

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**RESPONSE OF SHORT ROTATION FORESTRY TO DAIRY FARM-POND
EFFLUENT IRRIGATION**

A thesis presented in partial fulfilment of the requirements for the degree of
Master of Philosophy in Agricultural Engineering
At Massey University

Rebecca dela Peña Obando - Tungcul

1999

ABSTRACT

A growing concern to protect the environment has prompted Regional Councils in New Zealand to monitor compliance under the Resource Management Act (1991) covering the discharge of wastewater into waterways. To meet the desired standards, application of wastewater onto high dry matter producing short vegetation forests offers opportunity for the beneficial use of nutrients while renovating the wastewater.

A field trial was established near Palmerston North to determine the response of nine *Salix* clones and one *Eucalyptus* short rotation forest (SRF) species to dairy farm effluent irrigation and to determine their water and nutrient uptake potential. A micro sprinkler irrigation system was designed to operate at 100 kPa and supply each plot of 16 trees with either 7.5 mm, 15 mm, or 30 mm of dairy farm effluent every two weeks. Twenty-four applications were made covering two growing seasons with a break over winter. A control treatment of 7.5 mm of water + 187.5 kg N ha⁻¹ year⁻¹ was included, being equivalent to the nitrogen addition from the lowest effluent application rate. The three SRF species, *Salix matsudana x alba* (NZ 1295), *Salix kinuyanagi* (PN 386) and *Eucalyptus nitens* were selected for more detailed analysis than the other seven *Salix* clones. This included the measurement of evapotranspiration rates and a pot trial to determine the tolerance level of seedlings to higher levels of effluent application. Application of up to 90 mm of effluent per fortnight increased the biomass production and nutrient accumulation of potted PN 386 and *E. nitens*, whereas the NZ 1295 produced optimum biomass and accumulation of nutrients at 60 mm of effluent application per fortnight.

At the end of the first growing season, the above ground biomass of the ten tree species in the field trial was assessed using a non-destructive method followed by a destructive harvest at the end of the second growing season. Dry matter production in these short rotation forest crops varied with species and clones and with the amount of dairy farm-

pond effluent applied. *Salix* NZ 1296, PN 386 and NZ 1295 irrigated with the highest application rate of 30 mm of effluent per fortnight produced the highest biomass yields of 37.91, 37.87 and 37.58 ODt ha⁻¹ year⁻¹ respectively. NZ 1296 irrigated with 30 mm of effluent per fortnight accumulated 196 kg N ha⁻¹ year⁻¹, 37.6 kg P ha⁻¹ year⁻¹, and 103.6 kg Mg ha⁻¹ year⁻¹ in its above ground biomass. *E. nitens* irrigated with 15 mm of effluent per fortnight produced a comparable above ground oven dry biomass yield of 36.33 ODt ha⁻¹ year⁻¹ and accumulated the highest amount of potassium and calcium in its above ground biomass giving 145.4 and 148.1 kg ha⁻¹ year⁻¹, respectively.

Transpiration monitoring during the second growing season using a heat pulse technique showed that under the highest application rate (30 mm per fortnight) on a cloud-free day, 15 month old NZ 1295 trees each transpired the highest cumulative amount of 6.38 mm day⁻¹ compared to 2.71 mm day⁻¹ for trees irrigated at the lowest rate (7.5 mm per fortnight).

Results of this study overall suggest that increasing the rate of effluent irrigation will increase the soil pH, nitrates and exchangeable potassium, calcium and magnesium concentrations throughout the soil profile. Total nitrogen and total phosphorus levels decreased throughout the soil profile after the second growing season. The cation exchange capacity of the soil decreased with increased rate of effluent after the second growing season.

The soil-SRF treatment system renovated the nutrients in the effluent. The soil-*E. nitens* treatment system renovated the highest percentage of total nitrogen (17.2 t ha⁻¹ m⁻¹ depth) equivalent to 96.45% of total nitrogen supplied by both the soil and the 30 mm of effluent applied per fortnight. The soil-PN 386 treatment system renovated the highest percentage of total phosphorus (6.4 t ha⁻¹ m⁻¹ depth) equivalent to 92.72% of the total phosphorus available in the soil and supplied by the 7.5 mm of effluent treatment. The soil-NZ 1295 treatment system renovated the highest percentage of potassium (99.5%),

calcium (98.74%) and magnesium (95.63%) supplied by both the soil and the 30 mm of effluent treatment.

