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CHAPTER 7
GENERAL DISCUSSION

7.1 EFFECT OF AMENDMENTS ON SOIL CHEMICAL PROPERTIES

Because the fruits of groundnut develop underground, they are just as vulnerable to direct effects of soil acidity as the roots are, thereby necessitating an assessment of the effects of acidity both in the pod zone (0 – 10 cm soil depth) and root zone (20 – 30 cm soil depth) environments of groundnut. Results reported in Chapter 2 showed that with the exception of the control, gypsum (G) and superphosphate (SSP) treatments, lime treatments increased the soil pH in both soil depth layers at the two sites. The pH was raised more in the pod zone than the root zone. The largest pH increases were recorded in the 4000 kg ha^{-1} calcitic (CL) or dolomitic lime (DL) treatments. Combining gypsum and/or SSP with 2000 kg ha^{-1} CL did not affect soil pH differently than applying the lime alone.

In pot experiments reported in Chapter 3, gypsum increased the soil pH by up to 0.48 units, whereas CL and DL increased the soil pH by up to 1.28 and 1.48 units respectively. The small effect of gypsum on soil pH is most probably due to the "self liming" effect which hypothesizes that alkalinity is produced by ligand exchange that takes place between the added SO_4^{2-} and OH^- groups (Sumner, 1993). SO_4^{2-} adsorption neutralizes the positive charge present in acid soils, and generates a negative charge until the surface reaches a new zero point charge. This process determines the effect of gypsum on soil pH (Mora *et al.,* 1999). In this study, the small changes in soil pH due to gypsum application may imply the presence of a low positive charge in the acid soil, resulting in limited exchange between the SO_4^{2-} and OH^- ions.

The observed dissipation of the effects of ameliorants on soil pH by the third season, particularly in the pod zone supports the hypothesis that the groundnut plant is more exposed to soil acidity in the pod zone than in the root zone. Over the three seasons, the root zone pH values in the 4000 kg ha^{-1} lime treatment declined by 0.1 to 0.2 units at HRC, and 0.2 to 0.7 units at MES. In comparison, the decline in the pH values in the pod zone was by 0.9 to 1.0 units at HRC, and 0.6 to 0.8 units at MES. Scott *et al.* (1999) have reported a relationship between the rate of pH decline in the 0-10 cm soil depth with the pH increase achieved after lime application: the higher

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the initial pH increase after lime application, the faster the rate of the decline and *vice versa*. Similarly, in this study, the decline in soil pH was more pronounced at MES where initial increases in pH of >2.0 units had been observed. This may imply that it will be more advantageous to apply lower rates of lime regularly.

The overall effects of the different Ca sources on soil N, P, K, Ca and Mg levels have been demonstrated in field experiments reported in Chapter 2 and in pot experiments reported in Chapter 3. The ameliorants did not cause any appreciable changes in soil N, P and K levels. However, the improved mineral N levels observed in the pod zone in the second season, particularly in the limed plots, may be a reflection of the influence of lime on groundnut productivity during the previous season, resulting in more crop residues on some plots. The absence of any treatment effects on soil P content could partly be attributed to the adequacy of plant available P in the soils at both sites. The soil K levels in this study are considered too low for production of groundnut, which requires not less than 80 mg K kg^{-1} soil for optimal yields (Swanevelder, 1998). Therefore, potassium fertilization may be necessary to improve plant available K in the soils used in this study. The observed K changes in the root and pod zones due to the excreting of root-absorbed K through the pods have implications on the K-fertilization programmes in cropping systems that include groundnut. Shallow-rooted crops can be sequenced with groundnut so that the shallow-rooted crops can utilize the recycled K.

Significant increases in soil exchangeable Ca and Mg levels were observed with application of CL or DL, and the higher the application rate, the greater the increase. Gypsum application increased exchangeable Ca levels, but not Mg, whereas in the SSP treatment the Ca and Mg levels were generally not different from the control treatment. Most of the residual effect of the applied ameliorants on exchangeable Ca was found in the root zone, which agrees with the soil pH levels in that zone. This suggests that in this sandy soil most of the Ca applied will be leached out of the pod zone into the root zone within about three years after application.

The most consistent effect on soil acidity amelioration by gypsum was one of increased exchangeable Ca, whereas CL and DL increased soil pH and exchangeable Ca and Mg levels. The effects of applied ameliorants on soil N, P and K content were not always consistent, making

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the interpretations of improved plant growth difficult. Overall, the soil pH levels in the control, gypsum and SSP-treated plots were below the optimum levels (pH 5.5 to 6.2) for groundnut growth (Gibbons, 1980). The K and Mg levels were also limiting. The suggested optimum soil Ca levels for Spanish-type groundnuts are around 125 mg kg^{-1} (Cox *et al.,* 1982). In view of that, the Ca levels in the pod zone were adequate in all but the control plots at both sites, and the gypsum and SSP-treated plots at MES.

