

**Soil and Landscape Factors Affecting  
Phosphorus Loss from the Fitzgerald  
River Catchment in South West of  
Western Australia**

# **Soil and Landscape Factors Affecting Phosphorus Loss from the Fitzgerald River Catchment in South West of Western Australia**

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## Declaration

I declare that this thesis is my own account of my research and contains as its main content work which has not previously been submitted for a degree at any tertiary education institution.

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Rajesh Sharma

## **Abstract**

Following over 100 years of agriculture and continuous phosphorus (P) fertilizer application in the south west of Western Australia, there is a growing risk of P transport from cropping and pasture land to streams. However, soil and landscape factors affecting the likelihood of P losses and of stream water contamination have not yet been assessed for the South coast region of Western Australia. The present investigation was conducted in the Fitzgerald River catchment located ~ 400 km south east of Perth, to identify risk of P losses from agricultural land to streams, through an understanding of how P is retained within complex landscapes and released via surface and subsurface flow paths. The 104,000 ha catchment is in a moderately dissected landscape (average annual rainfall 450 mm) and discharges into the World Heritage listed Fitzgerald Biosphere. The main use of cleared land in the catchment is broad-scale agriculture, primarily winter grain cropping and pasture for livestock.

The aim of an initial study was to identify the areas with high soil P concentrations and their relationship to factors such as soil type, topography, management (e.g. fertilizer and manure inputs, and uptake by crops or forage) and how variations in soil P concentrations were related to soil physico-chemical properties, P fertilizer management and landscape position. A wide variation in P concentrations was observed across the catchment, but few of the samples exceeded Colwell extractable P levels of 30 mg/kg in the 0-10 cm layer which is regarded as a critical level for crop and pasture productivity. The western area of the catchment, which was cleared earlier (before 1966) than the eastern area had a greater prevalence of loam soils, and higher Colwell-extractable P concentrations (average

22 mg/kg vs. 13 mg P/kg) due to soil type effects and higher P accumulation over time. Risk of P loss from the east and west of the catchment is expected to vary due to textural and topographic differences and P history (P fertilizer input and uptake by crops). The CaCl<sub>2</sub>-extractable P in the catchment was negatively correlated with oxalate extractable Fe (Fe<sub>ox</sub>) in soils. This suggests that P may be transported as particulate P (PP) on loam and clay soils due to sorption of P on oxides surfaces, while on sand soil leaching losses may be more likely. On loam and clay soils, higher sodicity and the dispersive nature of subsoils may increase the risk of both dissolved P (DP) and PP loss due to the effects on hydraulic conductivity of the profile.

Hedley's fractionation scheme was used to quantify P fractions in the order of decreasing lability, viz: resin-P > NaOH-P<sub>i</sub> > NaOH-P<sub>o</sub> > acid-P (H<sub>2</sub>SO<sub>4</sub>-P) > residual-P. Surface soil had higher resin and NaOH-P<sub>i</sub>, which are regarded as water-soluble and readily exchangeable P forms, respectively and expected to contribute to DP in the runoff losses. The residual P was the largest fraction followed by the hydroxide extractable organic-P fraction (NaOH-P<sub>o</sub>): the former was positively correlated (r) with clay content, organic carbon (OC) and pyrophosphate extractable Fe and Al (0.48\*\*, 0.61\*\*, 0.69\*\* and 0.58\*\*, P < 0.01). A relatively higher value of NaOH-P<sub>o</sub> in the subsurface layer and positive correlation with OC (r = 0.45\*\*, P < 0.01) suggests potential mobility of P as soluble organic P in run-off, throughflow and leachate.

Phosphorus sorption and its relationship to soil properties was used to assess the potential P release from the catchment soils. Values of P sorption maxima varied from 1111-3333 mg/kg for surface soils and 1010-2917 mg/kg for subsoils. The P sorption isotherms conformed better to the Freundlich equation than the Langmuir

equation. A highly significant negative correlation between  $\text{CaCl}_2$  extractable P and  $\text{Fe}_{\text{ox}}$  in surface soils ( $r = -0.65^{**}$ ,  $P < 0.01$ ) suggests that P was bound to hydrated Fe oxide surfaces and this may determine the concentration and dynamics of loosely bound P equilibrating with leachates and eroded particulate materials. On the other hand, high surface organic matter and the high proportion of total dissolved P in organically bound form may inhibit P sorption on clays and sesquioxides, which would increase P mobility through leaching or runoff losses.

