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PERENNIALS FOR ACID SOILS:

DO PERENNIAL PASTURES REDUCE SOIL ACIDITY?

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Abstract: Perennial pastures utilise soil water and nitrogen more completely than annual pastures. This means they provide the opportunity for increased production while at the same time reducing the soil acidification rate and the rate of water loss to the water table. Therefore, perennial pastures can be more profitable and contribute less to soil acidification and dryland salting problems, so long as any extra costs of establishment and maintenance compared with annual pastures do not exceed the extra returns. This paper outlines the extent and nature of soil acidity in N.S.W., the causes and rates of soil acidification in different agricultural systems, the effects of soil acidity on plant yields, and describes how perennial pastures can be used to minimise nitrogen leaching, soil acidification and lime requirements.

THE EXTENT AND NATURE OF SOIL ACIDITY IN NSW

A survey of soil acidity in NSW has recently been published (Helyar *et al.*, 1990), that gives details of the pH of the surface soils of the state (All pH values used in this paper have been measured using the calcium chloride method). Information on acid addition rates and hence on the amounts of lime required to stop soils acidifying, is also presented in that paper. Soils with surface pH values below 5.0 occur where the annual rainfall exceeds 500 mm. In the north of the state, only very sandy soils are below pH 5.0 in the 500 to 750 mm rainfall zone, with the bulk of the strongly acid soils occurring in regions of higher rainfall. Within a rainfall region, sandy soils usually had pH values about 0.4 units lower than loam soils while the pH of clay soils was around 0.8 units higher than for the loam soils.

For NSW as a whole it was estimated that the areas of land with pH values below 4.5, between 4.5 and 5.0, and between 5.0 and 5.5, are 5.3, 8.4, and 5.7 million hectares, respectively. Large areas of the most acid land occur in the important pasture and pasture/ley farming systems of the Southern and Central Tablelands, and the South-west Slopes and adjoining plains.

Soils with lower surface pH values also are generaly more acid at depth, so where the surface pH is below 4.5 it is important to check the pH of the subsurface layers, especially between 10 and 50 cm where treatment of the acidity using lime is very costly. The pH of many of the less acid soils (*eg.* pH 5.5) and soils that have only been recently acidified in the surface, usually increases with depth. On the other hand soils that are strongly acid historically and sandy soils that have been strongly acidified under agriculture, can have pH values of 4.0 and below throughout the root zone. These contrasting soil types demand very different management regimes.

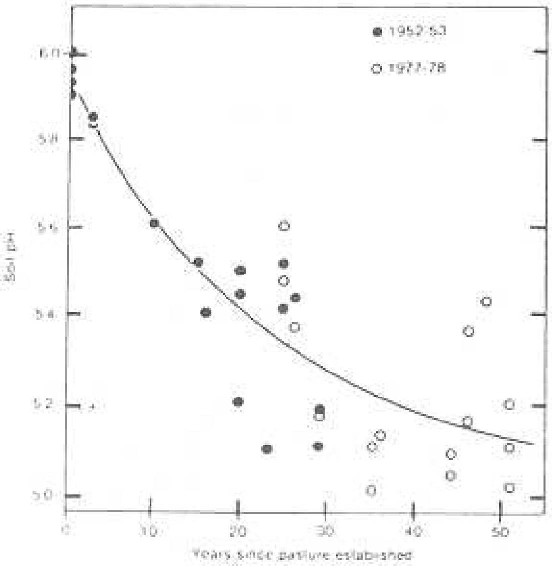
CAUSES AND RATES OF SOIL ACIDIFICATION

The causes and rates of soil acidification have been discussed in detail recently (Helyar and Porter, 1989; Helyar *et al.*, 1990; Ridley *et al.*, 1990 a, b, c).

