Cichota, C.; Kelliher, F.M.; Thomas, S.M.; Clemens, G.; Fraser, P.M.; Carrick, S. 2016. Effects of irrigation intensity on the preferential transport of solutes in a stony soil. In: *Integrated nutrient and water management for sustainable farming*. (Eds L.D. Currie and R.Singh). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 6 pages.

EFFECTS OF IRRIGATION INTENSITY ON THE PREFERENTIAL TRANSPORT OF SOLUTES IN A STONY SOIL

Rogerio Cichota[A], **Francis M. Kelliher**[A], **Steve M. Thomas**[B], **Gina Clemens**[B], **Patricia M. Fraser**[B], **Sam Carrick**[C]

[A]*AgResearch, Lincoln Research Centre, Lincoln, New Zealand*
[B]*Plant & Food Research -Lincoln, New Zealand*
[C]*Landcare Research, Lincoln, New Zealand*

Abstract

The use of irrigation has been increasing in New Zealand over the past 20 years; linked to the intensification of farming systems and particularly to the expansion of dairy farming. Most of the irrigated land is located in the South Island, the Canterbury region representing about 60% of the total area. The predominant irrigation system is the centre-pivot, considered an effective method for applying water uniformly. However, the instantaneous intensity of application varies considerably along its length, and by the end of the irrigation line it is far greater than that of typical rainfall. When irrigation intensity exceeds the soil infiltration capacity, water is likely to flow preferentially down cracks and large pores. If this occurs, the transport of solutes through the soil will involve only a fraction of pore space, increasing the rate of leaching. Determining this fraction is, therefore, crucial to evaluate the risk of leaching losses. Stony soils, considered vulnerable to nutrient leaching losses, are common in Canterbury and are present where most of the irrigation expansion is occurring.

To evaluate whether irrigation intensity has an effect on preferential solute flow in a stony soil, an experiment was performed at Lincoln using 12 steel-encased lysimeters containing a Lismore Stony Silt Loam soil under two irrigation intensities, 5 and 20 mm/h. Drainage was collected at regular intervals and the concentration in the leachate of non-reactive tracers, bromide and chloride, was determined. The Burns' equation was then fitted to these data, to estimate the fraction of the soil's water involved in solute transport. The results from the chloride leaching data indicate that irrigation intensity affects preferential solute transport and an exponential function can be used to describe this relationship. The data from bromide leaching suggest that antecedent soil moisture may also be important. Implications for management and further studies of nutrient leaching are discussed.

Introduction

The area of irrigated land in New Zealand has been increasing, especially linked to intensive land use, such as dairy farming. Irrigation is mostly concentrated in the South Island, with Canterbury region representing approximately 60% of the irrigated land area, where it is expanding fast on areas with stony soils. Such soils are considered vulnerable to nutrient leaching losses and are likely to exhibit preferential flow (Carrick et al. 2013). Information about the potential impacts of irrigation on such soils is scarce and greatly needed as there are increasing concerns on potential water contamination due to nutrient leaching losses.

Centre-pivot systems are the most popular irrigation system as they can be quite efficient to deliver irrigation water. However, the instantaneous intensity of application varies considerably along its length, with intensities of about 100 mm/h for the sprinklers 1000 m away from the centre in a system applying 5 mm/day (INZ 2007; Powers 2012). High precipitation intensities are linked to the occurrence of preferential water flow in soils (Clothier et al. 2008; Beven & Germann 2013) and are likely to greatly elevate the risk of leaching losses.

The term preferential flow is used to describe the effects of non-uniform flow of water through the soil (Clothier et al. 2008; Beven & Germann 2013). When preferential flow occurs part of the soil is not involved in the transport of water or solutes, momentarily reducing the storage capacity and increasing the flow rate, and thus enhancing the likelihood of leaching of surface applied solutes. Evidence for preferential flow has been shown for some soils of the Canterbury region (Toor et al. 2005; Carrick et al. 2014; McLeod et al. 2014) and indicates that stony soils deserve particular attention.

