Comparing the risk of phosphorus runoff following single and split phosphorus fertiliser applications in two contrasting catchments using rainfall simulation and Bayesian modeling

Lucy Burkitt[A], Warwick Dougherty[B], Ross Corkrey[A], Shane Broad[C]

[A]Tasmanian Institute of Agricultural Research, University of Tasmania, TAS, Australia, Email Lucy.Burkitt@utas.edu.au
[B]Science and Innovation, Industry and Investment New South Wales, Richmond, NSW, Australia.
[C]Tasmanian Institute of Agricultural Research, University of Tasmania and CSIRO Sustainable Ecosystems, TAS, Australia.

Abstract

In this study we applied a Bayesian modeling approach to investigate the comparative risk of P runoff following single and split P fertilizer applications in two catchments with contrasting rainfall/runoff patterns. Split P fertiliser strategies are commonly used in intensive pasture production in Australia and our results showed that 3 applications of 13.3 kg P/ha resulted in a greater risk of P runoff compared to a single application of 40 kg P/ha, when rainfall simulation experimental data and long term surface runoff data were combined in a Bayesian P risk model. Splitting P fertiliser applications increased the likelihood of a coincidence of fertiliser application and runoff occurring. We found that the overall risk of P runoff is also increased in catchments where the rainfall/runoff pattern is less predictable, compared to catchments where rainfall/runoff is winter dominant. We suggest that land managers apply P fertiliser less frequently and only during periods of the year when surface P runoff risk is low.

Introduction

The general increase in soil phosphorus (P) fertility concentrations to optimum or above optimum levels under intensively managed pastures in Australia has contributed to greater adoption of a strategy of split P maintenance applications, (i.e. multiple small applications within a year), which in total are equivalent to the annual maintenance P requirements. Although lower rates of P generally resulted in lower surface runoff P concentration in Australian (Greenhill *et al.* 1983; Austin *et al.* 1996; Dougherty *et al.* 2008), Chinese (Zhang *et al.* 2003) and USA studies (Sharpley 1982), there has been very limited research comparing P losses generated from several smaller applications of P to the same total P rate applied in a single application. This information is essential as lower runoff concentrations associated with multiple smaller applications may be countered by the greater likelihood of runoff occurring soon after one of these applications.

It is important that interactions between P fertiliser rate and timing of runoff are placed in a context which will allow farmers and advisors to make more informed nutrient management decisions. One method of achieving this is to use a Bayesian modelling approach to investigate the key periods in a year when the risk of surface P runoff from a particular P fertiliser strategy is highest. Bayesian risk models can be created using long term surface runoff data from catchments which broadly represent the rainfall/runoff pattern typical for the industry/region in question. Therefore, the objectives of the current study were to a) compare runoff P concentrations under simulated rainfall following 0 kg P/ha, a single application of 40 kg P/ha and 3 applications of 13.3 kg P/ha, and b) use this knowledge to assess the risk of the two different P fertiliser strategies on surface P runoff in two catchments with contrasting rainfall/runoff patterns using a Bayesian risk model.

Methods

Re-packed boxes and surface runoff

A sandy loam, classified as a Oxyaquic Hydrosol (Isbell 1996), with a high P fertility (Olsen P = 49 mg/kg) and low P buffering index (Burkitt *et al.* 2008) of 115 and low oxalate extractable Al concentration of 1193 mg/kg was sampled to a depth of 100 mm. The topsoil (0-20 mm) was collected separately from the subsoil (20-100 mm) and re-packed into 108 plywood boxes (800 mm long, 200 mm wide, 100 mm deep), using a modified method from SERA-17 (2004). Re-packed soil was sown with perennial ryegrass and 3 P fertiliser treatments [as triple superphosphate (21% P, 1% S)] were surface applied to soil once ryegrass had established and soil had equilibrated for a period of 4 months. Treatments included a control (0 kg P/ha), a single application of 40 kg P/ha (applied on day 0) and 40 kg P/ha applied as 3 split applications of 13.3 kg P/ha (applied on days 0, 25 and 50). Treatments were applied immediately after pasture was harvested at day 0, 25 and 50 and the experiment included 3 pasture regrowth cycles (total of 74 days). Surface runoff was generated by applying artificial rainfall (<0.01 mg P/L) to each box on 15 separate days (Figure 1), with boxes inclined at a slope of 5%, and receiving rainfall for 20 minutes after surface runoff began at an intensity of 50 mm/h ± 2 mm. Surface runoff sub-samples were filtered (<0.45 µm) and analysed for dissolved reactive P (DRP) using the molybdenum blue method. Unfiltered samples were analysed for total P (TP) and were analysed using an alkaline persulfate digestion followed by colorimetry.