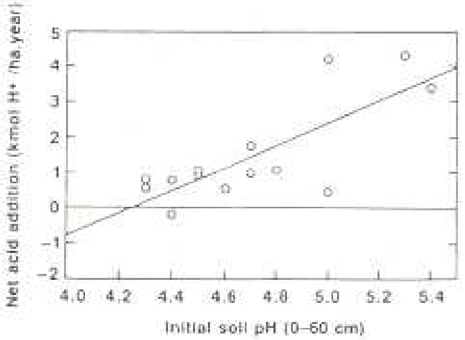
CAUSES

For all practical purposes the acids being added to Australian soils are produced as nitrogen and carbon are cycled through the soil - plant - organic matter system.

Acid rain, a major source of acid in industrial areas of the northern hemisphere, is of minor importance in our agricultural areas mainly because sulphur pollution is mostly blown offshore, or produced in desert areas (*eg.* Kalgoorlie and Mt Isa). The Gippsland area, especially in the lee of Melbourne and the brown coal power stations, may be an exception but I am not aware



(a) Relationship between age of subterranean clover pasture and pH (1:5 water) of surface 10 cm of soil in the Southern Tablelands (Source: Williams, 1980).



(b) Relationship between intial soil profile pH and net acid addition ($A_i = 3.17\ pH - 13.47$; $R^2 = 0.61$) (Source: Ridley *et al.*, 1990).

Figure 1: Examples of soil acidification under fertilized annual clover/grass pastures.

of sulphur accretion measurements to demonstrate this.

Acids are produced in the carbon cycle when neutral carbon compounds in plants and in the soil organic matter (*eg*. starch, cellulose, sugars) are converted to organic acids by plants or microbes. If these organic acids accumulate in the soil, acidification occurs. Secondly, if the acid component of the organic acid is secreted from roots into the soil, and the organic anion is exported in plant or animal products and waste products, net acid addition occurs.

For pasture ecosystems dependent on nitrogen fixation, acid is added to the soil at the site of mineralization of organic nitrogen (usually the topsoil), in proportion to the amount of N lost as nitrate by leaching and run- off. This occurs because the mineralization of organic N produces nitric acid. The acid is neutralized if the nitrate is absorbed by plants or microorganisms and reconverted to protein - an alkaline reaction. The acid is also neutralised if the nitrate is lost by denitrification - also an alkaline reaction. Therefore managing acid added through the nitrogen cycle involves managing nitrate leaching, plant uptake of nitrogen, and denitrification.

RATES

The key data relevant to acid addition rates to soils under pastures in the 500 to 800 mm rainfall zone are presented in Table 1 and Figure 1. The amount of lime needed to balance acid addition rates varies from low values of 130 kg lime/ha/year for perennial pastures on soils with pH values of about 5.0 on the Northern Tablelands and the North Coast, to over 300 kg lime/ha/year for annual pasture/wheat rotations on well drained red earth soils with pH values of 5.5 on the South-west Slopes.

Three main factors cause variation in soil acidification rates observed in different soils and production systems. These are:

- the soils capacity to resist a decline in pH as acid is added (the pH buffering capacity of the soil);
- the amount of acid consumed by the dissolution of soil minerals, and ;
- the amount of acid generated by the system.

(1) The soil pH declines faster if the soil has a limited capacity to resist a fall in pH when acid is added. Sandy soils, low in organic matter are in this category, whilst clay soils high in organic matter need more acid to reduce the pH, and conversely, more lime to increase the soil pH. Examples are listed in Table 2 for typical pasture soils.

(2) The second factor is the degree to which soil minerals dissolve as acids are added. Mineral dissolution increases as the soil pH declines. As the pH falls below pH 5.0, aluminium and manganese minerals dissolve faster and faster. The aluminium and manganese released are toxic to plants and are the main cause of acid soil infertility. In agricultural systems it is difficult to obtain pH values below about 3.9 because at that pH, clay minerals and oxides dissolve sufficiently rapidly to neutralise all the acid being added.

