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IRRIGATION MANAGEMENT TO REDUCE NITROUS OXIDE EMISSIONS AND NITRATE LEACHING LOSSES

Steve Thomas[1], Iris Vogeler[2], Tony van derWeerden[3], Sam Carrick[4]

[1]Plant and Food Research, Private Bag 4704, Christchurch 8140
[2]AgResearch, Ruakura Research Centre, Hamilton 3214
[3]AgResearch, Invermay Agricultural Centre, Private Bag 50034, Mosgiel 9053
[4]Landcare Research, P.O. Box 69040 Lincoln 7640
Email: steve.thomas@plantandfood.co.nz

Abstract

While the benefits of irrigation for dairy production are well established the environmental consequences are not well quantified. In particular how irrigation management practices affect losses of nitrous oxide (N_2O) to the atmosphere and nitrate (NO_3) to groundwater.

We used the APSIM (Agricultural Production Systems Simulator) model to simulate the effect of six different irrigation management scenarios on N_2O emissions from urine patches and non-urine areas on pasture of three different soil types. These were deep poorly drained (Otokia), deep well drained (Templeton) and shallow well drained (Eyre) soils. The effects of different climate and rainfall regimes were simulated using 20 years of data from two climate stations (Lincoln and Hororata, Canterbury). Simulation outputs included irrigation amounts, N_2O emissions, NO_3 leaching losses and pasture production.

Soil type, urine and the timing of urine application had the greatest influence on the variation of N_2O emission and NO_3 leaching. Greatest N_2O emissions were predicted from the Otokia soil, while emissions tended to be similar from the well-drained soils. More frequent irrigation resulted in the largest N_2O emissions and NO_3 leaching losses. Greatest NO_3 leaching losses were predicted from the Eyre soil with the higher rainfall regime. Least were predicted from the Otokia soil with the lower rainfall. Pasture production was largely unaffected by irrigation management, except for the shallow Eyre soil when some loss of production was predicted from the two less frequent irrigation scenarios.

Based on the model simulations and supporting field experiments, N_2O emissions and NO_3 leaching can be reduced without penalising production by irrigating less frequently and maintaining soil water deficits. The contribution of indirect N_2O emissions (produced from leached NO_3) will be greater from shallow well drained soils compared to deeper (poorly or well drained) soils.

Introduction

Irrigation in New Zealand has increased dramatically over the last three decades. Much of this expansion has focused on increasing pasture production for livestock and especially dairy. While the economic benefits of irrigation for increasing pasture and crop production are well established (NZIER, 2014) the environmental consequences are not well quantified, in particular how irrigation management practices affect losses of nitrous oxide (N_2O) to the atmosphere and nitrate (NO_3) to groundwater.

New Zealand irrigation practices are diverse, ranging from surface flood irrigation to subsurface drip irrigation. Most irrigation water in New Zealand is applied using a wide range of overhead sprinkler systems. Key characteristics of the management of these overhead systems are the depth and frequency that they apply water; for example centre pivot systems tend to apply small amounts of irrigation often, typically 5 to 15 mm per application, whereas some linear systems may apply 30 to 50 mm weekly or less frequently. Regionally, pasture or crop irrigation requirements will vary depending on rainfall inputs, while the nutrient losses are likely to be function of both the amount of irrigation and soil type (Carrick et al., 2013; Francis et al., 2006); N_2O emissions are very strongly related to the soil drainage characteristics and moisture content (van der Weerden et al., 2014).

With few field measurements to quantify the effect of irrigation on N_2O and NO_3 leaching and the pressing need for information to fill this gap we designed a full factorial simulation experiment to estimate N_2O emissions and NO_3 leaching for a range of typical irrigation scenarios, soil types and rainfall regimes from pasture with and without urine patches.

Methodology

We used the APSIM (Agricultural Production Systems sIMulator) model (Keating et al., 2003). The experimental factors were irrigation management, soil type, climate, urine and timing of urine. APSIM is run using a daily time-step and was run using the SWIM soil water module. APSIM has been modified and tested for a range of New Zealand pastoral and cropping conditions (Cichota et al., 2013; Li et al., 2011; Vogeler et al., 2013).