Long term catchment surface runoff data and Bayesian P runoff model

Long term modeled surface runoff data (1961-2008) from two contrasting catchments (Montagu catchment in far north west Tasmania and Ansons Bay catchment in north east Tasmania) were used to represent 2 contrasting rainfall/runoff patterns, which commonly support intensively managed pastures in Australia. Surface runoff for both catchments were estimated over the period 1960-2008 using modeled outputs from the Australian Water Balance Model (AWBM) (Boughton 2004). Rainfall and evaporation were estimated using catchment averages of an interpolated climate grid from the Australian Bureau of Meteorology SILO. The models were calibrated using river flow records from the Water Information Systems Tasmania and the Rainfall Runoff Library using the Rosenbrock Single start method (Rosenbrock 1960). Bayesian analysis was firstly used to determine the area under the curve (mg P/days/L) from the data in Figure 1, then used to obtain a measure of the annual P runoff risk throughout the year by firstly calculating the probability for every day of the year that the surface flow exceeded the 90th quantile and using this as the probability of P in surface runoff, if the initial runoff occurred on each day of the year (day 1-365) in turn, up to 74 days after initial P application. The maximum P concentration would be the area under the curve from T0 to T74, but this was reduced proportionally based on the probability of surface flow. A posterior distribution is the probability distribution for a parameter given the observed data and prior knowledge, and represents the probabilities of the values that a parameter may take; a posterior mean is simply the mean of the posterior distribution. We compared posterior statistics using a Bayesian test of significance and results were highly significant when $P > 0.95$ and suggestive of a significant difference when $P > 0.90$. We fitted the model using Markov Chain Monte-Carlo simulation by means of JAGS software (Plummer 2009). The model was run for 40,000 iterations and a 50% burn-in was used.

Results and discussion

Data from this study reveal that increases in P concentration with increasing P fertiliser rate are not linear and that higher rates of P fertiliser result in disproportionally higher P concentrations (Figure 1). The first application of 13.3 kg P/ha resulted in TP concentrations (mean of 9.5 mg P/L), which were approximately one fifth of that measured immediately following the application of 40 kg P/ha (mean of 44 mg P/L). These findings are consistent with those reported by Dougherty *et al.* (2008), but contrast with Austin *et al.* (1996) and Greenhill *et al.* (1983) who found a linear relationship between rate of P fertiliser applied and runoff P concentration. The apparent contrast between studies may reflect differences in soil properties as the low P sorbing soil used in the current study may have had insufficient P sorption sites to rapidly sorb the highest rate of P fertiliser applied.

Although the mean area under the curve suggested that a single application of 40 kg P/ha resulted in more P runoff (data not presented), when these data were incorporated into a Bayesian runoff P risk model that considered runoff probability, this finding did not hold. In the case of the Montagu catchment with the more strongly winter dominant runoff pattern, 3 applications of 13.3 kg P/ha significantly increased the risk of surface P runoff in comparison to a single application of 40 kg P/ha (Figure 2). Although the significance was only suggestive ($P > 0.90$), 3 applications of 13.3 kg P/ha were also more risky in terms of P runoff in the Ansons Bay catchment. These findings confirm that although the lower P rates used in the split P treatment resulted in less TP runoff (area under the curve), the greater number of P applications (3 vs 1) increased the risk of exposure of these P applications to surface runoff over an annual rainfall/runoff cycle. This suggests that in a nutrient management scenario, single, annual applications of P fertiliser are likely to result in lower risk of P runoff losses, especially if P fertiliser application can be applied when the chances of surface runoff are less likely (i.e. summer). When the risk of P runoff in the two catchments were compared, it was clear that the more erratic rainfall/runoff pattern typical of the Ansons Bay is inherently more risky in terms of P runoff, compared to winter dominant rainfall/runoff pattern of the Montagu catchment. Although it may be possible to slightly reduce the risk of surface P runoff by adhering to weather forecasts prior to P fertiliser application, there is anecdotal evidence that weather forecasts in catchments which have more erratic rainfall/runoff patterns – such as occurs more frequently as you move up the east coast of Australia, are less reliable, further complicating a manager’s capacity to reduce P runoff risk.