Figure 1 illustrates this effect in two ways. Firstly the data of Williams (1980) shows how the rate of decline in soil pH under subterranean clover pastures at Crookwell slowed as the pH approached 5.0 (Figure 1a). It is thought this was due to increased rates of mineral dissolution rather than to decreased rates of acid addition as the pH declined. Figure 1b shows decreased rates of soil pH decline where improved annual pastures were grown on initially more acid soils near Rutherglen. In this case acid being added by the pasture system was apparently being completely neutralised by soil mineral dissolution reactions at a soil pH near 4.2 (Figure 1b). This can be viewed as a soil "self-liming" effect. If the plants being grown can

Table 1: Typical acid addition rates measured under phosphate fertilized pastures in NSW (Source: Helyar *et al.*, 1990)

Site	Initial pH (i) or pH under unimpr'd pasture (u)	Pasture/ Fertilizer	Lime to neutralise acid added kg/ha/yr
Grafton; red/yellow duplex soil; 1020 mm rainfall	4.8u	Paspalum/carpet grass/ white clover (250 kg super/yr)	130
Armidale; yellow solodic/podzolic soil; 740 mm rainfall	4.8u	Phalaris/white clover (188 kg super/yr)	138
Crookwell; yellow podzolic soil; 700–900 mm rainfall	5.0–6.0i	Sub clover/annual grass weeds (125 kg super/yr)	173–211
Wagga Wagga; red earth soil; 560 mm rainfall	5.5i	Sub clover/annual grass weeds – wheat rotations (125 kg super/yr)	309–372

tolerate the Al and Mn levels in solution at the 'self-liming' pH, then soil mineral dissolution processes can be used instead of lime to stop further acidification. It is noted however that only the most tolerant species and cultivars perform satisfactorily at such low pH values, and the soils reserves of bases are being consumed in the process. There is some evidence that the "self-liming" pH is considerably higher, possibly as high as pH 5.0, for chocolate soils developed from basalt. These soils probably contain sufficient Ca and Mg minerals that dissolve rapidly enough at about pH 5.0 to delay the pH falling below 5.0 until these minerals are largely exhausted. Once that occurs the pH will fall to near 4.0, as for other soils. This has already occurred in the case of "red basalt" soils known as kraznozems (*eg.* Robertson, Dorrigo, Lismore). Thus, for mildly weathered soils developed from parent materials similar to basalt, soil "self-liming" reactions can probably be used for some time (possibly hundreds of years) to neutralise acid additions before Al and Mn toxicities develop.

Table 2: Approximate amounts of lime required to change the pH by one unit for soils varying in clay and organic matter content.

Soil Texture	Soil Composition		Lime required to increase the soil pH from 5.0 to 6.0 (t/ha)
	% Clay	% Organic Matter	
Clay	70	2	7.4
		4	7.8
Clay loam	34	1	3.6
		2	3.8
Loam	17	1	1.9
		2	2.1
Sand	5	1	0.7
		2	0.9

(3) The third factor causing variation in soil acidification rates is the rate acid is being added to the soil. Under pastures the amount of acid generated in the N and C cycles varies with the amount of nitrate leached, with the amount of product removal, with changes in the soil organic matter level, and with waste product removal to camp sites. Ridley *et al.*, (1990 b,c) and Helyar and Porter (1989) have estimated the amounts of acid contributed by the different processes under subterranean clover/annual grass pastures, and under phalaris/subterranean clover pastures. The results are summarised in Table 3.

Ridley *et al.*, (1990 b,c) estimated acid addition from carbon cycle acids to soils under annual- and phalaris- pastures fertilized with superphosphate, amounted to 40 to 50 percent of the acids added. Nitrogen cycle acids, reflecting nitrate leaching, accounted for the remainder. However the estimate of nitrate leaching is very imprecise as indicated by the range of estimates in Table 3. Contribution of the N cycle acids may be as high as 60 to 80 percent of the total.

The practical message is that it is likely that nitrate losses are in the range 28 to 56 kg N/ha/year, or the equivalent of 100 to 200 kg lime/ha/yr. There is a reasonable probability that losses are greater in situations where periods of cultivation occur in warm moist seasons, where the density of annual pastures is low, and where pH values above 5.0 favour high nitrification rates. Therefore opportunities exist to improve production and to reduce acid addition through improved utilization of soil N. Every 14 kg N saved reduces the amount of lime required to stop acidification by 50 kg.

