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LIMING IN ZIMBABWE

A Critical Look at the Potential Recovery from Acid Soil Infertility in the Communal Areas of Zimbabwe

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David K.C. Dhliwayo[1], Linus Mukurumbira[1]
Trust Sithole[1], Happymore Nemasasi[1]
Danisile Hikwa[2] and Tendai Gatsi[2]

[1]Soil Productivity Research Laboratory
Private Bag 3757, Marondera

and

[2]Agronomy Institute, P.O. Box CY 550
Causeway, Harare, Zimbabwe

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Summary

Soil acidity is one of the major biophysical constraints to crop production in the communal areas (CAs) of Zimbabwe. The Diagnosis and Recommendation Integrated System (DRIS) programme has established that many crops in fields with considerable P-fertility build-up respond poorly to fertilizer applications when the soil pH is not corrected. Upon correction of soil pH through liming there is often a substantial increase in NP fertilizer use efficiency as reflected by increased stover and grain yields and nutrient uptake. Maize grain yield increases, ranging from 0.6 t/ha to 2.64 t/ha, were realized on limed plots when compared with un-limed plots. Percent increase in gross margin per hectare ranged from 6 to 68 over the un-limed control.

In Chinamhora CA (a high potential area), 43% of the soils in 1992-94 had pH values (in 0.01M $CaCl_2$) of 4.0 to 4.5 (very strongly acid) compared with just 19% in 1982-84. In 1992-94, 34% of the soil samples were strongly acidic (4.6 to 5.0) compared with 22% in 1982-84. During the same period about 12% of the soils had become strongly acid. Soils with pH values above 5.0, which is the favourable range for most arable crops, had decreased by about 35%. The results indicated potential problems with crop production which include low fertilizer effectiveness in 77% of the soils with pH of 5.0 or less, and Al toxicity and P deficiency in 43% of the soils with a pH of 4.5 or less. For maize production, the granitic sandveld soils of Zimbabwe need to be limed to a pH value of about 4.7 (in 0.01M $CaCl_2$). Based on that criterion, 56% of the soils analysed in 1992-94 needed to be limed compared with 26% in 1982-84. The soil pH decline over a 10-year period is likely to become a major soil fertility constraint to crop production in CAs in the (near) future.

Cattle manure can also raise the pH of sands. Rates of 10, 20, 40 and 80 t/ha cattle manure progressively increased the soil pH, with a high N quality manure (1.29% N) being more effective than a low N (0.65% N) type.

1. Introduction

The use of lime has until recently been almost completely neglected in the communal areas (CAs) of Zimbabwe. Failure to use lime, together with the increased use of acidifying nitrogenous fertilizers during the 1980s and early 1990s, has resulted in a marked increase in acidity of many agricultural soils, particularly in the better rainfall areas (Nyamangara and Mpofu, 1996). Humphreys (1991) reported that the amount of fertilizer used by CA and small-scale commercial farmers increased from 27 113 tonnes in 1979/80 to 110 953 tonnes in 1989/90 mainly due to better access by these farmers to credit facilities to acquire the necessary inputs. However, the apparent increase in the use of fertilizers has not been matched by an increased use of lime to correct soil acidity in CAs.

Soil pH for satisfactory maize growth are known to be higher on the red or yellow-brown soils derived from basic igneous and meta-sedimentary rocks than on soils derived from granite or sedimentary sands (Grant, 1971; Grant, Tanner and Madziva, 1973; Tagwira, 1995). The threshold values for response to lime are pH 4.8 on the former and pH 4.3 on the sands. Manganese toxicity and molybdenum deficiency are possible causes of this difference in lime requirement, and greenhouse studies have shown molybdenum deficiency to be a major growth-limiting factor on a red clay-loam soil (Tanner, 1976) while very high concentrations of manganese have little effect on maize yield (Tanner, 1977a; 1977b).

When soils are cultivated, there is normally a progressive increase in acidity resulting from losses of soil nutrients, mainly through leaching and partly through crop removal (Grant, 1971). This process is greatly speeded up when fertilizers containing ammonia nitrogen are used, and becomes very rapid when heavy dressings of ammonium sulphate are used (Table 1). Acidity will develop particularly rapidly on sandy soils because of their low content of clay and basic minerals (Saunder, 1959; von Burkersroda, 1964; Grant, 1971; Grant, Tanner and Madziva, 1973; Tanner, 1976; Tanner and Grant, 1977). Shallow ploughing, which was reported to progressively increase soil acidity and magnesium deficiency (Grant, Meikle and Mills, 1979) is common practice in the CAs.

Soil fertility tends to decrease progressively with increasing soil acidity as most nutrients become unavailable (Saunder, 1959; Thomas, 1961; Tanner, 1976). Microbiological activity is reduced by quantities of H^+, Al^{3+} and Mn^{2+} (Saunder, 1959). Using regular dressings of lime is a basic principle of good farming, especially on soils that have a low buffering capacity (Cooke, 1975; Nyamangara and Mpofu, 1996). Liming eliminates acid toxicity, improves Ca supply, increases P and Mo availability and ensures optimal bacterial nitrogen fixation (Finck, 1982). Maintenance of soil pH through liming assures optimal conditions for organisms responsible for the decomposition of organic matter and transformation of N, P and S to available forms. However, over-liming may induce trace - element deficiency, especially on acid sandy soils.

Grant (1970a; 1981) reported that the need for lime in CAs was minimal because only small amounts of acidifying nitrogenous fertilizers were used at that time. The other reason was the use of manure, the traditional form of fertilizer, which reduces soil acidity (Grant, 1967; 1970a; Mugwira, 1984). Avila (1987), however, reported that the majority of CA farmers do not own enough cattle to produce adequate amounts of manure to apply to their lands for any significant liming effect.

The liming programme in the commercial agricultural sector in Zimbabwe is large.

Almost all commercial farmers bring their soils for pH testing. They lime their lands to correct the pH in winter in preparation for the following season.

There is, therefore, a strong need to raise the awareness of CA farmers about lime, as was the case with the use of fertilizers twenty years ago. The DRIS programme of the Soil Productivity Research Laboratory has since 1994 revived the use of lime in the CAs of Zimbabwe.

2. Zimbabwe Soil pH Classification

The Chemistry and Soil Research Institute (CSRI) of DR&SS has for some time been using a method of determining soil pH which employs a dilute solution of calcium chloride (0.01M $CaCl_2$) instead of distilled water as in the conventional methods. The calcium chloride method gives much more accurate laboratory results and, more important, it is a truer measure of what the soil acidity will be under field conditions during the growing season (DR&SS, 1974; Rowell, 1994). Table 2 shows a soil pH classification for Zimbabwe. Lime recommendations are based on the range 150 kg/ha to 250 kg/ha lime ($CaCO_3$) on sandy and clay soils, respectively, for every 0.1 pH difference below the optimum pH required (Grant, 1963; DR&SS, 1974; Nyamangara and Mpofu, 1996; Dhliwayo, Sithole and Nemasasi, 1998).