The relationship between soil P concentration and degree of P stratification in the top 0-10 cm of soils along five toposequences was examined to predict the effect on runoff P losses. The total Colwell-P content of the 0-10 cm layer of soils in the catchment was very low in comparison to other studies on P losses from agricultural soils, but soils showed higher P concentration at 0-1 cm depth compared to 5-10 cm (average 37 mg/kg vs. 19 mg/kg). The higher extractable P concentration in the 0-1 cm layer will create a greater P mobilization risk in surface runoff and leachate than analysis of the 0-10 cm layer might suggest. Assessment of P risk using the 0-10 cm data would still be reliable as P concentration in the 0-1 cm layer was linearly related ( $R^2 = 0.59$ ) with concentration in the 0-10 cm layer. The sampling at varied soil depths will result in different critical P levels for estimating the risk of P enrichment in runoff.

In a glasshouse study with intact soil columns, initial high P concentrations in leachate decreased with leaching events suggesting that macropore flow dominated in initial leaching events changing later to matrix flow. The hydraulic behavior of clay and loam soil below 10 cm depends largely on structure and the type of clay minerals and exchangeable Na. Higher levels of exchangeable Na in the subsoil

might increase dispersion of clay particles resulting in low permeability leading to ponding of surface water or lateral movement of water at the interface of sand A and clay B horizons. Lateral water movements increase the risk of P losses in the form of DP, dissolved organic P (DOP) or PP. The P concentration in all the P forms (DRP, DOP and TDP) increased significantly with P rates of application ( $P < 0.01$ ). The DRP concentration was  $< 2$  mg/l in unfertilized columns but an increase to 11 mg/l was observed with P application at 40 kg P/ha. The higher proportion of DOP relative to DRP and its correlation with TDP indicates that the DOP was the major form of P in leachate. However, the estimation of DOP which was by subtraction of DRP from TDP generally overestimates OP concentration.

The TDP load from unfertilized soil was  $< 0.20$  mg/l in runoff and  $< 2.40$  mg/l in throughflow but increased with P application (20, 40 kg P/ha) for both packed box and field studies. Under field conditions, higher P loss was found with broadcast P application compared to drill placement. The higher load of DOP as a proportion of TDP and its significant relationship with TDP in runoff ( $R^2_{\text{sand}} = 0.81$ ;  $R^2_{\text{clay}} = 0.79$ ) and throughflow ( $R^2_{\text{sand}} = 0.94$ ;  $R^2_{\text{clay}} = 0.98$ ) in field and box studies also suggests DOP was the major form of P loss from soil. Dissolved OP concentration increased significantly with increase in soluble organic carbon (SOC) in soil solution at 5 cm depth ( $P < 0.05$ ). Consequently, the amount of organic matter dissolved in soil solution may influence P sorption and mobility. Relatively higher affinity of soil for sorption of DRP compared to DOP might allow DOP to be more mobile through the profile. Higher PP load in clay soil in throughflow indicates subsurface lateral flow along the interface with the horizon of dispersive clay might be an additional risk factor regarding P mobility in clay soils of the catchment.

The runoff, throughflow and leachate were dominated by eroded particles of clay and colloidal organic materials. However, the soil solution collected through 0.1  $\mu\text{m}$  pores in the Rhizon samplers had a similar dominance of DOP to the  $< 0.45 \mu\text{m}$  filtered samples in runoff and throughflow. This reduces the likelihood that the so-called DOP fraction was mostly P associated with PP in the 0.1 to 0.45  $\mu\text{m}$  size fraction. The composition of DOP in soil solution collected through Rhizon samplers ( $< 0.1 \mu\text{m}$ ) might provide important insights for P mobility since this more effectively excluded PP than in the  $< 0.45 \mu\text{m}$  filtrate used for runoff and throughflow samples. The DOP in soil solution ( $< 0.1 \mu\text{m}$ ) might be associated with fine colloidal compound such as silicates, metallic hydroxides, humic acids, polysaccharides, fulvic acids and proteins. If so, then most, but not all of the DOP fraction would be organically bound. However, this requires verification.

