The effect of soil available P and P buffering on runoff P concentration from pastures

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Abstract

Phosphorus (P) in surface runoff from agriculture can contribute to the eutrophication of surface waters. A poor ability to predict which soils are particularly susceptible to P loss based on routine soil testing limits our ability to prioritise soils for nutrient management. We postulated that the combination of soil quantity and buffering measures may provide a better method of predicting runoff P concentration. In this study we examined the effect of soil P (Colwell P) and phosphorus buffering on runoff P concentrations for six soils with widely varying phosphorus buffering characteristics. For each soil there were 15 runoff trays encompassing a wide range of soil Colwell P. For each soil, there was a highly significant ($P \leq 0.01$) curvilinear relationship between Colwell P and runoff P. However, these relationships varied widely between soils. A simple model using the parameters Colwell P and phosphorus buffering index explained 80% of the variation in runoff concentration for all soils. The results show that soils with moderate to low P buffering and available P above the agronomic optimum should be a priority for improved P management.

Key Words

Phosphorus, runoff, modelling, buffering, available P.

Introduction

Concentrations of phosphorus (P) in runoff from intensively managed pasture used for dairying are often high. Elevated concentrations of P in surface waters can contribute to increases in algal growth and consequently a decline in the environmental health and amenity of waterways. In studies on one soil, or a narrow range of soil types, soil P is an important determinant of runoff P concentrations in pasture systems (for example Dougherty *et al*. 2008; Robertson and Nash 2008). Yet soil P concentrations poorly predict runoff P concentrations across widely differing soils.

Accurate identification of areas of land of greatest runoff P risk using indices such as recently developed Australian Farm Nutrient Loss Index (FNLI) (Gourley *et al*. 2007) is based upon an understanding of the effect of source factors on runoff P concentrations – soil P being one of these source factors. The poor accuracy of predictions of runoff P concentrations means that areas of risk cannot be reliably identified and consequently the potential benefits arising from implementing particular best management practices (BMPs) and the adverse effects of applying more nutrients are also poorly defined

The objective of the research reported herein was to evaluate the potential of routine measures of soil test P or associated parameters (such as the phosphorus buffering index - PBI) to predict runoff P on a suite of soils with diverse soil P buffering properties.

Methods

Soil collection and runoff tray establishment

Soil (0-10 cm) was collected from 6 sites (5 in NSW and 1 in South Australia), these sites having a wide range of soil P buffering properties as measured by the phosphorus buffering index (PBI) (Burkitt *et al*. 2008). Soil was mixed thoroughly (<5 mm) and rocks and large plant roots removed. For each site, 15 runoff trays were constructed (Anon 2002) into which soil was repacked and sown to pastures. Prior to this repacking, P was added as triple superphosphate at varying rates and mixed thoroughly in a cement mixer to generate a wide range of soil P for each soil type. The amount of P required to be added was estimated using relationships derived from Burkitt *et al*. (2002). The trays were incubated and pastures grown for eight months prior to rainfall simulations.

Table 1. Selected soil properties

Soil ID	Location	Soil type (Isbell 1997)	Total P	Colwell P^a	PBI	OxAl	OxFe
			mg/kg		-	mg/kg	
Camden	NSW	Brown Chromosol	510	39	87	3261	1305
Flaxley	SA	Brown Chromosol	690	10	110	3834	2518
Glenmore	NSW	Red Chromosol	1100	67	180	5143	2891
Moss Vale	NSW	Brown Kurosol	370	10	540	4391	4263
Richmond	NSW	Red Kandosol	220	36	32	974	1089
Robertson	NSW	Red Ferrosol	1200	28	1600	11143	5956

Rainfall simulations

The trays were placed at a slope of 5% then subject to rainfall simulation at 45 mm/hr using a TeeJet 3/8 HH SS 24 WSQ (Spraying Systems Co., Wheaton, IL). Rainfall simulation was continued for 30 minutes after runoff commenced. A single composite runoff sample was collected and immediately filtered <0.45 µm. The filtered samples were analysed for dissolved reactive P using colorimetry (Murphy and Riley 1962). Total P (TP) and total dissolved P (TDP) were determined on un-filtered and filtered samples respectively following digestion using an acidic persulfate procedure and subsequent determination of P using colorimetry (Murphy and Riley 1962).

For each tray, twenty soil (0-1 cm) cores (2 cm diam.) were collected and composited. Soil samples were air–dried at 40°C then ground and passed through a 2 mm sieve to remove stones and plant debris. The samples were then stored at 4°C prior to analysis. Soil Colwell P (Colwell 1963) was determined by shaking soil for 16 h at a soil:solution ratio of 1:100 and subsequent filtration (<0.45 µm) and determination of P using colorimetry (Murphy and Riley 1962).

Results

The additions of P achieved a wide range of Colwell P concentrations. For each soil type there was a consequent large range in runoff P concentrations (30-50 fold), that tended to increase with increasing Colwell P. In general, for a given Colwell P value, the runoff P concentrations appeared to be greater for the lower PBI soils and to decrease as PBI increased. The majority of runoff P was in the form DRP (~75%).

