CHAPTER 3

EFFECT OF CALCIUM SOURCE AND APPLICATION RATE ON SOIL CHEMISTRY, GROWTH, NUTRIENT COMPOSITION AND YIELD OF GROUNDNUT IN AN ACID SANDY SOIL

3.1 INTRODUCTION

The economic constraints to the use of liming materials in the smallholder-sector make it necessary to know their effect on crop yields as well as their potential benefits to the soil resource, namely the changes in soil properties that are expected to result from various rates of application. Studies have shown that the addition of Ca-containing materials to soil not only changes the chemical and physical properties of the soil, but also affects the availability of nutrients to plants (Simard *et al.,* 1988; McLay & Ritchie, 1993; Mora *et al,* 1999). The effects of these materials on the chemical composition of the soil solution, and on availability of both macro- and micronutrients differ with the material, and also with the soil type. Consequently, it is necessary to understand, and be able to predict the effects of Ca-containing materials on soil solution composition of the soils, and the resultant effects on plant growth.

Commercial liming materials containing various proportions of carbonates, hydroxides, and oxides of Ca and Mg, have been used for centuries to increase the pH of agricultural soils (Adams, 1980). **C**alcitic limestone ($CaCO_3$) or dolomitic limestone ($MgCO_3.CaCO_3$) are the most common amendments used to ameliorate acid soil infertility. Application of these materials to a soil results in a number of direct effects (increased Ca and Mg content in the soil; increased soil pH) and indirect effects as a result of improved pH like improved P and Mo availability, decreased Al concentration in soil solution, decreased availability of Mn, Cu, Fe and Zn (Ahmad & Tan, 1986; Fageria *et al.,* 1990). While liming is largely done to neutralize the acidity of the plough layer, it can simultaneously provide adequate Ca for maximum yield of groundnut when incorporated into the pegging zone before planting (Hodges *et al.,* 1993).

Gypsum (Ca SO_4), although not an inherently acid-neutralizing compound like limestone, has been shown to be a valuable soil amendment that can increase Ca and decrease Al activity in acid soils. While gypsum does not change the soil pH much, the dissociated sulfates (SO_4^{2-}) from gypsum combine with detrimental Al^{3+} ions to form aluminum sulfate that is less phytotoxic (Evanylo, 1989**;** Ismail *et al.,* 1993; Sumner, 1993). When applied to the soil surface, gypsum was shown to be more effective than surface applied limestone in improving crop yields on soils with acidic subsoils in Brazil, South Africa, and the United States (Shainberg *et al.,* 1989; Sumner 1993). In groundnut, the use of gypsum has been widespread because of its ability to supply readily available Ca to the developing pods (Snyman, 1972; Walker, 1975; Cox *et al.,* 1982; Hodges *et al.,* 1993).

A simultaneous increase in soil pH, Ca and Mg levels can be achieved by the use of lime. Though not liming materials *per se*, gypsum ($CaSO_4$) and single superphosphate [$Ca(H_2PO_4)_2.CaSO_4$] are compounds that can be applied to raise the status of Ca and Mg in soils, but their effects on soil pH depend on the soil type. Considering that the beneficial effect of gypsum and SSP application in acid soils is in part due to the increase of soil Ca, one way to evaluate this benefit in soil acidity amelioration is to compare them with limestone applied in equivalent amounts of Ca.

Differential effects of liming on nutrient availability in highly weathered soils have been reported (Haynes, 1984). This study hypothesised that applications of Ca-containing materials to groundnut may introduce imbalances of other nutrients in the soil because of either reduced solubility in the soil solution due to increases in pH, or uptake inhibition by Ca and/or Mg. Caution is needed to avoid inducing deficiencies of other essential nutrients when applying Ca/Mg-containing materials to ameliorate soil acidity for groundnut production.

The objective of this study was to apply various rates of calcitic lime, dolomitic lime, gypsum and single superphosphate to an acid sandy soil and observe (a) changes in soil pH and chemical composition and (b) subsequent growth and productivity of groundnut.

3.2 MATERIALS AND METHODS

A greenhouse experiment to study the effects of different Ca sources on an acid soil was set up at Harare Research Station during the summer period in 1999 and repeated in the summer of 2000. Soil was collected from the top 0 - 30 cm of an acid medium-grained sandy soil from a previously cultivated but unlimed field in the Mhondoro Communal Area in Natural Region II of Zimbabwe. Mean annual rainfall in this region is 750 to 1000 mm. The farmer articulated that groundnut yields had steadily declined over the past ten years, and attributed the decline to droughts and the fact that the soil is exhausted.

Four sources of calcium namely, calcitic lime, dolomitic lime, gypsum and superphosphate were used as liming materials. A brief description of the Ca sources is given in Chapter 2.

3.2.1 INCUBATION EXPERIMENT

To determine the influence of Ca sources on availability of soil nutrients, an incubation test was conducted on the soil collected from Mhondoro Communal Area during the summer period in 1999. The soil was air-dried and sieved through a 2 mm stainless steel sieve prior to being weighed in 3 kg samples that were placed into polythene bags. Four levels each of calcitic lime (CL), dolomitic lime (DL) and gypsum (G) to supply the equivalent of 115, 209, 380 and 690 kg ha^{-1} Ca were thoroughly mixed with the soil. Other treatments were single superphosphate (SSP) applied at 53 kg ha^{-1} Ca (a higher Ca equivalence required application of very high rates of SSP, which would result in toxic levels of P) or combined with CL, DL or gypsum. This resulted in a total of 17 treatments, including a control treatment in which no Ca-material was applied (Table 3.1). The amounts of ameliorants to be applied were calculated on the basis of application per ha to a depth of 30 cm. The statistical design for the experiment was a completely randomised design, with four replicates.

The soil was incubated at field capacity in the polythene bags for one week at 22^{o} C. Distilled water passed through a deioniser was added as and when required to keep the soil at field capacity. After incubation, samples (300 g) of soil from 0 to 5cm and 7 to 12cm depths from each bag were combined to make a composite sample. The samples were air dried and stored for subsequent chemical analysis. Soil pH was determined in calcium chloride ($CaCl_2$) solution, while phosphorus was extracted with bicarbonate using the Olsen method, and measured by the method of Murphy and Riley (1962). Exchangeable cations (K, Ca, and Mg) were extracted with 1*M* ammonium acetate; K was determined by flame photometry, while Ca and Mg were analysed by atomic absorption spectrophotometry. Mineral N was determined by the semi-micro Kjeldal procedure followed by steam distillation (Bremner & Mulvaney, 1982).

Table 3.1 Treatments applied in the incubation experiment and greenhouse experiment in 1999/2000 and 2000/01.