Six irrigation management scenarios were chosen to provide a wide range of irrigation frequencies and soil moisture contents that would be applicable to the range of irrigation systems used for pasture irrigation. Irrigation scenarios included applying different depths of irrigation (10, 30 and 50 mm) with trigger soil moisture deficits ranging from 10 to 60 mm (Table 1).

Table 1 Summary of irrigation scenarios used for APSIM modelling

Irrigation Scenario	Application amount (mm)	Trigger deficit (mm)
1	10	10
2	10	20
3	30	30
4	30	40
5	50	50
6	50	60

Rules allowed the intervals to vary and to prevent applying irrigation after rainfall. Three different soil types to represent typical irrigated pasture soils types were selected: 1) deep poorly drained (Otokia), 2)deep well drained (Templeton) and 3) shallow well drained (Eyre) soils. Earlier field experiments to investigate the effect of irrigation frequency on N_2O emissions had been used to parameterise the Eyre and Otokia soil in APSIM (unpublished data). To account for differences in rainfall regimes and year to year variability, simulations were run using 20 years of climate data between 1992 and 2011 from two climate stations located in the Canterbury region (Lincoln and Hororata) selected on the basis of having long term average annual rainfall of 634 and 841 mm, respectively. Urine was applied at rates of 0 or 600 kg N/ha, the latter representative of typical dairy cow urine N loading. To understand the effect of timing of deposition, urine was applied monthly. In total, 17280 simulations were run. Daily simulation outputs included irrigation amounts, direct and indirect N_2O emissions, NO_3 leaching losses and pasture production. These are presented as annual or summer amounts. Indirect N_2O emissions were calculated as 0.75% of the estimated annual N leached below 60 cm.

A sensitivity analysis procedure was used to quantify the variance of each model output in response to input factors. The measure of sensitivity of model outputs, to each input variable, was based on the sums of squares for each main factor relative to the total sums of squares from analysis of variance decompositions (Santner et al., 2003).

Results and discussion

Soil type had greatest influence on the predicted direct and indirect N_2O emissions from the APSIM (Figure 1) accounting for over 47% of the total variance from the analysis of variance. Timing of urine deposition during the year accounted for an additional 32%. Climate station, climate year and irrigation management had less influence on the total variance (2 to 3% each). Greatest N_2O emissions were predicted from the Otokia soil, while emissions tended to be similar from the well-drained soils (Figure 1). More frequent irrigation resulted in the largest N_2O emissions. The predicted average direct N_2O emissions from the Otokia and Eyre soil were similar in magnitude to those measured in recent field experiments (unpublished data).