SOIL ACIDITY AND PLANT YIELDS

Broad guidelines describing the effects of soil acidity on plant yields are given in this paper, with emphasis on pasture species grown in areas with annual rainfall in excess of 500mm. Description of the effects of soil pH on plant yields is not a simple task because the effect of pH on the availability of the main factors that reduce plant growth in acid soils - aluminium and manganese - varies with the soil type. In addition plant varieties can be tolerant of aluminium or of manganese, of both aluminium and manganese, or can be sensitive to both. Lastly, responses of plants

Table 3: Estimates of acid added from the carbon and nitrogen cycles to soils supporting improved pastures.

Source of Acid	Acid Added (kmol/ha/yr)	Lime to neutralise (kg/ha/yr)
i) Carbon cycle acids:	0.4 to 1.5	20 to 75
Increasing soil organic matter* levels under sub./annual and sub./phalaris pastures.		
Waste product removal (90%) plus product removal (10%) for sheep or beef cattle grazed at 10 d.s.e./ha	0.6	30
Contributions for other forms of product removed[f]:		
– milk	0.08	4
– grass hay	0.5	25
– clover hay	0.8	40
– lucerne hay	1.2	60
– cereal grain	0.05 to 0.18	3 to 9
– lupin grain	0.4 to 0.6	20 to 30
ii) Acids from nitrate leaching: (500 to 800 mm rainfall zone).		
N leaching loss estimates for sub./annual grass pastures[#]:		
– low estimate – 7 kg N/ha/yr	.05	50
– probate estimate – 28 – 56 kg N/ha/yr	2 to 4	100 to 200
– high estimate – 84 kg N/ha/yr	6	300
iii) Possible reduction in acidification through reduced N leaching under perennial pastures:		
Phalaris/sub. pastures[#] 14 kg N/ha/yr	–1.0	–50
More "summer-active" perennial grass sub. pastures (*eg.* lovegrass, cocksfoot, fescue)** 28 – 42 kg N/ha/yr	–2 to –3	–100 to –150

NOTES

* Note that this source of acid addition should approach zero once the soil organic matter levels have increased to the new level in equilibrium with the higher plant growth rate of the improved compared with the native pasture. Twenty five to fifty years is required for this change.

f Calculated from the data of Slattery *et al.* (1989).

\# Summarised from data presented by Helyar and Porter (1989), Ridley *et al.* (1990 b,c), and Strong *et al.* (1989).

** There is no direct experimental evidence for these values. They are at best estimates of what may be achievable.

Table 4: Tolerance categories for pasture species to aluminium and manganese.

General tolerance class	Balance of tolerance to Al & Mn	Species and cultivars
Very highly tolerant	Balanced tolerance	Kikuyu, Paspalum, Consul lovegrass, *Microlaena* sp., Rhodes grass
	More tolerant Al	*Themeda sp.*
	More tolerant Mn	-
Highly tolerant	Balanced tolerance	Blackbutt & Satu oats, Cocksfoot, Perennial ryegrass, Maku lotus
	More tolerant Al	*Danthonia racemosa*
	More tolerant Mn	Currency triticale
Tolerant	Balanced tolerance	Tyalla triticale, Phalaris, Fescue
	More tolerant Al	White clovers, Sub. clovers
	More tolerant Mn	Olympic & Matong wheats
Sensitive	Balanced tolerance	Buffel grass
	More tolerant Al	-
	More tolerant Mn	Most barleys, Egret, Eagle & Banks wheat
Highly sensitive	Balanced tolerance	Barrel medic, Lucerne, *Agropyron* sp.
	More tolerant Al	-
	More tolerant Mn	-

to changes in the surface soil pH (0-10cm) varies with changes in the subsurface pH (10-50cm) and with the degree to which the plant depends on subsurface resources of nutrients and water. Because of these effects and other less important factors (*eg.* differences in plant sensitivity to calcium deficiency and direct effects of acid on the growth of *Rhizobia* and plants), soil pH/yield relationships can only be approximate.

