Losses of phosphorus, carbon and other chemicals over four years from dairy pasture in South Australia

Nigel K. Fleming[1] and Jim W. Cox[2]

[1]South Australian Research and Development Institute, PO Box 397, Adelaide, SA 5000. Australia. www.sardi.sa.gov.au Email fleming.nigel@saugov.sa.gov.au
[2]CSIRO, Land and Water, PMB 2 Glen Osmond, SA 5064. www.csiro.au Email jim.cox@csiro.au

Abstract

Overland flow was measured and sampled over four years from two sub-catchments on a dairy farm in the Adelaide Hills, South Australia to quantify and then predict the losses of elements. Relationships were established for the wettest year and compared with those for all four years of data to determine if chemical loss can be accurately predicted with only one years sampling. That is, do the additional years of sampling storm events improve or worsen the prediction of elemental losses?

Sub-catchments were defined by installing exclusion drains on the most elevated parts of the slope and stainless steel barriers at the lower boundary. Flow was measured with flumes, and water was sampled automatically. Twenty chemical fractions were measured in runoff including phosphorus, carbon and nitrate.

Overland flow ranged from 0.4% to 9% of annual rainfall. Chemical loads and fractions in overland flow were examined to determine simple empirical relationships from event and site characteristics. All but five of the chemical fractions could be separated into one of two clear groups, Dissolved or Particulate fractions. The clear separation into these groups is consistent with the majority of chemical fractions moving from pasture by one of only two processes. Simple empirical variables in a multiple regression explained a high proportion of variation in chemical loads in runoff water ($r^2 = 0.96$ for both Dissolved and Particulate group regressions). From the four-year data set the Particulate data was more variable ($r^2 = 0.46$) than the Dissolved group ($r^2 = 0.86$). This was likely due to the particulate material moving in the latter years due to factors such as poorer pasture cover at the start of the winter (runoff) season; hence particulate loads were much more variable. It would appear that the data could be combined reasonably well across years, although with some loss of precision due to variability between years. These findings may have major implications in the sampling and prediction of chemical loads in runoff from agricultural catchments due to the possibility of modelling losses of a wide range of chemicals using simple empirical modelling.

Key Words

Chemicals, runoff, phosphorus, nitrate.

Introduction

Dairying is an intensive grazing industry and in southern Australia is often located on shallow texture-contrast soils (in this case a series of Chromosols to Dermosols down each hillslope). The mechanisms of chemical mobility through texture-contrast soil have been poorly understood until recently (Kirkby *et al.* 1997; Cox *et al.* 2000). The form of chemical moving from pastures is important, as the effectiveness of control measures may depend on the form of chemical.

Studies of chemical runoff from agricultural areas generally estimate values of chemical loss per unit area from large areas of land use types or from whole catchments. These allow comparisons between land use types, but do not show processes by which chemicals travel to waterways (McColl 1979). This information is needed to determine management techniques for controlling or minimising off-site chemical movement. In order to fully ascertain the environmental impact of farming practices we need to be able to predict the losses of a range of chemicals using easily determined landscape, soil and climatic parameters. We measured the pathways and forms of a range of elements in runoff from a grazed dairy pasture over a four-year period, so that processes relevant to chemical movement from dairy farms located on texture-contrast soils could be identified.

Materials and methods

Chemical concentrations and loads in runoff water were measured from 2 sub-catchments at Flaxley Agricultural Centre, Mount Lofty Ranges, SA, from 1996 to 1999. The sites, infrastructure and methods have been reported elsewhere (Fleming and Cox 1998; Fleming *et al*. 2001). Briefly, water samples were collected from grazed dairy pastures by autosamplers throughout storm events on a volume-weighted basis, as directed by flowmeters at sampling points.

