

NLWRA Theme 5 Project 4c

Acid Addition Rates for Land Uses

MILESTONE 1 REPORT

Project Leader: Dr P.W. Moody, QDNR, Indooroopilly Q4068

Milestone 1: Provide estimates of the net acid addition rates (AAR) applicable to the land use categories used in the NLWRA Land Use Project ('current practice')

Notes to accompany 'Acid Addition Rates for Land Uses'

R.C. Bruce and P.W. Moody (QDNR)

Methodology

Audit Commodities

The Australian scientific literature was searched to source published acid addition rates (AAR) for agricultural and pastoral systems used in Australia. This information was collated into the various Audit commodity groupings and is presented in Table 1. This table summarises the audit commodity, applicable agroecological region (AER), particular cropping system, mean AAR, range in AAR reported amongst the various studies, a management sensitivity index (described later) and data quality index.

This latter index has four categories of data quality, based on the following criteria:

High

Data obtained over several (>3) sites using clearly defined methodology.

Medium (1)

Data obtained over 2-3 sites using clearly defined methodology.

Medium (2)

Data obtained from 1 site using clearly defined methodology.

Low

Data obtained from 1 site without a defined methodology.

Rotations

Published AARs were available for several well-established crop rotation systems in various AER's. These rotations have been given an identifier number with an 'R' suffix in Table 1.

Sources of information on AARs for different systems are cited in the reference list.

Factors affecting calculated Acid Addition Rates (AAR)

The calculation of AAR for a particular depth increment (without considering units) is:

$$\text{AAR} = (\text{pH}_{\text{REF}} - \text{pH}_{\text{DEV}}) \times \text{pHBC} \times \text{BD} \times \text{V}$$

Where pH_{REF} and pH_{DEV} are the pH values of a depth increment of the reference and developed profiles respectively, pHBC is the pH buffer capacity of the depth increment averaged over the reference and developed sites, BD is the bulk density of the depth increment and V is the volume of the depth increment. AAR is summed over the entire profile and divided by the number of years of development. Units are kg CaCO₃ / ha.yr.

Different methods of measurement of the factors involved in the calculation of AAR may cause differences between published values. Some of these differences are:

Change in pH

Depth of sampling / depth of acidification

Time period

Initial pH

Linearity of pH change with time

Methodology for acid addition calculations (eg., survey, paired sites, 2 sampling times, N and C cycles)

Reference for pH changes (virgin, unfertilised, no legume etc.)

Site limed

Rainfall amount and distribution, soil texture, leaching

N fertilisers

Initial pH and rate of pH decline

Several authors have commented that higher initial pH values give higher rates of pH decline. Most acidification studies have only two sampling dates and the pH change over the period is assumed to be linear so that an annual rate of change can be calculated.

Factors impacting on the rate of pH decline include:

- Because most soils in the laboratory have linear titration curves over the pH range 4 to 6, it is generally assumed that the pH decline with uniform additions of acid should be linear over time.
- Because different mechanisms of pH buffering operate over different pH ranges, pHBC need not remain constant as pH declines. Hence pH may not decline linearly.
- Because soil organic matter changes with soil use and development (eg., increase under pasture, decrease under cropping), pHBC will also change with land use. This change in pHBC is rarely accounted for when calculating AARs.

Re-acidification after liming can alter the pH decline. Cregan *et al.* (1989) quote data from Mahoney and Uren (1982) to show that, after liming, soils re-acidify, and the annual rate of decline in pH is higher where the post-liming pH is higher.

The long residual value of lime applications also needs to be considered as undissolved lime can influence the pH BC (Bromfield *et al.* 1987, Scott and Cullis 1992).

Measurement of pH buffer capacity (pHBC)

The problems with pHBC have been well recognised (Helyar and Porter 1989, Ridley *et al.* 1990a, Ridley and Coventry 1995, Porter *et al.* 1995), in particular the short term nature of the laboratory measurement. Ridley and Coventry (1995) calculated AARs of 2.47 and 5.95 kmol H/ha.yr depending on how pHBC was measured.

Table 1. Published acid addition rates for Australian agricultural and pastoral systems.