7.2 EFFECT OF AMENDMENTS ON PLANT MINERAL COMPOSITION

The response trends of the leaf nutrient concentrations generally reflected the soil nutrient status. The direct and residual effects of ameliorants improved soil Ca and Mg levels, so did they improve the leaf Ca and Mg levels. Magnesium concentrations were within the established sufficiency ranges in all treatments, whereas adequate leaf Ca concentrations were mostly observed in plants growing in limed plots. The direct as well as residual effects of the applied ameliorants on leaf N, P and K concentrations were not significant, just like they were not significant for soil N, P and K levels. However, the concentrations of N and P in the shoots appeared to be adequate for unrestricted growth of groundnut, whereas K concentrations were deficient. The tendency for the leaf nutrient content to reflect the soil nutrient status demonstrates the value of leaf nutrient analysis for purposes of diagnosing nutrient deficiencies.

Despite the significant effects of applied ameliorants on the exchangeable Ca content of the soil, the kernel Ca content was not influenced to the same extent. The kernel Ca concentrations were within sufficiency levels in all but the control, gypsum and SSP treatments. Application of the ameliorants significantly influenced the kernel Mg concentrations, but had small and variable effects on N, P and K concentrations. The shell nutrient concentrations showed clearer and consistent responses to application of ameliorants, particularly Ca. It therefore appears that analysis of the shells rather than the kernels will give a more reliable indication of the soil Ca status.

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7.3 EFFECT OF AMENDMENTS ON GROWTH, PRODUCTIVITY AND QUALITY OF GROUNDNUT

The direct and residual benefits of application of ameliorants were manifested in improved plant stands, better growth, nodulation, productivity and quality of groundnut. From the pot experiments it was observed that increasing the Ca application rates of CL, DL and gypsum up to 403 kg ha^{-1} elicited the best effects on growth and productivity of groundnut. The better growth in the lime treatments appeared to be the result of the synergistic effects of favorable soil pH and Ca levels. Despite the reduced nodulation in the gypsum treated plots, growth was not retarded, and neither did the plants show any clear N-deficiency symptoms. Overall, the influence of the ameliorants on vegetative growth of groundnut was of the order CL>DL>G.

At equal Ca application rates, groundnut kernel yield from the gypsum treatment was comparable to that obtained with lime, particularly dolomitic lime. The similar yields appeared to result from the influence of gypsum on yield components. Results from the pot experiments showed that plants in the gypsum treatment had the highest proportions of mature pods per plant, sound mature kernels and shelling percentage, and the least percentage of pops. All these parameters influence kernel yield. These results confirm the superiority of Ca from gypsum in improving groundnut quality because of the higher solubility of gypsum. The higher yields in the CL treatment compared to gypsum are attributed to the added advantage of lime not only increasing the Ca and Mg status, but also creating favorable conditions by reducing toxicities of H, Al and Mn, if present.

Over the three seasons of the field experiments the yield responses to applied ameliorants were consistent, with the highest yields being obtained from the CL or DL treatments. It appears that the changes in soil Ca content were largely responsible for the observed increases in yield. The reasons for higher increases in yield in the second and third seasons compared to the first are not obvious. However, it is probable that in addition to the influence of seasonal variations in rainfall amount and distribution, there were additional benefits from application of the ameliorants such as improved Mo availability, more crop residues, improved microbial breakdown of organic matter and other spin-offs that would only manifest themselves after some time.

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Despite the various significant correlations between kernel yield, yield components and soil parameters, path coefficient analysis proved an effective tool for isolating the specific causes of poor groundnut growth on acid sandy soils. Pod number was the most important determinant of kernel yield, while plant stand and percentage of pops were the least important plant parameters influencing kernel yield. This implies that management strategies that increase number of pods per ha should be adopted. The soil parameters observed to be highly correlated with kernel yield were pH and Ca at both sites, in addition to Mg at MES. The greatest influence of soil pH on plant parameters was on plant stand, whereas Ca and Mg influenced the other plant parameters more than plant stand, leading to the conclusion that poor groundnut yields on the acid soils at both sites are largely caused by deficiencies of Ca and Mg, and by low pH *per se*.

