



Measurement and treatment of phosphorus and carbon subsoil movement

Project UAD10

Overview

October 1999

J.C.R. Varcoe, D.J. Chittleborough
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CSIRO Land and Water, Adelaide
Technical Report 36/99, October 1999



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EXECUTIVE SUMMARY

Experimental Design

- Paired subcatchments (3-5 ha) on two different soils at the Mt Bold and Myponga Reservoirs were selected and instrumented in 1996.
- Average annual rainfall at both sites is approximately 760 mm.
- Site selection was based on three criteria: degree of texture contrast, texture of A horizon, and structure of B.
- Soils at Myponga were sands over heavy clay and at Mt Bold, loams over light clay.
- Flow was monitored over 2.5 years: 1996 (part), 1997 and 1988.
- Phosphorus was spread at each site at a rate of 15 kg P/ha per year which is typical of local farmer usage.
- In 1998 gypsum was spread (at 15 T/ha) on 2 sites, on 1 subcatchment on each of the 2 soil types.
- Monitoring of flows and sample collection was from subsurface and surface flows.

Key Experimental Findings

- Differences in soil texture and structure of the two soil types resulted in different flow patterns, with total and surface flows greater in the Mt Bold soils.
- Total P losses were in proportion to total flows, with greater losses over both seasons at Mt Bold.
- Timing of fertiliser application is one of the most important factors in controlling total P loss. Least P was lost when applied after peak season flow.
- Gypsum application increased the proportion of particulate P.
- Gypsum causes a rapid reduction in P concentration especially in early season flows.
- Late season flows from the gypsum-amended and unamended soils had very similar P concentrations.
- Total DOC losses were also proportional to flow, however average concentrations were much higher in the Myponga flows confirming that the coarser the texture of the soil the greater the loss of DOC.
- Gypsum significantly reduced DOC concentrations.

OVERVIEW

Introduction

Phosphate is considered immobile in all but very sandy soils. Its presence in relatively high quantities in streams and water storages of southern Australia is attributed to surface soil erosion adjacent to the water course or point of source pollution. However our work on hillslope plots has demonstrated that relatively high fluxes of P as well as high concentrations of dissolved organic carbon (DOC), are moving by flow through the soil profile along the soil/rock interface rather than overland. The aim of this study was to quantify the proportion of P and DOC moving through soils by subsurface flow. Small catchments (3-5 ha in area) were instrumented to measure the amount of P and DOC moving overland and through the major horizons of the soil to bedrock. The effectiveness of a calcium soil amendment to reduce the movement of P and DOC was trialed using gypsum as a Ca source.

Experimental design

The locations of the monitored sites for project UAD10 were based on the following soil criteria: (1) degree of texture contrast, (2) texture of A horizon, and (3) structure of the B horizon. The sites selected, consisted of paired sub-catchments on two different soil types, one at Myponga the other at Mt Bold. The Myponga set of paired sub-catchments was located on a soil with a large texture contrast between A and B horizons viz loamy sand A horizon overlying a heavy clay B horizon, with a sharp boundary between the two. The Mt Bold set of sub-catchments was also on a texture-contrast soil; however the textural differentiation was not as great as Myponga. These soils consisted of silty clay loams overlying medium heavy clays. The clay B horizon at Myponga is commonly sodic and poorly structured, in contrast to the strong angular blocky well structured B horizon at Mt Bold.

The site instrumentation consisted of a surface flow interceptor barrier that channelled all surface flow into a calibrated flume. Surface flow rate was measured by the height of water passing through the flume, with a data logger recording the flow rate at 5 minute intervals. Subsurface flow was monitored through interceptor drains located along the A/B and B/C horizon interfaces in each of the subcatchments. This intercepted flow rate was measured via a tipping bucket installation located further

down slope. Again, this data was recorded at 5 minute intervals by the data logger. Samples were collected via automatic water samplers triggered by the data logger at pre-programmed changes in flow rate. Samples were regularly collected for analysis from the samplers and data downloaded onto a portable computer.

Sample analysis involved filtering of a sub-sample to remove the $>0.45\ \mu\text{m}$ fraction with the filtered portion classified as dissolved. Both dissolved and whole fractions were then analysed for phosphorus (P), dissolved organic carbon (DOC), total carbon (TC) and major cations by inductively coupled plasma emission spectroscopy (ICP), as well as pH and EC. Further selected sub-samples were sent to the CRC for Water Quality and Treatment for analysis of organic C species.