TREATMENTS IN 1999/2000			**TREATMENTS IN 2000/01**		
Treatment		**Ca rate Kg ha^{-1}**	**Treatment**		**Ca rate kg ha^{-1}**
1.	Calcitic lime	115	1.	Calcitic lime	115
2.	Calcitic lime	209	2.	Calcitic lime	403
3.	Calcitic lime	380	3.	Calcitic lime	690
4.	Calcitic lime	690	4.	Dolomitic lime	115
5.	Dolomitic lime	115	5.	Dolomitic lime	403
6.	Dolomitic lime	209	6.	Dolomitic lime	690
7.	Dolomitic lime	380	7.	Gypsum	115
8.	Dolomitic lime	690	8.	Gypsum	403
9.	Gypsum	115	9.	Gypsum	690
10.	Gypsum	209	10.	SSP	53
11.	Gypsum	380	11.	SSP + Calcitic lime	743
12.	Gypsum	690	12.	SSP + Gypsum	743
13.	SSP + Calcitic lime	743	13.	Control	0
14.	SSP + Dolomitic lime	743			
15.	SSP + Gypsum	743			
16.	SSP	53			
17.	Control	0			

3.2.2 GREENHOUSE EXPERIMENT

The experiment was conducted between November 1999 and April 2000, and repeated during the same period in the 2000/01 season. Ten kilogrammes of the same soil as that used in the incubation experiment was placed in each pot after being air-dried and passed through a 2 mm stainless steel sieve. In the 1999/2000 season the soil was treated with the same Ca sources and rates (17 treatments) as in the incubation experiment. In 2000/01, three levels each of calcitic lime, dolomitic lime and gypsum were applied to supply an equivalent of 115, 403 and 690 kg ha^{-1} Ca. Other treatments were single superphosphate applied at 53 kg ha^{-1} Ca or combined with CL or gypsum. This resulted in a total of 13 treatments, including a control treatment in which no Ca-material was applied (Table 3.1). Each pot received initial starter nitrogen equivalent to 20 kg ha^{-1} N as ammonium nitrate, and pre-planting applications of P, K, Zn, and Fe as per soil analysis.

Three uniform sized seeds of Spanish groundnut cv. *Falcon* were sown in each pot at a depth of 25 mm. The seeds were not inoculated with *Bradyrhizobium* spp. Ten days after emergence, the seedlings were thinned to one per pot. Throughout the duration of the experiment, the plants were watered using distilled water passed through a deioniser.

At peak flowering stage plants from three replicates were harvested to determine the effects of the treatments on leaf nutrient composition and vegetative growth of the groundnut. The youngest fully expanded leaves (YFEL) were sampled to determine uptake of N, P, K, Ca, and Mg. Each plant was separated into shoots (stem and leaves) and roots. The roots from each pot were washed over a 500µm sieve to ensure retrieval of most roots. The shoots and roots were oven-dried at 80^{o} C for 48 hrs to determine dry mass. The total number of nodules per plant was recorded, and the dry weight of nodules determined. In the 1999/2000 season the plants were harvested before physiological maturity, so only pod dry mass was determined. In 2000/01, in addition to pod yields, kernel yields as well as quality characteristics were also determined. Nutrient concentrations in the shells and kernels were determined. A nitric perchloric acid (HNO_3:$HClO_4$) digestion of the plant material was used to prepare all the plant samples for analysis.

Soil samples were taken at peak flowering from 0 - 5cm and 7 - 12cm depths in each pot, and mixed to make a composite sample. The samples were air dried and stored for subsequent chemical analysis. The chemical analyses were similar to those described for the incubation experiment.

The statistical configuration for the experiment was a completely randomised design with seven replicates. All data were subjected to analysis of variance or regression analysis using the General Linear Models procedure on SAS statistical software (SAS, 1996). The Duncan's least significant difference (LSD) test was used to separate treatment means.

3.3 RESULTS AND DISCUSSION

The initial chemical properties of the soil used in the experiments are shown in Table 3.2.

Table 3.2 Initial properties of the soil used in the experiments

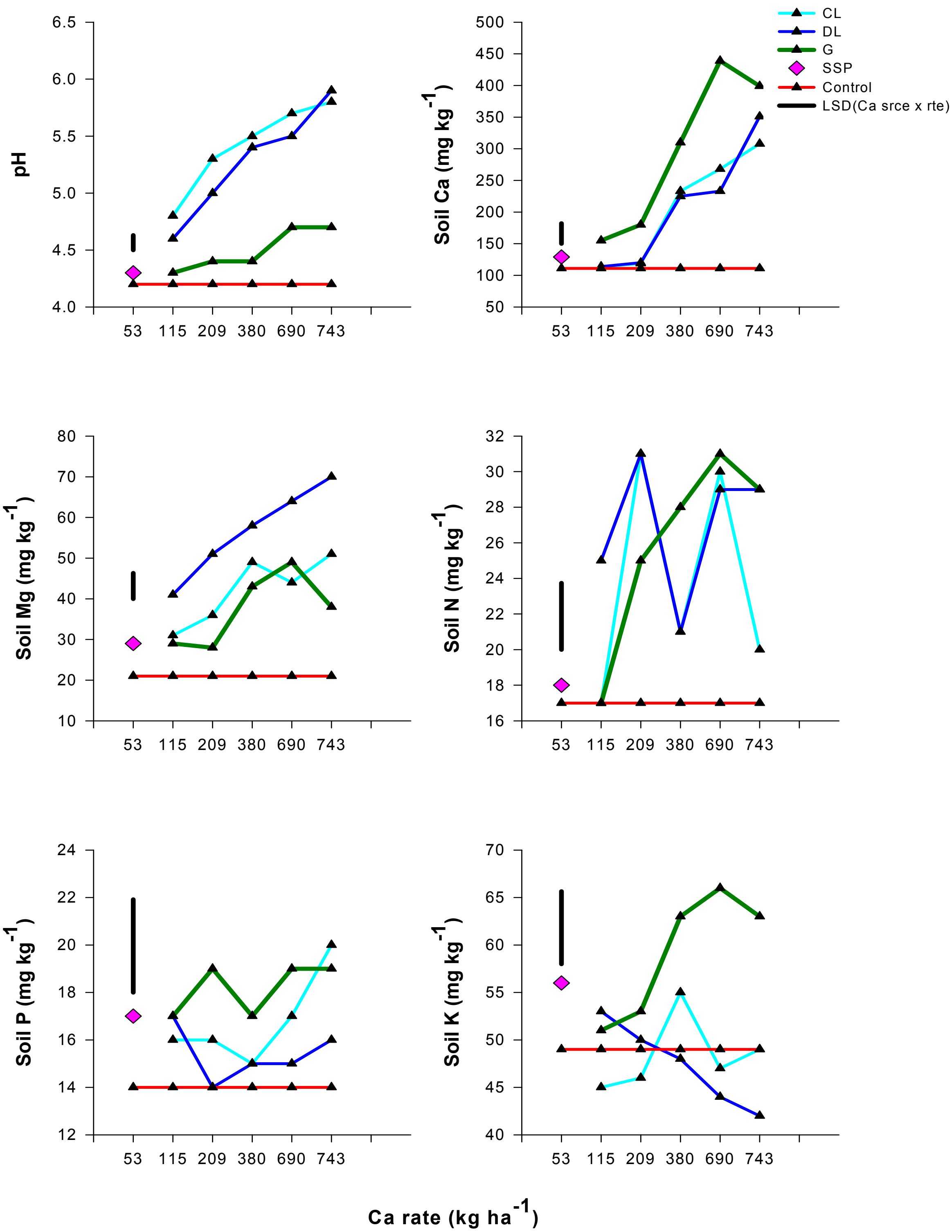
pH($CaCl_2$)	Soil nutrient level (mg kg^{-1})					Al^{3+}	Clay	Silt	Sand
	Ca	Mg	N	P	K	(mg kg^{-1})	(%)	(%)	(%)
4.1	92	25.6	18	14.4	44.7	0.044	4	3	93

The soil was extremely acid and low in N, P and the basic elements (Ca, Mg and K). At this pH level bacteria grow poorly while fungi thrive, and organic matter does not readily accumulate (DR&SS, 1974). The low soil pH value is probably a consequence of low levels of bases in the soil, since soil pH is largely determined by the amount of these bases in the soil (Adams, 1984). The nutrient status of this soil implies that macronutrient deficiency would be the major growth-limiting factor.