3. Soil Acidity Status in CAs of Zimbabwe

Most of the sandveld soils, on which the bulk of maize is produced in the CAs, are acidic and the Al saturation percent exceeds 20% of the CEC (Grant, 1971: Dhliwayo, Sithole and Nemasasi, 1998). In her studies, Grant (1971) found that 32% of the light coloured soils from siliceous rock and 31% of the red soils derived from basic rocks had pH values of 4.2 or less. In reviewing soil acidity factors affecting maize yields in Zimbabwe, Grant, Tanner and Madziva (1973) concluded that differences in response to lime were associated with Mg and Mo deficiencies and toxicities of Mn and Al; and pointed out that reduction in yield when soils are strongly acid (i.e. pH 4.2 [0.01M $CaCl_2$] or less) should be ascribed to Al toxicity. Informal surveys carried out by the Soil Productivity Research Laboratory (SPRL) in 1994 found that 21% of pale soils sampled from the CAs around Marondera had pH values that suggested potential Al toxicity. Current DRIS surveys of more than 2 900 CA fields indicate that soil acidity is one of the biggest problems in realizing the full potential of crop productivity.

Nyamangara and Mpofu (1996) compiled soil pH and texture results of soil samples submitted by and on behalf of Chinamhora (high potential area) CA farmers to the CSRI in the 1982-84 and 1992-94 periods (Table 3). The number of soil samples submitted for analysis by CA farmers in 1982-84 was relatively small (69) compared with 1992-94 (252). However, the majority of the samples, 62% in 1982-84 and 75% in 1992-94, were either sands or loamy sands. This was expected since the majority of CAs are located on sandy soils that cover two-thirds of Zimbabwe (Grant, 1981). The results showed that 43.25% of the soils in 1992-94 had pH values ($CaCl_2$) in the very strongly acid range (4.0 to 4.5) compared to 18.84% in 1982-84 (Table 3). In 1992-94, 33.73% of the samples were in the strongly acid range (4.6 to 5.0) compared to 21.74% in 1982-84. The remainder of the soils, 23.02% in 1992-94 and 57.97% in 1982-84 had pH values above 5.0 ($CaCl_2$). The data in Table 3 showed that about 24% of arable soils in CAs had become very strongly acid over a 10-year period. During the same period about 12% of the soils had become strongly acid. Soils with pH values above 5.0, which is the favourable range for most arable crops, had decreased by about 35%. The results imply increasing potential problems of crop production. These include low fertilizer effectiveness in 77% of the soils with a pH of 5.0 or less, and Al toxicity and P deficiency in 43% of the soils with a pH of 4.5 or less. The evident soil pH decline over a 10-year period may become a major soil fertility constraint to crop production in CAs in the future (Nyamangara and Mpofu, 1996). According to Grant (1971), for maize production, granitic sandveld soils must be limed to a pH value of 4.7 ($CaCl_2$). Based on that criterion, 56% of the soils analysed in 1992-94 needed to be limed compared with 26% in 1982-84 (Nyamangara and Mpofu, 1996).

In a survey involving eight CAs, Dhliwayo, Sithole and Nemasasi (1998) reported that 69% of the sites sampled had a pH less than pH 4.5 (Table 4). This again, shows the gravity of the soil acidity problem in CAs of Zimbabwe.

4. Soil Acidity and P Fertility Build-up in CAs

In a soil fertility survey in Murewa CA involving 165 farmers serviced by two extension workers, Mukurumbira and Dhliwayo (1996) reported available P_2O_5 in the 0-15 cm soil depth as the differential to establish soil fertility ranges. It was assumed that the resulting groups would indicate P build-up resulting from farmer fertilizer use frequency. Seven soil fertility groups (group 1 through to group 7) with P_2O_5 values of 0-18, 19-30, 31-42, 43-54, 56-66, 67-78 and >80 ppm for Gororo extension area (Table 5) and P_2O_5 values of 0-22.1, 22.2-34.2, 34.3-46.3, 46.4-58.4, 58.5-70.6, 70.7-82.6 and >82.7 ppm for Chikukutu extension area (Table 6) were classified as very poor, poor, bad, average, good, very good and very high for P, respectively. The levels of P_2O_5 in the plough layer of fields in groups 1, 2, 3 and 4 seem to indicate that farmers in these groups used fertilizer sparingly while farmers in groups 5 through to 7 appear to have applied a lot more fertilizer than the others over the years.

When pH values of the fields are considered as an indicator of good soil husbandry, however, it becomes clear that very little or no agricultural lime was used by all groups of farmers (Tables 5 and 6). There were no significant maize yield differences between the different management groups (Tables 5 and 6). Potentially high Al levels at pH values around 4.3 are suspected to interfere with efficient uptake of fertilizer (Grant, Tanner and Madziva, 1973).

Table 7 shows that there were maize grain yield increases ranging from 0.6 to 2.64 t/ha over the un-limed control with lime x fertility demonstration trials conducted at selected sites from Gororo and Chikukutu extension areas in the following 1995/96 season. Per cent increase in gross margin per hectare ranged from 6 to 68 over the un-limed control with one outlier site recording 1206%.

5. Beneficial Effects of Lime

Lime reaction in the soil was found to be rapid, with pH values for a red brown clay changing from 4.5 to 5.2, 5.5 and 6.0 three months after applying 1, 2 and 4 t/ha lime, respectively (Grant, 1970b). For a brown clay loam, pH values changed from 4.3 to 4.55, 4.6 and 5.2 within four months after applying 1, 2, and 4 t/ha lime. If incorporated properly, maximum pH values were reached within the first season after liming. Field trials have indicated that response of maize to lime in Zimbabwe tends to be greater in the second season than in the first and that the added response is related to increased uptake of phosphate by crop plants (Tanner and Grant, 1977). Improved effectiveness may have been due to the time required for completion of slow chemical reactions, or to depth of incorporation, as lime was incorporated by discing to a depth of 0-10 cm or 0-15 cm in the first season, and subsequently ploughed under to 0-30 cm in the second.

In work on the restoration of productivity of depleted sands, Grant (1970b) reported that maize yields were increased by lime and, to a greater degree by manure when these were applied separately, but when lime and manure were applied on the same land, yields were no better than with lime alone. In the same studies, lime also increased the plant population density by about 10%, and extra nutrients from fertilizer or manure increased the proportion of fruitful plants bearing cobs.

Grant (1971) and Grant, Tanner and Madziva (1973) indicated that maize yields are reduced on acid soils where manganese or aluminium is present in toxic amounts or where magnesium, and possibly calcium, is deficient. The reserves of manganese on red soils derived from dolerite or meta-sediments are high and may become soluble in toxic quantities if the soil pH is about 4.8 or lower. Aluminium is released from both granite sandveld soils and from red soils when the pH is less than 4.2. Because of this, Grant (1971) reported results of field trials with maize at 38 sites in which lime increased yields on eight red or brown clay sites, where the pH was 4.8 or lower, and on five granite sandveld sites, with pH 4.4 or lower. At the remaining sites, lime had no significant effect on crop production. Grant, Tanner and Madziva (1973) showed that liming can increase crop yield as imbalances in some of the nutrients such as Mn, Mg and Ca are alleviated (Tables 8 and 9).