Key Experimental Findings

Phosphorus

Total P losses at Myponga were approximately 1/3 to 1/6 the total P losses at Mt Bold. This was mostly a consequence of negligible surface runoff at the Myponga site compared to Mt Bold. Myponga soils had a high hydraulic conductivity because of the coarse-textured A horizon. In contrast, the Mt Bold topsoils had a much lower surface infiltration rate which lead to a much higher surface runoff. As a consequence, surface runoff was the major pathway of P loss at Mt Bold.

Average total P concentrations for Myponga were very similar in 1997 and 1998. This is a consequence of the very similar rainfalls and total flows during these years. Over the 1998 season average concentrations fell from approximately 0.7 mg/l to 0.3 mg/l. This resulted in total losses of 42 and 28 g/ha of P for Myponga East and West respectively. At the Mt Bold West site total losses in 1998 were approximately 75% of 1997. Again this was related to rainfall distribution. In 1998 the rainfall was slightly lower, but the distribution was more even. This resulted in a lower surface runoff rate (and increased infiltration) making way for reduced P losses. However, at the Mt Bold East site, total P losses in 1998 were 150% of the losses of 1997. This was the consequence of a single runoff event. At both Mt Bold sites, the initial P concentration was approximately 0.9 mg/l. The fall in concentration over time was greater at Mt Bold East (+ gypsum) than Mt Bold West. However, by late in the season,

concentrations of P at both Mt Bold sites were similar at 0.3 mg/l. Total P losses for Mt Bold East and West were approximately 322 g/ha and 124 g/ha, respectively.

At Mt Bold there was very little variation in the form of P over a single storm event. However, significant changes in the form of P were observed over a season: early season flows were significantly enriched in particulate P, (from 30 to 50%); by late season this had fallen to less than 15%. This suggests that the dominant form of particulate P may have been fine fertiliser granules. Over the season, increased retention time allowed more P to dissolve.

Comparison of P losses between seasons indicated that rainfall patterns exert significant control on the forms of P lost. The 1997 data showed that in the Myponga A horizon flow, particulate P was the dominant form whereas 1998 data revealed that dissolved P was dominant. The results of 1997 were unexpected as subsurface water movement would be expected to carry dissolved forms more readily. In such a coarse textured surface horizon it is also difficult to account for the source of mobile colloids to carry this P. It was hypothesised that the source of the particulate material was from dispersion of clays from the sodic B horizon. If this was the case, the cause of the low percentage of particulate P in 1998 and, indeed, the relatively low B horizon flow may also be accounted for by the low permeability of the sodic B horizon combined with the difference in rainfall distribution. The significant falls in April 1998 may have wet up the surface of the B horizon sufficiently to cause dispersion of the soil. These early rainfalls were subsequently followed by an extended dry period that appears to cause a hard-setting layer at the A/B interface that reduced infiltration.

Similarly, at Mt Bold, variations were seen in the forms of P between 1997 and 1998, particularly in the early season. These differences, whereas not as significant as Myponga, are still of interest. The 1997 figures indicate that in early season flow, dissolved P was 40-60% of the total, compared to 80% for 1998. This may be a function of the later application of P in 1998 when it was spread in the wet season. The potential for solubilisation was therefore much higher in 1998 because of the timing of the P application.

Implications of catchment characteristics and hydrology on P management

The results indicate that one of the major implications of catchment hydrology was the timing of P application. Total losses of P in 1998 at Mt Bold were dramatically different for the two catchments. This was primarily a function of the different hydrologic responses of the two catchments during the early to mid wet season. Hydrological data over the 1997 and 1998 seasons indicated that the Mt Bold West site had the greater hydrologic response to early season rainfalls. By mid season, volume of flows in the eastern site began to exceed the western site. In 1998 this transition occurred over the month of June (ie, June flow West > East; July Flow East > West). Bold West had already experienced peak flows when fertiliser was spread (at the end of June) but Bold East flows had not peaked. This led to substantially higher losses of P at Bold East in July, compared to minimal losses of P in Bold West (as peak flow took place prior to P application). This suggests that for best management of P a good understanding of the individual hydrologic characteristic at the subcatchment scale is essential. In some cases this could mean application of fertilisers in mid season if a particular catchment is known to have a peak response early in the season. In other cases, fertiliser could still be applied prior or early in the wet season, if it is known to have peak response later in the season. Results of this work indicate that such differences can occur in two relatively similar subcatchments on very similar soil types. Both soil type and topography interact in subtle ways to influence the flow regime and hence nutrient flux.

