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Phosphorus and nitrogen in soil, plants, and overland flow from sheep-grazed pastures fertilized with different rates of superphosphate

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Abstract

Eutrophication of waterways through delivery of phosphorus (P) and nitrogen (N) from farmland is a problem in many countries. Loss of nutrients from grazed grassland via overland flow is well demonstrated, but the sources of these nutrients and the processes controlling their mobilization into water are not well understood. Much of the nutrient loss in overland flow from grazed pastures may be due to generally increased fertility of the soil–plant system (i.e. background or 'systematic' nutrient loss) rather than to immediate loss after fertilizer application [Nash, D., Clemow, L., Hannah, M., Barlow, K., Gangaiya, P., 2005. Modelling phosphorus exports from rain-fed and irrigated pastures in southern Australia. Aust. J. Soil Res. 43, 745–755]. The main aim of this study was to measure the effects of long-term (25 years) superphosphate ($Ca(H_2PO_4)_2 + 2CaSO_4$) fertilizer application (0–23 kg/(ha year)) on P and N in soil, plants, and potential background P and N movement in overland flow (generated using a rainfall simulator) from sheep-grazed pastures in southern Australia. Measurements were taken in autumn, under dry soil conditions, and in winter, under wet soil conditions, 12 and 15 months after the last fertilizer applications, respectively. Superphosphate application caused a strong increase in plant P, soil total P, Olsen P, and Colwell P; and a weaker increase in plant N, soil total N, and inorganic N (ammonium and nitrate). Soil P and N were concentrated in the surface 25 mm of soil. Soil water-extractable P, calcium chloride-extractable P, and calcium chloride organic P were in general only poorly associated with fertilizer application. The concentration of P and, to a lesser extent, the concentration of N in overland flow increased with increasing fertilizer application and showed strong seasonal differences (0.06–0.77 mg P/L and 0.6–5.5 mg N/L in autumn; 0.04–0.20 mg P/L and 0.4–1.7 mg N/L in winter). The P in overland flow was predominantly dissolved reactive P in autumn and particulate P in winter. The N in overland flow contained significant proportions of dissolved organic N, dissolved inorganic N (ammonium and nitrate), and particulate N. The concentrations of P and N in overland flow usually exceeded State water quality targets (<0.04 mg P/L and <0.90 mg N/L), suggesting that background losses of nutrients from these pasture systems could contribute to the eutrophication of waterways.

Keywords: Nutrient loss; Temperate grassland; Phosphorus fertilizer; Seasonal effects; Water quality

1. Introduction

Eutrophication of waterways through delivery of phosphorus (P) and nitrogen (N) from farmland is an increasing problem in many countries (Haygarth and Jarvis, 1999). Significant off-site exports of nutrients from grazing land via surface runoff (overland flow) have been demonstrated in numerous studies (Nelson et al., 1996; Haygarth and Jarvis, 1997; Nash et al., 2000). However, the sources of these nutrients and the processes controlling their mobilization into water remain poorly understood, and this is limiting progress towards the development of remedial strategies (Nash et al., 2000).

In the high rainfall (550–750 mm) zone of south western Victoria, Australia, almost half of the monitored waterways

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are in poor condition with respect to P concentration, and more than half are in poor condition with respect to N concentration (Victorian Catchment Management Council, 2002). Dryland grazing, the dominant land use, is believed to be the main source of these nutrients (Glenelg-Hopkins Catchment Management Authority, 2002), although little information is available to verify this assertion. In a study on sheep-grazed hill pastures in this region (Melland, 2003), concentrations of P in overland flow (0.19–1.26 mg P/L) were found to be high when compared with water quality targets, particularly in high fertility situations where fertilizer applications and stocking rates were greatest.

Phosphorus and N concentrations in overland flow increase as a result of P and N fertilizer application (Sharpley and Syers, 1976; McColl and Gibson, 1979; McDowell and Catto, 2005; Nash et al., 2005; Barlow et al., 2007). While this effect can be large, it is often relatively short-lived, disappearing within several weeks or months (Sharpley and Syers, 1976; McDowell et al., 2003a; Nash et al., 2005; Owens and Shipitalo, 2006; Barlow et al., 2007). In a dryland dairy pasture, Nash et al. (2005) found that most of the annual P loss in overland flow was attributable to a general increase in P fertility in the soil–plant system that had occurred over many years of fertilizer application (i.e. the 'systematic' component of nutrient loss) rather than the immediate effects of fertilizer or grazing. Nutrient loss from recently applied fertilizers can be minimized by avoiding application when heavy rain is expected (McDowell et al., 2003a). However, with current knowledge, there is little a land manager can do to reduce losses from 'systematic' or background sources (Nash et al., 2005).