3.3.1 EFFECT OF THE CA SOURCES ON SOIL CHEMICAL PROPERTIES

a. Incubation experiment

Results of the chemical analysis after incubation are shown in Figure 3.1. Application of gypsum had the least effect on pH, whereas application of CL and DL significantly increased the soil pH.



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or DL or G @ 690 kg ha^{-1}.

Figure 3.1 **Effect of Ca source and rate on soil pH, Ca, Mg, N, P and K after a 7-day incubation period**

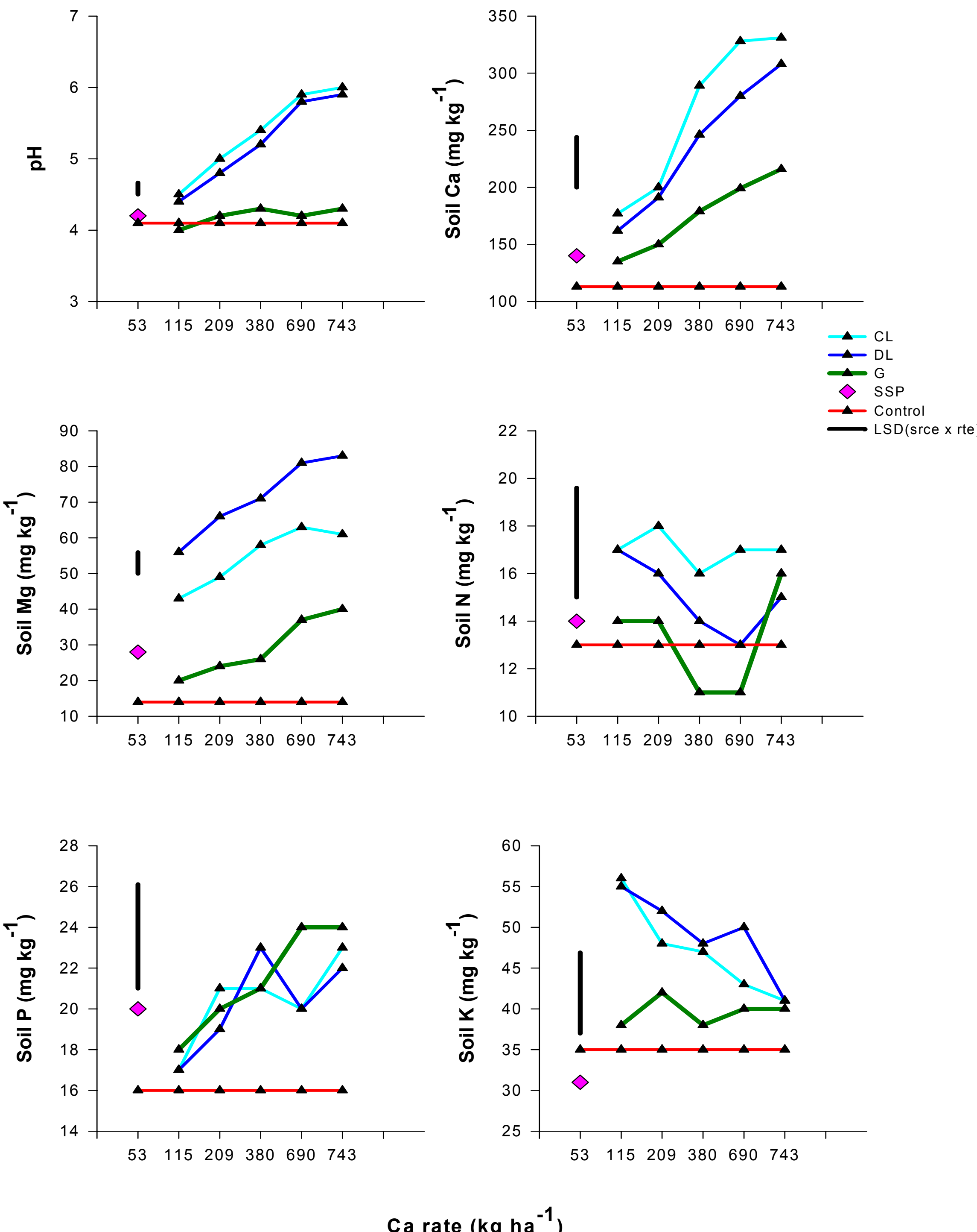
Gypsum application increased the soil pH by 0.08 to 0.48 units, whereas CL increased the soil pH by 0.61 to 1.28 units, and DL by 0.34 to 1.48 units. Similar effects were observed when the Ca materials were applied in combination with SSP. Single superphosphate on its own did not increase soil pH owing to its low Ca content together with low application rate (53 kg ha^{-1} Ca). For all the Ca materials increasing the application rate from 115 to 690 kg ha^{-1} Ca significantly increased the soil pH. Overall, application of CL or DL showed a rapid influence on the soil pH after one week of incubation. This could be attributed to the fineness of the liming material and the thorough mixing of the lime with the soil, which would ensure swift reaction with the soil.

Application of the different Ca sources resulted in significantly increased concentrations of Ca as the rate of applied Ca increased from 115 to 690 kg ha^{-1}. The increase in Ca concentration was highest with gypsum, despite similar Ca application rates of the three Ca sources. This could be explained by the high solubility of gypsum compared to the other Ca sources. The combination of SSP with lime increased the soil Ca levels more compared to application of lime alone. This could be attributed to the higher rate of Ca application (743 kg $ha^{-1)}$ in the treatment combinations compared to 690 kg ha^{-1} when the sources were applied individually. Soil Mg concentration was highest with application of DL, and increased with increase in the rate of DL applied. Mineral N and available P content were improved by application of the amendments, whereas exchangeable K levels were significantly affected by application of higher gypsum rates.

b. Greenhouse Experiment

1999/2000 and 2000/01 seasons

In the 1999/2000 season the soil pH values at the peak flowering period of the groundnuts ranged from 4.1 in the control treatment to 6.0 when SSP was combined with CL (Figure 3.2). With the exception of the SSP and the gypsum treatments, there was generally an improvement in pH for most of the treatments compared to the control. The largest pH increases were recorded from treatments in which either CL or DL was applied in combination with SSP. When similar rates of Ca were applied, DL and CL had similar effects on soil pH, although the values were slightly higher for the latter. Gypsum applied on its own did not have an effect on soil pH at all application rates. Similar treatment effects were observed in the 2000/01 season, with the largest pH increases recorded from treatments in which either CL or DL was applied either alone or in combination with SSP (Appendix Table A3.1).