Dissolved Organic Carbon

The DOC concentration was considerably greater at Myponga, although given the higher flow volume, more DOC was transported per hectare at Mt Bold. The nature of the DOC was more strongly related to soil interactions than microbial interactions. Throughflow water from the B horizon of both sites contained greater quantities of the more soluble polar organic compounds (amide/amine and alcohol/ether). These compounds are not charged at moderate pH and so are less likely to be adsorbed by electrostatic forces associated with charged clay particles in the B horizon. Overland and A horizon flows at Mt Bold were very similar in the nature of DOC, but flows had a higher amide/amine character than at Myponga. This would be expected for the A

horizon because it has a higher clay component than Myponga. The similarity in A and surface flow is strong evidence for the occurrence of return flow (ie, a process of flow alternating between surface and subsurface flow down the toposequence). There were also lower proportions of carboxylates in the Mt Bold A horizon flow compared to Myponga, a result which is consistent with the higher adsorption capacity, itself a function of silicate and clay and Fe and Al oxide concentration.

Over time, the DOC character appears to be significantly influenced by microbial processes. In general there is a reduction in molecular weight of DOC over time, as a result of microbial breakdown (Kaye Spark pers. com.). The nature of the DOC fluctuated to a greater extent than at Myponga. This is probably a consequence of the fluctuation in the microbial population.

Colloids

Total solids removed per hectare from Myponga (calculated indirectly from turbidity) were much greater than for Mt Bold. The highest turbidity recorded at Mt Bold appeared to coincide with peak flow, a result consistent with the expectation that this is the most erosive period in an event. There appears to be a more rapid reduction in turbidity through the event early in the season compared to late in the season, although this may simply be a consequence of rainfall and flow intensity. Mineralogical analysis indicated the negligible occurrence of minerals in the $<0.2 \mu\text{m}$ fraction. In the $>0.2 \mu\text{m}$ fraction the dominant minerals at all sites were illite and kaolinite, with some smectic occurring at Myponga. The proportions of illite and kaolinite varied between treatments at Mt Bold. The untreated west site contained illite and kaolinite in proportions of approximately 1/3 to 2/3, whereas the gypsum-treated east site was dominated by illite. Gypsum was also evident in the suspension from Bold East. Insufficient flows at Myponga meant that event based fluxes could not be characterised mineralogically.

Evaluation of Gypsum

Phosphorus

The results of this study agree with other international studies that gypsum as a soil amendment is effective in reducing the solubility of P. The effect was most significant

in early season flows when P flux is most significant. The mechanism by which this works is unclear however. X-ray diffraction analysis of the throughflow indicated that at Mt Bold it may have been as a result of two mechanisms. This data indicated the presence of gypsum in suspension. It may be that gypsum acts as a P transporting medium. The results indicated that illite was increased in suspension also in the gypsum-treated site. The greater surface charge that this carries compared to kaolinite suggests that this may account for some of the increase in particulate P. Gypsum was not however successful in reducing total P losses at either site. This may be because no mechanisms at these sites are in place to reduce erosion. Such measures as riparian strips, contour banking etc combined with soil amendment by gypsum, could well be an effective strategy to reduce P movement from soils into streams. Results from this study suggest that in the first season, if all the P moving in particulate form could be arrested by erosion control, reductions of up to 25-40% of total P normally lost in early season flow, could be achieved. Overall this may account for 10 to 20% of total P losses through a season.

Dissolved organic carbon

This study indicated that gypsum, at both sites, significantly reduced the movement of DOC in the early season flows by between 30 and 50%. Previous studies have found that gypsum is effective in flocculating high molecular weight (HMW) DOC. Thus it would appear that gypsum will be most effective in abating DOC movement when applied early in the season, given the transformation of HMW to low molecular weight (LMW) forms over the season.

Other benefits and disadvantages of gypsum

Other proven benefits of gypsum are in increasing the infiltration by improving soil structure of sodic soils. More recent work has shown that gypsum may also be effective in improving soil structure in some low sodic soils. Gypsum is also proving beneficial in ameliorating the detrimental effects of subsoil acidity, ie, Al toxicity and nutrient deficiency (nb, Ca). Gypsum is now becoming a more favourable alternative for this practice than lime because it is more soluble than lime, and as such is able to ameliorate subsoil acidity with minimal topsoil disturbance. Gypsum is also able to resolve these problems directly, not by increasing pH, but by locking up the Al in

insoluble forms (by various mechanisms: ion pairing, *self liming*, precipitation of Al-SO₄ minerals and by salt sorption) and providing Ca to the roots where it is required for root elongation. Detrimental effects of gypsum include elevated levels of soluble salts, potentially to levels which limit plant growth, and some evidence indicates increased leaching of plant nutrient (specifically Mg).