Audit Commodity ID	Audit Commodity Classification	Agroecological region	Cropping System	AAR mean (kg CaCO ₃ /ha.yr)	AAR range (kg CaCO ₃ /ha.yr) (Management Sensitivity Index) ^A	Data Quality
2	Agroforestry#	6. Subtropical slopes and plains	Leucaena	50		M2
2	Agroforestry#	9, Temperate highlands	Eucalypt forest	45		M2
3.1	Grazed pasture	1, NW wet/dry tropics	Stylosanthes spp - based pastures	60	25-90 (1.1)	M1
3.1	Grazed pasture	3, NE wet/dry tropics	Stylosanthes spp - based pastures	60	0-175 (2.9)	H
3.1	Grazed pasture	6, Subtropical slopes and plains	Stylosanthes spp - based pastures	55		M2
3.1	Grazed pasture	7, Wet subtropical coast	White clover / paspalum/ carpet grass	125	60-180 (1.0)	M1
3.1	Grazed pasture##	8. Wet temperate coasts	Continuous grazing	55	12.5-132 (2.2)	H
3.1	Grazed pasture##	8. Wet temperate coasts	Continuous grazing with feed supplements (intensive dairy)	25	-10.5-95 (4.2)	H
3.1	Grazed pasture	9, Temperate highlands	Sub clover / annual grasses; sub clover /perennial grasses	120	40-220 (1.5)	H
3.1	Grazed pasture	10, Temperate slopes and plains	Continuous pasture; dryland lucerne	50	25-80 (1.1)	H
9	Pasture cut for hay	4, Wet tropical coast	Grass - legume pasture; grass + N	320	50-550 (1.6)	H

9	Pasture cut for hay	8, Wet temperate coasts	Regular hay cutting; med to high intensity grazing	85	5-145 (1.6)	H
6	Seed production	3, NE wet/dry tropics	Stylosanthes seed production	530		M2
4	Cereals excluding rice	9, Temperate highlands	Continuous wheat ± N	105	45-230 (1.8)	H
4	Cereals excluding rice	10, Temperate slopes and plains	Continuous wheat (fertilised with N and P)	80	20-145 (1.6)	H
6	Legumes	9, Temperate highlands	Continuous lupin	625		M2
6	Legumes	10, Temperate slopes and plains	Continuous lupin	72.5		M1
7	Oilseeds	10, Temperate slopes and plains	Canola	128		M1
8	Sugar cane	4, Wet tropical coast 7, Wet subtropical coast	Sugar cane monoculture	170	140-235 (0.6)	H
11	Other non-cereal crops	3, NE wet/dry tropics	Tobacco monoculture	-120	-260-25 (2.4)	H
20	Plantation fruit	4, Wet tropical coast	Banana monoculture	1710	1400-2000 (0.4)	H
21	Grapes	6, Subtropical slopes and plains	Grape monoculture	95	65-125 (0.6)	M1

^AManagement Sensitivity Index = (Range in AAR/Mean AAR)

Data on AARs under agroforestry very limited. Some trees (eg. white cedar) are known to cause net alkalinisation of the surface soil.

The AAR for agroforestry should therefore be treated with caution as it will be dependent on the species grown.

It is important to distinguish between grazed pasture, and grazed pasture with feed supplements, as the latter can cause net alkalinisation.

Assume an AAR of 1.1 for Region 8 under continuous grazing, but an AAR of 0.02 for dairy pastures.

Rotations

22R	Wheat/pasture rotation	9, Temperate highlands	Wheat - pasture, - N	115	62.5-195	H
22R	Wheat/pasture rotation	10, Temperate slopes and plains	Pasture - wheat	20	10-40	H
23R	Wheat/lupin rotation	9, Temperate highlands	Wheat - lupin	140	70-205	H
23R	Wheat/lupin rotation	10, Temperate slopes and plains	Wheat - lupin, pasture-wheat-lupin	20	10-30	H
24R	Summer crop rotations	3, NW wet/dry tropics	Summer crop - winter fallow	75	40-150	H
24R	Summer crop rotations	6, Subtropical slopes and plains	Summer crop - winter fallow	125	70-175	M
25R	Summer crop /pasture rotation	3, NW wet/dry tropics	Crop - pasture rotation	75		M
26R	Winter crop/pasture rotation. (wheat, barley, canola, peas, beans)	8. Wet temperate coasts	Crop - pasture rotation	110		H
26R	Winter crop/pasture rotation. (wheat, barley, canola, peas, beans)	10, Temperate slopes and plains	Crop - pasture rotation	110	25-345	H
27R	Continuous winter crop (wheat, barley, canola, peas, beans)	10, Temperate slopes and plains	Continuous crop, or mainly so	220	170-320	H
28R	Irrigated rice /wheat/pasture rotations	10, Temperate slopes and plains	Rice - wheat - pasture (irrigated)	470	395-520	H

