Are reduced acidification rates a feasible, achievable option for future agricultural systems?

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Abstract

Soil acidity is a major soil constraint impacting on the productivity and sustainability of Australian agriculture. While soil acidification is a natural process it is accelerated by agricultural production. Application of lime is an effective means of neutralising soil acidity. However, the cost and availability of sources of lime in some areas, increased cost of accessing and spreading lime, variable yield responses to liming and a drive to improve the environmental sustainability of current agricultural systems have lead to interest in farming systems that are less acidifying. To date there has been little work to examine the feasibility or practicality of reducing acidification rates.

We used a simple, mechanistic model to estimate the likely impact on acidification rates of a range of crop management options. Data from a factorial of runs of a simulation model were used to provide probabilistic estimates of nitrate leaching under different crop management. From these analyses we concluded that rates of acidification could only be reduced by from 5–30%. These values represent the upper limit of estimates from this analysis.

Key Words

Soil acidity, acidification rates, nitrate leaching, liming, cropping systems

Introduction

Soil acidity is one of the major constraints to agricultural productivity and sustainability in Australia. It has been estimated that half of the agricultural land in Australia is acidic ($pH_{(CaCl2)} \leq 5.5$) , with up to half of that requiring immediate remedial action ($pH_{(CaCl2)} \leq 4.8$) (NWLRA 2001). In the wheatbelt of Western Australia (WA) two-thirds of the soils are acidic or at risk from soil acidification (Porter et al. 1995). Recent soil monitoring has estimated that up to half of the agricultural soils in WA have acidic sub-soils (Carr et al. 2008, Andrew et al. these proceedings).

Since ancient times, the management of soil acidity in agricultural soils has been achieved through the application of lime (Semple 1928) and this continues to be an accepted practice (e.g. Johnston 2004). The application of lime is recognised as a cost-effective means of neutralising soil acidity (Davies et al. these proceedings).

While this is generally the case, liming sources are a non-renewable resource and are not always readily available (Johnston 2004) and this along with the increased cost of accessing and spreading lime, variable yield responses to liming, greenhouse gas emissions and a drive to improve the environmental sustainability of current agricultural systems has lead to interest in farming systems that are less acidifying. While such a concept relates well to an idealised perception of agricultural systems, there has been little work to examine the feasibility or practicality of reducing acidification rates.

Acidification in agricultural systems is predominantly caused by uncoupling of the carbon and nitrogen cycles (Bolan and Hedley 2003). In WA, 80–>90% of the acidification has been attributed to nitrate leaching (Dolling and Porter 1994; Dolling et al. 1994). Due to this, and the fact that the export of alkaline produce is inherently part of productive agricultural systems, approaches to reducing acidification rate are focussed on increased efficiency of fertiliser use, predominantly nitrogen, and on the use of less acidifying fertilisers.

In this paper we used a simple, mechanistic model to estimate the likely impact of a set of management options on acidification rates. Data from a factorial of runs of a simulation model were used to provide probabilistic estimates of nitrate leaching under different crop management and the likely benefits and costs of moving to a less acidifying agricultural system.

Methods

Estimating acidification rate

Fisher et al (2003) developed the Lime and Nutrient Calculator (LNC), a simple, mechanistic model to estimate net acidification rates, as lime equivalents, for Western Australian agricultural systems. The model has been expanded and adapted for systems throughout Australia (Helyar et al. 2005). We used the procedures from the LNC to estimate the net acidification rate for wheat crops using a factorial of nitrogen fertiliser application, production system and soil type at three locations in the WA wheatbelt.

Estimate of leaching

Estimates of nitrate leaching were taken from WA Wheat, a database of simulated wheat production produced by Scanlan et al. (2003) using APSIM-wheat version 1.55S (Asseng 2004; Keating et al. 2003). Values for nitrogen leached beyond the root zone of wheat crops were extracted from the WA Wheat database for Merredin, Cunderdin and Kojonup. The region has a Mediterranean-type climate, typified by hot, dry summers and cool, wet winters (Table 1).