In trials on 12 sites with maize, Tanner (1977b) reported that on un-limed plots only, the foliar manganese concentration at four weeks was related to oxalate-extractable Mn (r^2=0.303) and to soluble Mn (r^2=0.183) and was best predicted by a multiple regression including both factors (R^2=0.543). Liming resulted in a marked decrease in soluble manganese that was not accompanied by equivalent decreases in foliar manganese; consequently when data for limed and un-limed plots were combined foliar manganese and soil soluble manganese were not significantly related. Manganese contents of leaves sampled at four weeks and at ten weeks were low (reaching 300 ppm at only one site) and below toxicity levels. Liming decreased leaf manganese concentrations on the most acid sites in the second season after liming but had little effect otherwise.

In a greenhouse study, lime in the absence of molybdenum significantly increased plant mass but did not wholly eliminate molybdenum deficiency symptoms (Tanner, 1976). There was a greater mass increase with molybdenum than with lime and the effects were not additive (Table 10). Plant samples from all the un-limed pots contained well in excess of 1 000 ppm Mn (Table 11). These values are far higher than those normally found in field crops of maize. On acid red clay soils Grant, Tanner and Madziva (1973) reported values of 100-200 ppm foliar Mn. The increased uptake of manganese in pots is possibly due to a salt effect, similar to that described for aluminium by Reeve (1970). Liming decreased plant manganese markedly from an average of 1470 ppm to 210 ppm. The lime x incubation interaction was highly significant as in the absence of lime the seven-week incubation procedure increased plant manganese concentration but in the presence of lime, incubation decreased the manganese concentration. It is possible that the incubation process *per se* may release additional plant-available manganese through dimutation of manganese hydroxides in acid soil, while where lime has been added it allows ageing of the precipitated manganese compounds and a decrease in plant manganese. Application of molybdenum to the soil did not significantly affect plant manganese concentration, despite a three-fold increase in plant mass. The evidence shows that molybdenum deficiency was the most important acidity factor in this red fersiallitic soil and response to lime was due to reduction of molybdenum deficiency. While lime decreased the need for molybdenum treatment through its effects on molybdenum availability, liming alone did not release sufficient molybdenum for optimum growth. Manganese toxicity was not a major factor (Tanner, 1976).

In 13 field experiments, no response to lime or to molybdenum occurred where soil pH ($CaCl_2$) was above 4.8 (Tanner and Grant, 1977). Below pH 4.8 young maize plants developed molybdenum deficiency symptoms, resulting in deaths and reduced plant stand. Molybdenum was equal to or more effective than lime for improving early growth of maize where soil pH was between 4.4 and 4.8 but lime in addition to molybdenum was required at pH 4.3. For grain production, the lime requirement was higher; liming to raise the soil pH to 4.6 was necessary for maximum yield, but molybdenum and lime were equally effective between pH 4.6 and 4.8. On the more acid soils, liming significantly increased foliar phosphate concentrations in a very wet season but not in a normal or a very dry season.

The sorption of phosphate and molybdate by clays and clay loams, measured as the amount sorbed by soil in equilibrium with solutions containing 0.1 μg Mo/ml or 0.2 μg P/ml, was determined on 71 samples from the sites of 13 field trials (Tanner, 1978). The values for Mo-sorption capacity ranged from 6 μg/g in a sandy clay loam of pH 5.85 to 267 μg/g in a clay of pH 4.40 and averaged 125 μg Mo/g soil. At each site, there was a close inverse relation between Mo-sorption capacity and soil pH. However, there were substantial differences in the relation at different sites, and over-all the linear regression of soil pH accounted for only 57 per cent of the variation in Mo sorption capacity. The sorption of molybdate was significantly related to six other factors, namely exchange acidity, exchange capacity, clay content, exchangeable aluminium and dithionite/citrate and oxalate extractable iron, several of which were strongly interrelated. When values were tested with soil pH (linear and quadratic functions) in a stepwise multiple regression technique which included only those factors that contributed significantly to the regression equation it was found that only pH and exchangeable acidity contributed significantly to the regression. The final equation was:

$$\text{Mo sorption capacity } (\mu g/g \text{ soil}) = 1518 - 524 \text{ pH} + 43.65 \text{ pH}^2 + 16.78 \text{ EA}$$
$$R^2 = 0.792$$

The residual variation was not significantly related to any measure of iron, aluminium or manganese oxides or clay; the inclusion of all parameters measured only increased the correlation coefficient to 0.81. Simple regression analysis showed that phosphate sorption was not related to exchange capacity, exchange acidity, clay content and dithionite/citrate extractable iron. These factors were dependent, as shown in the correlation matrix, and when their contribution to phosphate sorption was tested with the stepwise multiple regression procedure, several lost significance. P sorption was best predicted by the equation:

$$P\ sorption\ (\mu g/g\ soil) = 75.18 + 0.1351\ Fe - 0.3312\ Mn + 3.35\ EC$$
$$R^2 = 0.612$$

Phosphate sorption was highly related ($P<0.001$) to exchange capacity, which is a measure of clay colloid activity, and also ($P<0.001$) to iron extracted by dithionite/citrate, while aluminium extracted by dithionite/citrate did not contribute significantly. As changes in soil pH had no effect on phosphate sorption capacity, increased uptakes of phosphate (due to liming) recorded in several field trials (Tanner and Grant, 1977) may be due more to increased effectiveness of the root system and plant uptake than to effects on P solubility in the soil. This is in contrast to the effect of soil pH on molybdate sorption capacity, which causes the well-documented increase of available molybdate with liming (Tanner, 1976; 1978; Tanner and Grant, 1977).

The total sulphur content of maize grain and stover in field trials was studied in relation to yield, variety, soil and fertilizer sulphate, and liming to give an estimate of crop requirement of sulphur (Grant and Rowell, 1976). Lime, which increases the availability of soil-S by decreasing retention on the clay (Jordan and Ensiminger, 1958), increased yield in the absence of sulphur but not when sufficient fertilizer-S was applied. Sulphur concentration in the grain of the unfertilized plots was the lowest recorded at any site, and total sulphur uptake was increased in all seasons by fertilizer-S and in two seasons by liming in the absence of sulphur fertilizer. The effect of liming on sulphur uptake was most marked in the first season when the effect on soil pH was greatest. Results for several sites in that season are shown in Table 12. At most sites liming increased the sulphur concentration of stalks and leaves, and consequently increased total sulphur uptake by 1-1.5 kg/ha S. However, as the increase in uptake was associated with increase in soil pH it did not occur where liming did not raise soil pH sufficiently, as at Trelawney (Table 12).