The capacity of the three SRF species to renovate total nitrogen, phosphorus and potassium from the effluent decreased with increasing rates of application. PN 386 irrigated at 7.5 mm of effluent renovated the highest percentage of 99.45% of total nitrogen (114.25 kg ha⁻¹ over two growing seasons) and 79.18% of total phosphorus (35.60 kg ha⁻¹ over two growing seasons). The amounts of calcium and magnesium renovated by the SRF species were more than the amount supplied by even the highest rate of effluent (30 mm per fortnight).

Salix PN 386, NZ 1295 and *E. nitens* are recommended SRF species to grow in a land treatment scheme for dairy farm pond-effluent when applied at a rate of 30 mm per fortnight over the growing period on to a silt loam soil. Pot trials showed higher volumes of effluent renovation on to PN 386 and *E. nitens* may be applicable when applied up to 90 mm of effluent per fortnight but further evaluation is needed before this can be recommended.

ACKNOWLEDGEMENTS

My sincere and most profound gratitude to the following people for their invaluable contributions for the completion of this thesis:

Associate Professor R. E. H. Sims, Director, Centre for Renewable Energy, Massey University and my chief supervisor for his encouragement and able guidance towards the realisation of this project.

Mr. I. Mason, from whom I learned a lot about wastewater and treatment. His expertise in this field was very useful in carrying out this study.

Professor G. Wall, head of department of the then Agricultural Engineering, for giving me the chance to be employed as graduate assistant of the department and for giving me the opportunity to further my study at Massey University.

To Dr. W. R. Edwards and Mr. B. Bullock for their expertise and technical help in setting up the study.

To all the staff of the then Agricultural Engineering and Soil Science Departments for their valuable friendship and technical assistance.

Helen E. Akers Scholarship; HortResearch, Palmerston North, Massey University; Land Treatment Collective of New Zealand; Environment Waikato; and Massey University Agricultural Research Foundation for their financial support and assistance.

Friends, especially Price and relatives for their technical help, moral support and endless encouragement during difficult times. My family, Andy, my sons Fernan and Francis, who were my inspirations in completing this work.

TABLE OF CONTENTS

ABSTRACT.....	ii
ACKNOWLEDGEMENTS.....	v
TABLE OF CONTENTS.....	vi
LIST OF TABLES.....	xii
LIST OF FIGURES.....	xiv
CHAPTER 1. INTRODUCTION.....	1
CHAPTER 2 LITERATURE REVIEW.....	4
2.1 Introduction.....	4
2.2 Short Rotation Forestry.....	5
2.2.1 Importance of SRF trees.....	5
2.2.2 Nutrition of SRF trees.....	7
2.2.3 Waste effluents as source of nutrients for SRF trees.....	10
2.3 Sources of waste effluents.....	12
2.3.1 Sewage wastes.....	12
2.3.2 Industrial wastes effluents.....	15
2.3.3 Agricultural wastes effluents.....	16
2.4 Treatment of waste effluents.....	18
2.4.1 Physical treatment of waste effluent.....	18

2.4.2	Chemical treatment of waste effluent	19
2.4.3	Biological treatment of waste effluent.....	19
2.4.3.1	Land application of waste effluent.....	22
2.4.3.2	Wetland system.....	24
2.5	Health effects associated with wastewater treatment, disposal and reuse ...	24
2.6	Resource Management Act (RMA) 1991	26
2.7	Effects of land application of waste effluents to plants and trees.....	28
	the potential of short rotation forestry (SRF) for a landbased	
	treatment scheme.....	29
2.7.2	SRF biomass production.....	30
2.7.3	SRF nutrient accumulation and evapotranspiration.....	30
2.7.4	Performance of SRF crops irrigated with municipal and	
	industrial wastewaters.....	37
2.7.5	SRF crops versus grass	38
2.8	Effect of land application of waste effluents on the soils and	
	environment	40
2.8.1	Physical effect of waste effluent application	40
2.8.2	Chemical effect of waste effluent application	42
2.8.3	Biological effect of waste effluent application	44
2.9	Research directions	44
2.10	Conclusions and recommendations.....	48
CHAPTER 3	GROWTH, BIOMASS PRODUCTION AND NUTRIENT	
	ACCUMULATION BY TEN SPECIES OF SHORT ROTATION	
	FORESTS	49