Data filling

Chemical loads from unsampled runoff events were estimated from multiple regression equations of chemical load, developed from the data of sampled events. Chemical load (dependent variable) was analysed using a second order regression equation with the following independent variables:

i. slope - 7% West, 13% East. Differences in pasture slope are likely to affect runoff characteristics. Slope also acts as a variable for site, as there were only two catchments monitored;
ii. volume - per event ('000 L). A flow event is defined as a body of water that flowed continuously through the measurement flume. The start and finish of an event is defined by "cease to flow";
iii. volume^2 - quadratic effect of volume;
iv. event - the median event was set to zero, event number reducing by one for each earlier event and increasing by one for each following event. This variable accounted for variation caused by factors which changed gradually over the period of the runoff season, e.g. from a flushing effect of the soil system;
v. event^2 - this variable was high at the beginning and end of the season and zero in the middle;
vi. peak - peak flow rate during the event in litres/second. Peak flow is likely to affect surface erosion;
vii. ratio - peak flow rate divided by volume per event. This is a measure of event intensity as two events with the same volume may have peak flow rates which differ by an order of magnitude. This factor accounts for differences between long slow flow events and short intense ones with similar volumes;
viii. date - calendar days from the start of the runoff season, beginning at 1 on the first day of the first runoff event in each year;
ix. year – the year in which the runoff event occurred (one to four); and
x. relrain – annual rainfall of each year as a proportion of the long-term average.

Precipitation-based variables (such as rainfall intensity) were not included in these analyses as the intention was to develop relationships, which could be combined with water runoff volumes predicted from a hydrologic model such as TOPMODEL (Beven and Kirkby 1979).

A maximum of two evident outliers were discarded from each regression, which thus included up to 56 data points.

Pattern analysis

Multiple regression analyses of overland flow loads for each chemical fraction showed clusters of data in two patterns. The statistical method used is shown schematically in Figure 1. For a detailed description see Fleming and Cox (2001).