Table 1. Western Australian Wheat sites for which nitrate leaching data were extracted.

Location	Lat.	Long.	Elev (m)	Annual	Growing season (April-October)
Merredin	-31? 29	118? 17	315	328	250
Cunderdin	-31? 39	117? 14	221	367	296
Kojonup	-33? 50	117? 09	305	530	442

For each location, estimated nitrate leaching was obtained from a factorial of simulated data incorporating two times of sowing (10th May and 5th June), two rotational settings (continuous wheat and pasture-wheat), and three nitrogen fertiliser treatments (0 kg N/ha or 100 kg N/ha at sowing or split 50/50 between sowing and four weeks after sowing) for two soil types (deep sand and sandy earth). Rotation treatments consisted of initialised soil nitrogen and residue types (continuous wheat 30 kg N in top 50 cm, pasture/wheat 90 kg N/ha in top 50 cm), with all scenarios initialised at soil lower limit on 1 April. Initialisation on 1 April is a reasonable simplification of starting conditions as less than 30% of years have quantities of summer rain resulting in storage of soil water (data not shown). A more detailed description of these factors is provided elsewhere (Abrecht et al. 2004; Abrecht et al. 2006).

For each combination in the factorial, the upper and lower quartile and median of nitrogen leached was used to calculate the estimated acidification rate due to nitrate leaching as lime equivalent by multiplying the quantity of nitrate leached by 3.6. The additional acidification associated with four types of nitrogen fertiliser (diammonium phosphate, calcium ammonium nitrate, urea ammonium nitrate and urea) were calculated based on Fisher et al (2003).

Results

Soil type, rainfall (location) and rotation were the main determinants of nitrate leaching and calculated acidification rates (Table 2). Calculated acidification rate was three to four times higher for deep sand compared with sandy earth at the same location, sowing time, rotation and fertiliser application. These figures compare with empirical data for this environment and soil type (Anderson et al. 1998; Dolling 2001).

The estimated acidification rate due to nitrate leaching was several orders of magnitude greater (5 to 100 times) for the high rainfall location (Kojonup) compared to the other two locations (Table 2). At Kojonup, there were large quantities of nitrate leached below deep sand, compared with a wider distribution of values for sandy earth. The quantity of nitrate leached was not related linearly to rainfall (data not shown), in contrast to the simple relationship used in the LNC (Fisher et al. 2003). This is not surprising given the importance of the distribution and intensity of rainfall events on the mineralisation and leaching of nitrate.

The acidification rate with nil fertiliser application was relatively high in all situations when compared with an application of 100 kg N/ha (Table 2). In all scenarios the estimated acidification due to nitrate leaching was greater for a pasture-wheat rotation compared with continuous wheat, except for the later time of sowing on sandy earth at Cunderdin and Kojonup and on deep sand at Cunderdin. Split fertiliser application resulted in a 5–10% reduction in acidification rate compared with single application (Table 2). Similarly, acidification rate decreased by 5–10% with a later sowing date (5th June compared to 10th May).

The choice of nitrogen fertiliser used has a potentially large impact on net acidification rate, irrespective of any nitrate leaching, particularly at the high rates of fertiliser application used in this analysis (Table 3). The values in this paper are at the upper limit of what can be achieved due to the moderate to high rates of fertiliser application used, especially for locations such as Cunderdin and Merredin.

Table 2. Lower quartile (Q1), median (M) and upper quartile (Q3) of estimated acidification rate, as lime equivalent (kg $CaCO_3$/ha.year) due to leaching of nitrate below wheat crops grown on a deep sand or sandy earth at three locations in WA (Merredin (ME), Cunderdin (CU), Kojonup (KO)). Data from WA Wheat database for simulated crops sown on 10th May or 5th June with 0 (nil), or 100?kg/ha N (100) at sowing or 50/50 kg N at sowing and four weeks after sowing (split) for continuous wheat (CW) or pasture-wheat (PW) rotations.