Tagwira (1995) carried out greenhouse and field experiments to assess the effect of lime and phosphate fertilization on growth, yield, phosphorus and zinc uptake by maize grown on two major agricultural soils of Zimbabwe. In the Chiota (sandveld soil) pot experiment, liming significantly increased total dry matter yield. The highest yield was at pH 4.8 ($CaCl_2$). An increase in pH from 4.4 to 4.8 increased shoot dry matter yield by 25 per cent and 43 per cent where 120 and 240 kg/ha P_2O_5 had been applied. There was no significant increase in yield with lime where P was not applied. In the Gwebi (red-brown clay soil) pot experiment, there was a reduction in yield at pH values beyond 5.9. An increase in pH from 5.9 to 6.8 decreased the shoot dry matter yield by 9 per cent and 10 per cent where 120 and 240 kg/ha P_2O_5 was applied, respectively. Increasing pH in the Chiota soil was observed to significantly increase resin P concentration in the soil solution (Table 13). In the control (0 kg/ha phosphate), a change in pH from 4.5 to 6.3 increased P_2O_5 from 1.5 ppm to 4.2 ppm, while at 240 kg/ha P_2O_5 the increase in P concentration over the same pH range was from 14.2 ppm to 26.7 ppm P_2O_5. An increase in resin phosphate concentration with liming was also observed in the Gwebi soil. There was a general increase in pH in both Chiota and Gwebi soils with liming (Table 14). Application of 1 200 kg/ha lime increased plant tissue phosphate concentration by 122 and 75 per cent in shoots and roots, respectively, in the Chiota soil. In the Gwebi soil, a lime application of 4 000 kg/ha increased plant tissue phosphate concentration by 109 and 55 per cent in shoots and roots, respectively. Change in pH due to liming had a very strong effect on zinc concentration in maize plants. As the pH increased, the concentration of zinc was greatly reduced. In the Chiota pot experiment, a pH change of 0.8 units (from 4.4 to 5.2) reduced the zinc concentration by about 65 per cent in the shoots and by about 61 per cent in the roots. In the Gwebi pot experiment, on the other hand, for a pH increase of 1.0 unit from pH 4.9 to 5.9, there was a decrease in zinc concentration of about 40 per cent in shoots and 50 per cent in roots. Where lime and phosphate fertilizers are applied regular zinc availability will be reduced, hence the need to use zinc containing fertilizers at some stage. In the field experiments at Makosa (sandveld soil) and Gwebi, the yield response to liming observed in this study (Table 15) is probably due to improved nutrient availability, especially phosphate due to liming as also shown by Tagwira (1991).

Liming increased maize grain yields by between 0.2 and 1.6 t/ha in Mangwende CA in the 1997/98 season (Table 16a). In these experiments 40 to 94% additional grain was realized by just liming (Table 16b). Stover yields were increased by 0.3 t to 2.5 t/ha (Table 16c). These increases represent 22 to 91% more biomass over the un-limed crop (Table 16d). The effect of lime might have been more dramatic if the rates had been split into two applications to avoid pushing the buffer capacity to extreme.

6. Cattle Manure and Soil pH

Grant (1967) found that under continuous cultivation an annual cattle manure application of 3 or 6 t/ha increased the fertility of a sandveld soil by progressively increasing the cation exchange capacity, exchangeable bases and pH. Manure was also found to increase exchangeable magnesium at Grasslands Research Station while it decreased where fertilizer was used (Grant, 1970a).

Mugwira (1984) reported the differential effectiveness of manure of different nutrient contents on soil pH. In addition to increasing the nutrient supplying power of the soil, increasing manure rates of 10, 20, 40 and 80 t/ha progressively increased the soil pH (0.01M $CaCl_2$) with the high analysis manure (1.29 % N) being more effective than the low analysis (0.65 % N) type after three crops in the greenhouse. Only the 10 t/ha rate of low analysis manure did not significantly affect soil pH from its original value of 5.0. The pH of the soil was significantly decreased in pots containing the untreated soil and even more so with the application of inorganic fertilizer, as expected.

7. Lime Application Practices

In lime application practice, we need to consider the amount of lime required, timing of application, method/depth of incorporation, frequency of application, place of lime in the rotation, and type of lime materials.

7.1 Amounts of lime required

The degree of acidity of a soil and its immediate lime requirement can only be assessed by a soil test. It is necessary to know the soil pH as well as the type and amount of clay before the correct lime application can be calculated. Haphazard liming should never be attempted, as there is always the danger of over-liming as well as of under-liming. Over-liming can often lead to nutritional disorders since the availability of certain minor elements (e.g. zinc) may be reduced, or to increased disease hazards with certain crops such as potatoes.

Soils must be limed according to soil type to different pH values depending on the relative danger of aluminium or manganese toxicity and magnesium deficiency developing (Grant, Tanner and Madziva, 1973). Sufficient lime must be applied to bring the sandveld soils, and other pale soils derived from rocks with low manganese content, to about pH 4.7. Red soils must be limed for maize whenever the pH value falls to about 4.8 and should be maintained at about pH 5.0 or higher to eliminate manganese toxicity. Sufficient lime must be applied to acid red soils to bring the pH value to about 5.2 (Grant, 1967, 1970a, 1970b, 1971, 1981; Grant, Tanner and Madziva, 1973; Tanner, 1976; 1977a, 1977b; Tanner and Grant, 1977; Tagwira, 1995).

On very sandy soils, 1 t of agricultural lime may raise the pH of the soil in the plough layer over a hectare by 0.5 - 1 unit, while on red clays the same amount may only raise the pH by 0.2 – 0.33 of a unit (Saunder, 1959). Grant (1963) indicated that for every 0.7 unit rise on the calcium chloride scale, 1000 kg/ha of lime is required to a 25cm depth on the sandy soils and 2500 kg/ha on clay soils. Regardless of the initial pH of the soil, 1 t/ha for sandy soils, 2 t/ha for sandy loam, and clay soils brought the soil pH into the 5.2 to 5.8 range (Grant, 1970a, 1970b; Butai, 1987). For every 0.1 pH difference below the optimum pH required, 150 kg/ha lime is required on sandy soils and 250 kg/ha on clay soils (DR&SS, 1974; Nyamangara and Mpofu, 1996; Dhliwayo, Sithole and Nemasasi, 1998).

Magnesium deficiency is most likely on acid sands at about pH 4.3 or lower, and should be corrected by application of up to 500 kg/ha of a magnesium-rich lime such as dolomite or liming slag. Maize production on very acid sands may be limited both by magnesium deficiency and aluminium toxicity, and such soils must be treated with sufficient lime to correct both. Five hundred to one thousand kilograms per hectare of magnesium lime in the first season followed by another 500-1000 kg/ha calcitic lime in the second is the most effective way to improve the lime status throughout the plough zone of leached sands (Grant, 1971).

7.2 Timing of application

It is important to remember that lime is a soil amendment and not a fertilizer (Federal Government Notices, No. 86 of 1961 and No. 43 of 1963). To be of benefit therefore it must not only be applied in amounts sufficient to produce the required effect on acidity but also in sufficient time for this to have largely occurred before the crop is grown (Saunder, 1959). Grant (1971) indicated that lime should be ploughed in or disced in during winter ploughing (3 months before the growing season) to allow pH correction before the next crop. When a heavy application of lime was required to immediately correct acidity, this was best done by splitting it into two and applying in successive seasons to ensure the correction of acidity throughout the plough depth and consequently the pH of the rooting zone to remain satisfactory for a long time. The splitting of lime application, besides correcting pH for a longer time, also reduced the dangers of trace element deficiency induced by applying large amounts of lime (Grant, 1967, 1970a, 1970b, 1971; Butai, 1987).