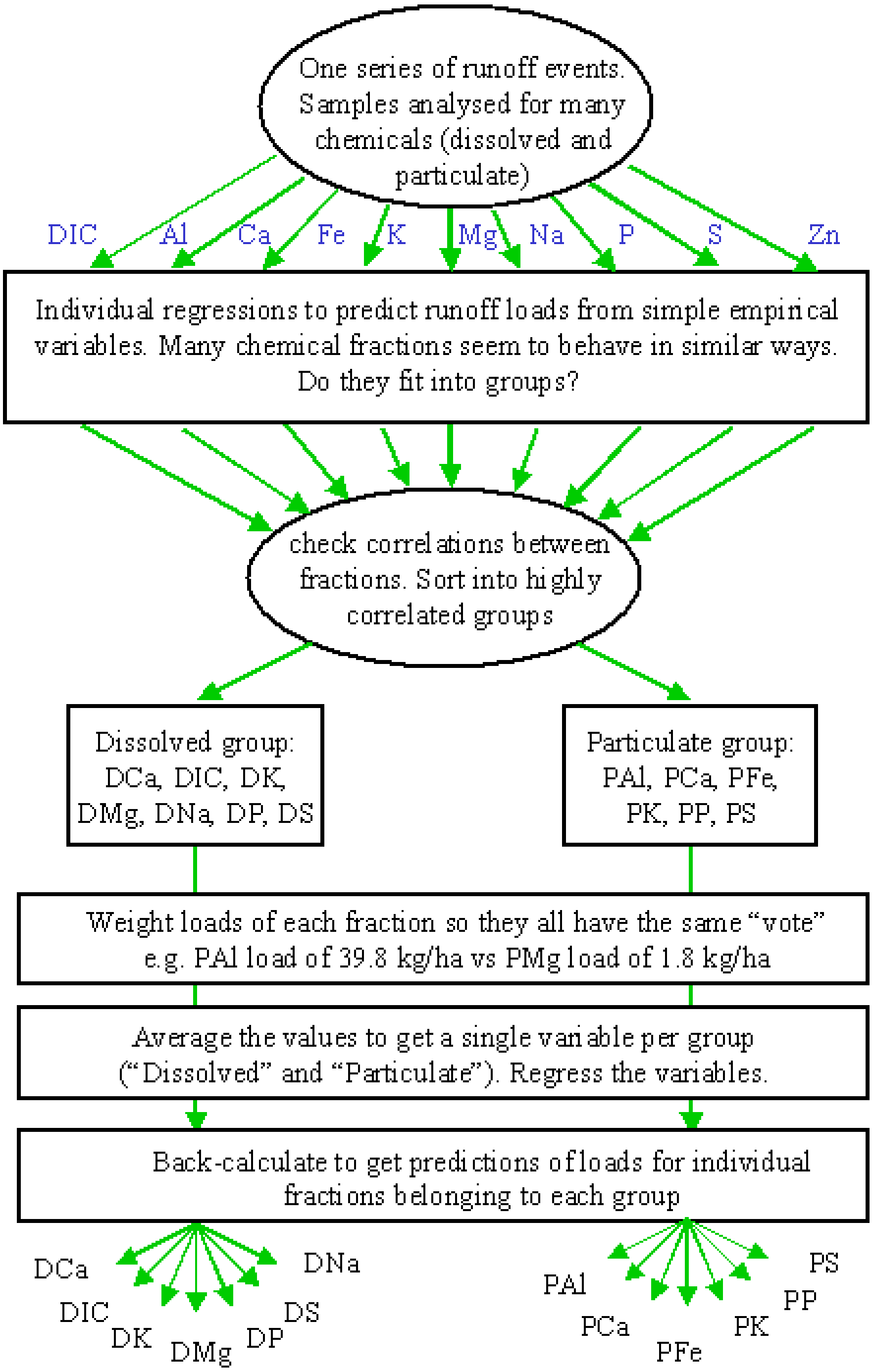

Figure 1. Flow diagram of method used for pattern analysis.

Pattern analysis groups are presented for the first year of the study (1996) and for the grouped data over a four-year period.

Results and discussion

Of the four-year study period, 1996 was by far the wettest year and had the most overland flow. Annual rainfall and key parameters for the Flaxley East catchment are shown in Table 1.

Table 1. Annual rainfall, number of overland flow events, total overland flow volume and P loads from Flaxley East catchment 1996 to 1999.

Year	rainfall (mm)	runoff events	volume (kL/ha)	DP (g/ha)	PP (g/ha)
1996	863	30	298	947	1 278
1997	503	9	148	288	147
1998	546	10	30	65	11
1999	527	4	31	109	11

The wettest year was 1996, with more than twice as many runoff events and total runoff as any of the other years. Regression equations for chemical loads in overland flow during 1996 are summarised below.

Table 2. Proportion of variance explained (R^2) and statistical significance of regressions of chemical loads in overland flow using independent variables of flow and physical catchment features at Flaxley in 1996 and in 1996 to 1999 (combined data).

nutrient	1996 R^2	significance	1996-1999 R^2	significance
DAl	id		id	
PAl	0.98	***	0.68	***
DFe	id		id	
PFe	0.96	***	0.69	***
DK	0.95	***	0.94	***
PK	0.98	***	0.81	***
DCa	0.96	***	0.85	***
PCa	0.96	***	0.84	***
DMg	0.96	***	0.64	***
PMg	0.45	**	0.73	***
DNa	0.96	***	0.51	***
PNa		ns		ns
DS	0.84	***	0.77	***
PS	0.85	***	0.75	***
DP	0.91	***	0.87	***
PP	0.96	***	0.77	***
DZn	id		id	
PZn		ns	0.54	***
DIC	0.91	***	0.73	***
DOC	0.98	***	0.75	***

id = insufficient data for analysis; ns = not significant, * = $P<0.05$, ** = $P<0.01$, *** = $p>0.001$

Multiple regression analyses using simple variables and physical catchment features explained a surprisingly large amount of variation in chemical loadings of overland flow in the 1996 data (average R^2 of more than 90%). This was despite the simple variables that were used, and the omission of some variables, which are considered to be of major importance, e.g. pasture cover (Costin 1980) and time since grazing (Sharpley and Syers 1976).
Slightly less of the variation was explained in the combined data (average $R^2 = 0.74$) than in the single year.

Pattern analysis identified two major groups of chemical fractions, named "Dissolved" and "Particulate" after their predominant components. The Dissolved group consisted of the following fractions: DCa, DIC, DK, DMg, DNa, DP and DS. The Particulate group consisted of: PAl, PCa, PFe, PK, PP and PS.