7.4 GENOTYPIC VARIATION IN NUTRIENT USE EFFICIENCY

The study on variation in efficiency of nutrient uptake and utilization by groundnut genotypes showed that there are genetic differences in groundnut yield potential and nutrient utilization efficiency. The genotypes that were able to extract more nutrients from the soils generally produced high yields. Since the adaptation of plants to acid soils requires highly efficient uptake and/or utilization of nutrients, particularly Ca, Mg and P (Marschner, 1995), identification of genotypes with greater tolerance to low soil levels of these nutrients has potential to improve groundnut productivity on acid soils. It is suggested that the most appropriate parameter to identify groundnut genotypes with high yield potential in acid soils is Ca use efficiency in kernel production. It should, however, be realized that genotypes more efficient in the uptake/utilization of nutrients like Ca, Mg, P, Mo, provide only an interim solution to the acid soil problem. Ultimately, liming to ameliorate acid soil infertility will be essential to sustain productivity.

7.5 EFFECT OF PH AND CA ON VEGETATIVE AND REPRODUCTIVE PRODUCTIVITY

In this study, low pH *per se* did not have a major impact on the final germination of groundnut seed, given that germination percentages as high as 86% were attained at pH 3.0. However, the slower germination observed at low pH suggests that the imbibed seeds in the soil could have been more vulnerable to soil fungal and bacterial pathogens, leading to reduced seedling

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establishment. This assertion is supported by the highly significant path coefficients relating soil pH to plant density reported in Chapter 2.

Low soil pH was shown to significantly influence the seedling survival and early growth of groundnut, with the adverse effects more pronounced in the absence of Ca. Seedlings survived best in the pH range 5.0 - 6.0. Seedling growth (root and shoot dry mass, root length and root surface area) was also best in the pH range 5.0 - 6.0. Rooting environments low in exchangeable Ca present a hostile environment for root proliferation, and any increase in soluble Ca is likely to promote rooting (Hanson, 1984). Thus, the poor root growth observed at low solution pH and Ca concentrations would be expected because high H^+ concentration in the root zone interferes with nutrient uptake (Foy, 1992). Competition between H^+ with Ca on absorption sites may induce Ca deficiency, which results in inhibited root growth as a consequence of reduced mitosis and cell elongation (Rost-Siebert, 1985),

There were substantial increases in kernel Ca content as the pH was increased from pH 4.0 to 7.0, and adequate kernel Ca concentrations were observed at pH levels ≥ 5.0. The increases in kernel Ca concentration as the pH was increased from pH 4.0 to 7.0 perhaps reflect increased abundance and longevity of pod hairs as the pH increased. While peg and pod hair initiation took place at low pH, the longevity of the hairs was short. At pH 5.0 and above, hair density was higher, and the hairs lived longer, which could most likely improve Ca uptake by the reproductive structures during the crucial pod initiation, pod expansion and seed embryo formation stages, hence production of healthy pods. However, the increases in kernel Ca content with increasing pH could also result from a reduced amount of the H^+ ion in competition with Ca for uptake by the developing pods.

Low pH levels of 3.5 in the pod zone had detrimental effects on pod initiation and development. The effects included delayed pod expansion, which could be alleviated to some extent by increasing the solution Ca concentration from 500 to 2000 μM (Chapter 5). The significant delay in pod expansion caused by low pH could reduce the number of mature pods per plant at harvest. With pod number being the most influential determinant of kernel yield (Chapter 2), the

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importance of adopting management practices to improve the proportion of mature pods per plant cannot be overemphasised.

Microscopic examinations of the excised seeds showed that normal embryos were formed at pH 5.0 and above. This result is of importance to the smallholder farmers who recycle groundnut seed for several years, as it partly explains the poor crop stands generally observed in their fields. Planting poor quality seed in soils with low soil pH values could also exacerbate the poor crop stands (see Chapter 2). The occurrence of necrotic embryonic axes at low pH could be the result of Ca deficiency or caused by nutrient complexities in the pod zone associated with the low pH. The importance of maintaining favourable pH levels in the pod zone by applying lime is clear.

7.6 IMPROVEMENT OF SEEDLING SURVIVAL THROUGH SEED PELLETING OR PRIMING WITH CA

The advantages of treating seed (either pelleting or priming with Ca) to improve seedling survival and early growth were demonstrated. Pelleting or priming the seeds significantly reduced seedling mortality. Of all the Ca sources used to prime the seed $CaSO_4$ was the most effective. Significant improvements in numbers of surviving seedlings were obtained with concentrations as low as 250 μM Ca.