7.3 Method /depth of incorporation

Because lime is less effective when it is ploughed in than when incorporated by a discing operation, lime should always be mixed into the soil by discing or by rotary cultivation as deeply as possible (Grant, 1970b). This holds true regardless of whether the lime is required for maintenance of soil pH or for immediate remedial reduction of acidity, and farmers should take into account the economy of using lime in the most efficient way compared with the cost and convenience of different methods of incorporation. Ploughing in lime does not reduce acidity at the bottom of the plough layer, but when lime has been incorporated by discing a subsequent deep ploughing redistributes the lime rich layer of soil so that the acidity of the whole ploughed zone is reduced (Grant, 1970a, 1971).

7.4 Frequency of lime application

Farmers should have their soil tested for pH at least once every three years and where crops are grown in rotation lime should always be applied during the season when a crop with high pH requirements is grown (Saunder, 1959; Grant, 1970a, 1971).

7.5 Place of lime in the rotation

The amount of lime to be applied in individual cases will also depend to some extent upon the crop to be grown, but in general a pH of 5.0-6.5 is desirable, the higher values being more suitable for legumes and certain market crops such as brassicas and the lower values for general field crops such as maize and tobacco (Saunder, 1959; Grant, 1967, 1970a, 1970b, 1971; Table 2).

7.6 Type of lime materials

Lime is usually applied in the form of "agricultural" lime (ground limestone rock), which may often be "dolomitic" (contain magnesium as well as calcium carbonate) and which should be reasonably finely ground so that it will react readily with the soil. Industrial "by-product" limes that generally contain burnt or slaked lime (calcium oxides) may also be used. They are just as effective as ground limestone when applied at equivalent rates, but they are temporarily somewhat caustic and should not therefore be applied to growing crops or immediately before planting (Saunder, 1959).

When purchasing an agricultural liming material it is always desirable to ascertain what its neutralizing power is (Farm Feeds and Remedies Act, 1961). This is usually given in terms of the "calcium carbonate equivalent", or the amount of material that has an effect equivalent to that of 100 kg pure limestone.

On Sandy soils, where available magnesium may often be scarce, it is generally desirable to use a dolomitic limestone containing a reasonable proportion of magnesium, say about 10 per cent (expressed as the oxide).

8. Economics of the Lime Technology

Table 7 shows that per cent gross margin (GM) per hectare ranged from 6 to 68 over the un-limed control, with one outlier recording 1206%. When the GM per $ invested analysis is done, it was found that at three sites (Chisaira, Dengezi and Rengton) the GM/$ invested was higher for limed compared with un-limed. However, at four sites (Mukurazhizha, Manyame, Bande and Kamini) the GM/$ invested for limed was lower compared with un-limed, possibly because lime is reported to be more effective in the second season than in the first (Tanner and Grant, 1977). Unfortunately, data to assess the residual effects of lime in the second season to assess the economic benefits over more than one season are not available, and need to be generated.

9. Summary Lime Recommendations

Lime should be ploughed in or disced in during winter ploughing (3 months before the growing season) to allow pH correction before planting the next crop. The small-scale farmers usually plough in the lime due to lack of discing equipment but remix the soil again on re-ploughing prior to seeding the land. Farmers should have their soils tested for pH at least once every three years and where crops are grown in rotation, lime should always be applied during the season when a crop with high pH requirements is grown. Lime application should be split with half the recommended rate being applied during the first year and another half being applied the following season at winter plough since 75% of CA soils are weakly buffered sands and a single heavy dose of lime to correct pH results in severe nutrient imbalances that are unfavourable to crops. In "A Guide to the Meaning of Soil Analysis" (DR&SS, 1974), pH (in 0.01M calcium chloride 1:5 soil and solution ratio) values below 4.5 are "very strongly acid". Values between 4.5 and 5.0 are described as "strongly acid". At these low pH values, severe soil infertility is likely and liming is essential before planting. Dolomitic lime is usually recommended for Mg deficient soils where a field recommendation is required on the spot. The general recommendation is that for every 0.1 pH difference below the optimum pH required apply 150 kg/ha to 250 kg/ha lime ($CaCO_3$) on sandy and clay soils, respectively.

10. Future Research Needs

A lot of work on lime has been done in Zimbabwe. However, some knowledge gaps remain and more research needs to be done in the following grey areas:

- Economics of use of lime, including the residual effects of lime and transport economics.
- Optimal pH values for different field crops with regard to different soil textural classes.
- Research on the policy issue on land degradation is required to enlighten all stakeholders on the restoration of depleted soils in the communal areas.

11. Conclusion

Lime is but one of the factors for good maize production and it will not reduce the need for fertilizers when the reserves of phosphate, nitrogen, etc. in the soil are very low, as they are on most granitic sands. On soils with pH <4.3 and poor buffer capacity, lime application should be split, with half the recommended rate being applied the following season at winter plough. A quick lime requirement determination using the soil pH (0.01M $CaCl_2$) test is adequate for Zimbabwean soils. The use of manure for soil pH amendment is very encouraging especially because it is a resource that most CA farmers may secure.

7. References

Avila, M. 1987. Integrating livestock with cropping systems. In: *Cropping in the semi-arid areas of Zimbabwe.* Proceedings of a workshop held in Harare, 24th to 28th August 1987, and sponsored by GTZ-Cart, Masvingo and AGRITEX, Zimbabwe.

Butai, P.C. 1987. Review of research on fertilizer and soil fertility in Zimbabwe. In: *Proceedings East and Southeast African Fertilizer Management and Evaluation Network Workshop,* 27-29 May 1987. (Eds. H. Ssali and L.B. Williams). IRDC, Nairobi, Kenya.

Chemistry and Soil Research Institute, Department of Research and Specialist Services, Annual Report 1997/98.

Cooke, G.W. 1975. Fertilising for Maximum Yield. 2nd Edition. Granada Publishing, UK.

Dhliwayo, D.K.C., Sithole, T. and Nemasasi, H. 1998. Soil acidity - Is it a problem in maize-based production systems of the communal areas of Zimbabwe? In *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe* (eds. S.R. Waddington, H.K. Murwira, J.D.T. Kumwenda, D. Hikwa and F. Tagwira). Proceedings of the Soil Fert Net Results and Planning Workshop held from 7 to 11 July 1997 at Africa University, Mutare, Zimbabwe. Soil Fert Net and CIMMYT - Zimbabwe, Harare, Zimbabwe. pp. 217-221.

DR&SS, 1974. Department of Research and Specialist Services (DR&SS). *A Guide to the Meaning of Soil Analysis.*

Farm Feeds and Remedies Act 1961. Zimbabwe Government Printers, Harare.