A regression equation for the combined group Particulate for 1996 is shown in Figure 1.

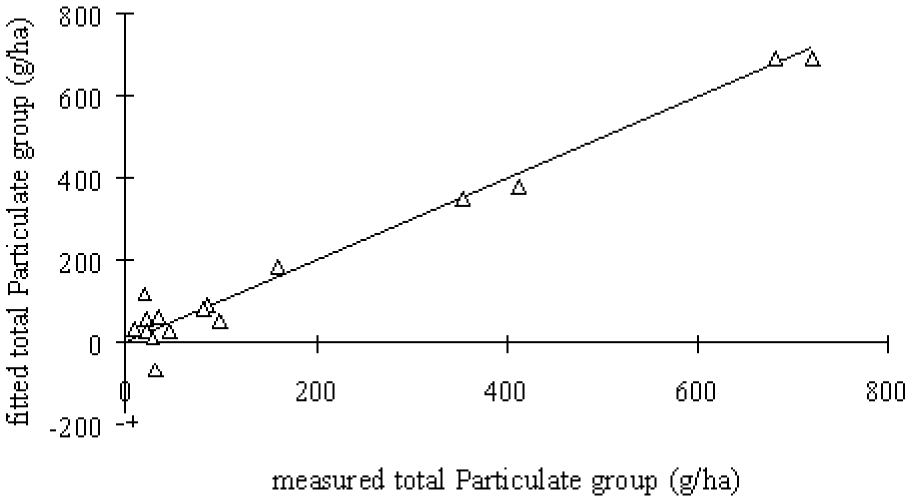

Figure 2. Particulate group (1996). The regression equation is Particulate = -424.0 + 61.6*slope + 0.025*volume^2 - 10.4*event - 0.96*event^2. R^2 = 0.96. The outlier is marked with a cross.

There is a good relationship between observed and predicted loads of the Particulate group (R^2 = 0.96). A regression equation for the combined group Dissolved for 1996 is shown in Figure 2.

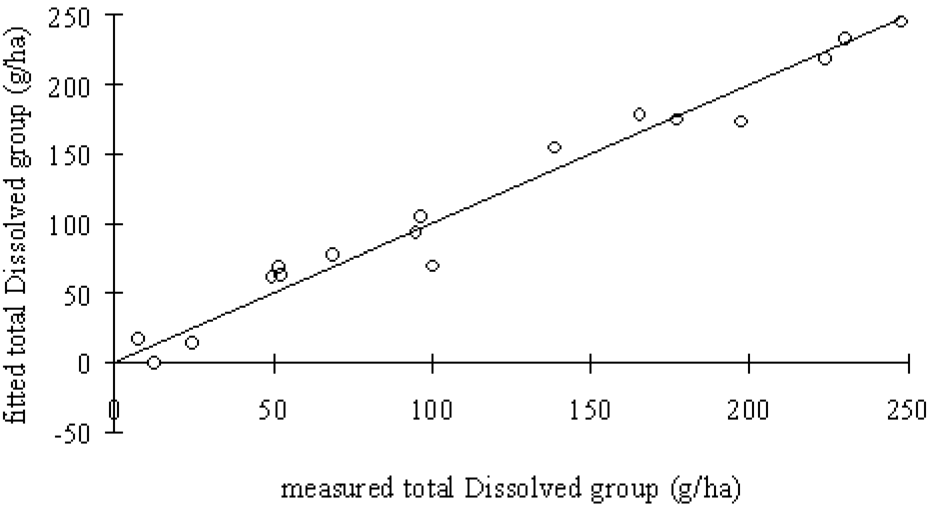

Figure 3. Dissolved group (1996). The regression equation is Dissolved = -150.0 + 12.5*slope + 2.2*volume - 1.5*event - 3.5*peak + 230.3*ratio. R^2 = 0.96.

There is a good relationship between observed and predicted loads of the Dissolved group (R^2 = 0.96). A regression equation for the combined group Particulate for grouped data from 1996 to 1999 is shown in Figure 3.