The relationship between Colwell P and runoff DRP are shown in Figure 1. For each of the soils, there was a highly significant ($P < 0.01$) curvilinear (exponential) relationship between Colwell P and DRP. However, these relationships varied widely. The concentration of P in runoff was higher for the soils with lower PBI. For example, the Richmond soil (PBI ~ 30) had very high runoff P concentrations whereas the Robertson soil (PBI~1500) had very low runoff P concentrations. There was no relationship ($P > 0.05$) between Colwell P and DRP for all soils combined. These data clearly show that Colwell P is an extremely poor indicator of runoff P concentrations across a wide range of soil P buffering properties.

We postulated that a model that included soil quantity and buffering terms may provide a better prediction of runoff P concentrations. This was tested using the following model:

$$\ln P = \alpha + (\beta \times \ln \text{Colwell P}) + (\gamma \times \ln PBI) + (\delta \times \ln \text{ColwellP} \times \ln PBI) \quad (1)$$

where the dependent variable 'P' refers to the various forms of runoff P (i.e. DRP, TDP and TP). In the case of all runoff P fractions, the term lnPBI was eliminated after being found not-significant ($P > 0.05$). The curvilinear nature of the relationship is consistent with a decreasing P buffering capacity of the soils as P is added (Barrow *et al.* 1998). This decrease in buffering is confirmed by the exponential relationship between Colwell P and $CaCl_2$-P – an approximation of a quantity-intensity relationship (not shown).

Table 1. Model parameters and estimates. Values in parentheses are standard errors of parameters.

Term	DRP	TDP	TP
Constant	-12.752 (0.679)	-12.215 (0.841)	-9.607 (0.630)
lnColwell P	2.503 (0.123)	2.396 (0.153)	1.016 (0.114)
lnColwellP × LnPBI	-0.130 (0.009)	-0.130 (0.011)	-0.100 (0.008)
r^2	0.84	0.76	0.79
Significance	$P < 0.001$	$P < 0.001$	$P < 0.001$

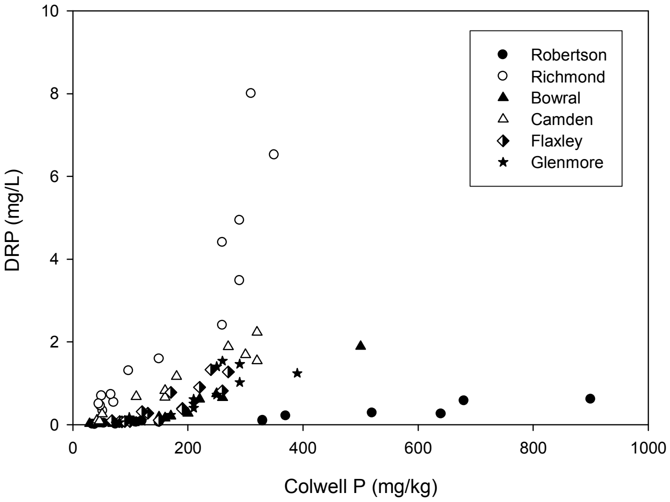

Figure 1. The relationship between Colwell P (0-1cm) and runoff DRP for six soil types ranging in P sorption capacity.

We subsequently used our results, a previously determined relationship between soil P 0-1 cm and 0-10 cm (Murray Hart pers comm.) and rainfall simulation and field scale runoff P concentrations (Dougherty *et al*. 2008) to model the effect of soil PBI and multiples of the agronomic soil P optimum (0-10 cm) on field scale runoff P concentration (Figure 2).

The modelled relationships in Figure 2 show that efforts should be made to constrain available P to the agronomic range to limit excessive concentrations of P in runoff, particularly for soils with PBIs <200. Farmers on soils with high PBIs, such as >1500, will have relatively minor water quality impact from P in runoff but should still actively manage their P inputs to minimise costs associated with wasted nutrient inputs and minimise any slight potential environmental impact.

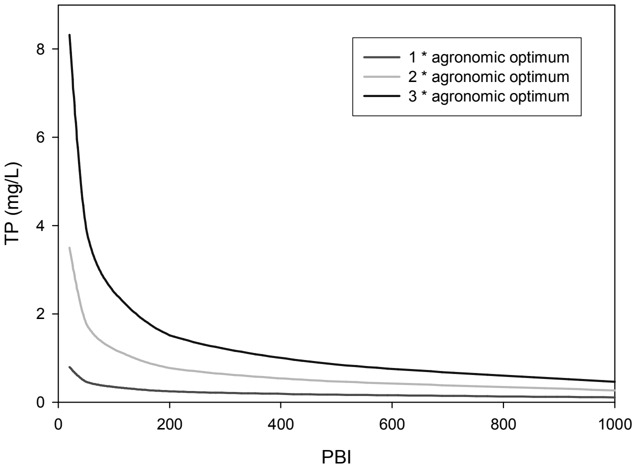

Figure 2. The modelled relationship between PBI (0-10 cm) and runoff TP for multiples of the agronomic optimum.

Conclusion

Routine measures of soil P status such as Colwell P are poor predictors of runoff P concentration. However, combining Colwell P values with information on soil P buffering provides a means of predicting runoff P concentrations. The large range of soil properties represented in this study, the careful preparation of the soils and the shallow sampling depth (0-1 cm) allowed these principles to be demonstrated. Extension to the field, with its intrinsically greater variability is yet to be demonstrated; nonetheless, it is clear that P additions to soils with low P buffering disproportionately increase runoff P concentration; consequently, such sites should be a priority for improved P management to reduce environmental risk.

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