THE CHANGING SOIL ENVIRONMENT:

HAVE WE PROBLEM SOILS OR PROBLEM PLANTS?

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Abstract. Soil amendment and plant selection are examined as two approaches to overcoming plant mineral deficiencies or toxicities. The problem of soil acidity in broadacre Australian agriculture is frequently used as an example. It is concluded that both approaches are legitimate and probably complementary. However, in practice overcoming nutrient deficiencies has involved fertiliser addition but not general soil amendment. In overcoming mineral toxicities plant breeding has been more extensively used. Both soil amendment (liming) and breeding for tolerance are seen as complementary approaches to overcoming the problem of soil acidity in our agriculture.

The title of this paper expresses the view that either the plant or the soil alone (and not both) will provide answers to our agricultural problems. I believe that "soil" problems or "plant" problems are better expressed as agricultural production or sustainability problems. This approach enables technical issues to be considered with an ultimate economic overlay. This also permits some rationale for addressing problems within their agricultural context. It is particularly relevant in considering how our agricultural production systems can respond to soil and plant constraints.

In this review I will discuss the use of soil treatment and plant selection and breeding as complementary approaches to improving agricultural production. Where possible I will draw examples from soil acidity or nutrition research in permanent pastures.

Correcting nutrient deficiencies in plants

Nutrient deficiencies in plants can be corrected by soil amendment, addition of nutrients or by selecting more suitable plants. My separation of soil amendment from addition of nutrients is deliberate. Molybdenum (Mo) deficiency can be overcome by adding lime to the soil and decreasing acidity. However, the addition of small quantities of Mo (70 g/ha) can overcome deficiency in subterranean clover pasture and substitute for lime application (Anderson and Moye, 1952; Drake and Kehoe, 1954).

Phosphorus (P) deficiency in pastures and crops is overcome, in practice, by the addition of fertiliser. However the timing of P application to pasture and the method of application to both pastures and crops are intended to meet the P requirements of the plant rather than to 'amend' the soil P status. Examples of plants benefiting from P applied as a band at depths in the soil can be found for crops (Jarvis and Bolland, 1991) and annual medic pastures (Scott, 1973). This highlights the method of application of P as being important in meeting the plant's P requirement. In neither case is P applied in order to elevate the soil P status.

The alternative approach, selecting plants for greater P 'efficiency', has been explored but appears to have made little progress, becoming confused by a wide divergence of opinion over the definition of nutrient 'efficiency' (Blair, 1993). Frequently plants adapted to soils with nutrient deficiencies are able to survive rather than be productive under these deficient conditions.

There are also situations where the addition of nutrients to some soils does not improve their availability to plants. This can be the case with manganese (Mn) deficiency on alkaline soils. In this situation there has been some success in breeding for Mn 'efficient' cereals (Graham, 1988).

Correcting mineral toxicities in plants

Overcoming toxicities of aluminium (Al) and manganese (Mn) on acid soils requires high inputs of lime. However, the amelioration of an acid soil below about 15 cm is prohibitively expensive. Equally, boron (B) toxicity is a problem in some subsoils in South Australia (Cartwright *et al.*, 1984), and its correction by amendment is impractical. It is in these situations that breeding or selecting plants for tolerance is attractive and probably the only realistic course of action.

Tolerances of Al by some species and varieties are given in Table 1. On the tablelands and slopes of NSW, a pasture system based on subterranean clover, ryegrass and cocksfoot is tolerant of aluminium. There

Table 1. Aluminium tolerance of some crop and pasture plants (From Fenton *et al.*, 1993).

Aluminium tolerance category	Plant
Highly sensitive	lucerne and most annual medics
Sensitive	canola
	wheat (*eg*. Vulcan, Sunstar, Rosella, Shrike, Grebe)
	most barley
	buffel grasses
	most phalaris genotypes
Tolerant	ryegrasses
	tall fescue
	white clover
	cocksfoot: Currie and Porto
	wheat (*eg*. Matong, Hartog, Dollarbird)
	subterranean clover
	albus lupins
Highly tolerant	Wana cocksfoot
	Pioneer rhodes grass
	Consol lovegrass
	paspalum
	kikuyu
	Maku lotus
	narrowleaf lupins
	slender serradella
	most oats
	most triticale
	yellow serradella
	cereal rye

may be scope for using other legumes such as serradella and lotus, although these have other soil and management requirements. Breeding within a species (*eg*. wheat) is also possible.

Breeding for tolerance

Breeding for tolerance is only feasible if:

(1) there is a reasonable range of variability within the species;

(2) the character is heritable and some estimate of heritability is available;

(3) there are no strong, undesirable genetic correlations with tolerance; and,

(4) an estimate can be made of the level of improvement attainable in the field.

Breeding has been undertaken in Australia for tolerance of B toxicity in barley (Moody *et al*., 1993) and Al tolerance in wheat (Fisher and Scott, 1987; 1993). In both instances breeding has successfully produced yield increases in field experiments. Similar progress has been made in breeding phalaris for tolerance of Al. Tolerance has been identified (Culvenor *et al*., 1986) and shown to be useful in the field on an acid soil (Oram *et al*., 1993).