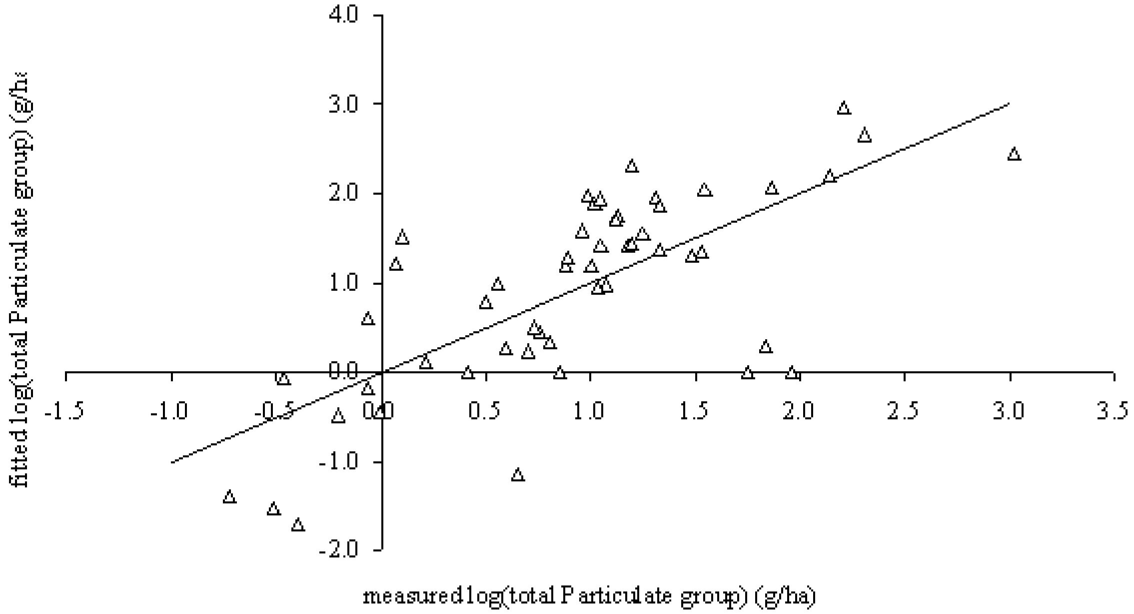

Figure 4. Particulate group (1996-1999). The regression equation is log (particulate) = 5.6 + 0.047*peak – 2.2*ratio – 0.84*year – 2.9*relrain. R^2 = 0.46.

There is a poor relationship between observed and predicted loads of the Particulate group (R^2 = 0.46). The ability to predict Particulate loads was reduced by including all four years in the data set. This is most likely due to the fact that the Particulate loads were much smaller in the three drier years following 1996 (see Table 1). Hence there is more noise in the grouped data.

A regression equation for the combined group Dissolved for grouped data from 1996 to 1999 is shown in Figure 4.