In conclusion, soil P levels across the catchment were never very high when assessed in the 0-10 cm layer, but levels in the 0-1 cm layer were more than twice as high. Overall,  $< 1 \%$  of land area of the upper Fitzgerald River catchment had Colwell-P levels  $> 30 \text{ mg/kg}$  (0-10 cm) and hydrological connection to streams. In addition, another 7 % of land had Colwell-P levels  $> 15 \text{ mg/kg}$ , which appears to be a change point in soils for the release of  $\text{CaCl}_2$  extractable P. These areas, which are predicted to represent critical source areas of the catchment, need careful management. The high proportions of TDP as DOP in runoff, throughflow and soil solution suggest DOP was the major form of P loss from soil. Phosphorus losses from the catchments are also likely in the form of PP in clay and loam soil but leaching losses are more likely in sand. High exchangeable Na in the subsoil of loam and clay soils increases dispersion of clay particles resulting in low permeability of



subsoil and greater lateral P mobility as throughflow at the interface of sand and clay textured horizons.

In general, soils of Fitzgerald River catchment had low soil P, but nevertheless significant risk of P loss at Colwell-P > 15 mg/kg. This study provides baseline information for P loss risks in the wheatbelt of WA. Stream water quality monitoring instruments were installed in the upper Fitzgerald River Catchment at 5 stream locations by CSIRO to measure base line concentrations of P. The measured P concentrations were higher than ANZECC trigger values (> 0.05 mg P/l) for management response over the three-year monitoring period (2005-07). Hence this and many other catchments on the south coast and wheatbelt of south west Western Australia need assessment for P loss risks. Previous emphasis in south west Western Australia on P losses from sandy coastal soils under pasture may need to be reconsidered. In the South coast region, cropping land in the medium rainfall zone may still represent a risk of P loss to waterways and risk to water quality. The present study evaluated the risk of P loss based on soil P forms and their mobility. It suggests greater attention needs to be given to the difference between clay and loam soils with dispersive or non-dispersive sub-soils, and to the composition and mobility of DOP. However, a more complete understanding of P loss risks depends on follow-up studies on hydrological flow and connectivity in the upper Fitzgerald River catchment and similar landscapes of south west Western Australia.

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## Abbreviations and Symbols

|         |   |
|---------|---|
| <       | less than   |
| >       | more than   |
| Al      | aluminum  |
| °C      | degree centigrade   |
| Ca      | calcium   |
| CEC     | cation exchange capacity                                    |
| cm      | centimetre  |
| cmol/kg | centimole of charge per kilogram (Cation exchange capacity) |
| CSA     | critical source area  |
| DAP     | diammonium phosphate  |
| DCB     | dithionite citrate bicarbonate                              |
| DDI     | deionised distilled water                                   |
| DI      | deionised water   |
| DOC     | dissolved organic carbon                                    |
| DOP     | dissolved organic phosphorus                                |
| DP      | dissolved phosphorus  |
| DPS     | degree of phosphorus saturation                             |
| DRP     | dissolved reactive phosphorus                               |
| EC      | electrical conductivity                                     |
| EPC     | equilibrium phosphorus concentration                        |
| Fe      | Iron  |
| FRC     | Fitzgerald River Catchment                                  |
| FRNP    | Fitzgerald river national park                              |
| g       | Gram  |
| h       | Hours   |
| HRA     | hydrological risk areas                                     |
| kg      | Kilogram  |
| m       | Metre   |
| M       | Molar   |
| MBC     | maximum buffer capacity                                     |
| mg/l    | milligram per litre   |

|                |                            |
|----------------|----------------------------|
| Mg             | Magnesium                  |
| mS/cm          | millisiemen per centimetre |
| Na             | Sodium                     |
| NAS            | nutrient accounting system |
| NS             | not significant            |
| OC             | organic carbon             |
| OM             | organic matter             |
| OP             | organic phosphorus         |
| Ox             | Oxalate                    |
| P              | Phosphorus                 |
| PP             | particulate phosphorus     |
| ppm            | parts per million          |
| Pyro           | Pyrophosphate              |
| r              | correlation coefficient    |
| R <sup>2</sup> | regression coefficient     |
| RBD            | randomized block design    |
| rpm            | revolutions per minute     |
| SE             | standard error             |
| SOC            | soluble organic carbon     |
| TP             | total phosphorus           |
| TDP            | total dissolved phosphorus |
| TSS            | total solids               |
| vs             | Versus                     |
| WA             | Western Australia          |

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