These complexities mean that simplified descriptions of the effects of acidity on yield must be qualified. For the purpose of this paper, the general picture of soil acidity effects on yield is shown in Figure 2. Note, that the response curve for plants within one of the general tolerance categories shown on the figure (highly tolerant to highly sensitive) can vary widely around the mean response curve. The arrows on the figure indicate the extent of variations in response curves for different soil types, and differences in the balance of tolerance to Al and Mn .

Table 4 gives guidelines for the tolerance characteristics of the main pasture and crop plants used in acid soil areas. Table 5 lists groups of soils that support characteristically different levels of Al and Mn solubility as the soils acidify. The appropriate response curve for a given species or cultivar depends on the balance of tolerance to Al and Mn and on the soil Al and Mn solubility characteristics, as well as on the general tolerance class. For example if the Mn solubility in the soil is high (Table 5) and the plant is less tolerant to Al than to Mn (Table 4), then the response curve to use (Figure 2) is one lower than the general tolerance class for the species shown in Table 4). A lower response curve is also appropriate for the combination of a soil with high Al solubility and a plant less tolerant to Al than Mn. These examples illustrate the complexities involved in factors determining plant response to lime. More complete description of the

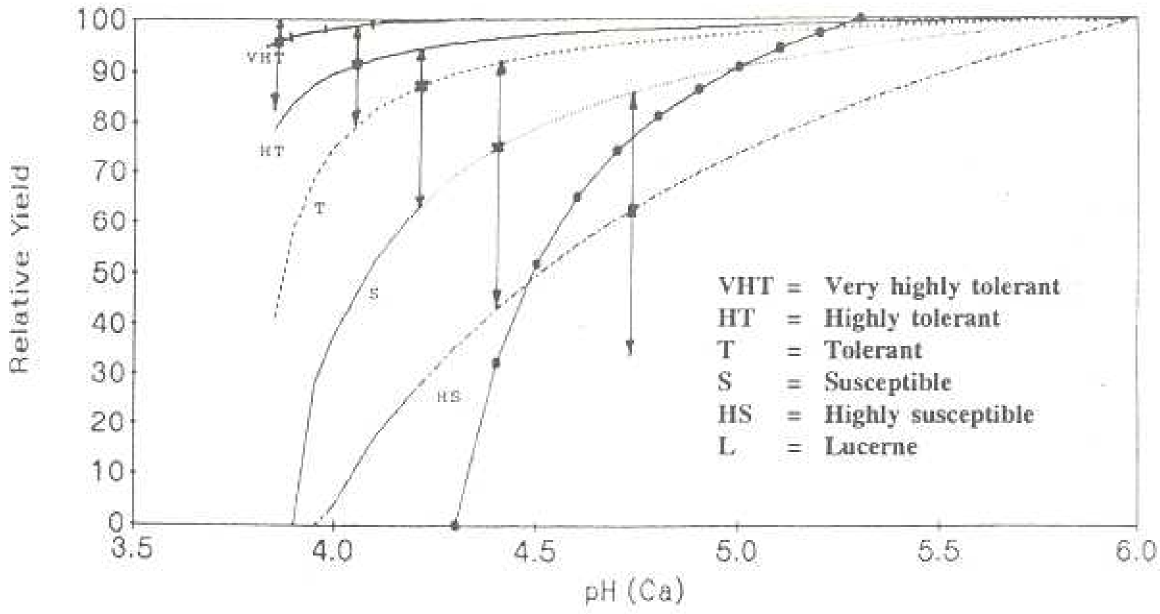


Figure 2: Yield-soil pH relationship for plants with different degrees of tolerance to soil acidity. The arrows indicate variation in responses that occur on soils with different levels of subsoil pH; soils that differ in the solubility of Al and Mn, and for plants in the same tolerance category but which differ in their relative tolerance to Al and Mn.

Table 5: Soil groups that maintain different levels of Al and Mn in solution in acid soils.

