Land Treatment of Dairy-farm Effluent Using Short Rotation Forestry

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Abstract

Under the Resource Management Act (1991) New Zealand dairy farmers are required to dispose of dairy-farm effluent in such a manner as to have no adverse effect on the receiving environment. This study investigated the land treatment of pond treated effluent to short rotation forestry (SRF). The study involved both field trials and modelling work to assess sustainability of these systems in terms of nitrogen leaching to groundwater.

A lysimeter study investigated 3 SRF species, 2 evergreen species of Eucalypts (*Eucalyptus saligna*, *E. nitens*) and a deciduous willow (*Salix kimuyanagi*) in the treatment of dairy farm effluent. Trees were grown in lysimeters (1.8 m diameter, 1.0 m depth) to enable measurement of water and nitrogen balances. A bare-soil treatment was used as a control. The application of dairy-farm oxidation-pond effluent totaled 218 g N lysimeter^{-1} (equivalent to 872 kg N ha^{-1}) over 2 irrigation seasons (December 1995-June 1996 and September 1996-April 1997). Effluent was applied weekly during the irrigation seasons at a rate of 21 mm week^{-1}. No effluent was applied during the winter period.

The drainage period of the *E. nitens* was shorter than that of the *S. kimuyanagi*, and rates of leaching were respectively lower. Both these treatments leached for shorter periods than *E. saligna*. Leaching of the bare-soil treatment was consistently high throughout the experiment. Water use through evapotranspiration was found to have a large impact on drainage volume and timing.

The trees were shown to improve effluent treatment because high evapotranspiration rates reduced the volume of leachate passing beyond the root zone. Further, uptake of nitrogen by the trees reduced the quantities of nitrogen available for leaching. In this study both *E. nitens* and *S. kinuyanagi* were more suitable for land treatment than the other 2 treatments evaluated. The low nitrogen concentration in the leachate under the *S. kinuyanagi* is the key criterion which determines the suitability of this tree species for land treatment of effluent. The low total loading of nitrogen to the groundwater of the *E. nitens* treatments is the key criterion in determining *E. nitens* suitability. Although the nitrogen concentrations in the leachate of the tree treatments were generally less than the bare soil treatments, they were still greater than the New Zealand drinking water standard (NZDWS) of 11.3 mg NO_3^--N, during certain periods of the experiment. From the lysimeter experiment it was concluded that the leachate nitrogen concentrations might have been reduced if the amount of nitrogen applied in the effluent was reduced.

Total production of above-ground biomass in the 2.5 years, based on the stocking rate of 4000 stems ha^{-1} was equivalent to 15.6, 30.6, and 21.3 Mg ha^{-1} yr^{-1} for *E. saligna*, *E. nitens*, and *S. kinuyanagi* respectively. Although scaling up biomass estimates from small plot trials and particularly lysimeters introduces associated errors, the estimates fell within the ranges measured elsewhere in New Zealand.

The lysimeter study was complemented by the modelling of the water and nitrogen balances of SRF land treatment systems. Ultimately, the aim of the model was to investigate the effect of changes in management practices on sustainability in terms of nitrogen leaching of SRF systems treating dairy-shed effluent. The model selected for this purpose was a lumped parameter model (LPM). The water and nitrogen balances of

the bare soil and *E. nitens* treatments were simulated with the model to determine the applicability of an LPM scheme to predict system behaviour. The model predicted, with broad agreement, the measured water and nitrogen balances of the lysimeter experiment. The model was then used to simulate the behaviour of a SRF plantation receiving dairy-shed effluent at a rate of 200 kg N ha^{-1} yr^{-1} over 27 years. This simulation predicted the occurrence of high nitrate concentrations in the leachate. This would be a limiting factor for the long term sustainability of such a system. A sensitivity analysis of the model was used to reveal the important parameters of water movement and nitrogen cycling that effect both nitrogen concentration and quantity in the leachate moving below the root zone. Water movement was most sensitive to root zone depth, effective rainfall, available water and crop water use. The nitrogen fate parameters with greatest effect on leachate nitrogen concentration and quantity were denitrification activity and volatilisation. Plant growth parameters of light utilisation efficiency, maximum leaf nitrogen concentration and specific leaf area strongly effected leachate nitrogen concentration and quantity. Mineralisation rates of the soil humus and the senescence rates of plant material also impacted on quantity and concentration of nitrogen leaching.

The model's applicability as a decision support tool was demonstrated by examining the impact of various effluent loading rates on the leachate concentration and quantity. Based on leachate nitrate concentrations being on average lower than the NZDWS, the key finding was that the sustainable loading rate for the simulated system was found to be around 75 kg N ha^{-1} yr^{-1}.

The major finding of both the lysimeter experiment and the modelling study was the high nitrogen concentrations leaching from SRF dairy-shed effluent treatment systems. The LPM model clearly provides a platform from which to investigate many other possible scenarios of management to minimise the leaching of the high concentrations of nitrogen into the ground water.

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Table of Contents

List of Figures

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Tables

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Symbols

Definition	Symbol	Unit
Water balance equations		
Evapotranspiration	ET	mm
Potential Evaporation (Penman monteith)	E_p	mm day^{-1}
Evaporation	E	mm day^{-1}
Drainage	D	mm
Irrigation	I	mm
Soil water storage	W	mm
Total rainfall	R_t	mm
Effective rainfall	R_e	mm
Soil water content	θ	m^3 m^{-3}
Constant (Eq 3.11)	c	mm day^{-1}
Time	t	day^{-1}
Water movement		
Maximum water content	θ_s	m^3 m^{-3}
Field capacity	θ_f	m^3 m^{-3}
Wilting point	θ_w	m^3 m^{-3}
Saturated hydraulic conductivity	K_s	mm day^{-1}
Beta constant	β	
Soil bulk density	ρ_b	Mg m^{-3}
Root zone depth	z_R	m
Maximum soil evaporation	E_s	mm day^{-1}
Nitrogen parameters		
Nitrate adsorption	k_{DN}	L kg^{-1}
Ammonium adsorption	k_{DA}	L kg^{-1}
Nitrification	k_2	day^{-1}
Denitrification	k_3	day^{-1}
Denitrification zone below θ_f	δ_D	m^3 m^{-3}
Volatilisation (days time evaporation rate)	k_v	days
C:N ratio	r_o	
Critical N content for growth	N_{crit}	kg N ha^{-1}
Decomposition of litter	k_{lit}	day^{-1}
Decomposition of humus	k_{hum}	day^{-1}
Crop parameters		
Crop factor	k_c	
Drought tolerance	τ	
Light utilisation efficiency	ε	g DM MJ^{-1}
Senescence rate of roots	γ_R	day^{-1}
Senescence rate of stems	γ_W	day^{-1}
Senescence rate of leaves	γ_F	day^{-1}
Maximum leaf N content	N_f	mg N g^{-1}
Allocation to leaves	A_l	
Allocation to stems	A_s	
Allocation to roots	A_r	
Specific leaf area	σ_f	ha-leaf kg-DM^{-1}