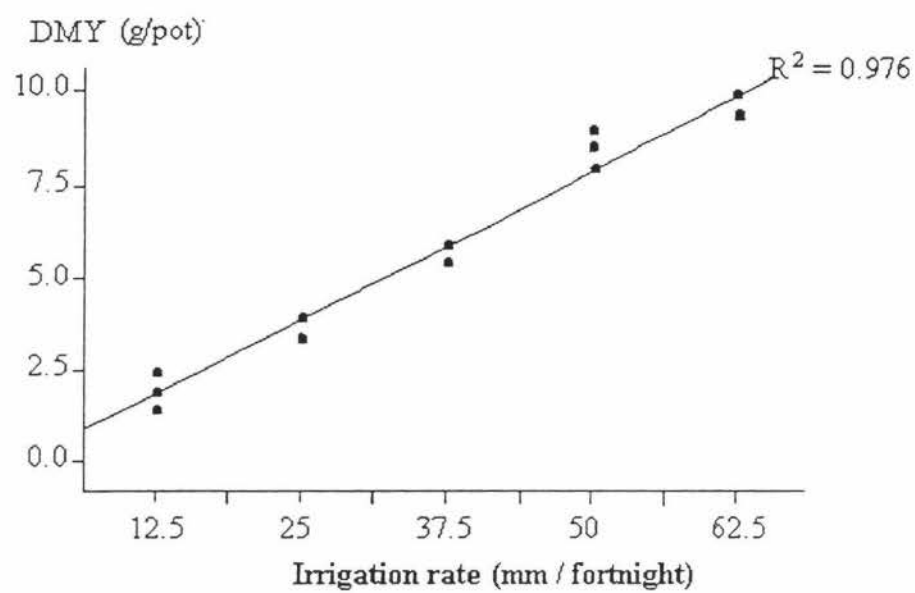(Piggery effluent treatment)**

Figure 25. The relationship of the DM yields (g/pot) with irrigation rate

(Dairy effluent treatment)