Phosphorus budgeting and distribution on dairy farms in coastal New South Wales

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Abstract
With dairy production becoming more intensive, stocking rates are increasing and there is a greater dependence on supplementary feeding. Phosphorus budgets for seven NSW coastal dairy farms revealed that the annual amount of P entering a farm using a high intake of introduced stockfeed can be nearly 100 kg /ha, but only 10 – 30 kg P/ha on farms more dependent on pasture. P fertiliser inputs ranged from 7 kg /ha to 117 kg/ha on a whole farm basis. Pasture production is rain fed supplemented with some spray irrigation and estimated losses of P in runoff are low. P outputs in milk and livestock (10 -37 kg / ha) are seldom high enough to prevent P from accumulating on the farm.

Within the farm P is accumulating unevenly. In unfertilised holding yards and laneways, topsoil (0-10 cm) P levels can be very high (>1000 mg/kg Colwell P). P sorption of topsoils in these areas may be depressed to the point where P is desorbed from the soil. Subsoil P levels may also be elevated in these areas. Paddocks receiving effluent from the dairy can also be P enriched (200 - 400 mg/kg Colwell P). The risk of P losses in runoff increases as P accumulates. The topsoils of some heavily fertilised grazing paddocks may also contain over 200 mg/kg Colwell P. On the other hand, pasture paddocks remote from the dairy and hence receiving no effluent, little fertiliser or feed, but used for hay-cutting and silage production are often low in P. The challenge for the dairy industry is to address the impact of high levels of P accumulation in specific areas within the farm, while recognising that improved pasture and on-farm forage production still require P inputs.

Introduction
Dairy farming has become more intensive in coastal NSW in recent years, following an industry-wide trend (DRDC 2000). Declining milk prices have forced farmers to increase production just to maintain returns. Increased stocking rates and greater use of feed supplements are reducing the amount of home-grown feed as a percentage of the overall diet of the herd. Phosphorus (P) arrives at the farm gate not only in the fertiliser but also in stockfeed. The amount of feed brought in increases during droughts and in winter as pasture growth falls, although the seasonal difference is less marked than in Victoria or Tasmania. Year-round calving in New South Wales means that seasonal fluctuations in fresh milk production are much less than in the southern states.

Rainfall in coastal NSW is generally spread more evenly throughout the year than in other states, with a pronounced trend to summer dominance in the north. Pasture production is predominantly rain-fed, supplemented with some spray irrigation. P fertiliser is spread mainly in autumn, with many farms using a second application in the spring.

The coastal dairy farms have a range of soil and landscape types, from river flats to rolling hilly uplands. Many are located in drinking water catchments, leading to increasing concerns about their impact on water quality, particularly with respect to P. Soils used for dairying include hydrosols in swamp areas, rudosols and tenosols along river flats, dermosols and chromosols on terraces and lower slopes, and kurosols and sodosols on hillsides. Ferrosols and vertosols are also important for dairying in several districts. There is also a wide range in soil P sorption capacity, but acidic clay subsoils with high P sorption are common (Dilli 1999). Available P levels in the topsoil are largely controlled by management, but sorption differences have a major effect on P availability and hence on recommended fertiliser rates.

On farm P inputs in feed and fertiliser are reduced by outputs mainly in milk and livestock sales. Losses of P in runoff and sales of fodder usually make a much smaller contribution to off-farm P export. The

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objective of this study was to quantify P balances on 7 dairy farms in coastal NSW and to use soil tests to determine how the P was distributed around the farms.

Materials and method

The farms selected for the study are located at Albion Park 100km south of Sydney, in the Camden district 70km south west of Sydney, and near Richmond 60km north-west of Sydney. Data on the quantity and type of P fertiliser, stockfeed and concentrates used on each farm was collected from information supplied by the farmers. Details of milk production, livestock and fodder sales were also collected. P budgets were compiled at the farm gate level, and in some cases at the paddock level. Information on management practices affecting P movement within the farm (fertiliser rates, effluent treatment and handling, grazing practices, and stocking rates) was also collected. Using the information on management practices, soils were sampled for P testing. Taking into account the distribution of soil types, subsoils as well as topsoils were sampled at Albion Park with the aim of assessing any downward P movement. Areas where no fertiliser was applied were also sampled including swamps, laneways, holding yards, calf rearing and cow feed-out areas.

Four of the farms are typical commercial enterprises (three near Camden and one at Albion Park), two are run by educational institutions(University of Sydney, also near Camden and the University of Western Sydney, UWS, near Richmond), and one is used for research (Elizabeth Macarthur Agricultural Institute EMAI). The area used by the milking herd for grazing and forage crop production ranged from 44 to 150 ha, and the number of cows milked ranged from 117 to 300 (see Table 1).

Surface soils tested were composites of 20, 30 or 40 cores, 0-10cm depth. Profile samples were composites of 5 undisturbed cores collected in a cluster within an area 5m across. Samples were analysed for extractable P (Bray, Olsen and Colwell extracts – Rayment and Higginson 1992), and some samples from Albion Park and EMAI tested for total P (hot acid extract) and a number of P sorption measures (Burkitt et al 2002, Blakemore et al 1987, Rayment and Higginson 1992).