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or DL or G @ 690 kg ha^{-1}.

Figure 3.2 **Effect of Ca source and rate on soil pH, Ca, Mg, N, P and K at peak flowering period of groundnut in 1999/2000 season**

Varied effects of gypsum on soil pH have been documented. Sullivan *et al.* (1974) observed a decrease in soil pH by 0.4 units after application of 673 to 1346 kg ha^{-1} gypsum. Other studies have observed increases in soil pH after gypsum application, and attributed the phenomenon to a self-liming effect resulting from the dislocation of OH^- by SO_4^{2-} on the surface of soil particles, or if the H^+ originating from the hydrolysis of Al^{3+} does not exceed the release of OH^- (Alva *et al.*, 1988; Noble *et al.,* 1988; Alva *et al.*, 1991; Carvalho & van Raij, 1997). Mora *et al.* (1999) state that gypsum application may decrease, increase or not affect soil pH depending on how close the soil pH is to zero point charge. The latter regulates pH changes produced by ligand exchange when SO_4^{2-} displaces OH^- on the surface of soil particles. Carvalho & van Raij (1997) explain that beside the ligand exchange reaction, Ca^{2+} displaces H^+ and Al^{3+} (which suffer hydrolysis, liberating H^+). Therefore, the effect of gypsum on soil pH will depend on the magnitude of occurrence of these reactions. The effect of pH on pod development is examined in Chapter 5.

The mean exchangeable Ca content of the soil in the control plot was 113 mg kg^{-1} in the 1999/2000 season (Figure 3.2), and 104 mg kg^{-1} in the 2000/01 season (Appendix Table A3.1). In both seasons, a significant increase in exchangeable soil Ca levels was obtained by increasing the application rate of CL and DL, and the increases were higher with the former. The higher Ca content of the CL treated soil could be expected since CL contains 23% Ca compared to 18% in DL. Gypsum application also significantly increased the levels of exchangeable Ca, but the increases were of a lower magnitude compared to CL and DL. This result is at variance with the earlier observations in the incubation experiment, and can be attributed to Ca leaching because of the higher solubility of gypsum than lime. It could also be due to increased uptake of Ca by the plants because (a) gypsum is more efficient than lime in providing Ca and (b) gypsum does not produce additional cation exchange sites that make Ca inaccessible to the plants (Evanylo, 1989). These phenomena would result in faster depletion of Ca in the gypsum plots.

In the 1999/2000 season, the level of exchangeable Mg in the control treatment was 14 mg kg^{-1}, and was increased up to 27 mg kg^{-1} in the gypsum treatment, 63 mg kg^{-1} in the CL treatment and 81 mg kg^{-1} in the DL treatment (Figure 3.2). Application of the Ca sources in 2000/01 season increased the exchangeable Mg content from 21 mg kg^{-1} in the control treatment to 82 mg kg^{-1} in the DL treatment (Appendix Table A3.1). In both seasons, significant increases in the soil Mg levels were observed as the application rate of CL and DL increased from 115 to 690 kg ha^{-1} Ca, and the increases were higher for DL. Increasing the gypsum application rate did not result in significant increases in the soil Mg levels. The lower Mg status in the CL and gypsum treated soil could be expected, since application of 690 kg ha^{-1} Ca as CL supplied 216 kg ha^{-1} Mg, while gypsum applied at the same rate supplied only 35 kg ha^{-1} Mg, compared to 414 kg ha^{-1} supplied with DL. The SSP treatment increased the Mg levels of the soil, whether applied alone or in combination with lime and gypsum.

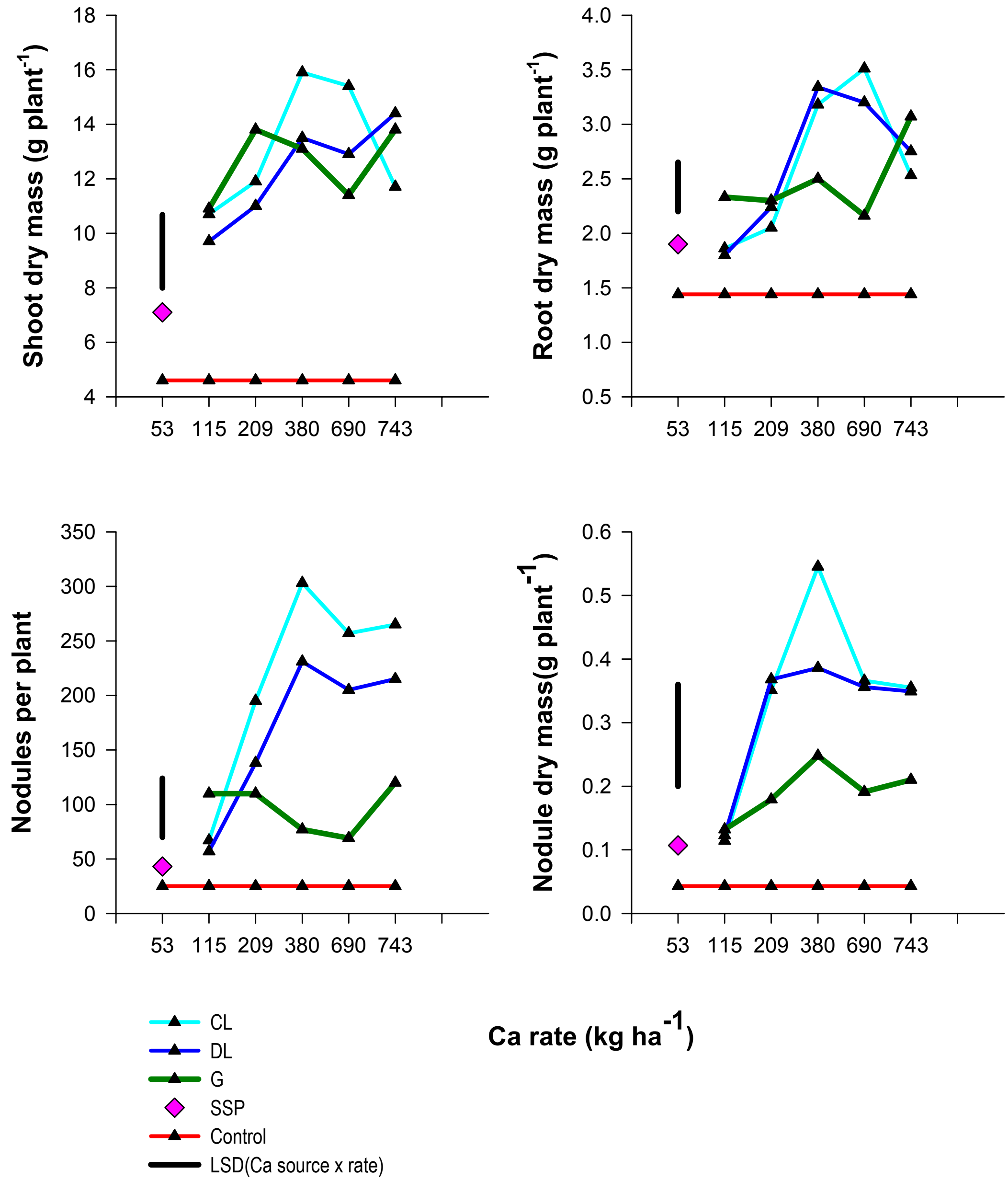
The nitrogen levels of the soil were affected by application of CL and DL at lowerCa application rates in both seasons (Figure 3.2, Appendix Table A3.1). Gypsum application tended to result in lower N levels than the other Ca sources. The overall low N levels could have been influenced by the initial low soil N content of the soil, or by the low soil P levels triggering the plants to have a lower $N\text{-}_2$ fixing ability and probably take up more nitrates from the soil relative to $N\text{-}_2$ fixation (Marschner, 1995). Phosphorus is essential in nodulation and N fixation (de Mooy & Pesek, 1966). The phosphate levels of the soil were increased by application of all three Ca sources. The P levels were generally higher in treatments where SSP was combined with either type of lime. Reports on the effects of lime on P availability have been varied, partly because of the confounding effects of Ca, Mg and other elements affected by pH changes which have been shown to interact with P (Sumner & Farina, 1986). In situations where increases in soil extractable P have been observed after liming, the effect has been related to intense mineralisation of organic P at a rate which may sometimes exceed that of plant uptake (Häussling & Marschner, 1989).