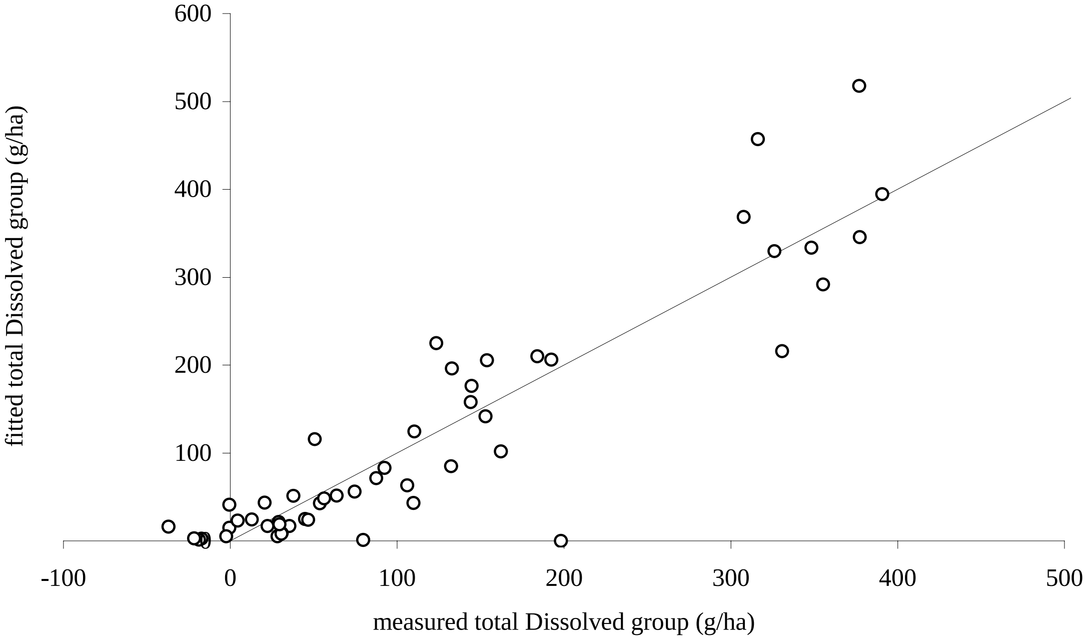

Figure 5. Dissolved group (1996-1999). The regression equation is Dissolved = -73.6 - 2.4*peak + 7.6*slope + 5.2*volume – 0.014*volume^2. R^2 = 0.82.

There is a relatively good relationship between observed and predicted loads of the Dissolved group (R^2 = 0.82). It would appear that processes giving rise to Dissolved nutrient movement from the pasture sites are more consistent between years than those giving rise to Particulate movement. Thus the inclusion of more Dissolved data has had relatively little impact on the amount of variation explained by the regression equation.

Broader implications of these findings would be that the loads of many chemical fractions may be predicted by simple empirical equations, based on only two regression formulae. These calculations could be performed on the output of a GIS-based hydrological model to predict runoff of chemical fractions from a larger area. Firstly, however, this approach would require testing in other locations where chemical runoff data is available, to see if it is generally applicable to other areas or whether the relatively good predictions obtained at Flaxley are site-specific and of less relevance in other areas.

Conclusions

Data for predictive modelling of Dissolved chemical loads in overland flow could be combined reasonably well across years at the Flaxley site, with minor loss of precision i.e. we can predict the loss of any chemical in any year with reasonable success. However, prediction of particulate loads was adversely affected by inclusion of more years of data. This is primarily due to the small particulate loads measured in the latter years of monitoring due to factors such as poor pasture cover at the time of runoff in drier years. Thus the prediction of Particulate loads of all chemicals in a given year required additional knowledge of factors such as pasture cover at the time of runoff commencing.

Pattern analysis of chemical fractions in water runoff has shown promise for relatively simple prediction of a wide range of chemicals in runoff from grazed pasture. It is yet to be seen if this approach is successful in other locations or is site specific.

References

Cox JW, Kirkby CA, Chittleborough DJ, Smythe LJ, Fleming NK (2000). Mobility of phosphorus through intact soil cores collected from the Adelaide Hills, South Australia. *Australian Journal of Soil Research* **38**, 973-990.

Beven K and Kirkby MJ (1979). A physically-based variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin* **24**, 43-69.

Costin AB (1980). Runoff and soil and nutrient losses from an improved pasture at Ginninderra, Southern Tablelands, New South Wales. *Australian Journal of Agricultural Research* **31**, 533-546.

Fleming NK, Cox JW (1998). Chemical losses off dairy catchments located on a texture-contrast soil: Carbon, phosphorus and sulphur and other chemicals. *Australian Journal of Soil Research* **36**, 979-95.

Fleming NK, Cox JW, Chittleborough DJ, Dyson CB (2001). An analysis of chemical loads and forms in overland flow from dairy pasture in South Australia. *Hydrological Processes* **15**, 393-405.

Kirkby CA, Smythe LJ, Cox JW, Chittleborough DJ (1997). Phosphorus movement down a toposequence from a landscape with texture contrast soils. *Australian Journal of Soil Research* **35**, 399-417.

McColl RHS (1979). Factors affecting downslope movement of nutrient in hill pasture. *Progress in Water Technology* **11**, 271-85.

Sharpley AN and Syers JK (1976). Phosphorus transport in surface run-off as influenced by fertiliser and grazing cattle. *New Zealand Journal of Science* **19**, 277-282.