The advantage of pelleting over priming the seed was manifested in improved overall plant growth (dry mass production, leaf development and leaf area). However, priming had the advantage of earlier germination and complete emergence in a short period. The top layer of sandy soils dries easily, thereby reducing plant stands of seeds that take long to germinate. On these soils, seed priming would be beneficial in improving plant stands. Overall, lime pelleting was superior to gypsum pelleting, although the differences were not statistically significant.

7.7 CONCLUSIONS

- This study has shown that there is potential for improving productivity of groundnut on acid sandy soils of the smallholder-farming sector of Zimbabwe by applying Ca-containing materials to ameliorate soil acidity. Application of the Ca materials resulted

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in increases in soil pH, which in turn significantly increased concentrations of Ca and Mg in the soil, leaves, kernels and shells of groundnut, but had small or variable effects on N, P and K concentrations. Annual applications of 200 kg ha^{-1} gypsum and 250 kg ha^{-1} SSP were not as effective as the traditional liming materials in ameliorating acid soils in which nutrient deficiencies and low pH *per se* are limiting groundnut growth and productivity. The observed rapid dissipation of the lime effect on soil pH implies that most of the Ca applied would be leached from the pod zone in a period of three years, thereby necessitating reliming. Application of lime at 2000 kg ha^{-1} was as effective as combining the same rate with either gypsum or SSP, implying that the combinations would impose an unnecessary cost burden.

- While calcitic and dolomitic lime were superior to gypsum in improving the vegetative and reproductive growth of groundnut, gypsum was superior in improving pod and kernel quality of groundnut, thus supporting the argument for dusting short-season groundnuts with gypsum in order to improve kernel quality.

- Path coefficient analysis identified the reasons for poor growth on the acid soils at HRC and MES as deficiencies of Ca and Mg, and low pH *per se,* and showed that pod number was the most influential determinant of kernel yield, implying that management strategies that increase number of pods per ha should be adopted.

- Variation existed among groundnut genotypes in yield, nutrient efficiency ratio (NER) and nutrient use efficiency (NUE) when grown on acid sandy soils. However, use of nutrient efficient genotypes to increase crop production should be augmented with judicious use of lime and fertilizers so that sustainable groundnut productivity on acid soils can be achieved.

- Use of the split-medium technique, in conjunction with pod culturing in nutrient solutions enabled a better assessment of the separate effects of pH and Ca in the pod zone. Results on the effects of pH and Ca on early growth and productivity of groundnut support the hypothesis that the direct toxicity of the H^+ ion concentration *per se* causes poor seedling

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establishment, growth, yield and quality of groundnut. The negative effects are aggravated by the absence or low Ca supply. These results imply that growth and productivity of groundnut can be improved in strongly acid soils if adequate Ca is made available to the germinating seed, and to the developing pods.

- Pelleting seeds with $CaCO_3$, or priming with $CaSO_4$ appeared to provide sufficient Ca to enable groundnut seedlings to establish better in acid soils.

7.8 RECOMMENDATIONS

- With the magnitude of the yield responses and economic returns to lime demonstrated in this study, it is clear that the practical solution to poor groundnut productivity on acid sandy soils is to apply either calcitic or dolomitic lime. It is suggested that smallholder farmers cropping on acidic soils be encouraged to invest in lime, arguably still one of the more affordable inputs, in order to improve and maintain groundnut productivity. For those farmers who cannot afford to purchase the lime, amelioration of acid soil infertility using modest annual applications of gypsum or super phosphate is the most attractive ameliorative strategy for economic reasons.

- It is suggested that the breeding lines 106/96 and 418/93 that had high nutrient use efficiency (NUE) and nutrient efficiency ratios (NER) when grown on acid soils could be used in breeding programs screening for tolerance to soil acidity. This work needs to be carried out in conjunction with research on agronomic strategies to improve nutrient use efficiency in groundnut cropping systems so that sustainable groundnut productivity on acid soils can be achieved.

- The persistence and density of the pod hairs during the crucial pod initiation stage is envisaged to ensure adequate Ca supply, which would result in normal pod development. Studies on the genetics of peg hair formation and persistence at low pH would go a long way in assisting the plant breeders to improve the tolerance of groundnut to Ca deficiency.

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- Efforts to optimise conditions for better seedling establishment in acid soils by providing starter Ca to the seed should be further investigated for consideration in situations where adequate lime cannot be applied. Furthermore, studies are needed to establish whether the effects of seed priming and pelleting observed during the early vegetative stages will persist into the reproductive stage.