Within legumes, progress has been more limited. In this case a tolerant host plant and rhizobia are required and, in association and under stress, they need to produce an effective symbiosis. With regenerating pastures, such as subterranean clover, the rhizobia need to survive in reasonable numbers from season to season in the acid soil. They must then be able to nodulate young clover plants, and form efficiently functioning nodules. This is clearly a more difficult problem than that encountered by grasses.

Tolerance of Al and Mn has been identified in subterranean clover host plants when supplied with mineral nitrogen (Osborne *et al*., 1981). Subsequently, Mn tolerance was identified as a host plant characteristic (Evans *et al*., 1987). The rankings of tolerance of genotypes was similar for plants supplied with mineral nitrogen or reliant on symbiotic nitrogen, suggesting that the symbiosis was not specifically affected.

Subterranean clover cultivars in an acid solution culture system nodulated differently under Al stress. Using the commercial inoculant (WU95), both Dalkeith and Junee nodulated well with no Al stress but, with Al added to solution (40 µm Al), both nodulated poorly (Evans, 1991). With the rhizobium strain NA3001, Dalkeith nodulated well under Al stress. However the usefulness of these tolerances in subterranean clover has not been confirmed in the field.

Relationship between tolerance and lime application

I believe that lime use and plant tolerance of acidity constraints are complementary approaches to a difficult problem. The title of this paper merely emphasises the extremity of opinion which may be expressed.

Some researchers enthusiastically endorse the usefulness of tolerance (*eg*. Vose, 1981,1983; Frey, 1985), while others express doubts. Fox (1980) describes the use of tolerance as like, 'the hazard of flying a low-powered aircraft up a narrow canyon. The course starts easily and the scenery is beautiful, but options run out very quickly, and to continue is to invite disaster'. This view envisages tolerance as an alternative to liming. The concern is that the introduction of a range of tolerant cultivars would negate the need for liming and, in acidifying agricultural systems, acidity problems would intensify unchecked.

However, there are a number of reasons to believe that lime use alone will not be an adequate answer to problems faced in broadacre Australian agriculture. First, economic constraints are real, and lime use can be difficult to justify on short-term (10 year) economic grounds in some pasture situations (Hochman *et al*., 1989). Second, soil acidity can be present in a soil profile below the depth to which lime can be incorporated economically, and this can reduce the rooting depth of sensitive cultivars even in limed situations. Third, variability of the acidity problem across a site results in insufficient lime being applied in some very acid areas following treatment at a single lime rate. Fourth, poor spreading or incorporation of lime may leave areas or portions of soil unlimed. Fifth, liming just prior to sowing may leave young plants exposed to an acidity stress, as the reaction of lime with the soil may be incomplete. Finally, the farmer's practice of 'hedging' or reducing fertiliser rates to less than those recommended may leave acidity problems only partially amended.

I believe that using the plant's tolerance of acidity is an important complementary approach to soil amendment (*eg.* liming), and this is particularly true in the extensive agriculture practised in most of Australia. The adoption of liming is limited by its high cost in Australia in systems which have relatively low profitability per hectare. Table 2 presents data on the cost/value of product over a range of locations and industries. The conclusion is that in the extensive agriculture practised in southern NSW, and with our expensive lime cost, lime use is difficult to justify solely on short or medium term economic grounds.

Results from experiments on cereals in southern NSW demonstrate the relationship which has been observed between Al tolerance and lime application (Figure 1). All varieties responded to the addition of lime, including the highly tolerant Tyalla triticale. The differences in Al tolerance were expressed in the grain yield (both with and without lime addition) rather than in the response in yield to lime addition. The explanation I believe is that the soil below the depth of lime incorporation (0 to 10 cm) was acid at this site and remained acid. Tolerant varieties of cereal presumably were better able to exploit nutrients and water deeper in the profile. Maximum yields were obtained with both lime application and the use of Al tolerant cere-

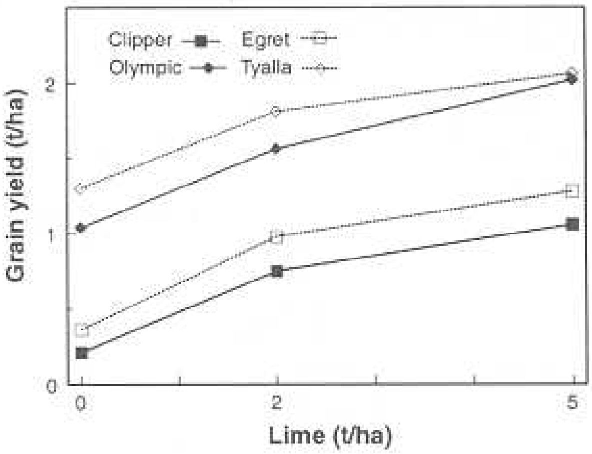

Figure 1. Average yields and the effect of lime on wheat (Olympic, Egret), barley (Clipper) and triticale (Tyalla) over five seasons (1981-1985) at an acid soil site 30 km east of Wagga. The lime was applied as a single dressing in 1981, prior to sowing and was incorporated to about 10 cm depth (from Scott, 1986).

als. Similar results for cereals were obtained in north east Victoria (Brooke *et al.*, 1989).