Soil group	Al solubility	Mn solubility	Soil types
1	Low	High	Red–brown earths, red earths, podzolised red earths, non–calcic brown soils, grey–brown clays, black earths, chernozems, chocolate soils, prairie soils.
2	Moderate	Moderate	Yellow, brown and red podzolics, yellow and red solodics, xanthozems.
3	High	Low	Acid earthy–sands, sands, podzols.
4	High	High	Kraznozems

subject is available in Agfacts from District Agronomists.

PERENNIAL PASTURES AND REDUCED ACIDIFICATION RATES

Over the last fifteen years losses of nitrate have been suggested as a major contributor to soil acidification of pastures. As outlined above, evidence is slowly accumulating to support this suggestion. It has been found in Southern Australian environments, and in very different plant and climatic environments in Europe and North America, that if plant growth is restricted during warm-moist conditions, leaching of the nitrate formed in the acid nitrification process is likely. Cultivation during warm- moist autumn periods, and the use of annual pastures that are dead over summer, are the main avenues for nitrate leaching in our agricultural systems.

The objective of efficient utilization of nitrogen in the ecosystem can be achieved if plant demand for N is matched to the soil N supply. Nitrate leaching from the root zone means one of two things. Either the soil nitrogen supply exceeds the demand of the plant system when it is growing at it's potential as limited by the climate, or the plant demand is below its potential for some reason. In regard to plant demand for N, perennial pastures are more capable of reaching the climatic potential for growth and hence maximise demand for soil N. They utilize the rainfall and soil nutrient reserves more completely than annual pastures. Perennial pastures also produce a valuable "green pick" in response to small rains in summer, they produce significant quantities of feed from heavier summer rains, and produce feed more rapidly than annual pastures in response to the break of season in autumn. Lastly they dry the soil profile out to a greater depth than annual pastures, thus reducing leaching past the base of the root system, reducing the loss of nitrate accumulated in the dry surface soil over summer, and reducing water addition to the water table - the cause of dryland salting.

In regard to the soil N supply, improving pastures using introduced legumes fertilized with superphosphate, molybdenum, and sometimes other fertilizers, has resulted in greatly increased plant growth and levels of nitrogen fixation relative to the native pastures. At the same time competition betweeen native perennial grasses and vigorous annual clover and grass species aided and abetted by the use of set stocking rather than rotational grazing, has eliminated the native perennial grasses from many pastures. This has created a situation where the supply of soil nitrogen exceeds plant and microbial demand in summer and autumn, leading to nitrate leaching and acidification.

Therefore it is desirable to use perennial species from the standpoints of achieving maximum pasture yields and for reducing nitrate leaching, soil acidification, and water accretion to the water table. Why haven't they been generally adopted? Arguments against the use of perennial grasses in the 500 to 800mm rainfall zone include:

- the difficulty and cost of establishment, particularly in the drier areas and on non-arable land;
- increased difficulty and cost of using rotational grazing rather than set stocking;
- the lack of suitable species and cultivars, illustrated by the problem with phalaris pastures (a species with good characteristics from many points of view), of stopping the development of rank growth in spring with stocking rates able to be supported in autumn and early winter;
- the strong competition between perennial grasses and annual legumes that reduces the legume content of the pasture to low levels (often less than 10%) resulting in nitrogen deficient and low quality pastures.

A number of these issues will be dealt with in other papers. I will deal mainly with the last two because they are directly relevant to soil acidification.

The species that have the greatest potential to reduce acidification of soils that are already acid, are acid tolerant perennial ryegrass and cocksfoot cultivars in the high rainfall areas and lovegrass in lower rainfall areas. There is also evidence that Holdfast phalaris is more tolerant than other cultivars of phalaris. In the future native perennials such as *Microlaena*, *Themeda* and *Danthonia* may contribute strongly on acid soils if varieties sufficiently responsive to N that are also competitive under grazing, can be selected or bred. More acid tolerant cultivars of phalaris, cocksfoot and fescue will increase their usefulness on acid soils. Breeding programs for phalaris are well advanced.