This study aimed to investigate whether irrigation intensity has an effect on preferential solute transport in a typical stony soil of the Canterbury region. Data was gathered from an experiment performed in large lysimeters under different irrigation regimes where a non-reactive tracer was applied on the soil surface. The Burns' equation was fitted to the measured data to infer the fraction of soil water that takes part in the solute transport at different irrigation intensities. This approach was then used to describe the potential risk of leaching losses under a centre-pivot irrigation system.

Material and methods

Experimental setup

The experiment was conducted under a rain-out shelter in December 2014 at the lysimeter facility of Plant and Food Research at Lincoln, NZ. Twelve lysimeters, 500 mm in diameter and 700 mm in length, were collected from a grazing livestock farm following the procedure described by Cameron et al. (1992). The soil was a Lismore Stony Silt Loam (Typic Dystrustept), with total porosity averaging 57% (fine earth fraction) and stone content varying between 17% in the surface to 64% at the base of the lysimeters. The mixed sward in the lysimeters, dominated by ryegrass, was not actively growing as the soil was near wilting point at the beginning of the experiment.

The experiment consisted of two irrigation treatments, with application intensities of 5 mm/h and 20 mm/h, kept constant during the experiment. The irrigation lasted until the equivalent of approximately three pore volumes of leachate was collected. All lysimeters received an application of bromide (as KBr, at a rate equivalent to 50 kg/ha) at the start of the experiment and chloride (as KCl, at a rate equivalent to 400 kg/ha) after approximately one water-filled pore volume had been leached. Leachate was collected at regular intervals, stored at 4^{o}C, and subsequently analysed using ion exchange chromatography.

Modelling approach

The Burns' equation, following the approach presented by Scotter et al. (1993), was used to describe the leaching series of each tracer in each irrigation treatment. In this approach, the proportion, X, of a solute leached below a given depth, z (mm), is given as a function of cumulative drainage, I (mm):

$$X = \exp\left(\frac{-z\theta_{FC} f_t}{I}\right)$$

where θ_{FC} (m^3/m^3) is the soil water content at field capacity, and f_t represents the fraction of water that effectively takes part in the solute transport. An exponential function was then used to describe the relationship between f_t and the irrigation intensity, J_R (mm/h):

$$f_t = 1 + m[\exp(bJ_R) - 1]$$

where m and b are fitting parameters. It was assumed that f_t should be equal to one as irrigation intensity approaches zero, that is, the whole soil water takes part in the solute transport.

The two functions above were used to infer the value of f_t as function of the irrigation intensity, as it varies across the length of a centre-pivot, and subsequently to estimate the potential risk of solute leaching losses for different sizes of this irrigation system.

Results and Discussion

The results from the leaching of both tracers provided strong evidence for the presence of preferential solute transport in the Lismore stony soil, and are in agreement with other studies with stony soils in New Zealand (Carrick et al. 2014; McLeod et al. 2014). Bromide was applied to very dry soil and the interpretation of its results involve considering antecedent soil moisture. Therefore, in this paper we concentrate mainly the results for chloride.

The Burns' equation described the experimental data very well (Figure **1**) and, following the interpretation of Scotter et al. (1993), it was used to characterise the fraction of soil water (f_t) that takes part on the transport of solute. This fraction is inversely related to extent of preferential flow in the soil. The use of Burns' approach has advantages: it is simpler than most models, it requires only basic soil properties and has only one fitting parameter (f_t). Based on the estimated values of f_t, irrigation intensity was found to have a significant effect on preferential solute transport ($P < 0.05$). The mean value of f_t was reduced from 0.85 for 5 mm/h to 0.58 for 20 mm/h. Such values are in general agreement with estimates for other similarly stony New Zealand soils (Pang et al. 2008; McLeod et al. 2014). A smaller value for f_t means faster movement of water and solute transport, therefore representing higher risk of leaching losses.

With the assumption that the fraction of soil water that takes part on solute transport is equal to one as precipitation intensity approaches zero, an exponential function was found reasonable for describing the relationship between irrigation intensity and f_t. This function suggests that f_t decreases as the irrigation intensity increases, and it reaches a plateau beyond approximately 50 mm/h, with an asymptote of 0.35. This relationship can be employed to estimate the likely values of f_t along the length of a centre pivot system.