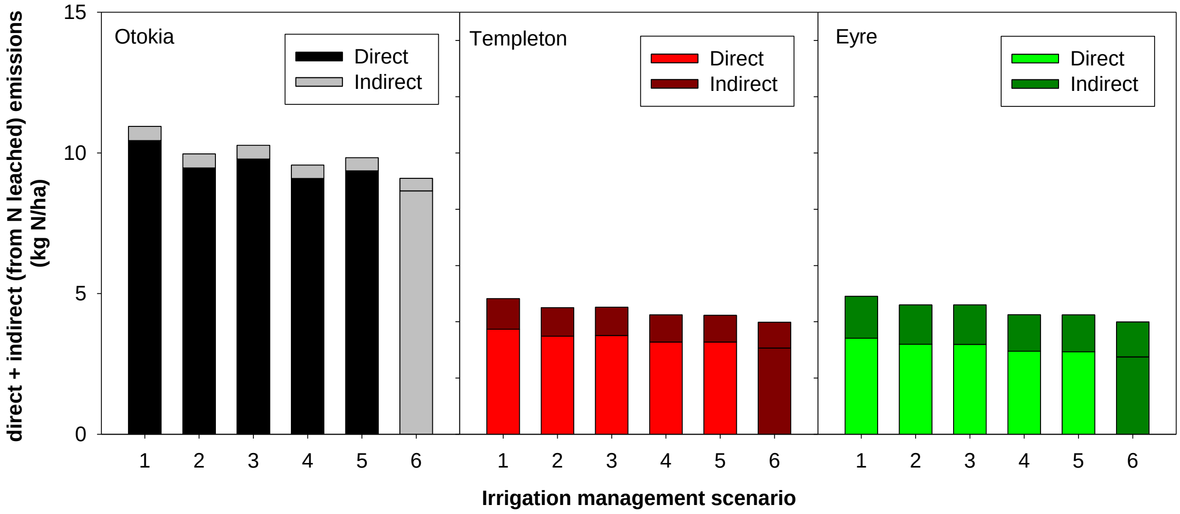

Figure 1. Effects of irrigation triggered at increasing soil water deficits (scenarios 1 to 6) on estimated total direct and indirect (from leached N) N_2O emissions from below urine patches applied to three soil types; a) Otokia, b) Templeton and c) Eyre.

Simulated annual NO_3 leaching was strongly affected by soil type, rainfall regime, irrigation management and leaching depth. Greatest annual NO_3 leaching losses were predicted from the Eyre soil with the higher Hororata rainfall regime while least were predicted from the Otokia soil with the lower Lincoln rainfall. Irrigation management scenarios also affected leaching. Least was predicted when a larger soil moisture deficit was used to trigger irrigation. Annual leaching estimates from the soils without urine applied were <1 kg N/ha. Simulated summer NO_3 leaching was similarly affected by soil type, rainfall regime, irrigation management and leaching depth (Figure 2).

Nitrate leaching losses were low from the urine applied soils during summer except for the shallow Eyre soil. Leaching from this soil was predicted from all irrigation scenarios and was appreciably more for the higher Hororata rainfall regime, whereas there was no or very low amounts of leaching predicted for the other soils for the Lincoln rainfall and some low amounts predicted for the higher Hororata rainfall regime (Figure 2). This largely reflects the low water storage capacity of the shallow Eyre soil compared to the deeper Templeton and Otokia soils, and that normal summer rainfall is sufficient to regularly exceed the capacity of the shallow soil, particularly if recently irrigated. Therefore, some leaching losses will be unavoidable for these soils. The amounts will vary, greatly dependent on the rainfall and irrigation amounts and timing.

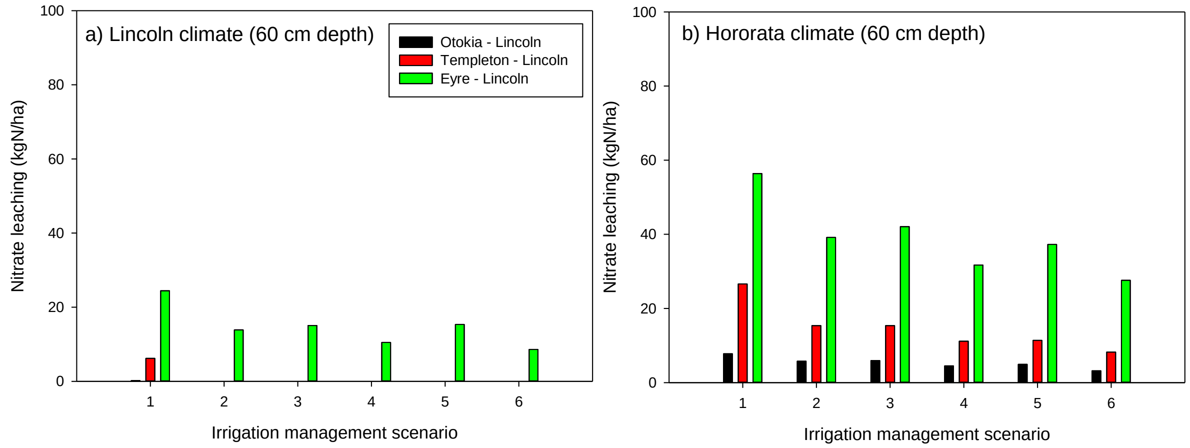

Figure 2. Effects of irrigation triggered at increasing soil water deficits (scenarios 1 to 6) on estimated mean summer nitrate leaching below urine patches from three soil types. Leaching was simulated by the APSIM model from 60 cm below a urine patch under two rainfall regimes: a) Lincoln and b) Hororata. Urine was applied at 600 kg N/ha.