Federal Government Notices No. 86 of 1961 and No. 43 of 1963. Government of Zimbabwe. The Efficient Use of Fertilizers and Lime.

Finck, A. 1982. Fertilizers and fertilization - Introduction and practical crop fertilisation. Verlag Chemie, Weinheim, Germany.

Grant, P. M. 1963. Some factors affecting the growth of soyabeans. *Rhodesia Journal of Agricultural Research* 1:12-17.

Grant, P.M. 1967. The fertility of a sandveld soil under continuous cultivation. Part II. The effect of manure and nitrogen on the base status of the soil. *Rhodesia, Zambia, and Malawi Journal of Agricultural Research* 51:117-128.

Grant, P.M. 1970a. Restoration of productivity of depleted sands. *Rhodesia Agricultural Journal* 67:131-137.

Grant, P.M. 1970b. Lime as a factor in maize production. Part 1. The efficiency of liming. *Rhodesia Agricultural Journal* 67:1-8.

Grant, P.M. 1971. Lime as a factor in maize production. Part 2. The effect of lime on yield and mineral composition of maize plants. *Rhodesia Agricultural Journal* 68(2):1-8.

Grant, P.M. 1981. The fertilization of sandy soils in peasant agriculture. *Zimbabwe Agricultural Journal* 78:169-175.

Grant, P.M. and Rowell, A.W.G. 1976. Studies on sulphate fertilizers for Rhodesian crops. I. Effect of sulphur in fertilizer compounds on the yield and sulphur status of maize. *Rhodesia Journal of Agricultural Research* 14:101-109.

Grant, P.M., Meikle, G.J. and Mills, W.R. 1979. A comparison of plough types and depth of annual ploughing for maize monoculture with varied manuring. *Rhodesia Journal of Agricultural Research* 17:99-119.

Grant, P.M., Tanner, P.D. and Madziva T.J. 1973. Soil acidity factors affecting maize yield in Rhodesia. *Fertilizer Society of South Africa Journal* 1:39-44.

Humphreys A.J. 1991. The Zimbabwe fertilizer market. IFA regional conference for Sub-Saharan Africa, 24 March 1991, Harare, Zimbabwe.

Jordan, H.V. and Ensminger, L.E. 1958. The role of sulphur in soil fertility. *Advances in Agronomy* 10:408-418.

Mugwira, L.M. 1984. Relative effectiveness of fertilizer and communal area manures as plant nutrient sources. *Zimbabwe Agricultural Journal* 81(3): 85-90.

Mukurumbira, L.M. and Dhliwayo, D.K.C. 1996. Using the Diagnosis and Recommendation Integrated System (DRIS) in Zimbabwe. In *Research Results and Network Outputs*. Proceedings of the second meeting of the Soil Fertility Network Group, held at Kadoma Ranch Motel, Kadoma, Zimbabwe, 18-21 July 1995. CIMMYT-Zimbabwe, Harare, Zimbabwe. pp. 127-130.

Nyamangara, J. and Mpofu, S.E. 1996. Soil pH and lime requirement for high potential communal areas of Zimbabwe. *Journal of Applied Science in Southern Africa* 2:77-81.

Reeve, N.G. 1970. Soil acidity and liming in Natal. PhD Thesis, University of Natal, South Africa.

Rowell, D.L. 1994. Soil acidity and alkalinity. In: *Soil Science. Methods and Applications.* Longman Group, UK. pp. 153-174.

Saunder, D.H. 1959. Use of lime to maintain soil fertility. *Rhodesia Agricultural Journal* 56:47-49.

Tagwira, F. 1991. Zinc studies in Zimbabwean soils. D.Phil. Thesis. University of Zimbabwe.

Tagwira, F. 1995. Growth, yield, phosphorus, and zinc uptake by maize as affected by lime and phosphate applications. *Zimbabwe Journal of Agricultural Research* 33:69-82.

Tanner, P.D. 1976. Manganese toxicity and molybdenum deficiency effects on maize grown in an acid fersiallitic red sandy clay loam. *Rhodesia Journal of Agricultural Research* 14:95-99.

Tanner, P.D. 1977a. Toxic effects of manganese on maize as affected by calcium and molybdenum applications in sand culture. *Rhodesia Journal of Agricultural Research* 15:25-31.

Tanner, P.D. 1977b. Uptake of manganese by maize (*Zea mays* L.) in relation to manganese concentration in acid clays and clay loams as affected by lime. *Rhodesia Journal of Agricultural Research* 15:151-161.

Tanner, P.D. 1978. Relations of sorption of molybdate and phosphate by clays and clay loams to soil pH and other chemical factors. *Rhodesia Journal of Agricultural Research* 16:31-41.

Tanner, P.D. and Grant, P.M. 1977. Response of maize (*Zea mays* L.) to lime and molybdenum on acid red and yellow-brown clays and clay loams. *Rhodesia Journal of Agricultural Research* 15:143-149.

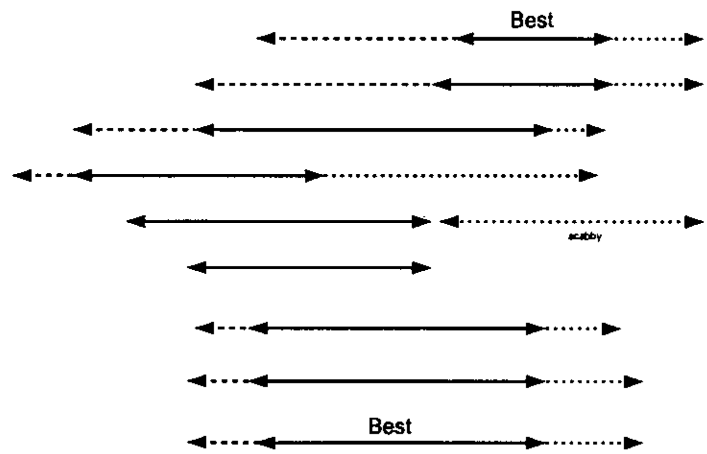
Thomas, R.G. 1961. The need for lime and its correct use. *Rhodesia Agricultural Journal* 58:344-349.

von Burkersroda, K.W. 1964. Fertilising maize in Rhodesia. *World Crops*, June 1964 6 pp.

Table 1. Acidifying effects of nitrogenous fertilizers.