The primary objective of this work was to measure the effects of long-term superphosphate ($Ca(H_2PO_4)_2 + 2CaSO_4$) fertilizer application on P and N in soil, plants, and potential background (systematic) P and N movement in overland flow from sheep pastures in the high rainfall (550–750 mm) zone of southern Australia. Our specific objectives were (1) to measure the effects of different rates of P fertilizer application on accumulation of P in soil and plant pools, (2) to measure the effects of different rates of P fertilizer application on the amount of N contained in soil and plant pools, (3) to measure potential P and N loss in overland flow, (4) to determine the chemical forms of P and N in overland flow, (5) to determine how P and N in overland flow are related to fertilizer history and P and N in soil and plant pools, and (6) to compare the aforementioned relationships in two seasons, autumn and winter. A secondary objective was to investigate soil and plant measurements that may be useful for identifying sites susceptible to P and N loss in overland flow. These measurements included 'agronomic' tests that are commonly used to assess plant nutrient availability, and 'environmental' tests that have been developed in an attempt to relate soil nutrient availability to nutrient losses in water (Pote et al., 1999; McDowell and Condron, 2004; Schroeder et al., 2004).

2. Methods

2.1. Experimental site

The experimental site was near Hamilton, Victoria, Australia (37°49′S, 142°04′E, altitude approximately 205 m), where the average rainfall is 700 mm/year (Fig. 1). The soil, derived from basalt, was classified as a Brown Chromosol (Isbell, 1996) and an Acrisol (FAO, 2006). Five plots (paddocks of approximately 0.6 ha) were selected from a long-term experiment (for more details see Cayley et al., 1999) which had been sown with a mixture of perennial ryegrass (*Lolium perenne* L.), phalaris (*Phalaris aquatica* L.) and subterranean clover (*Trifolium subterraneum* L.) in 1977. Fertilizer treatments of 0, 4, 8, 16 or 23 kg P/ha (as single superphosphate) had been applied annually since 1978. The superphosphate contained 8.8% P, 11% sulphur, and 19% calcium. The pastures were grazed with sheep at 15 dry sheep equivalents/ha (approximately 11 sheep/ha). The experiment was unreplicated.

2.2. Rainfall simulation

The rainfall simulator used in the study is well described elsewhere (Humphry et al., 2002; Sharpley and Kleinman, 2003). It delivered rainfall at an intensity of 70 mm/h (±1 mm, 95% confidence interval for repeat simulations) from a single nozzle (TeeJet® 50 WSQ, Spraying Systems Co., USA), positioned 3 m above ground level. Rainfall simulations were conducted twice: in autumn (6 April–12 May 2005), under dry soil conditions, and in winter (24 August–27 September 2005), under wet soil conditions. Two locations were selected in each paddock for overland flow measurements (1–4% slope). At each location, duplicate plots were established by inserting steel frames into the ground (750 mm wide × 2000 mm long and 40 mm above- and below-ground). Overland flow was collected in steel

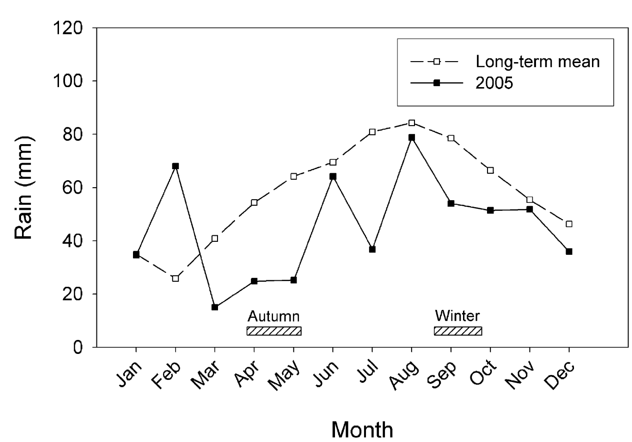

Fig. 1. Monthly rainfall during the experimental period (2005) and the long-term average (1968–1999). Bars indicate timing of autumn and winter rainfall simulations.