3.1 Introduction.....	49
3.2 Methodology.....	50
3.2.1 Nutrients in the effluent	52
3.2.2 The experimental site.....	53
3.2.3 Establishment.....	54
3.2.4 Maintenance.....	56
3.2.5 Monitoring	57
3.3 Results and discussions.....	58
3.3.1 Growth of SRF trees	58
3.3.1.1 Cumulative height of SRF trees.....	58
3.3.1.2 Dry matter assessment	60
3.3.1.3 Stem biomass	63
3.3.1.4 Leaf biomass	64
3.3.2 Nutrient uptake of SRF trees.....	66
3.3.2.1 Nitrogen uptake.....	66
3.3.2.2 Phosphorus uptake	70
3.3.2.3 Potassium uptake	72
3.3.2.4 Calcium uptake	75
3.3.2.5 Magnesium uptake.....	77
3.4 Conclusions and recommendations.....	79
 CHAPTER 4	
EFFECT OF THE APPLICATION OF DAIRY FARM-POND EFFLUENT ON THE SOIL UNDER SRF TREES	81
4.1 Introduction.....	81
4.2 The experimental site.....	83
4.3 Methodology.....	83

4.4 Results and discussions.....	85
4.4.1 Total nitrogen in the soil.....	85
4.4.2 Soil nitrate.....	89
4.4.3 Total phosphorus in the soil.....	95
4.4.4 Exchangeable potassium in the soil.....	99
4.4.5 Exchangeable calcium in the soil.....	103
4.4.6 Exchangeable magnesium in the soil.....	107
4.4.7 Exchangeable sodium in the soil.....	109
4.4.8 The cation exchange capacity (CEC) of the soil.....	112
4.4.9 Soil pH.....	114
4.4.10 Soil bulk density.....	117
4.4.11 Soil infiltration rates.....	119
4.5 Conclusions.....	122
 CHAPTER 5 UPTAKE OF NUTRIENTS.....	 127
5.1 Introduction.....	127
5.2 Methodology.....	128
5.3 Results and discussions.....	132
5.3.1 Renovation of total nitrogen.....	132
5.3.1.1 Soils.....	132
5.3.1.2 SRF species.....	134
5.3.2 Renovation of phosphorus.....	136
5.3.2.1 Soils.....	136
5.3.2.2 SRF species.....	138
5.3.3 Renovation of potassium.....	140
5.3.3.1 Soils.....	140
5.3.3.2 SRF species.....	142

5.3.4 Renovation of calcium	143
5.3.4.1 Soils.....	143
5.3.4.2 SRF species.....	145
5.3.5 Renovation of magnesium	146
5.3.5.1 Soils.....	146
5.3.5.2 SRF species.....	148
5.4 Conclusions.....	149
CHAPTER 6	EFFECT OF DAIRY FARM-POND IRRIGATION ON THE EVAPOTRANSPIRATION
	150
6.1 Introduction.....	150
6.2 Methodology.....	153
6.2.1 Climatic regime of the experimental area.....	153
6.2.2 Selection of SRF species and instrumentation.....	156
6.3 Results and discussions.....	157
6.3.1 Evapotranspiration and climatological factors.....	157
6.3.2 Leaf area effect on evapotranspiration.....	161
6.3.3 Leaf area in relation to evapotranspiration	163
6.3.4 Climatic impact on evapotranspiration rates.....	165
6.3.4.1 Evapotranspiration versus temperature.....	165
6.3.4.2 Evapotranspiration versus the vapour pressure deficit	165
6.3.4.3 Evapotranspiration versus global radiation.....	166
6.3.5 Water requirements of three SRF species	167
6.4 Conclusions and recommendations.....	169

