Does irrigation prevent phosphorus and sediment loss via wind erosion and benefit surface water quality?

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Abstract

The Mackenzie Basin of New Zealand contains many highly valued and pristine phosphorus (P)-limited lakes. There is a proposal to increase the area of intensive dairying and irrigating pasture in the region. It is accepted that intensive dairying and irrigation of pasture increases P lost by runoff compared to dryland, but in the wind erosion prone Mackenzie Basin, many have hypothesized that irrigation may decrease Aeolian losses and overall, counter any increased losses by runoff. An 18 month study was conducted to determine if wind erosion of P and sediment from sheep-grazed irrigated pasture was less than from dryland. Concentrations and loads of P and sediment were greatest near the soil surface due to saltation of particles, where more P but less sediment was lost from irrigated pasture, but no differences were noted above 1 m. Loads of P and sediment at 5 m, likely to travel the farthest, were low (about 0.058 kg P/ha and 70 kg sediment/ha) and generated mostly in summer when foehn winds coupled with low soil moisture yielded the greatest wind erosion. An example calculation for Lake Tekapo estimated inputs of P to the lake by deposition were small (< 11%) compared to that in the lake or from fluvial or lacustrine sources. The data refutes the hypothesis that irrigated pasture compared to dryland would decrease P loads to the lakes and benefit water quality, but suggests that irrigation of pasture may be beneficial to prevent soil loss by wind erosion.

Key Words

Deposition, water quality, foehn winds, dryland

Introduction

Wind erosion is recognised as an important mechanism for the loss of topsoil and entrained nutrients, including P (Larney *et al.* 1998). Using Cs^{137} techniques, Basher and Webb (1997) measured a loss of 2.2 cm of topsoil between 1953 and 1992 from the Mackenzie Basin in the central South Island of New Zealand. The basin is thought to be prone to wind erosion due to a combination of: sandy soils, often low in organic carbon; frost heave in winter; strong winds and soil moisture deficits in summer; infestations of rabbits leading to bare ground; and treading damage by grazing sheep and cattle (Basher and Webb 1997; Cuff 2001; Floate *et al.* 1994). A recent scoping study by Brown and Harris (2005) looked at the social, economic and environmental impact of irrigating land. While economic and social benefits were evident, potential environmental impact on the Basin's nationally treasured rivers and lakes by nutrients have thus far precluded development. However, Brown and Harris (2005) also note that one spill-over benefit of irrigation is decreased soil loss, via wind erosion, due to better ground cover. Since short-range atmospheric transport has been shown to be a source of P entering oligotrophic lakes (Cole *et al.* 1990), the potential decrease in erosion has also been used as a hypothesis by interested parties that irrigation will not affect water quality. However, no data exists to confirm this. This paper examines wind erosion and deposition rates of P within sheep-grazed irrigated pasture and dryland areas to test this hypothesis.

Methods

Study site

The study sites were located within 1 km of one another at an elevation of 630-680 m above sea level and within a 20 km radius of Lake Tekapo in the upper Waitaki catchment of the Mackenzie Basin. Landuse at the study sites was either dryland pasture (annual rainfall ranged 440-600 mm) or irrigated pasture with 300 mm of additional water supplied via flood irrigation between October and May (provided sufficient water was available for irrigation). Soil at both study sites was mapped as an acidic-weathered Orthic Recent (New Zealand soil classification) Mackenzie sandy loam by Webb (1992). They are usually shallow (commonly < 50 cm deep) and typically have, in the 0-12 cm depth of topsoil, little water holding capacity (~21% v/v), low organic C (~24 g/kg) and N (~1.7 g/kg), and a bulk density of *c.* 0.96 g/cm^3.

Management of the dryland site involved extensive grazing by sheep (1-2 stock units [su]/ha), with P and S applied sparingly every 2-3 years. In contrast, the irrigated sheep site supported about 17 su/ha, and in addition to summer applications of 20 kg P/ha and 30 kg S/ha, up to about 150 kg N/ha is used to boost production during the relatively short growing season.

Sample collection and analyses

Trap units (4) were made according to the design of Li *et al*. (2004) and installed in the middle of each site with at least 1 km in any direction before landuse changed. Trap units collected windblown material at 1 cm above the soil surface, (termed "ground") and airborne dust deposition at 0.5, 1, 2, and 5 m above the soil surface. At each level, traps had duplicate containers (3 L volume and 200 cm^2 surface area) that were open to collect dust. Deionised water (2 L) was added to each trap to assist dust trapping, the solution collected after 21-days, and another 2 L added. Sampling began in March 2008 and stopped in October 2009. Weather stations were installed at the top of each unit to measure wind speed and direction and generate a wind rose (Figure 1).

