Appendix 2. RECENT METHODOLOGY FOR CORRECTING AL TOXICITY

Since the mid-1960s, the preferred method of making liming recommendations to correct Al toxicity in acid mineral soils has been to base them on the equation:

meq Ca/ 100 g soil = 1.5 meq exch. Al/ 100 g soil,

as recorded by Mohr (1960), Cate (1965), and Kamprath (1970), rather than on liming to a given pH. Nevertheless, Evans and Kamprath (1970), Kamprath (1971), and subsequent workers, includingspain (1976), have indicated that, for many crops, the equation usually grossly overestimates liming requirements, partly because of varying degrees of plant tolerance to Al.

In recent years, Spain (I 976), Rhue and Grogan (I 977), and Salinas (1978) have shown that consistent differences in Al tolerance are found among plant species and cultivars within species. It is evident, therefore, that crop tolerance to Al should be taken into account in estimating the amounts of lime needed to correct Al toxicity. Another problem with the above equation is that it is based solely on the amount of exchangeable Al in the soil; it does not take the levels of exchangeable Ca, Mg, and K already in the soil into account. The level of these exchangeable cations is important in determining liming requirements.

An Improved Liming Equation

In 1980, Cochrane et al. published the following equation for liming acid mineral soils to compensate crop aluminium tolerance and take the levels of exchangeable Ca and Mg in the soil into account:

Lime required
($CaCO_3$ equiv. tons/ha) = 1.8 [Al -RAS (Al +Ca + Mg)/ 100]

in which:

Al	=	meq Al/ 100 g soil, IN KCI extract
Ca	=	meq Ca/ 100 g soil, *IN* KCI extract
Mg	=	meq Mg/ 100 g soil, IN KCI extract
RAS	=	required % Al saturation of the effective cation exchange capacity.

In this equation, the lime requirement estimated by the formula is multiplied by 1-1/3 if it exceeds the value of the meq Al/100 g soil, I*N* KCI extract.

It is noted that:

1. In order to calculate the minimal liming requirement of a soil for a given crop, the RAS will be the same as the percentage of Al saturation at which the crop tolerates soil Al;
2. This formula assumes that the apparent specific gravity of the soil is about 1.2. For a soil with a known apparent specific gravity, a correction may be made by dividing the estimated lime requirement by 1. 2 and multiplying by the known specific gravity.

Virtually no exchangeable Al or soil solution Al is found in mineral soils (containing less than 7% organic matter) with a pH higher than 5.4, as noted by McCart and Kamprath (I 965) and Pratt and Alvahydo (1966). Therefore, the term "acid mineral" soil is used in the context of a soil having a pH less than 5.5 and an organic matter content less than 7%.

In acid mineral soils, soil solution Al and percentage Al saturation are related, as shown by Evans and Kamprath (1970) and Breenes and Pearson (1973). Furthermore, Nye et al. (1961) have shown that the amount of Al in soil solution is low until an Al saturation of about 60% is reached.

Several investigators, including Evans and Kamprath (1970), Abruña et al. (1975), and Sartain and Kamprath (I 975), have shown a close relationship between Al saturation and plant response. Evans and Kaniprath (1970) noted that maize tolerated up to 70% Al saturation compared with 30% for soya bean. Upland rice, cassava, cowpea, groundnut, and many pasture species are tolerant to quite high rates of Al saturation,as shown by Spain(1976). Recently, Salinas (1978) has identified varietal tolerances to Al toxicity in wheat, maize, sorghum, rice, and beans as part of a low-input strategy to manage Brazilian Oxisols.

These concepts were integrated to formulate the equation for liming mineral acid soils. This equation estimates minimal liming needs at different levels of Al saturation. It is clear that lime should only be applied to soils with pH values lower than 5.5, and that it should reduce Al saturation to a level commensurate with the tolerance of the crop to Al. The equations were derived in the following way.

Assuming that all the Al is in the exchangeable form, the following relationship would express the basic liming concept:

$Al_y = Ca_x$ [2]

where:

Al_x = meq of Al/100 g soil replaced by liming in the exchange complex, and

Ca_x = meq of Ca/ 100 g soil added to the exchange complex.

Likewise, in order to calculate the amount of Ca that should be added to the exchange complex to reduce the Al saturation to a given level, the equation:

$$(Al - Al_y)/(Al - Al_y + Ca + Ca_x + Mg) = RAS/ 100 \quad [3]$$

could be used in which:

Al = meq of Al/100 g soil in the original exchange complex;
Al_y = meq of Al/100 g soil replaced by liming;
Ca =meq of Ca/100 g soil in the original exchange complex;
Ca_x = meq of Ca/100 g soil added to the exchange complex;
Mg =meq of Mg/100 g soil in the original exchange complex;
and
RAS = required percentage Al saturation.

By using equation [2], each occurrence of All, in equation [3] can be replaced by Ca_x. Then, solving the resulting equation for Ca_x, gives:

$$Ca_x = Al - RAS\ (AI + Ca + Mg) / 100 \quad [4]$$

Since not all the Al replaced by liming is exchangeable, as emphasized by Kamprath (1970), the right side of the equation should be multiplied by a factor of 1.5 when moderate levels of Al saturation are required, and by a factor of 2 when very low levels are needed. Equation [4] then becomes:

meq Ca/100 g soil
required for liming $= 1.5\ [Al - RAS\ (Al + Ca + Mg)/ 100]$ [5]

where the factor 1.5 is replaced by 2 when the estimated liming requirement using the factor 1.5 is greater than the chemical lime equivalent of the exchangeable Al. This criterion follows from the calculated data. It is clear that the highest lime requirement estimated by the equation is twice the chemical lime equivalent of the exchangeable Al.

Equation [5] was used for estimating field lime requirement, as given by equation [1]. It assumes that a soil has an apparent specific gravity of 1.2; that 1 hectare of soil to the 20-cm depth would weigh 2.4 million kg.

Testing the Equation

Cochrane et al. (1980) tested the equation using data from other authors' field and incubation studies over a variety of soils ranging from North Carolina state in the United States to São Paulo state in southern Brazil. This included Kamprath's (1970) incubation data for four North Carolina Ultisols; L.A. Leon's (CIAT, pers. comm.) incubation data from Colombian Oxisols and Ultisols; field data from a Central Brazilian Acrustox (Salinas, 1978); data from field trials on an Acrustox from Siio Paulo (van Raij et al., 1977); and data from further field trials on a Central Brazilian Acrustox (González-Erico, 1976). It gave a very good estimation of the field-proven lime rates needed to reduce the percentage of Al saturation to a required value.

Soil Analysis for the Equation

The use of the equation requires no soil analysis beyond the 1*N* KCI extraction of Al, Ca, and Mg. There is ample literature on crop tolerance to Al, in terms of percentage of Al saturation, to use as a preliminary guide to make reasonable RAS (required Al saturation in percent) estimates. Additional information is accumulating rapidly. Interestingly, where specific liming trials have been carried out, the equation may be used in a converse sense to estimate the tolerance of a particular crop accession or cultivar.

Summary

The equation synthesizes what has been established to date concerning the problem of Al toxicity in soils to permit a realistic prediction of minimal lime requirements. Inherent to its development was the organization of current knowledge concerning soil Al. The equation should only be used for establishing liming requirements to solve Al toxicity problems. This emphasis is required because liming is also used to reduce excessive amounts of soil Mn, to supply trace elements found as impurities in liming materials, and to make a trace element like Mo more available. (It might be noted that in liming to correct Mn toxicities, soils should be properly drained as a prerequisite for overcoming such problems.)