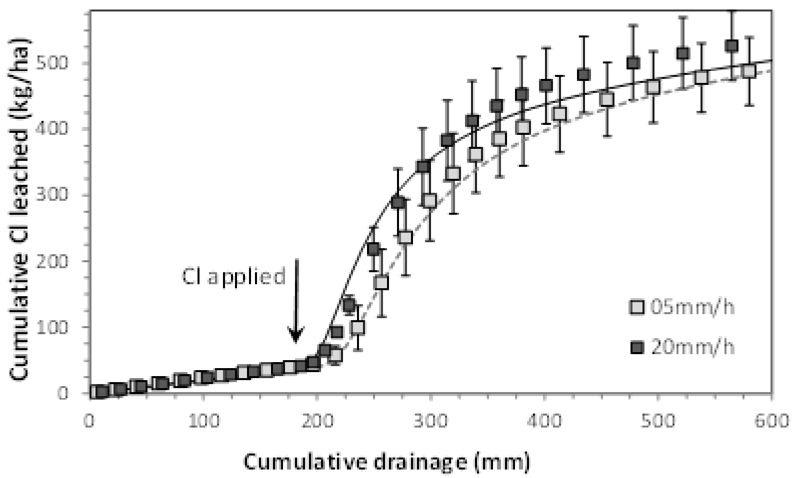

Figure 1. Measured (squares) and modelled (lines) average cumulative chloride leached from lysimeters irrigated with 5 mm/h or 20 mm/h. Whiskers represent one standard deviation

Centre pivots have variable application intensities along their length in order to compensate for the greater flow from of nozzles away from the pivot (Figure **2**). Considering the results of our study, lower values of f_t can be expected with increasing distance from the centre of the pivot and thus will induce a higher risk of leaching loss. Moreover, the area irrigated by each nozzle is much larger away from the centre (Figure **2**). The potential risk for N leaching, i.e. the fraction of solute leached below a given depth, as function of centre pivot length can thus be estimated by combining the results from Burns' equation and the area irrigated (Figure **3**).

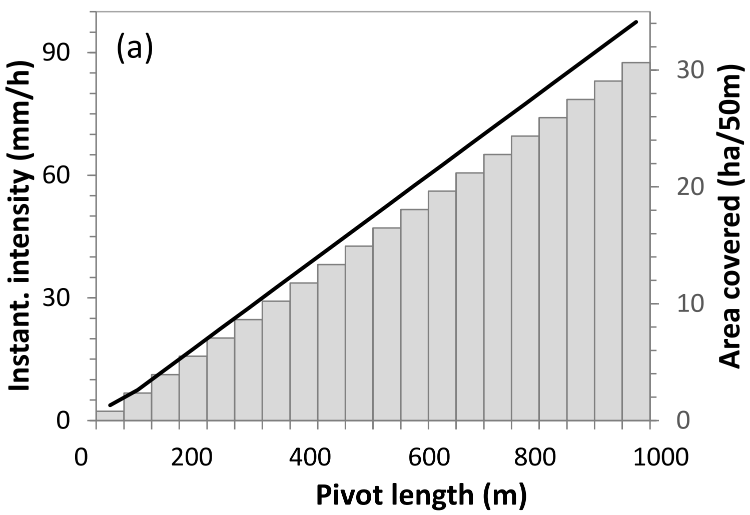

Figure 2. Instantaneous irrigation intensity and area irrigated as function of length for a centre pivot applying an average irrigation of 5.0 mm/day