Management Strategies for Reducing Accelerated Soil Acidification

Causes of soil acidification

The causes of accelerated soil acidification due to agricultural practices can be conveniently apportioned between components of the carbon and nitrogen cycles which are associated with net proton accumulation or depletion in the agricultural system (Helyar and Porter 1989). While there are numerous components in the cycles which affect proton status, a first approximation can assume that the following factors are most likely to determine the net acidification rate:

- ammonium and/or nitrate addition,
- nitrate export by drainage,
- removal of alkalinity in harvested product.

Over the period that the acidification rate is being calculated for, assumptions made in this approximation are:

- there is no change in the organic carbon status of the soil. This is a reasonable assumption when the soil has a long history of agricultural production, but invalid when undeveloped land is brought into production or when there is a pasture component in the rotation.
- there is no change in the nitrate or ammonium status of the profile.
- neither the sulfur cycle nor bicarbonate partitioning has a significant effect on acidification rate. The latter assumption may be invalid where alkaline water is being used for irrigation.
- there is no significant import of organic matter (eg., animal manures, supplementary feed).

This simplistic first approximation has been used to calculate the net acidification rate of agricultural systems for which there are no measured data in the literature. This approach allows acidification to be apportioned between the carbon and nitrogen cycles, with the useful output that management strategies can be suggested for reducing acidification.

Strategies for minimising soil acidification

Strategies for minimising soil acidification include:

Nitrogen cycle

- reduce nitrogen fertiliser application rate
- change nitrogen source from ammonium-based to nitrate-based (see Table 2 for acidification rates of various nitrogen fertilisers)
- ensure nitrogen inputs do not exceed crop demands
- ensure irrigation does not result in deep drainage
- early sowing after fallow to minimise nitrate leaching
- grow perennial rather than annual species
- reduce legume dominance in mixed pastures
- manage stock to disperse camp sites

Carbon cycle

- retain plant residues on site
- return plant residues to areas of active root growth (i.e., the plant row area)
- reduce tillage frequency
- apply carbonaceous waste products to soil (eg., animal manures)

Table 2. Acidification rates (expressed as kg CaCO₃ required per kg of applied nitrogen to neutralise the acidity produced) of various nitrogen fertilisers under different losses of nitrate-N by drainage.

Form	Drainage loss of applied N (%)		
	Nil	50	100
Ammonium sulfate	3.6	5.4	7.2
Mono-ammonium phosphate (MAP)	3.6	5.4	7.2
Di-ammonium phosphate (DAP)	1.8	3.6	5.4
Ammonium nitrate	0	1.8	3.6
Urea	0	1.8	3.6
Anhydrous or aqua ammonia	0	1.8	3.6
Nitrate fertilisers (eg. KNO ₃)	-3.6	-1.8	0

Contribution of carbon and nitrogen cycles to soil acidification

Table 3 summarises the mean measured acidification rates collated in Table 1 and either measured maximum and minimum acidification rates, or rates calculated from components of the carbon and nitrogen cycles as outlined above under ‘Causes of acidification’. Values used for the components in the various commodity groups are presented in Appendix 1.

Where the acidification rate has been calculated, the minimum rate is based on no loss of applied nitrogen as nitrate by drainage, whereas the maximum rate assumes a 25% loss of applied nitrogen by nitrate leaching. For these calculations, it has been assumed that the nitrogen fertiliser used in all systems is urea (which has no net acidifying effect if no nitrate is lost by drainage). If other forms of nitrogen fertiliser are used, then the acidification rate will be altered according to the acidifying potential of the nitrogen source as presented in Table 2. The acidification rate will also be increased if more than 25% of the applied nitrogen is lost by drainage.