Oram *et al.* (1993) tested a range of phalaris and cocksfoot cultivars for yield on limed and unlimed plots at Swanpool, Victoria. They concluded that sensitivity to Al toxicity was the primary cause of poor growth of phalaris on acid soils. The genotype AT88, bred for tolerance of Al, gave highest yields on unlimed soil. However, it did not perform as well as Australian and Sirosa when the soil was limed. This interaction was not significant and does not support the contention that Al tolerant cultivars are essentially lower yielding on non-acid or limed soils.

Manganese (Mn) toxicity is also a problem of subterranean clover grown on the acid soils of the south west slopes (Siman *et al.*, 1974; Cregan *et al.*, 1989; Scott and Cullis, 1992). The use of lime is seldom a complete answer for Mn toxicity. Siman *et al.* (1974) point out that extreme climatic conditions can cause

Table 2. Cost of lime as a fraction of product value for various crops and locations (From Hochman *et al.*, 1989).

Crop	Location	Value of product ($/t/ha/year)	Cost of lime[1] ($)	Cost/value (x100)
Lucerne (for hay)	Mayfield, Kentucky, USA	260	33	12.7
Soybean	Crossville, Alabama, USA	595	33	6.5
Corn	Southern Coastal Plain, Virginia, USA	740	33	4.5
Winter wheat	Central Clay area, Netherlands	3551	380	10.7
Potatoes	Central Clay area, Netherlands	9450	380	4.0
Dairy pasture	Volcanic Ash Soils, New Zealand	460	42	9.1
Sheep pasture	'Easy Hill Country', King country, New Zealand	300	71	23.7
Pasture for sheep	Southern Slopes, New South Wales, Australia	211	150	71.1
Wheat	Wagga Wagga, New South Wales, Australia	264	150	56.8

[1]Lime applied at 2.5 t/ha

Mn to become plant available, even after liming. Scott and Cullis (1992) observed elevated Mn concentrations in subterranean clover pastures after liming and suggested that soil Mn below the depth of lime incorporation was also a source of substantial Mn supplies to plants. Breeding for tolerance of Mn appears necessary, even when lime is applied.

Variability of the soil in the 0 to 10 cm layer and variability of lime application and incorporation can conceivably leave some very acid soil sites unlimed following a broadacre lime application. Figure 2 shows the variability in soil pH both before and after lime application. The points to note are that while the unlimed soil has a mean paddock pH of 4.6, many sites are considerably more acid. After liming, the mean paddock pH is near 5.0 but there are 50% of sites more acid than this, and some remain extremely acid (H 4.6). The use of plant tolerance of Al in this limed soil is likely to have benefits in terms of crop or pasture production.

The complementarity of lime use and plant tolerance of Al is more strikingly clear in the case of a deep acid soil. Here the application of lime to the surface layer (0 to 10 cm) is all that can be economically justified. Tolerant plants have more roots in the subsurface soil and can take up water and nutrients in this acid layer. The uptake of nitrate is a process which adds alkalinity. Sensitive cultivars do not have as many roots at depth and are restricted in executing this amendment process.

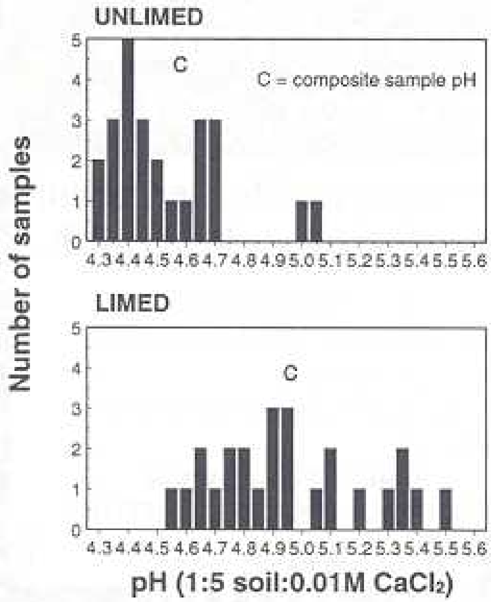

Figure 2. Frequency distribution of pH in a limed and unlimed basaltic soil near Robertson, NSW. The limestone was applied at 5 t/ha by a direct drop machine and incorporated with a dics plough 18 months prior to sampling (from Conyers, 1983)

Conclusions

Changing the soil to suit the plant and changing the plant to suit the soil are both legitimate approaches to solving agricultural production and sustainability problems. In the context of plant nutritional deficiencies, the application of fertilisers is generally pursued, but with the aim of meeting plant requirements rather than 'amending' the soil. Where mineral toxicities exist, both soil amendment and plant selection are used. In the area of boron toxicity, plant breeding alone has been used. In the management of soil acidity both liming and breeding have complementary roles to play.

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