Table 6: Key characteristics of some perennial grass species and cultivars in relation to soil acidity and utilization

Species and Cultivar	Features relative to acidity and N utilization
Phalaris	
● cv Australian, Sirosa, Sirolan	Moderate tolerance to acidity; Poor competitive ability in acid soils.
Holdfast	Poor utilization acid subsoils; Summer dormancy restricts its value as a summer nitrate sink; Winter-spring growth strongly competitive with sub clover.
Cocksfoot	
● cv Currie, Porto	Tolerant to soil acidity; Better than phalaris on acid soils; Still at competitive disadvantage to highly tolerant annual grasses and weeds; More summer active than phalaris, probably better N sink; Winter-spring growth strongly competitive with sub clover.
Perennial ryegrass	
● cv Kangaroo Valley, Ellett, Victorian	Tolerant - highly tolerant to acidity; Adapted to higher rainfall areas; Only moderate summer growth after flowering; Less competitive with sub clover than phalaris or cocksfoot
Lovegrass	
● cv Consol	Very high tolerance to acidity; Presumably highly competitive on acid soils; Summer growth pattern favourable as summer nitrate sink; Growth pattern favours low competition with sub clover; Relatively low digestibility of green leaf but summer green leaf far superior to dry residues of annual pastures.
Fescue	
● cv Demeter, Triumph	Tolerance to acidity similar to phalaris; Most summer active of the European perennials; Restricted to higher rainfall areas.
Native Perennial Grasses	Limited information on growth potentials and management requirements on high N soils; Some are very highly tolerant to acidity (eg. *Microlena* sp., Table 4), so have potential on soils with acid subsurface horizons; Some *Danthonia* sp. and *Themeda* sp. are highly tolerant to Al but less tolerant to Mn toxicity; They may be suited to acid soils without high Mn levels but not recently acidified soils high in Mn; Others highly susceptible to acidity (eg. *Elymus* sp., Table 4) so should be avoided in acid soil areas.

In regard to matching N demand to supply, the perennial grass used needs to be sufficiently summer active to absorb the N mineralised in that season. Secondly, the grass should not be so competitive with the legume that N fixation levels become inadequate to maintain sufficient soil N to support the yield potential dictated by the climate. This frequently occurs with grass pastures dominated by strong perennial grasses such as kikuyu and paspalum in summer rainfall areas, and phalaris and cocksfoot in environments with winter/spring growth seasons. The lovegrass/subterranean clover mixture is an intriguing possibility in the south of NSW. This mix combines the summer growth potential for nitrate utilization, with relatively low grass competition with the legume in winter/spring, thus enabling high rates of N fixation to be combined with efficient utilization of soil N (see current research comparing lovegrass and phalaris pastures at Wagga and Canberra - Johnstone and Lee). Phalaris/lucerne is also a good example of a system that can achieve high N fixation and utilization together, so long as the soil is not too acid for lucerne growth. The contribution of white clover to production on acid soils can also be inhibited if the legume is competing against highly tolerant grasses such as kikuyu or *Vulpia* sp. Because of the imbalance in acidity tolerance between species, lime may be required to maintain a satisfactory legume/grass proportion in the pasture despite minimal responses by either species in pure swards. Alternatively, use of a grass that is less tolerant to acidity than the legume may be a means of restricting the dominance of a very vigorous grass. A legume contribution of about 30 to 40 percent to total pasture growth is a practical guideline, and is close to the level required for fixation of sufficient N to support a total pasture growth rate equal to the climatic potential.

CONCLUSION

The object of minimising soil acidification while maximising pasture production is not impractical. Both objectives involve managing a pasture production system that efficiently utilizes soil nitrogen and water - two of the most important factors that limit pasture production. Matching N supply and plant demand for N are of key importance in achieving the objectives. Perennial grasses play a critical role by providing a consistent means of efficiently utilizing water and nitrogen through the seasons of the year. Major considerations when choosing the best combination of legume and perennial grass for a given situation are the soil pH, climate, lime, and fertilizer needs, species growth patterns and tolerance to acidity, to optimise the legume contribution to pasture growth.

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