It is apparent from Table 3 that the removal of harvested product (i.e. the carbon cycle component of acidification) makes up a considerable proportion of the acidification in several of the systems (eg. apple, citrus, tropical plantation fruits). This acidification is unavoidable, and must be minimised through the regular application of ameliorants. The nitrogen cycle accounts for a variable portion of acidification, and generally increases in importance as the rate of ammonium-based nitrogen fertiliser increases. The application rate, timing and form of nitrogen fertiliser are therefore critical decisions when attempting to minimise acidification.

Table 3. Mean, maximum and minimum net acidification rates for Audit commodities, and the relative contributions of the nitrogen and carbon cycles to soil acidification.

Audit commodity	Audit No.	AER	Acid'n Rate (kg CaCO ₃ /ha.yr)			Contribution of N and C cycles for 25% N leaching loss (% N:% C)	
			Mean	Min.	Max		
Agroforestry	2		50	45	50		
Apples	15			103	211	50:50	
Berry fruit	19			34	169	80:20	
Cereals excluding rice	4	9	105	45	230		
		10	80	20	145		
Citrus	14			173	308	45:55	
Cotton	10			25	169	85:15	
Grapes	21		95	65	125		
Legume	6	3	530				
		9	625				
		10	70				
Non-cereal; forage crops	9	4	320	50	550		
		8	85	5	145		
Nuts	18			17	116	85:15	
Oilseed	7		130				
Other non-cereal crops	11		Too diverse				
Other vegetables	12			1	114	99:1	
Pasture	3	1, 3, 6	60	0	175		
		7	125	60	180		
		8	55	12	132		
		9	120	40	220		
		10	50	25	80		
Pear	16			41	149	70:30	
Plantation fruit Banana, pawpaw, passionfruit Pineapple Other tropicals	20		1710	1400	2000		
				60	420		85:15
				13	32		40:60
Potato	13			10	154	95:5	
Rice	5		nil				
Stone fruit (assumed same as pear)	17			41	149	70:30	
Sugar cane	8		170	140	235		

Sensitivity of agricultural systems to strategies for minimising soil acidification

It is suggested that a wide range in **measured** acidification rates for a particular agricultural system is indicative of the effects of different managements on acidification. It follows, then, that management strategies exist for reducing acidification rates in that system. To identify these systems, a **management sensitivity index** has been calculated as:

$$\frac{\text{Range in acidification rate}}{\text{Mean acidification rate}}$$

Values for this index are presented in Table 1. Agricultural systems where this index exceeds a value of 2 are taken as systems where a significant reduction in acidification rate is possible through management strategies. These systems are *Stylosanthes* pastures in the NE dry tropics, pastures on the wet temperate coast, particularly where grazing animals are given supplementary feed (eg. dairy cattle), and tobacco.

It is most likely that the lowest acidification rates in these systems were attained by, respectively:

- low intensity grazing (therefore little export of ‘harvested product’), and grass rather than legume dominance in the pasture,
- high levels of supplementary feed imports (i.e. high input of organic anions),
- use of nitrate-based fertilisers.

Systems with an index <2 are considered to have less opportunity for reducing acidification apart from regular applications of ameliorants. However, a relatively small variation in acidification rate within a particular system does not always indicate that there is little that can be done to reduce acidification. For example, the high, but relatively constant, acidification rate observed for banana is simply a reflection of the small variation in rate (around 300 kg N/ha) and form of nitrogen (urea) used throughout the industry. It has been calculated that reducing the applied rate of nitrogen to 250 kg N/ha, using nitrate-based fertiliser, and returning crop residues to the row rather than the interrow could reduce the acidification rate by 83% (Moody and Aitken 1997). Similar strategies would greatly reduce the acidification rate of sugar cane, cotton and horticultural tree crop production systems.

Conclusions

Soil acidification is an inevitable consequence of agricultural production. The management, and minimisation, of this acidification is dependent on understanding the major factors contributing to the acidification. Partitioning these factors into components of the nitrogen and carbon cycles is extremely useful for deciding management strategies. Acidification due to harvested product removal (a component of the carbon cycle) is unavoidable, and must be countered by regular application of ameliorants. Efficient nitrogen fertiliser management is the key to minimising acidification, and several strategies can be adopted to achieve this end. It is suggested that knowledge of the acidification due to product removal and undertaking a critical appraisal of N fertiliser use efficiency are the first steps in developing an acidification minimisation strategy for individual industries.

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