Whilst application of the Ca materials had a significant effect on exchangeable K content, increasing the rate of application did not increase the soil K levels (Figure 3.2, Appendix Table A3.1). Rather, the K levels tended to decrease at the higher Ca application rates. Snyman (1972) observed the same trend, and ascribed it to either increased leaching of the nutrient from the gypsum treated plots, or a loss from the soil as a result of increased K uptake by higher-yielding plants in the gypsum plots. Mora *et al.* (1997) also observed reduced soil K in lime and gypsum-treated plots and in the control treatment and described the phenomenon as an illustration of the poor buffering capacity of the soil to removal of exchangeable K by plants. The observed effect of Ca sources on soil K implies that in soils where available K is marginal, the lime or gypsum induced reduction in K may have a negative impact on plant growth.

3.3.2 PLANT GROWTH

1999/2000 and 2000/01 seasons

Shoot and root dry mass data from the 1999/2000 and 2000/01 seasons are shown in Figure 3.3 and Appendix Table A3.2 respectively. Application of the Ca sources produced significant increases in shoot dry mass production, and the largest increases were recorded in the CL and DL treatments. Overall, increases in shoot dry mass relative to the control ranged from 111 to 246% in the 1999/2000 season, and 72 to 163% in the 2000/01 season. The best growth was produced at the intermediate lime rates (209 - 403 kg ha^{-1} Ca), and no further response was observed at 690 kg ha^{-1} Ca. Blamey & Chapman (1982) also observed that haulm yields increased significantly with lime rates of up to 1600 kg ha^{-1}, whereas liming above this rate was of no further significant benefit. Gani *et al.* (1991) reported that shoot dry mass was generally maximized at 500 to 1000 kg ha^{-1} lime, with no further benefit from increasing the lime application rate. In the present study, the decline in dry mass production at the highest Ca application rates alludes to a potential for nutritional problems if overliming occurs in these soils. Application of SSP alone increased the shoot dry mass by 37 to 54%, while significantly higher dry mass values were observed when SSP was applied together with lime or gypsum. Gypsum also increased shoot dry mass, with the best growth being observed at the intermediate application rate. Retarded groundnut growth in gypsum-treated plots compared to the control or lime treatments has been observed by Mann (1935) and by Blamey & Chapman (1982).



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or DL or G @ 690 kg ha^{-1}.

Figure 3.3 **Effect of Ca source and rate on shoot dry mass, root dry mass, nodule number and nodule dry mass in 1999/2000 season**

All the Ca sources produced significant increases in root dry mass (Figure 3.3; Appendix Table A3.2). The response of root dry mass to application of Ca sources was similar to that of shoot dry mass, with no further increases in growth at the highest Ca application rate. The addition of lime combined with SSP did not result in larger root dry mass than the application of lime alone. Although gypsum application significantly increased root dry mass relative to the control treatment, there was a tendency for the root dry mass to decrease as the rate of gypsum increased. However, the general improvement in root dry mass due to gypsum application compared to the control is an indication that gypsum was effective in reducing the negative effect of the H^+ ion on root growth. The significant root dry mass response to application of Ca sources was reflected in the good shoot growth observed.

3.3.3 NODULATION

1999/2000 season

Although inoculation was not performed on the seeds, the soils contain reasonable populations of indigenous rhizobia for nodulation to occur. In pot experiments conducted using similar acid soils at Marondera, Zimbabwe, van Rossum *et al.* (1994) observed better nodulation with indigenous *Bradyrhizobium* spp. at low soil pH compared to neutral pH, with nodule numbers increasing by 21% at pH 5.0 compared to pH 6.5. Assessment of nodulation in the present study showed that numbers of nodules per plant were significantly influenced by Ca sources (Figure 3.3). In the control treatment an average of 25 nodules per plant were found as compared to 303 in treatments receiving 380 kg ha^{-1} Ca as CL. Nodule numbers were highest in the CL treatments, followed by the DL treatments and least in gypsum treatments. Application of SSP alone (Ca rate 53 kg ha^{-1}) did not influence nodulation.

The propensity for gypsum to reduce nodulation of groundnut has been noted by Mann (1935) and by Blamey & Chapman (1982), who suggested the possibility of an increase in activity of Al-ions due to gypsum application as a cause, or reduced Mo availability due to the antagonistic effect of SO_4^{2+} on Mo availability as observed by Reisenauer (1963). There was a tendency towards higher numbers of nodules at the intermediate Ca application rate (380 kg ha^{-1} Ca). Reasons for the decreased nodulation at higher Ca application rates were not clear. However, depressed nodulation at high lime application rates has been attributed to decreased P availability, since P is essential in nodulation and N fixation (de Mooy & Pesek, 1966).

Nodule dry mass per plant was significantly influenced by application of Ca (Figure 3.3). The lowest nodule dry mass was observed in the control and SSP treatments (0.04 – 0.11 g plant^{-1}), and the highest (0.545 g plant^{-1}) in the CL treatment.

The largest nodules were formed at the lowest Ca application rate and *vice versa* (Appendix Table A3.2). Overall, fewer but larger nodules were formed at low pH. In the control or 115 kg ha^{-1} Ca treatments with less than 75 nodules per plant, the mean size per nodule ranged from 5.81 to 11.18 mg, while in the high Ca treatments with more than 200 nodules per plant, the nodule size decreased to less than 5.0 mg nodule^{-1}. Mengel & Kamprath (1978) documented similar results with soybean. They observed that nodules formed at low pH were large and concentrated mainly on the taproot, and as the pH increased, nodules were initiated on the lateral roots, but the nodule size decreased. These observations support the assertion that soil acidity has little effect on nodule development and activity once the infection process and nodule initiation has occurred (Evans *et al.,* 1980).