CHAPTER 7	POT TRIAL OF HIGH RATES OF EFFLUENT IRRIGATION ON TO SHORT ROTATION FORESTRY CROPS.....	171
7.1	Introduction.....	171
7.2	Methodology.....	172
7.2.1	Chemical composition of effluent.....	174
7.3	Results and discussions.....	177
7.3.1	SRF biomass yield.....	177
7.3.2	Nutrients in the biomass.....	179
7.3.2.1	Nitrogen.....	179
7.3.2.2	Phosphorus.....	181
7.3.2.3	Potassium.....	183
7.3.2.4	Calcium.....	185
7.3.2.5	Magnesium.....	187
7.3.3	Effect of effluent on the soils.....	189
7.3.3.1	Soil pH.....	189
7.3.3.2	Nitrogen.....	190
7.3.3.2.1	Nitrate-nitrogen.....	194
7.3.3.3	Phosphorus.....	195
7.4	Conclusions and recommendations.....	198
CHAPTER 8	GENERAL CONCLUSIONS AND RECOMMENDATIONS	199
REFERENCES	206

LIST OF TABLES

Table 2.1	Optimal proportion by weight of the essential mineral nutrient compounds in a fertiliser for achieving maximum willow production.9
Table 2.2	The proportions of the five main nutrients in secondary treated dairy farm-pond effluent compared to the nutrient requirement of willows (<i>Salix</i> spp.) for maximum production12
Table 2.3	Characteristics of various wastewater effluents13
Table 2.4	Summary of standards in New Zealand in the disposal of wastewater to surface water as prescribed by regional councils and governed under the RMA (1991).27
Table 2.5	Total transpiration and total dry matter increment of spruce trees.....32
Table 2.6	Foliage nutrient concentration of unfertilised SRF crops at different age of stands.....33
Table 2.7	Biomass and nutrient concentration of a 4-year-old <i>E. globulus</i>33
Table 2.8	Stemwood and litterfall biomass (tonnes/ha/yr) and nutrient content (kg/ha/yr) of 4-year old SRF crops irrigated with municipal effluent.....35
Table 2.9	Nutrient contents of a cloned basket willow (4/68T)36
Table 2.10	Comparison of the N and P (kg/ha/yr) in the total litterfall of a 3 -year old and 5- year-old regrowth <i>E. diversicolor</i> treated with N and P fertilisers36
Table 2.11	Biomass production and mean nutrient concentration of 4-year old trees irrigated with municipal effluent36

Table 2.12	Biomass production and foliage nutrient concentration of 2.8-year-old <i>E botryoides</i> irrigated with meat processing wastewater.....	37
Table 2.13	Fuel crop and turfgrass uptake of N and P	39
Table 3.1	Total nutrients contained in the effluent applied to SRF trees over two growing seasons.....	52
Table 5.1	Renovation of total nitrogen in a soil-SRF species treatment system after two years of effluent irrigation.....	133
Table 5.2	Renovation of total phosphorus in a soil-SRF species treatment system after two years of effluent irrigation.....	137
Table 5.3	Renovation of potassium in a soil-SRF species treatment system after two years of effluent irrigation.....	141
Table 5.4	Renovation of calcium in a soil-SRF species treatment system before and after two years of effluent irrigation.....	144
Table 5.5	Renovation of magnesium in a soil-SRF species treatment system after two years of effluent irrigation.....	147
Table 6.1	Water balance for 2 years old three SRF species irrigated either at 7.5 or 30 mm of effluent for one growing season.....	168
Table 7.1	Chemical characteristics of dairy farm oxidation pond effluents.....	175
Table 7.2.	The total amount of nutrients applied to SRF crops for ten weeks	176
Table 7.3	Renovation of total nitrogen in a potted soil-SRF treatment system.....	193
Table 7.4	Renovation of total phosphorus in a potted soil-SRF treatment system	195