At the EMAI farm (near Camden) runoff P was measured using large grazed runoff plots (Dougherty *et al*.2004). On the other farms P losses in runoff were estimated using data from these plots. There was only minor use of spray irrigation on most farms and pastures were dominantly rain fed.

Table 1: Details of farms studied

Farm name	Area used by milking herd (ha)	No. of milking cows	Year data collected
Albion Park	61	300	1999/2000
EMAI	44	117	1999-2003
University of Sydney	100	250	2003/04
Camden – A	125	150	2003/04
Camden – B	150	180	2003/04
Camden – C	80	300	2003/04
UWS Richmond	130	250	2003/04

Results

With the exception of Camden-B, all farms had a large net P surplus. The main P output on all farms was in milk, with livestock sales and weight gain a minor output. Only at EMAI was P moved off farm in fodder (average 2kg/ha/yr). The P balances in Table 2 do not include P lost in runoff. The amount of P lost from pastures is relatively low (at EMAI < 1.2 kg/ha), but losses from areas such as laneways and holding yards could be potentially much greater on a per hectare basis. The total annual contribution of farm runoff to P outputs is estimated at 4 kg / ha (see also Baginska et al.1996), and is likely to be influenced greatly by rainfall patterns.

Table 2: Annual major P inputs and outputs (kg/ha)

Farm	Inputs		Outputs	Balance
	Feed	Fertiliser	Products sold	
Albion Park	95	10	37	68
EMAI	36	52.5	15.5	73
University of Sydney	20	117	24	113
Camden – A	18	21	10	29
Camden – B	6	7	12	1
Camden – C	72	90	35	127
UWS Richmond	15	43	16	42

Most of the P surplus is likely to be stored in the soil, although some may accumulate in the effluent pond, or in manure spread around the farm. Topsoil samples had a wide range in P concentration with those coming from paddocks receiving effluent, or used for calf feeding, or as night paddocks having high concentrations. Laneways and holding yards can have even higher topsoil P concentrations (see table 3). Fertilisers also influence topsoil P content. For example at EMAI where fertiliser use was tightly controlled and monitored for 4 years soil P levels increased more than six fold at the highest P application rate (Table 4).

Table 3: Colwell P concentrations (mg/kg) in topsoil (0-10cm) at different locations within the farm

Farm	Sampling Location				
	Laneway/ holding yards	Effluent Paddock	Calf-feeding Paddock	Night Paddocks	Other Paddocks
Albion Park	980*	378*	250	(302*)	15 - 187
EMAI	nt	nt	nt	-	[33 – 197]
Univ. Sydney	720	240	160	220 - 440	77 - 140
Camden – A	1390	203	535	74 - 125	25 - 72
Camden – B	1300	260	200	240 - 550	140 - 280
Camden - C	1200	230	86	290 - 370	17 - 200
UWS - Richmond	nt	nt	nt	84 - 167	18 - 79

Notes: * mean of 3 replicate samples, ( ) paddock used as a feed-out area, nt - not tested and [ ] range for all paddocks in spring 2002.

Table 4: P test and total P (mg/kg) in topsoil (0-10 cm) in grazed 0.5ha paddocks after 3.5 years of receiving P fertiliser in spring and autumn (a = mean of 15 paddocks; b=mean of 30 paddocks) (Havilah *et al.* 2004).

	Annual P fertiliser rate (kg/ha)				
P test	0_a	20_b	40_b	80_b	140_a
Olsen	11	21	26	38	69
Bray	12	25	34	54	99
Colwell	33	60	79	117	197
Total P	650	nt	nt	nt	1050

nt = not tested

While most of the surplus P is likely to be confined to the topsoil, elevated subsoil P concentrations were common, particularly in areas where manure and effluent accumulated (Table 5). Despite the high topsoil levels, the P content of the deep subsoils at Albion Park was generally very low, except on the young alluvial soils.

Table 5: Soil P content (mg/kg) down the profile at paired sites with contrasting land use at Albion Park

Soil	Depth (cm)	Horizon	Bray P		Colwell P		Total P	
			f1	**e**	**f1**	**e**	**f1**	**e**
Chernic	0-10	A1	22	125	95	730	1655	3092
Tenosol	10-20	A1	5	41	25	176	1086	1392
On	50-60	B	5	10	31	44	900	578
Young alluvium	90-100	B	5	6	31	27	534	587
			f2	**m**	**f2**	**m**	**f2**	**m**
Brown	0-10	A1	115	125	171	650	978	1721
Kurosol	10-20	A1	19	54	27	290	562	870
On	50-60	B2	2	5	21	7	101	214
Ancient alluvium	90-100	C	3	nt	2	nt	86	nt

Notes: **f1, f2** - fertilised pasture paddocks, **e** - **effluent**-irrigated paddock, **m** - holding yard (**manure**)
nt - not tested

The P sorption capacity of the surface soils from representative profiles at EMAI, Camden and Windsor were generally low (Table 6). Topsoils of the Albion Park farm had a very wide range in P sorption, from negative values (in the holding yard and laneway) to very high in one grazing paddock. Most grazed paddocks had low or moderately sorbing topsoils (Table 7).