TOS	Loc	Fert	Deep sand						Sandy earth					
			Q1		M		Q3		Q1		M		Q3	
			CW	PW	CW	PW	CW	PW	CW	PW	CW	PW	CW	PW
10th	ME	nil	0	0	13	13	68	92	0	0	0	0	0	0
May		100	0	0	11	9	68	88	0	0	0	0	0	0
		split	0	0	11	17	66	89	0	0	0	0	0	0
	CU	nil	35	4	97	61	217	179	0	0	0	0	0	0

		100	5	3	51	65	131	193	0	0	0	0	0	0
		split	5	3	49	62	121	187	0	0	0	0	0	0
	KO	nil	145	261	211	418	246	494	15	3	51	55	100	108
		100	220	338	352	552	436	692	6	0	54	51	106	121
		split	204	325	312	503	410	664	5	0	52	50	108	125
5th	ME	nil	0	0	17	18	69	90	0	0	0	0	0	0
June		100	0	0	17	17	68	89	0	0	0	0	0	0
		split	0	0	17	9	68	85	0	0	0	0	0	0
	CU	nil	43	15	111	73	233	189	0	0	23	0	47	0
		100	18	18	58	75	126	199	0	0	0	0	0	0
		split	18	0	57	75	119	197	0	0	0	0	0	0
	KO	nil	155	263	217	411	257	500	15	6	58	53	107	119
		100	170	276	269	454	376	607	4	0	46	45	102	112
		split	161	262	242	435	334	576	3	0	45	44	95	104

Table 3. Acidification rate as lime equivalent following the addition of nitrogen as various types of fertilisers.

Fertiliser	kg $CaCO_3$/kg N	kg $CaCO_3$/50 kg N	kg $CaCO_3$/100 kg N
Diammonium phosphate (DAP)	1.8	90	180
Calcium ammonium nitrate (CAN)	-0.7	-35	-70
Urea ammonium nitrate (UAN)	0	0	0

Urea	0	0	0

Discussion and Conclusion

Our results indicate that changes in management have at best a moderate impact on net acidification associated with nitrate leaching, especially in high rainfall areas with soils prone to leaching. This suggests that it is not possible to reduce acidification rates to a level to obviate the need for the application of lime. However, there are steps that can be taken to reduce acidification rate and the maintenance lime requirement.

Selection of nitrogen fertilisers that are non-acidifying can have a significant impact on acidification rate, especially at high rates of fertilisation. Fertiliser inputs in WA commonly range from 20 kg N/ha in lower rainfall environments to over 100 kg N/ha for crops with a higher yield potential. Initial fertiliser applications are usually made as urea, but second applications are often made using ammonium-based nitrogen fertilisers or UAN. There is likely to be a reduction in net acidification rate if this type of fertiliser is used in place of ammonium-based fertilisers, In addition, there is likely to be a small decrease in the net acidification rate associated with split nitrogen applications compared with a single application.

The decreased nitrate leaching and associated acidification from split nitrogen application is likely to be the result of improved growth and thus better utilisation of nitrogen by the crop. This highlights the importance of matching crop growth with the timing of the production of nitrate from an agricultural system. However it also shows the difficulty in achieving this in rainfed systems in which there is a spike of mineralisation and nitrate leaching from autumnal rains (Anderson et al. 1998). This problem could be worse if there is an increase in the use of legume-derived nitrogen in response to increasing prices of fertiliser nitrogen.

In conclusion, our results indicate that net acidification rate can be reduced by between 5–30% by matching nitrogen inputs to crop production potential and through the use of less acidifying fertilisers. These suggestions can be applied in any circumstance, but it is important to note that they will not remove the requirement for lime application to remediate soils that are already acidic to the level that impacts on production (pH($_{CaCl_2}$)?<?5.5), nor to neutralise acidification resulting from production.

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