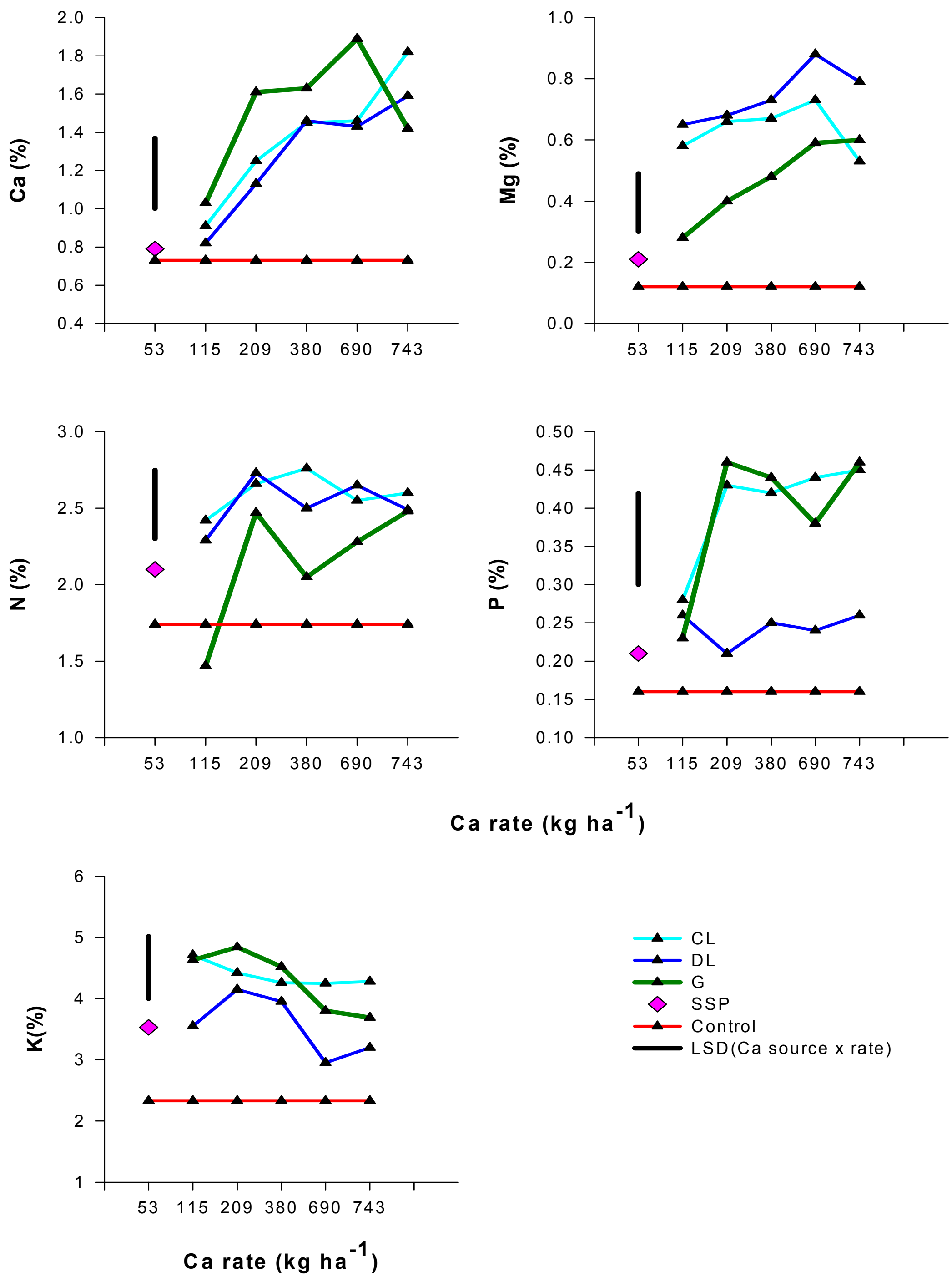
3.3.4 LEAF NUTRIENT COMPOSITION

1999/2000 and 2000/01 seasons

Tissue concentrations of all the elements analyzed in 1999/2000 season are shown in Figure 3.4. The mean leaf Ca concentration in the control treatment was 0.8 %, and it increased up to 1.9% with application of gypsum at 690 kg ha^{-1} Ca. In 2000/01 season the Ca concentration in the control treatment was 0.76%, and was increased up to 2.1% in the gypsum treatment, and 1.5% in the CL and DL treatments (Appendix Table A3.3). In both seasons, all the Ca sources generally increased leaf Ca concentration, but the increases were highest with gypsum application at the intermediate application rates. Snyman (1972) also recorded significantly higher Ca concentration in groundnut vegetative material from gypsum-treated plots compared to the plots treated with calcitic or dolomitic lime. He further noted that the response of the Ca content of the vegetative material to gypsum was quadratic, with peak Ca concentrations being observed at the intermediate application rates. Overall, leaf Ca concentrations in the CL and DL treatments were not significantly different, but when combined with SSP the Ca concentration was significantly higher in the SSP + DL treatment. For all the Ca sources, the lowest level of Ca did not have any effect on leaf Ca concentration, but application of the intermediate rates significantly increased the leaf Ca levels. The low Ca application rate did not increase the leaf Ca content to the levels indicated to be adequate for good growth of Spanish-type groundnuts, which are 1.25 to 2.0% according to Gascho & Davis (1994.

Leaf Mg levels in the control and SSP treatments were 0.12% and 0.21% respectively in the 1999/2000 season (Figure 3.4), while the critical leaf Mg level for Spanish-type groundnuts is 0.3% (Gascho & Davis, 1994). In the 2000/01 season the leaf Mg levels ranged from 0.25% in the control treatment to 0.79% in the DL treatment (Appendix Table A3.3). The highest Mg levels were recorded in plants sampled from the DL treatment, and lowest in plants sampled from the gypsum treatment. Magnesium levels in the CL treatment were intermediate. Increasing the Ca application rate from 115 to 690 kg ha^{-1} significantly increased the leaf Mg concentration only in the DL treatment. Depressions in leaf Mg concentration were observed when lime or gypsum were combined with SSP.

Leaf N concentrations ranged from 1.7% in the control treatment to 2.8% in plants grown in the CL treatment at 380 kg ha^{-1} Ca in the 1999/2000 season (Figure 3.4). In all the treatments, the N levels were below sufficiency levels for groundnut, which range from 3.0 to 4.5% according to Gascho & Davis (1994). Similar treatment effects were observed in 2000/01 season, with the N levels below sufficiency levels in all the treatments (Appendix Table A3.3). No symptoms of N deficiency were observed on plants in the CL and DL treatments even though they had $<3\%$ N, whereas plants in the control and gypsum treatments exhibited a yellowish colour associated with N deficiency. The low N content of the control and gypsum treatments could be attributable to the low soil pH that affects the efficacy of rhizobium bacteria (Sullivan *et al.,* 1974). Another explanation offered for low N content in gypsum plots is the possibility of increased translocation of N from the leaves to fruits created by the heavier fruiting (Sullivan *et al.,* 1974), but since in my experiment the plants were sampled at peak flower, the explanation could not be verified.