LISTS OF FIGURES

Figure 3.1	Schematic diagram of each plot of SRF species irrigated with dairy farm- pond effluent and water + N	53
Figure 3.2	Experimental layout of ten species of SRF trees irrigated with dairy farm-pond effluent or water + nitrogen	55
Figure 3.3	Salix and eucalyptus newly established in the experimental site	56
Figure 3.4	Average heights of ten tree species irrigated with 3 rates of dairy farm-pond effluent and water + nitrogen and measured at four stages over two growing seasons	58
Figure 3.5	Above ground biomass yields ten tree species irrigated with effluent or water after one growing season derived from tree height and diameter and measured after the destructive harvest in year two	61
Figure. 3.6	Mean annual increment of stem biomass of ten species with irrigation treatments averaged over two growing seasons.....	64
Figure 3.7	Mean annual increment of leaf biomass of ten species with irrigation treatments averaged over two growing seasons.....	65
Figure 3.8	Above ground TN of ten SRF trees irrigated with dairy farm-pond effluent and water (7.5 mm) + N (187.5 kg ha ⁻¹ year ⁻¹) over two years	67
Figure 3.9	Above ground total phosphorus of SRF trees irrigated with dairy farm-pond effluent and water + N (187.5 kgN/ha/year) over two years	71
Figure 3.10	Above ground K of SRF trees irrigated with dairy farm-pond effluent and water (7.5 mm) + N(187.5 kg ha ⁻¹ year ⁻¹) for two years.....	73
Figure 3.11	Above ground Ca in the biomass of SRF trees irrigated with dairy farm-pond effluent and water (7.5 mm) + N (187.5 kg ha ⁻¹ year ⁻¹) over two years.	76

Figure 3.12	Mg in the above ground biomass of SRF trees irrigated with dairy farm-pond effluent and water (7.5 mm) + N (187.5 kg ha ⁻¹ year ⁻¹) for two years.	77
Figure 4.1	Total nitrogen of soil under three SRF trees irrigated with different rates of dairy farm-pond effluent.....	86
Figure 4.2	Total nitrogen of soil under three SRF trees irrigated with different rates of dairy-farm pond effluent and water + nitrogen after 1 year growth and 2 year growth.....	88
Figure 4.3	Nitrates in the soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after two growing seasons	93
Figure 4.4	Nitrates in the soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after 1 year growth and 2 year growth	94
Figure 4.5	Total phosphorus in the soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after two growing seasons	96
Figure 4.6	Total phosphorus in the soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after 1 year growth and 2 year growth	99
Figure 4.7	Exchangeable potassium in soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after two growing seasons.....	101
Figure 4.8	Exchangeable calcium in soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen over two growing seasons.....	103

Figure 4.9	Exchangeable magnesium in soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen over two growing seasons	107
Figure 4.10	Exchangeable sodium in soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen following two growing seasons	110
Figure 4.11	Cation exchange capacity in soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen following two growing seasons	113
Figure 4.12	pH of soil under three SRF trees irrigated with different rates of dairy farm pond effluent and water + nitrogen following two growing seasons ...	115
Figure 4.13	Bulk density of soil under three SRF trees irrigated with different rates dairy farm-pond effluent and water + nitrogen after two growing seasons	118
Figure 4.14	Infiltration rates of soil under three SRF trees irrigated with different rates of dairy farm-pond effluent and water + nitrogen after two growing seasons.....	120
Figure 5.1	Percentage of total nitrogen uptake by SRF trees from the effluent applied after one growing season.....	135
Figure 5.2	Percentage of phosphorus uptake by the three SRF species from the effluent irrigated per year.....	139
Figure 5.3	Percentage of potassium uptake by the three SRF species from the effluent irrigated per year.....	142
Figure 5.4	The yearly amount of calcium supplied by the effluent and taken up by the SRF trees over two growing seasons	146
Figure 5.5	The yearly amount of magnesium supplied by the effluent and taken up by the SRF trees over two growing seasons	148