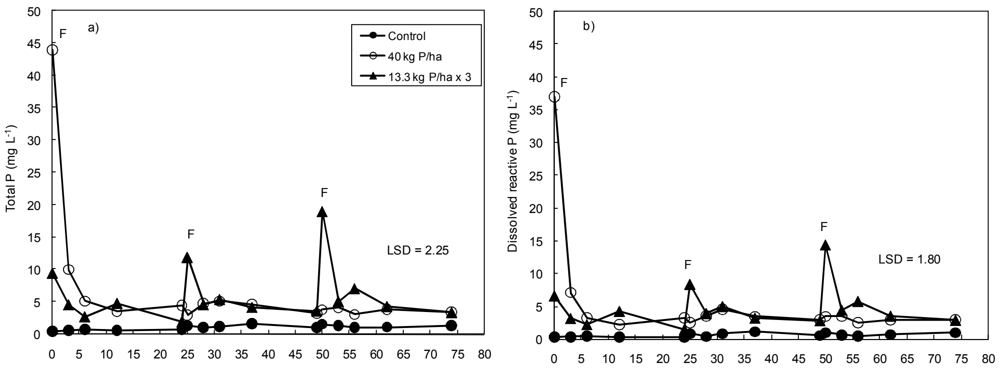

Figure 1. Relationships between a) TP and b) DRP concentration (mean of replicates) in surface runoff and cumulative day for the control, 40 kg P/ha and 3 x 13.3 kg P/ha treatments. LSD represents the least significant difference for cumulative days. Fertiliser applications are indicated by F.

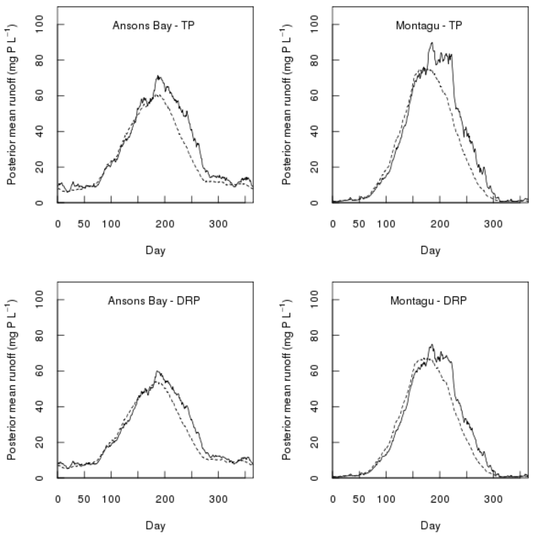

Figure 2. Bayesian posterior mean TP and DRP runoff (mg P/L) for Ansons Bay and Montagu catchments for the single application of 40 kg P/ha (solid line) and 3 applications of 13.3 kg P/ha (dashed line).

Conclusions

Although higher rates of P fertiliser resulted in disproportionally higher runoff P concentrations from individual events, the Bayesian risk modeling used in the current study suggested that splitting P fertiliser applications into 3 applications tended to increase the overall risk of P loss in runoff, in comparison to a single application. We found that the risk of P runoff from these split P fertiliser strategies was even greater in catchments where the rainfall/runoff pattern was less predictable. Land managers should be encouraged to only apply P fertiliser when absolutely necessary to optimise pasture production. If P fertiliser is to be applied, it should be applied either in dry periods of the year, or applied less frequently to minimise runoff risk.

References

Austin N, Prendergast J, Collins M (1996) Phosphorus losses in irrigation runoff from fertilized pasture. *Journal of Environmental Quality* 25, 63-68.

Boughton W (2004) The Australian water balance model. *Environmental Modelling and Software* 19, 943-956.

Burkitt L, Sale P, Gourley C (2008) Soil phosphorus buffering measures should not be adjusted for current phosphorus fertility. *Australian Journal of Soil Research* 46, 676-685.

Dougherty WJ, Nicholls PJ, Milham PJ, Havilah EJ, Lawrie RA (2008) Phosphorus fertilizer and grazing management effects on phosphorus in runoff from dairy pastures. *Journal of Environmental Quality* 37, 417-428.

Greenhill NB, Peverill KI, Douglas LA (1983) Nutrient concentrations in runoff from pasture in Westernport, Victoria. *Australian Journal of Soil Research* 21, 139-145.

Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO Publishing: Melbourne).

Plummer M (2009) Just another Gibbs sampler software. 7/9/2009. (SourceForge Open Source Software).

Rosenbrock HH (1960) An automatic method for finding the greatest or least value of a function. *Computer Journal* 3, 175-184.

SERA-17 (2004) National research project for simulated rainfall-surface runoff studies. http://www.sera17.ext.vt.edu/Documents/National_P_protocol.pdf

Sharpley AN (1982) Prediction of water-extractable phosphorus content of soil following a phosphorus addition. *Journal of Environmental Quality* 11, 166-170.

Zhang H, Cao Z, Wang G, Zhang H, Wong MH (2003) Winter runoff losses of phosphorus from paddy soils in the Taihu Lake Region of South China. *Chemosphere* 52, 1461-1466.