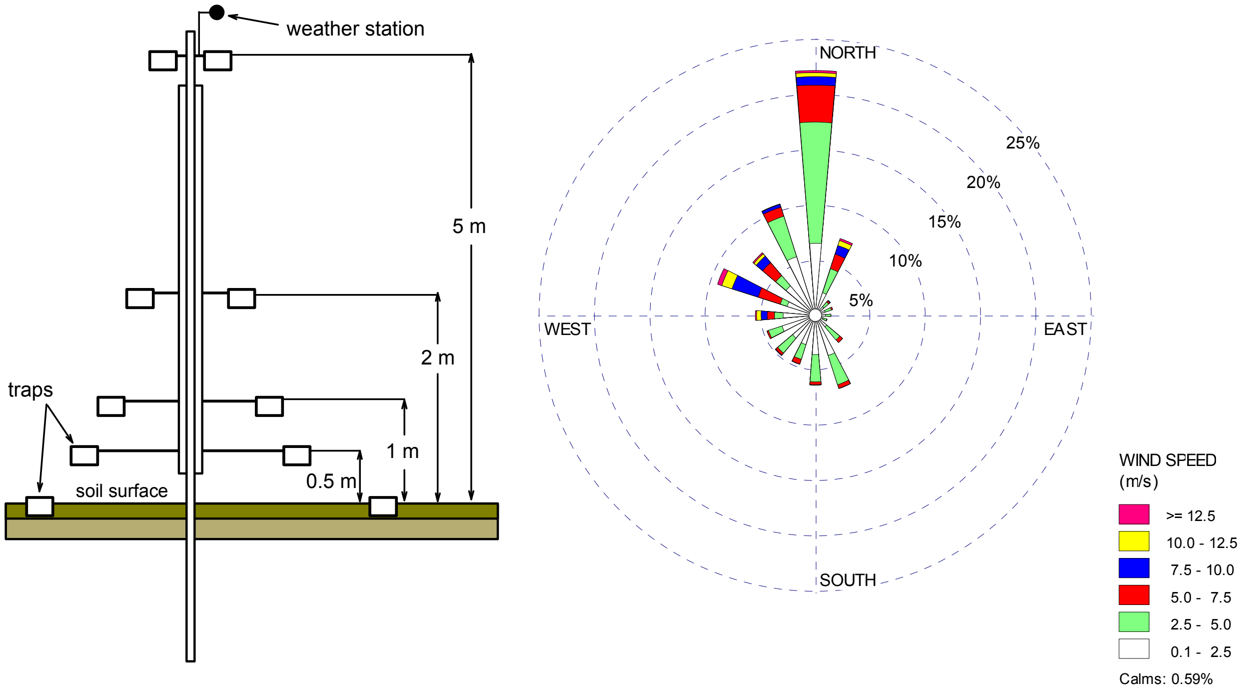

Figure 1. Design of trap units used for the collection of airborne dust (adapted from Li *et al.* 2004) and the resulting wind rose plot for the combined wind speed and direction at both sites during the 18-month study.

Soil samples (0-7.5 cm depth) were taken in November 2008 (mid study) every 2 m along north, south east and west transects away from the trap unit for 10 m and bulked for each trap unit. These samples were air-dried, crushed, sieved (< 2-mm) and analysed for Olsen P. For each water sample, molybdate colorimetry was used to determine total P (hereafter referred to as just P) on a sub-sample that had been first digested with persulphate. Sediment in each sample was determined gravimetrically on a 200-500 mL sub-sample after filtration through a 0.7 µm glass fibre paper.

Results and Discussion

The mean loads of P trapped at up to 1 m above the soil surface were greater for irrigated pasture than for dryland (Table 1). This contrasted with the load of sediment which was greater for dryland than sediment (Table 1). McDowell and Sharpley (2009) found that loads of P tended to increase with sediment deposition, but this was for soils of similar P concentration. In the present study, soil Olsen P concentration of the irrigated pasture < 10 m away from the traps was about 4 times (31 mg Olsen P/L) greater than for dryland. It would appear that the P concentration, and not mass of sediment, controlled the P trapped.

With increasing height, the load of P and sediment tended to decrease (e.g., $\text{P load}_{\text{irrigated}} = 1.22 \times \text{height}^{-0.6}$; R^2=0.98, P< 0.01; Table 1). However, while at 5 m the load of sediment had decreased by 84-92% compared to the load at 0.5 m, P had decreased by only 40-60% over the same distance (Table 1). This may be explained by the well known decrease in P concentration with increasing particle size (Sharpley 1980) coupled with the decrease in particle size with increasing height established at a site 60 km to the north of the present study by McGowan and Sturman (1997). McGowan and Sturman (1997) attributed most of the difference to a change at about 1 m from particles lifted and deposited within a short distance (saltation) to lighter particles that are lifted and remain suspended in airflow (suspension). About 10% of mean hourly wind speeds at the sites (Figure 1) were above the 7.5 m/s necessary for suspension (McGowan 1997).

Table 1. Mean load of phosphorus and sediment deposited at each height within each landuse during the 10-mo study. The least significant difference at $P<0.05$ is given for the interaction between landuse and height.