Nitrogen Fertilizer	**Lime requirement**
1 t urea	1.8 t $CaCO_3$
1 t ammonium nitrate	1.8 t $CaCO_3$
1 t ammonium sulphate	5.2 t $CaCO_3$

Table 2. Zimbabwe soil pH classification and soil and crop relationships.

pH (0.01M $CaCl_2$	<4.2	4.5	5.0	5.5	6.0	6.5		7.5
Description	Extremely acid	Very strongly acid	Strongly acid	Medium acid	Slightly acid	Neutral	Alkaline	Strongly alkaline
Occurence	Frequent	Most soils in wet areas when not limed		Soils when limed			On account of presence of free lime	Rare
	Tonnes of lime per hectare to bring pH to 5.0. (Approximate guide)							
Sandy soils	1.2	1.0	0.8	0				
Silt loams	1.6	1.3	1.0	0				
Clay soils	2.0	1.6	1.3	0				
Range of crop tolerance to acidity (pH 5.5 best for most crops)	Sweet clover Alfalfa Cotton Maize Potato Tobacco Soyabean/ groundnut Tomato Wheat and barley							
Soil situation at different pH values	Low availability of: Phosphate (fixed by iron) Calcium (leached out) Potash (leached out) Magnesium Bacteria grow poorly here Fungi thrive Organic matter does not readily accumulate				Best pH for phosphate, Calcium and for Nitrogen fixation by legume organisms, organic matter accumulates here			Phosphates fixed by Ca. Boron, Iron, Magnesium, Manganese and Potash are likely to be very deficient

Recommendation: Lime to a pH as near to 5.0 as possible

Table 3. Soil sample pH ($CaCl_2$) categories for soil samples submitted to Chemistry and Soil Research Institute by CA farmers in 1982-84 and 1992-94.

pH range	1982-84	1992-94
Below 4.0	1 (1.45)	0 (0)
4.0 to 4.5	13 (18.84)	109 (43.25)
4.6 to 5.0	15 (21.74)	85 (33.73)
5.1 to 5.5	21 (30.43)	32 (12.70)
above 5.5	19 (27.54)	26 (10.32)
Total	69 (100.00)	252 (100.00)

Notes: Soil samples in each pH category - number and percentage (brackets)

Source: Nyamangara and Mpofu (1996)

Table 4. Soil acidity status (percentage of sites) in eight communal areas in Zimbabwe.

Communal Area	pH Range			
	4.15-4.19	4.25-4.50	4.57-4.84	5.01-5.61
Mhondoro	15	55	20	10
Chiota	60	30	10	0
Wedza	33	0	33	34
Zvimba	12	48	28	12
Murehwa	80	0	0	20
Nharira	40	30	20	10
Buhera	50	10	40	0
Serima	40	50	10	0
Mean	41	28	20	11

Source: Dhliwayo, Sithole and Nemasasi (1998)

Table 5. Yield data in DRIS fields for Murehwa area, Ngomamowa, Makuvaza, Chinhoyi, Chanetsa wards (1994/95 season); Extension Worker: Gororo. Grouping according to P_2O_5 ranges. Number of farmers sampled = 89; Number of groups = 7

Group	Class	μg P_2O_5/g range	pH value	Grain t/ha	Stover t/ha	% of farmers
1	very poor	0-18	4.33	2.17	2.48	17.98
2	poor	19-30	4.62	2.81	3.22	32.58
3	bad	31-42	4.60	3.16	4.12	20.22
4	average	43-54	4.62	3.43	3.48	15.73
5	good	55-66	4.65	3.33	3.87	3.37
6	very good	67-78	4.50	2.33	3.49	6.74
7	very high	>80	4.66	-	-	3.37

% of farmers on average = 15.73, % of farmers above average = 13.48, % of farmers below average = 70.78.
Source: Mukurumbira and Dhliwayo (1996).

Table 6. Yield data in DRIS fields for Murewa area "44" (1994/95 season) Extension Worker: Ms Chukukutu. Grouping according P_2O_5 ranges, Number of farmers sampled = 76 . Number of groups = 7						
Group	**Class**	**$\mu gP_2O_5/g$ range**	**pH value**	**Grain t/ha**	**Stover t/ha**	**% of farmers**
1	very poor	<22.1	5.99	1.03	1.79	17.11
2	poor	22.2-34.2	5.16	1.99	2.62	39.47
3	bad	34.3-46.3	4.62	1.59	1.90	23.68
4	average	46.4-58.4	4.94	1.42	3.53	6.58
5	good	58.5-70.6	4.53	2.55	2.91	9.21
6	very good	70.7-82.6	4.48	-	-	1.32
7	very high	>82.7	4.37	-	-	2.63

% of farmers on average = 6.58, % of farmers above average = 13.16, % of farmers below average = 80.26.

Source: Mukurumbira and Dhliwayo (1996)

Table 7. Maize grain yields (t/ha), gross margin (GM) and GM per $ invested in the lime x fertility demonstrations trials in Murewa in 1995/96 season.

Farmer	**Grain yield t/ha**		**pH before liming**	**Yield gain t/ha**	**GM/ha ($)**		**% increase in GM/ha over unlimed**	**GM/$ invested ($)**	
	Limed	**Unlimed**			**Limed**	**Unlimed**		**Limed**	**Unlimed**
Mukurazhizha	5.80	5.20	4.40	0.60	14 541	13 719	6	2.75	3.37
Chisaira	7.35	4.90	4.98	2.45	19 842	12 693	56	3.75	3.12
Manyame	4.52	3.57	5.02	0.95	10 164	8 145	25	1.92	2.00
Dengezi	3.92	1.37	5.08	2.55	8 112	621	1 206	1.53	0.15
Bande	6.09	5.25	4.74	0.84	15 533	13 890	12	2.93	3.42
Rengton	7.19	4.55	4.11	2.64	19 295	11 496	68	3.64	2.83
Kamini	4.70	3.80	4.35	0.90	10 779	8 931	21	2.04	2.20

All fields were limed to pH 5.20
Compound D (8N: $14P_2O_5$: $7K_2O$, 6.55) applied at 300 kg/ha at $6 220/t
Ammonium nitrate (AN) (34.5%N) applied at 75 kg N/ha at $6 330 / t AN.
Lime: $1.00/kg (cost, transport)
Assumption: For lime users, for 900 kg lime /ha, one requires an additional grain yield of 137 kg/ha to cover cost and transport of lime and labour to apply the lime.

Selling price of maize: $3 800/t (moderate grade)

Table 8. Effects of liming on an acid red-brown clay-loam derived from dolerite near Marondera.

Parameter	**Control**	**Limed**
Lime applied, kg/ha	Nil	6 000
Soil pH	4.60	5.60
Exchangeable Mn, ppm	62	28
Leaf Mn, ppm	86	68
Leaf Mo, ppm	0.20	0.18
Yield, t/ha	5.32	6.92
Stand, plants/ha	21.900	30 00
Grain / plant, g	250	235

Source: Grant, Tanner and Madziva (1973)

Table 9. Effect of magnesian limes on magnesium status of acid granite sands.

Lime applied kg/ha	Soil pH	Exch Mg me%	Leaf Mg %	Yield t/ha
Pale grey sand in Kwekwe CA				
Nil	4.3	0.06	0.14	4.16
400 Mg lime, (5 % Mg)	4.5	0.11	0.16	4.59
400 Mg Lime + 800 calcite	5.2	0.12	0.19	4.75
Yellowish-grey loamy sandy in Holdenby CA				
Nil	4.0	0.04	0.05	1.26
2 000 liming slag, (2% Mg)	4.8	0.25	0.15	3.50

Source: Grant, Tanner and Madziva (1973)

Table 10. Effects of molybdenum and lime on the mass (g) of young maize plants.