Urine was the most important factor in the variation of pasture production accounting for over 80% of the variance. Irrigation management accounted for < 2% of the total variance. Except for the Eyre soil at large soil moisture deficits (simulating irrigation events of 50 mm; scenario 6) there was little evidence that pasture production was impacted by our soil moisture trigger deficits (Figure 3). This was similarly observed from field experiments (unpublished data).

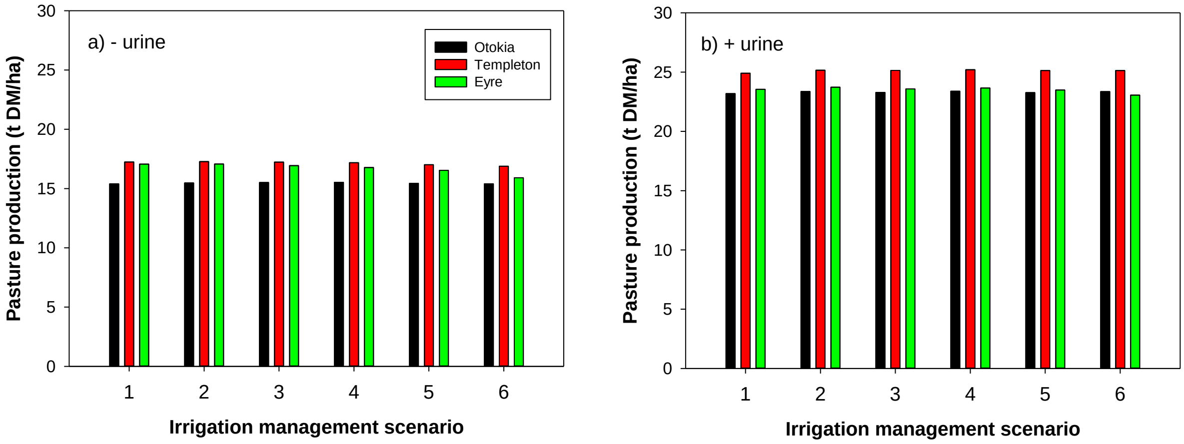

Figure 3. Effects of irrigation triggered at increasing soil water deficits (scenarios 1 to 6) on estimated mean annual pasture dry matter production estimated by the APSIM model from a) pasture with no urine applied and b) urine patches applied at 600 kg N/ha.

While soil type and urine had greatest effect on the variance of N_2O emissions and NO_3 leaching, the model simulations and supporting field experiments indicate that both N_2O emissions and NO_3 leaching can be reduced by irrigating less frequently and maintaining soil water deficits, and based on our simulations this can be achieved without penalising production.

Concluding remarks

Our simulations highlight the challenges for managing irrigation on highly permeable shallow stony soils with low water holding capacity to minimise leaching.

Our use of APSIM simulations has enabled us to investigate how a range of factors important to managing irrigation are likely to affect environmental losses. It has enabled us to run a large number of simulations way beyond our experimental capacity. We have confidence in our findings as they are supported by field measurements and from previous modelling. A note of caution, simulation modelling is not a substitute for field measurements. More experimental studies are required to measure N_2O emissions and NO_3 leaching from irrigated soils. These will help provide further confidence in the simulation modelling.

We recommend that farmers should irrigate at frequencies and amounts that maintain relatively large soil moisture deficits after irrigation to reduce the likelihood of NO_3 leaching losses and N_2O emissions. This increases the opportunity to capture rainfall thereby also reducing potential irrigation and labour costs.

Acknowledgments

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