Landuse/ constituent	Height (m) Ground	0.5	1.0	2.0	5.0
Phosphorus (kg/ha)					
Dryland	8.00	0.94	0.54	0.61	0.56
Irrigated	21.76	1.49	0.98	0.86	0.60
$LSD_{05} = 0.21$					
Sediment (Mg/ha)					
Dryland	1.45	0.92	0.51	0.08	0.07
Irrigated	0.96	0.42	0.21	0.06	0.07
$LSD_{05} = 0.19$					

During the study, large variations in the concentrations (and loads) of TP and sediment were noted, especially close to the soil surface (Figure 2). Maxima in sediment loads have been attributed to wind erosion, in the absence of precipitation, associated with warm dry and gusty foehn winds from the north-west (McGowan and Ledgard 2005). It would appear that P concentrations and loads follow a similar temporal pattern as sediment. Shoulders either side of the maxima near ground level have been attributed (at least for sediment transport) to the erosion of particles made aerodynamically rough by freeze-thaw cycles in spring and autumn (McGowan 1997).

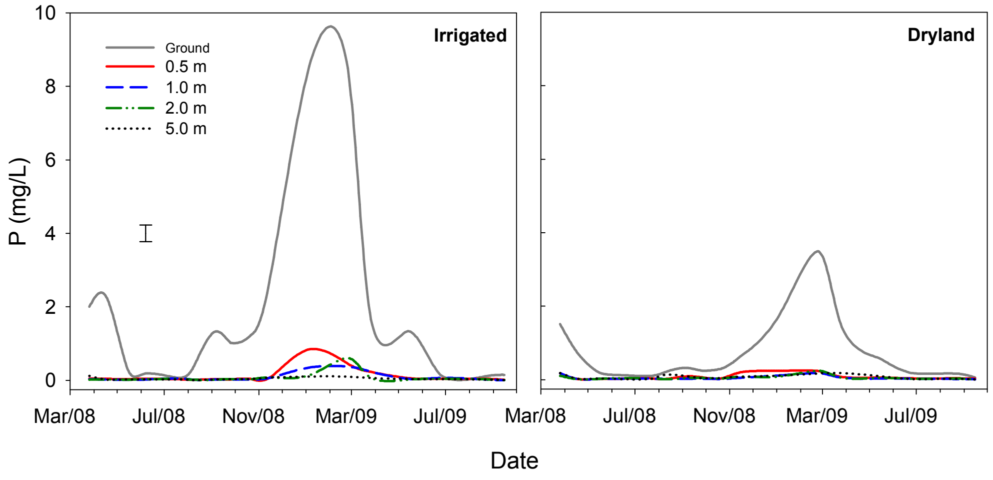

Figure 2. Mean concentration of P for each trap height with time at the irrigated and dryland sites showing seasonal variation. The least significant difference at $P<0.05$ is given for the interaction of landuse and height.

McGowan and Ledgard (2005) calculated the mean soil loss from the study of Basher and Webb (1997) as 6320 kg/ha/yr, but more importantly Basher and Webb (1997) noted that this ranged from zero to a maximum of 8690 kg/ha/yr (as calculated by McGowan and Ledgard 2005). Excluding transport by saltation (likely to be short range), deposition at 2 m and higher was about 60-80 kg/ha (for the 18 months of the study), this agrees well with the 54.3 kg/ha/yr deposition noted at 2 m height by McGowan and Ledgard (2005), but also suggests that mean soil loss is occurring at a rate about 100 times greater than deposition.

Significance for surface water quality

Cole *et al.* (1990) demonstrated that the load of sediment deposited on the surface of Mirror Lake (New Hampshire) had reached a steady state from 25 m onwards that was about one fifth of that deposited near the shore. This may enrich water near the shore with P and sediment due to saltation, but is a moot point given the small proportion of lake shore compared to the surface area of the Mackenzie Basin's lakes. Deposition has been voiced by locals as a significant source of P into the Basin's lakes and therefore an important factor in surface water quality. However, an example calculation shows this not to be true. Lake Tekapo, the closest to the sampling sites has a surface area 9750 ha, a mean volume of 6834×10^6 m^3, and P concentration of 4.7

mg/m^3 (unpublished NIWA data). This yields a load of 32119 kg P in the lake at any one time. In contrast, deposition of 0.38 kg P/ha/yr (annualised from deposition at 5 m height), equates to 3705 kg P/ha/yr deposited. Although comparing well to the <1% of annual stream loads within a mixed landuse catchment in the northeast United States (McDowell and Sharpley 2009), annual deposition to Lake Tekapo would likely account for a maximum of 11% of P in the lake with at least 89% originating from fluvial or lacustrine sources.

Conclusion

The main feature of this work is that when considering all heights, irrigation to support additional pasture growth decreases the wind erosion of sediment compared to dryland, but not P due to greater topsoil P concentrations in the irrigated pasture. Movement of P and sediment increases closer to the soil surface due to saltation of particles, but is unlikely to travel far. Wind erosion, suspending particles > 2 m above the soil surface, which travel further and may have off-site impacts (e.g. affect surface water quality), was found to be similar between landuses. In one example, deposition at 5 m was estimated to be a minor contributor to P loads in Lake Tekapo. This data refutes the hypothesis that increasing land in irrigated pasture compared to dryland pasture would decrease P loads and benefit surface water quality. However, this does not preclude the benefits to decreasing soil erosion by increasing plant cover.

Acknowledgements

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