Table 6: P sorption data for surface soils(0-10cm or 0-15cm) from the EMAI dairy farm and two other nearby farms, one in the Camden district; the other at Windsor near the UWS -Richmond farm (Burkitt pers.com.).

Location	Soil (Isbell 1996)	P Sorption test			
		PBC	**NZPRI**	**PBI**	**PBI rating**
EMAI	Black Vertosol (pH_{ca} 5.1)	6.38	17.01	68.0	Low
EMAI	Brown Chromosol (pH_{ca} 5.0)	8.71	20.23	90.4	Low
Camden	Red Chromosol (pH_{ca} 5.1)	11.25	22.59	113.5	Moderate
Windsor	Black Dermosol (pH_{ca} 6.4)	8.87	11.72	72.3	Low

Notes: **PBC** – phosphorus buffering capacity (Ozanne & Shaw 1967)
NZPRI – phosphate retention (Blakemore *et al.* 1987)
PBI – phosphorus buffer index (Burkitt et al 2002).

Table 7: P sorption index (Method 9I1 – Rayment & Higginson 1992) and Bray P contents of topsoils (0-10cm, 20 core composites) at Albion Park.

Sampling location	P sorption index	P sorption rating	Bray P (mg/kg)
Major laneway	-46	negative	490_a
Dairy holding yard	-38	negative	435_b
Calf rearing paddock	29	very low	115
Fert. grazing 1	39	low	65
Fert. grazing 2	39	low	48
Cow feed-out area	39	low	73_a
Fert. grazing 3	40	low	46
Fert. grazing 4	43	moderate	62
Effluent irrigation paddock	48	moderate	78_a
Fert. grazing 5	49	moderate	34
Fert. grazing 6	52	moderate	32
Fert. grazing 7	56	moderate	70
Fert. grazing 8	62	high	6
Minor laneway	65	high	62_a
Fert. grazing 9	85	very high	19

Notes: a – mean of 3 replicate samples, b - mean of 2 replicate samples.

Discussion

Surplus P has been found in dairy farms elsewhere in Australia (Fleming *et al.* 2003), in New Zealand (Power *et al.* 2002) and Europe (Haygarth 1997). The surplus is distributed unevenly within the farm, with paddocks close to the dairy (often used for calf feeding, receiving effluent, or as night paddocks) frequently accumulating P, while other paddocks more remote from the dairy which are receiving low P inputs are losing P. Unfertilised areas like yards and laneways, and areas where large quantities of introduced feed are supplied are also accumulating substantial amounts of P.

P inputs and outputs vary widely between farms, even within particular dairying districts. The diversity found in the lower Murray district of South Australia (Fleming *et al.* 2003) is also apparent in the data from the three Camden farms. At the Camden B farm, although the P inputs and outputs are nearly balanced for the year of the study, there are high soil P test levels in all paddocks, indicating high P inputs in fertiliser and/or feeds in previous years. In farms with large milking herds where the contribution of home grown feed is very minor (e.g. the Albion Park and Camden-C farms), the size of the P surplus is likely to be much greater than in other pasture based farms less dependent on introduced feed.

Some paddocks have soil test levels well above the point where pastures will respond to additional P, derived either from fertiliser, effluent, or introduced feeds. By basing P fertiliser applications on regular soil testing some farmers could substantially reduce input costs. Appropriate feeding strategies produce a direct benefit for milk production (e.g. Warren *et al.* 2004) and feed inputs are less easily reduced, particularly for larger herds on small areas. In such cases P fertiliser use could be drastically curtailed. Different dairy farming systems around Australia will need different approaches.

A soil P surplus in the unfertilised parts of the farm such as laneways and holding yards can have impacts on runoff. Soil properties can reduce the impact of the P surplus. Most soils used for dairying in Coastal NSW have at least one moderate or high P sorbing horizon (Dilli 1999). P loadings can be so high that P sorption is depressed, sometimes to that point where P is desorbed (as was recorded at the Albion Park farm). A similar effluent related depression of P sorption was found in coastal dairy farms in the Dungog area, 200 km north of Sydney (Holford *et al.* 1997). Although these unvegetated areas may cover only 5% of the total farm area, their contribution to P lost in runoff could potentially be greater than the amount lost from the grazed and fertilised paddocks. Annual runoff P losses from intensive dairy farms of up to 6.4 kg/ha have been reported (Baginska *et al.* 1996), much higher than those reported from many grazed pastures in Australia (Nash and Halliwell 1999).

Collection and sale or redistribution of manure could help to achieve a more even P distribution within the farm. Rotation of dairy effluent application around several paddocks would also help. Producing more stock feed on the farm would reduce P inputs as well as reduce costs to some farmers, especially if the manure was used as a P fertiliser.

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