Figure 6.1	Ten-year mean monthly evaporation and rainfall in the experimental area at HortResearch, Aokautere, Palmerston North.....	153
Figure 6.2	Ten-year mean monthly maximum air temperature and vapour pressure deficit in the experimental area at HortResearch, Aokautere, Palmerston North	154
Figure 6.3	Ten-year mean monthly daily wind run and sunshine hours at the experimental area HortResearch, Aokautere, Palmerston North.	155
Figure 6.4	Evapotranspiration over a 12 day summer period of three SRF species that were irrigated with either 30 or 17.5 mm of dairy farm-pond effluent (E) per fortnight.....	157
Figure 6.5.	The wind speed (a), humidity (b), rain (c), temperature (d), vapour pressure deficit (e) and global radiation (f) of the SRF trees plantation taken during the 19th to the 30th day of the Julian calendar of the second growing season	160
Figure 6.6	Average cumulative evapotranspiration of three SRF species irrigated with either 30 or 7.5 mm of dairy farm-pond effluent during the month of January of the second growing season	162
Figure 6.7.	Average leaf area during the summer of the second growing season of three SRF species irrigated with either 30 or 7.5 mm of dairy farm-pond effluent per fortnight over two growing seasons	163
Figure 6.8	The relationship between the average daily cumulative evapotranspiration and the leaf area of three SRF species irrigated with either 30 or 7.5 mm per fortnight of dairy farm-pond effluent.....	164
Figure 6.9.	The relation between evapotranspiration rate of SRF trees and temperature in the plantation site at HortResearch, Aokautere, Palmerston North	165

Figure. 6.10.	The relation between the evapotranspiration rate and vapour pressure deficit (mb) in the SRF plantation	166
Figure 6.11	The relation between evapotranspiration rate and global radiation (W/m^2) in the SRF plantation	167
Figure 7.1	Potted SRF species irrigated with effluent and water over ten week period with five irrigation	176
Figure 7.2	Total oven dry biomass of three pot grown SRF species seedlings irrigated either with effluent or water per fortnight for ten weeks.....	177
Figure 7.3	Leaf area of three pot grown SRF species seedlings irrigated either with effluent or water per fortnight for ten weeks	178
Figure 7.4	Total nitrogen content of the three selected potted SRF species irrigated with either effluent or water every fortnight for ten weeks	180
Figure 7.5	The relationship between the biomass and total nitrogen in the biomass of three selected pot grown SRF species irrigated with effluent or water per fortnight for ten weeks.....	181
Figure 7.6	Total phosphorus content of selected three pot grown SRF trees irrigated with effluent or water per fortnight for ten weeks	182
Figure 7.7	The relationship between the biomass and total phosphorus in the biomass of three selected potted SRF species irrigated with effluent or water per fortnight for ten weeks	183
Figure 7.8	Potassium content of three selected pot grown SRF trees irrigated with effluent or water per fortnight for ten weeks	184
Figure 7.9	The relationship between the biomass and potassium in the biomass of three selected pot grown SRF species irrigated with effluent or water per fortnight for ten weeks.....	185
Figure 7.10	Calcium content of selected three potted SRF trees irrigated with effluent or water per fortnight for ten weeks	186

Figure 7.11	The relationship between the biomass and calcium in the biomass of three selected pot grown SRF species irrigated with effluent or water per fortnight for ten weeks.....	187
Figure 7.12	Magnesium content of selected three potted SRF trees irrigated with effluent or water per fortnight for ten weeks	188
Figure 7.13	The relationship between the biomass and magnesium in the biomass of three selected pot grown SRF species irrigated with effluent or water per fortnight for ten weeks.....	189
Figure 7. 14	pH of potted soil under three selected pot grown SRF species irrigated with effluent or water per fortnight for ten weeks (pre-treatment soil pH = 5.85).....	190
Figure 7.15	The fate of TN in the effluent applied to the three potted SRF seedlings at rates of (a) 30 mm, (b) 60mm and (c) 90 mm.....	192
Figure 7.16	The amount (a) and percentage (b) of TN renovated from the effluent by the three selected potted SRF species	194
Figure 7.17	Nitrate-nitrogen of soil under three selected pot grown SRF species irrigated with effluent or water per fortnight	197

CHAPTER 1

INTRODUCTION

Many dairy farms treat the dairy shed washings in anaerobic/aerobic ponds before discharge of the treated effluent to pasture or waterways. This system can still have a large impact on receiving waterways as the effluent contains relatively high levels of nutrients and pollutants which threaten the environment once discharged or allowed to percolate into the ground water (Mason, 1994). Potassium and nitrogen contents of dairy farm-pond effluent is particularly higher compared with sewage effluent.