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or DL or G @ 690 kg ha^{-1}.

Figure 3.4 **Effect of Ca source and rate on leaf Ca, Mg, N, P and K concentrations at peak flowering of groundnut in 1999/2000 season**

Phosphorus concentrations in the leaves sampled in 1999/2000 ranged from 0.16% in the control treatment to 0.46% in the gypsum treatment (Figure 3.4). Similar leaf P concentrations were observed in the 2000/01 season, with values ranging from 0.15% in the control treatment to 0.48% in plants grown in the CL+SSP treatment (Appendix Table A3.3). The critical leaf P content for groundnut is 0.25% (Gascho & Davis, 1994), and plants grown at 115 kg ha^{-1} Ca in the DL and gypsum treatments were deficient in P. Leaf P content was generally high with application of intermediate Ca rates irrespective of the Ca source, but the DL treatment resulted in lower P concentrations than the CL and gypsum treatments.

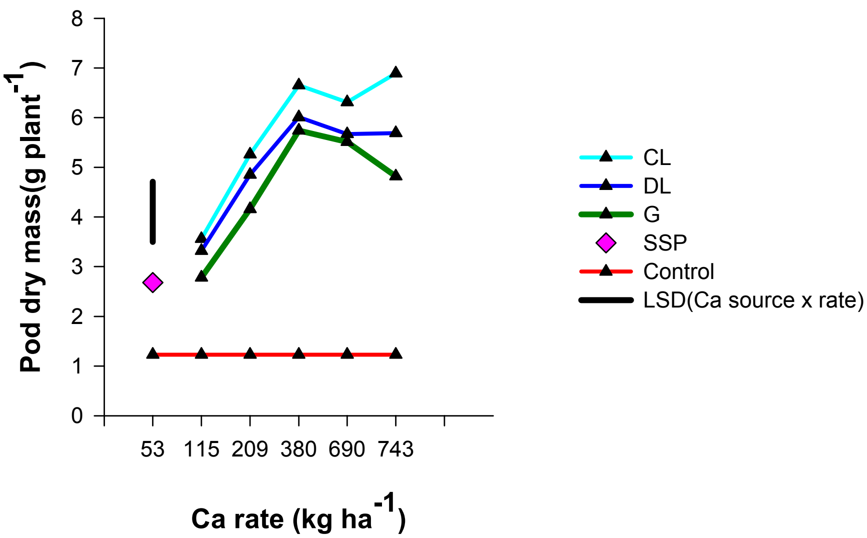
In both seasons the K concentrations were adequate in all treatments, the sufficiency values being 1.7 to 3.0% as suggested by Gascho & Davis (1994). Values for leaf K concentrations were high in plants grown in the ameliorated soils compared to the control, and ranged from 2.33% in the control treatment to 4.84% in plants grown at 209 kg ha^{-1} Ca in the gypsum treatment (Figure 3.4). In the 2000/01 season the leaf K concentrations ranged from 2.21% in the control treatment to 4.52% in plants grown in the gypsum treatment at 403 kg ha^{-1} Ca (Appendix Table A3.3). In both seasons, the leaf K concentrations tended to decrease at the higher Ca application rates. The observed leaf K values were much higher than those observed in the field experiments, and this could be attributed to higher soil K levels (44.7 mg kg^{-1}) in the soil used in the greenhouse experiment compared to 19.5 – 27.4 mg kg^{-1} K in the field experiments. Bartlett & McIntosh (1969) observed reduced plant uptake of K on limed soils and attributed it to the reduction in percentage K saturation of the cation exchange complex because of lime-induced increase in cation exchange capacity.

3.3.5 POD AND KERNEL YIELDS

1999/2000 season

Mean pod yield per plant in the control treatment was 1.23 g, and application of CL at 380 kg ha^{-1} Ca increased the pod yield to 6.7 g plant^{-1} (Figure 3.5). Pod yield response to SSP alone was significantly better than in the control treatment. For all Ca sources, increasing the application rate from 115 to 380 kg ha^{-1} Ca significantly increased the pod yields. However, increasing the application rate to 690 kg ha^{-1} Ca did not result in a further increase in pod yields.

Notwithstanding the low pH in the gypsum treatments, the yields were not significantly different from those in the CL or DL treatments. This indicates that changes in the Ca status of the soil are the major reason for improved kernel yield and not improved pH *per se*.



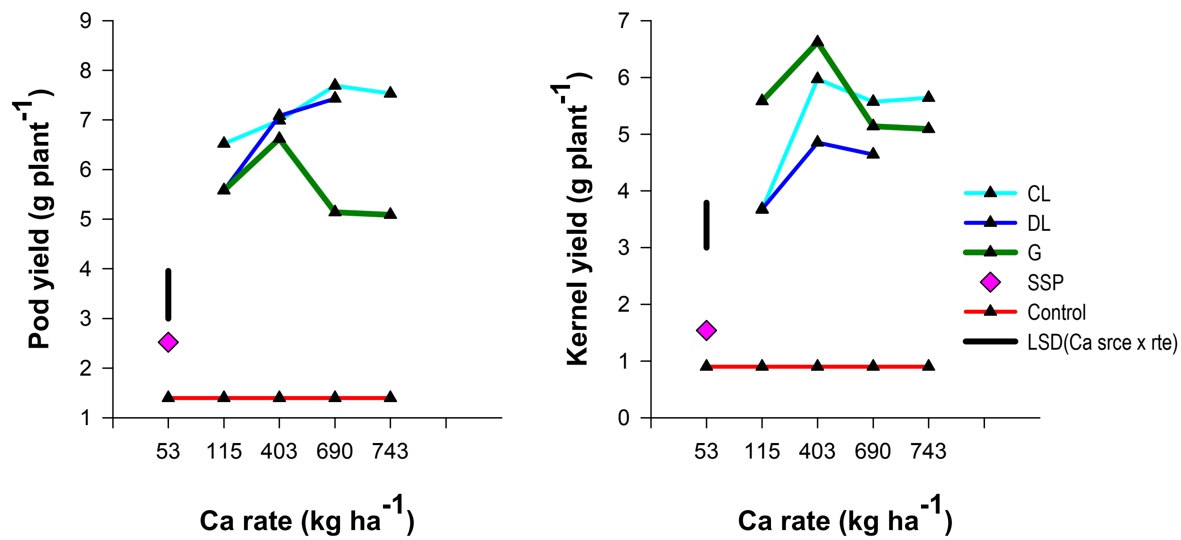
** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or DL or G @ 690 kg ha^{-1}.

Figure 3.5 Effect of Ca source and rate on pod yield in 1999/2000 season

2000/01 season

The pod yield response to application of CL and DL in 2000/01 was analogous to that observed in the 1999/2000 trial, while application of higher gypsum rates tended to depress yield (Figure 3.6). The pod yield response to SSP was not significantly different from the control treatment. When equal rates of Ca were applied as either CL or gypsum, similar yields were produced.