Mo applied, ppm	0	1	10	100	Significant effects
No lime	3.5	13.3	13.0	14.6	Lime**
Lime	11.8	11.8	14.4	15.3	Mo***
Mean	7.7	12.5	13.7	14.9	Lime x Mo **

S.E. (body of table) = 0.8
S.E (means) = 0.6
***Significant at P≤ 0.01; *** significant at P≤0.001*
Source: Tanner (1976).

Table 11. Effects of molybdenum, lime and pre-incubation on the Mn concentration (ppm) in young maize plants.

Mo applied, ppm		0	1	10	100	Mean	Significant effects
No lime (pH 4.2)	Incubated	1835	1465	1750	1550	1650	Lime***
	Not	1650	1175	1135	1200	1280	
Mean		1720	1320	1445	1375	1465	Lime x Incubation**
No lime (pH 5.6)	Incubated	155	120	150	190	150	
	Not	130	310	335	320	270	
Mean		145	215	240	255	210	

S.E. (body of table) = 150
S.E. (means of Mo treatment) = 106
S.E (means of incubation treatment) = 75
***Significant at P ≤ 0.01; *** significant at P ≤ 0.001*

Source: Tanner (1976)

Table 12. The effect of liming on sulphur content at harvest of maize plants grown without sulphur fertilizer.

Site and available sulphate	Lime applied kg/ha	Soil pH		Sulphur concentration, ppm S			Total uptake kg S/ha
		0-30cm	0-30cm	Leaf	Stalks	Grain	
				Fersiallitic clay soils			
Gwebi	0	5.01	5.07	740	410	850	8.0
(29 ppm S)	2 000	5.61	5.55	900	480	820	9.3
Glendale I	0	4.83	4.94	600	190	750	4.9
(3 ppm S)	2 000	5.32	5.08	770	250	750	6.5
				Granite sands			
Umvukwes	0	4.57	4.47	600	300	870	5.4
(10 ppm S)	1 000	4.76	4.68	710	360	920	7.0
Trelawney I	0	5.21	4.97	760	340	1050	6.9
(11 ppm S)	1 000	5.25	5.08	710	390	1020	6.8

Source: Grant and Rowell (1976)

Table 13. Effect of pH change on P availability in Chiota soil.

pH	Phosphate applied (kg/ha P_2O_5)	Resin P_2O_5 (ppm)
4.5	0	1.5
4.5	120	6.3
4.5	240	14.2
4.8	0	2.0
4.8	120	7.4
4.8	240	20.0
5.3	0	2.8
5.3	120	9.1
5.3	240	22.6
6.3	0	4.2
6.3	120	11.9
6.3	240	26.7
Significance pH		**

$^{**}P<0.01$

Source: Tagwira (1995)

Table 14. Effect of soil pH on P concentration of maize shoots and roots.

Lime applied (kg/ha)	Chiota pot experiment (%P)		Gwebi pot experiment (%P)	
	Shoots	Roots	Shoots	Roots
0	0.167	0.163	0.101	0.191
600 (2 000)	0.303	0.198	0.217	0.270
1 200 (4 000)	0.344	0.223	0.238	0.273
2 400 (8 000)	0.351	0.234	0.261	0.275
Lime	**	*	**	*

( ) = Lime rates for Gwebi soils
$^{*}P<0.05$; $^{**}P<0.01$

Source: Tagwira (1995)

Table 15. Effect of lime application on yield of maize.				
Fertilizer rate (kg/ha)	**Maize yield (tonnes/ha)**			
	Makosa	**Gwebi Year 1**	**Gwebi Year 2**	**Gwebi Year 3**
0	1.71	5.15	6.74	3.40
800 (2 000)	2.05	5.95	8.63	3.88
3 200 (8 000)	2.21	4.89	7.20	3.64
Significance				
Lime	*	*	***	NS

( ) = Lime applied to Gwebi trials
*NS = not significant; *P<0.05; *** P < 0.001*

Source Tagwira (1995).

Table 16a. Maize grain yield increase (kg/ha) over the no lime control in Mangwende communal area in 1997/98.

Farmer/Site	**Grain yield increase over the no lime control[a]**			
	No lime	**≥pH5.2**	**pH on Al^{3+} titration**	**25 t/ha manure**
Zinhu	(990)	968	889	1349
Dzama	(283)	195	330	917
Nyandoro	(437)	940	729	1332
Magwenzi	(87)	1116	905	891
Chibanda	(83)	943	1328	1651
Chirodza	(203)	1146	1434	1836
Makombe	(493)	387	279	849
Zangaziko	(170)	1549	1350	2306

[a]Figures not bracketed indicate treatment increase over the control.

Table 16b. Percent maize grain yield increase over the no lime control in Murehwa communal area in 1997/98.

Farmer/Site	**Grain yield increase over the no lime control[a]**			
	No lime	**≥pH5.2**	**pH on Al^{3+} titration**	**25 t/ha manure**
Zinhu	-	49	47	58
Dzama	-	41	54	76
Nyandoro	-	68	63	75
Magwenzi	-	93	91	91
Chibanda	-	92	94	95
Chirodza	-	85	88	90
Makombe	-	44	36	63
Zangaziko	-	90	89	93

Source: Chemistry and Soil Research Institute Annual Report (1997/98)

Table 16c. Maize stover yield increase (kg/ha) over the no lime control in Murewa communal area in 1997/98.

Farmer/ Site	Grain yield increase over the no lime control[a]			
	No lime	≥pH5.2	pH on Al^{3+} titration	25 t/ha manure
Zinhu	(1133)	707	316	498
Dzama	(877)	654	929	1180
Nyandoro	(503)	1198	1084	1695
Magwenzi	(397)	806	779	1025
Chibanda	(290)	2816	2541	3464
Chirodza	(760)	1439	1697	2066
Makombe	(987)	866	545	1116
Zangaziko	(1057)	2509	2016	4175

[a]Figures not bracketed indicate treatment increase over the control.

Table 16d. Percent maize stover yield increase over the no lime control in Murehwa communal area in 1997/98.

Farmer/ Site	Grain yield increase over the no lime control[a]			
	No lime	≥pH5.2	pH on Al^{3+} titration	25 t/ha manure
Zinhu	-	38	22	31
Dzama	-	43	51	57
Nyandoro	-	70	68	77
Magwenzi	-	67	66	72
Chibanda	-	91	90	92
Chirodza	-	65	69	73
Makombe	-	47	36	53
Zangaziko	-	70	66	80

Source: Chemistry and Soil Research Institute Annual Report (1997/98)

Soil Fertility Network for Maize-Based Cropping Systems in Malawi and Zimbabwe

Soil Fertility Network Coordinator
CIMMYT Maize Research Station
P.O. Box MP 163
Mount Pleasant
Harare, Zimbabwe

The University of Zimbabwe Farm
12.5 km Peg
Mazowe Road

Phone: (263) 4 301807
Fax/Phone: (263) 4 301327

E-Mail: CIMMYT-Zimbabwe@cgiar.org
S.Waddington@cgiar.org