A growing concern to protect the environment has prompted regional councils in New Zealand to monitor compliance under the Resource Management Act (1991) covering the discharge of wastewater into waterways. To meet the desired standards, application of wastewater onto high dry matter producing short rotation forests (SRF) offers opportunity for the beneficial use of nutrients while renovating the wastewater (Barton et. al, 1989).

Irrigation of land with dairy farm-pond effluent is one of the alternatives to discharge and a soil-SRF treatment system has the potential to effectively treat the effluent when applied at a regulated hydraulic loading rate. The soil particles can filter suspended solids and can fix dissolved components in the effluent by adsorption, ion exchange or precipitation. Micro-organisms in the soil can transform and stabilise the nutrients from the wastewater. The growth of SRF species on treatment site can enhance absorption and utilise nutrients from the wastewater for growth and production. The SRF root system can also help improve the infiltration capacity of the soil.

SRF crops like willows and eucalyptus are fast growing species and are known to produce high dry matter. Sims et. al (1992) recommended coppice willows to be ideal attachment for land treatment of wastewaters due to its fibrous root system that has the

ability to utilise large quantity of water and nutrients. Barton (1989) emphasised the potential use of coppice eucalyptus for wastewater treatment being able to accumulate high amounts of nitrogen. These SRF species has also the potential to provide non-polluting sources of renewable energy while renovating waste waters.

Aside from preventing the possible risk of ground water contamination and eutrophication of waterways, it is desirable to recycle nutrients from wastewater wherever feasible to support sustainable crop production. Hence, it is the purpose of this study to investigate the performance of short rotation forest species, *salix* and *eucalyptus* as part of a land treatment scheme for dairy farm-pond effluent.

Specifically, this study aimed to:

- identify suitable SRF species for dairy farm-pond effluent irrigation;
- quantify the level of dairy farm-pond effluent irrigation suitable for the production of SRF species;
- determine the effect of dairy farm-pond effluent to the physical and chemical properties of soils;
- quantify the amount of waste nutrients from dairy farm-pond effluent renovated by the SRF species;
- quantify the amount of nutrients renovated by the soil-SRF system that were supplied by the soil and the effluent and;
- determine the evapotranspiration of SRF species when irrigated with varying rates of dairy farm-pond effluent.

An overview of previous work is given in chapter two of the thesis.

The responses of ten species to different rates of dairy farm-pond effluent irrigation and water + nitrogen in terms of biomass production and nutrient accumulation were evaluated (chapter 3). The three most suitable species or clones of SRF trees for treating dairy farm-pond effluent irrigation were identified and the level of irrigation that produced optimal biomass production and nutrient uptake and accumulation into the biomass was determined.

The effects of applying different rates of dairy farm-pond effluent to the physical and chemical properties of the soil were discussed in chapter 4. Samples were analysed before treatment began and after harvesting the trees at two years old.

The portion of waste nutrients in the dairy farm-pond effluent applied at the various application rates that was removed by the SRF trees and filtered by the soil matrix over the two growing periods was quantified (chapter 5).

The effect of dairy farm-pond effluent irrigation on the evapo-transpiration of the three selected species was monitored during a short period of the growing season and is reported in chapter 6.

Finally, the responses of seedling of the three selected SRF species to particularly high rates of dairy farm-pond effluent irrigation were determined in a pot trial described in chapter 7. The maximum irrigation level of dairy farm-pond effluent irrigation that was tolerated by each of the three SRF species in terms of maximum growth, biomass production and nutrient accumulation was determined.

The results of these studies were brought together in concluding section (chapter 8) and practical recommendations made along with suggestions for further studies.