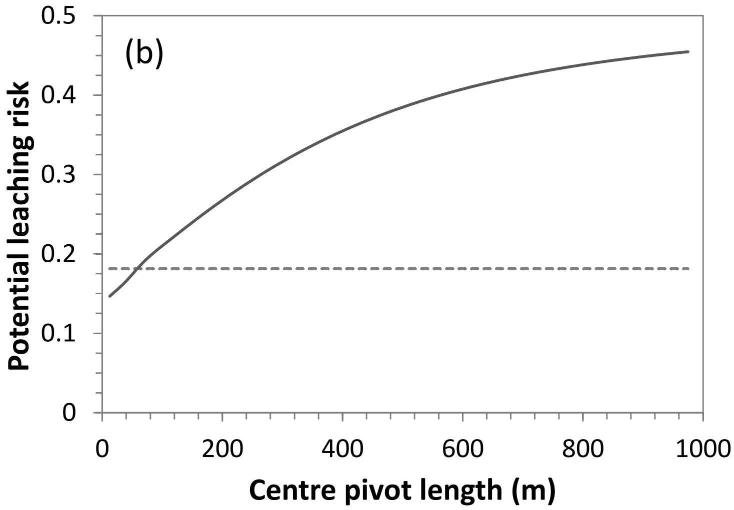

Figure 3. Estimated potential risk for solute leaching as function of length for a centre pivot applying an average irrigation of 5.0 mm/day. Leaching was considered for a depth below 0.5 m for a total drainage of 100 mm. Also shown is the estimated risk of leaching for a constant 5.0 mm/h irrigation (dashed line)

Concluding remarks

The experimental data was successfully described using appropriate solutions of Burns' equation, which was used to quantify the fraction of the soil pore space (f_t) involved in solute transport. The results confirmed that, for the stony soil of this study, there was a significant effect of irrigation intensity on preferential solute flow. The presence of preferential flow is a concern as it suggests that the risk of leaching losses should increase as the instantaneous irrigation intensity increases. An exponential function was used to relate the values of f_t and irrigation intensity and employed to assess the risk of N leaching under irrigation by a centre pivot. More studies are needed to expand the data to different soils in order to better understand this relationship. This approach could be used to aid the design and management of irrigation systems.

Acknowledgements

This work was conducted under the Land Use Change and Intensification programme of The New Zealand Institute for Plant & Food Research Limited

References

Beven K, Germann P 2013. Macropores and water flow in soils revisited. Water Resources Research 49(6): 3071-3092.

Cameron KC, Smith NP, McLay CDA, Fraser PM, McPherson RJ, Harrison DF, Harbottle P 1992. Lysimeters without edge flow: an improved design and sampling procedure. Soil Science Society of America Journal 56(5): 1625-1628.

Carrick S, Cavanagh J, Scott J, McLeod M 2014. Understanding phosphorus, nitrogen, and cadmium transfer through a young stony soil. In: Currie LD, Christensen CL ed. Nutrient management for the farm, catchment and community. Palmerston North, New Zealand, Fertiliser and Lime Research Centre. Pp. 1-11.

Carrick S, Palmer D, Webb TH, Scott J, Lilburne L 2013. Stony soils are a major challenge for nutrient management under irrigation development. In: Currie LD, Christensen CL ed. Accurate and efficient use of nutrients on farms. Palmerston North, New Zealand, Fertiliser and Lime Research Centre. Pp. 1-8.

Clothier BE, Green SR, Deurer M 2008. Preferential flow and transport in soil: Progress and prognosis. European Journal of Soil Science 59(1): 2-13.

INZ 2007. Irrigation code of practice and irrigation design standards. 73 p.

McLeod M, Aislabie J, McGill A, Rhodes P, Carrick S 2014. Leaching of Escherichia coli from stony soils after effluent application. Journal of Environmental Quality 43(2).

Pang L, McLeod M, Aislabie J, Šimůnek J, Close M, Hector R 2008. Modeling transport of microbes in ten undisturbed soils under effluent irrigation. Vadose Zone Journal 7(1): 97-111.

Powers JW 2012. Defining practical limits for centre-pivot length and irrigation management on Lismore soils. Masters Thesis, Lincoln University, Christchurch, New Zealand. 115 p.

Scotter DR, White RE, Dyson JS 1993. The Burns leaching equation. Journal of Soil Science 44(1): 25-33.

Toor GS, Condron LM, Cade-Menun BJ, Di HJ, Cameron KC 2005. Preferential phosphorus leaching from an irrigated grassland soil. European Journal of Soil Science 56(2): 155-168.