# The mobilisation of soil phosphorus in surface runoff from intensively managed pastures in south-east Australia

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# Abbreviations

| | | |
|---|---|---|
| $CaCl_2$-P | – | molybdate reactive P in 10 mM calcium chloride soil extracts |
| $CaCl_2$-TP | – | total P in 10 mM calcium chloride soil extracts |
| $CaCl_2$-UP | – | un-reactive P in 10 mM calcium chloride soil extracts |
| DOC | – | dissolved organic carbon |
| DRP | – | dissolved (<0.45 μm) molybdate reactive P |
| DUP | – | dissolved (<0.45 μm) un-reactive P (TDP minus DRP) |
| EC | – | electrical conductivity |
| EPC | – | equilibrium P concentration |
| EDI | – | effective depth of interaction |
| ICPAES | – | inductively coupled plasma emission spectroscopy |
| LLD | – | lower limit of detection |
| LSD | – | least significant difference |
| NMR | – | nuclear magnetic resonance |
| OC | – | organic carbon |
| P | – | phosphorus |
| $P_i$ | – | soil inorganic P |
| $P_o$ | – | soil organic P |
| SE | – | standard error |
| TDP | – | total dissolved (<0.45 μm) P |
| TP | – | total soil P |
| * | – | $P<0.05$ (in statistical analysis and interpretation) |
| ** | – | $P<0.01$ (in statistical analysis and interpretation) |
| *** | – | $P<0.001$ (in statistical analysis and interpretation) |

# Abstract

The application of substantial quantities of phosphorus (P) has been required to increase productivity on many Australian soils. Unfortunately, these applications have often resulted in increased concentrations of P in surface runoff that contributes to excessive algal growth in surface waters and consequently a decline in their quality. The concentrations of P in runoff from intensively managed pastures are often high (1-5 mg/L) and typically at least an order of magnitude higher than water quality targets. Although a substantial amount of research has been devoted to the problem of P accumulation and mobilisation in arable systems (in which P is typically mobilised by the action of raindrop impact and subsequently transported in particulate form), there has been substantially less research in intensively managed pasture systems. Consequently, there is a paucity of knowledge concerning the fundamental processes and factors responsible for P in runoff from these systems and a dearth of truly effective remedial strategies.

In this thesis, the accumulation of P in soil under intensively managed pastures used for dairying and the processes responsible for its mobilisation in surface runoff were investigated. This research was undertaken at two research sites in South-east Australia, i.e. Camden in New South Wales and Flaxley in South Australia.

A number of factors relating to scale and hydrology may influence the processes of P mobilisation and its concentration in runoff. A comparison was made of the forms and concentrations of P in runoff between a typical rainfall simulation methodology and large runoff plots. The effect of rainfall intensity on the forms and concentrations of P was also investigated. The concentrations of P in runoff from small-scale, high-intensity rainfall simulations were on average 33% lower than those from large plots (approximating hillslopes) although the processes of mobilisation (as evidenced by runoff P forms) were similar. Increasing rainfall intensity resulted in decreasing P concentrations, but similar forms of P. It was hypothesised that changes in hydrological characteristics (residence time and depth of runoff) were responsible for the differences in the P concentrations. A model of P mobilisation (incorporating hydrological and P-release characteristics) was developed and shown to successfully predict runoff P concentrations under a range of rainfall intensities. These findings and the subsequent model were used in the successful modelling of landscape-

scale nutrient exports based on rainfall simulation data as part of a separate, but complementary project.

There is anecdotal evidence to suggest that Australian soils are relatively ‘leaky’ in terms of P in runoff compared to soils overseas. Consequently, comparisons of the labile soil P characteristics and soil P-runoff P relationships were made between Australian soils and soils of similar fertility from the USA, UK and New Zealand (using both experimental data and data sourced from the literature). It was concluded that Australian soils leak more P than soils of similar fertility in the USA, UK and New Zealand, although it was beyond the scope of the thesis to make more detailed comparisons between Australian and overseas soils.

The accumulation and mobilisation of P in two soils used for intensive pasture production in Australia were investigated. In intensive pasture systems P accumulated in the shallowest zones of the soil and principally as inorganic P. The concentrations of labile P were 3-5 times higher in the top 0.01 m than in the top 0.1 m. Using a simple model, it was estimated that only the top several mm of soil influence runoff P concentrations. The dominant form of P in runoff was shown to be orthophosphate although in low to moderate fertility soils, dissolved organic P can constitute a substantial proportion of the P in runoff. These results confirm the need to reduce the pool of P available for mobilisation in the immediate topsoil in order to reduce runoff P concentrations.

Because P is stratified, it was hypothesised that one method to reduce the pool of P available for mobilisation is to de-stratify the soil (i.e. mix the topsoil). The effect of this technique on runoff P concentrations was investigated in laboratory and rainfall simulation experiments. These experiments revealed that reductions in runoff P concentrations between 45 and 70% can be achieved by de-stratification of soils under permanent pastures. It was hypothesised that the benefits of de-stratification could be maximised using a combination of information relating to catchment hydrology and the spatial distribution of soil P and that this would result in large reductions in P exports with a relatively small degree of inconvenience to land managers. Given the limited opportunities identified in previous research to reduce P exports in runoff, the strategic utilisation of de-stratification is a potentially important option in water quality management for the dairy industry and warrants further investigation.

# Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in a university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis being made available in the University Library.

Components of the research described in this thesis have been published (as listed below). The author acknowledges that copyright of published material contained within this thesis resides with the copyright holders of those works.

**Warwick J Dougherty** ………………………………………….

## Publications arising from this thesis

- **Dougherty WJ**, Fleming NK, Cox JW, Chittleborough DJ (2004) Phosphorus transfer in surface runoff from intensive pasture systems at various scales: A review. *Journal of Environmental Quality* **33**, 1973-1988.

- **Dougherty WJ**, Smernik RJ, Chittleborough DJ (2005) Application of spin counting to the solid-state P-31 NMR analysis of pasture soils with varying phosphorus content. *Soil Science Society of America Journal* **69**, 2058-2070.

- **Dougherty WJ**, Nash DM, Chittleborough DJ, Cox JW, Fleming NK (2006) Stratification, forms and mobility of phosphorus in the topsoil of a Chromosol used for dairying. *Australian Journal of Soil Research* **44**, 277-284.