The total kernel yield per plant was significantly increased by all Ca treatments (Figure 3.6). The mean kernel yield in the control treatment was 0.91 g plant^{-1}, and application of Ca increased the yield up to 5.97 g plant^{-1}. On average, the differences in kernel yields obtained from the different Ca sources were not statistically significant at the lowest and highest Ca application rates. With application of 403 kg ha^{-1} Ca, CL had higher yields than gypsum. Combining CL or gypsum with SSP did not result in significant yield increases compared to applying the materials individually; neither did kernel yield response to SSP alone significantly differ from the control treatment.



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or G @ 690 kg ha^{-1}.

Figure 3.6 Effect of Ca source and rate on pod and kernel yield in 2000/01 season

Significant increases in kernel yield were obtained when the Ca rate was increased from 115 to 403 kg ha^{-1} Ca in the CL treatment, but not in the gypsum and DL treatments. For all the Ca sources, there was no yield advantage due to application of 690 kg ha^{-1} Ca. Studies by Zharare (1997) on Ca requirements for pod growth of a Spanish type cultivar showed a wide range of optimal Ca concentrations in the pod zone, suggesting that varied yield responses to Ca application might be expected. Decreases in kernel yield due to application of high rates of DL have been attributed to an imbalance of the K: Mg ratio, especially in soils with high Ca levels and a high K: Mg ratio (Strauss & Grizzard, 1948). The soil in the present study was not high in exchangeable Ca, but the significant increases in Mg content due to application of Ca materials, coupled with the tendency for K levels to decrease at the higher Ca application rate caused an imbalance in the K: Mg ratio, resulting in the decreased yields.

Partitioning of the total kernel yield into basal and apical kernel yields showed that the response of the two to application of Ca sources was similar to that of total kernel yield per plant (Appendix Table 3.4). Because the basal cavities have a higher percentage seed-set than the apical cavities, the basal kernel yields were higher than apical kernel yields in all treatments. The ratio of basal to apical kernels was lower in the gypsum treatment, an indication of better seed-set in the apical ovarian cavities of the two-compartmented pods of this cultivar. The better seed-set in the gypsum treatment is probably an indication of the superiority of this Ca source in supplying adequate Ca for fruit production.

3.3.6 PROPORTION OF MATURE PODS AND EMPTY PODS (POPS)

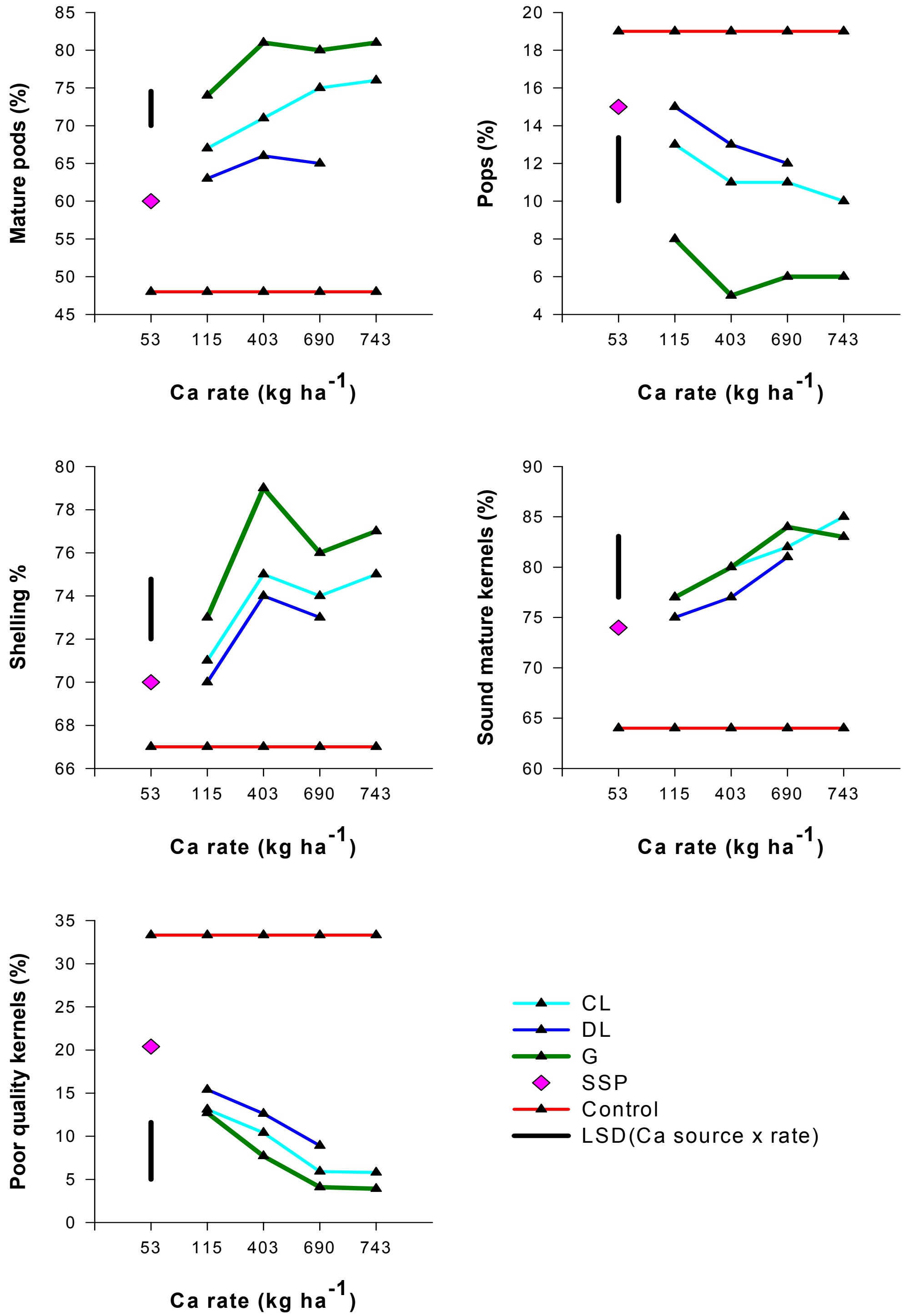
2000/01 season

The percentage of mature pods per plant was significantly higher on plants grown in lime or gypsum treated soils relative to the control treatment, and the higher the application rate the higher the number of mature pods per plant (Figure 3.7). The proportions of immature pods and pops were highest in the control plots (Figure 3.7), and application of Ca sources, especially the gypsum treatment reduced their proportions. The mean percentage of pops in the gypsum treatment was 6.3%, compared to 11.7% in the CL treatment, 13.7% in the DL treatment and 19% in the control. Blamey & Chapman (1982) also observed a significant reduction in pops by both lime and gypsum. Snyman (1972) observed that gypsum was the only Ca source having a marked influence in decreasing the percentage of unfilled pods compared to CL and DL.

3.3.7 KERNEL QUALITY

2000/01 season

Application of the Ca sources resulted in highly significant effects on some of the kernel quality parameters measured (Figure 3.7). Shelling percentage was significantly increased by application of the Ca sources, and ranged from 67% in the control plot to 79% with application of 403 kg ha^{-1} Ca as CL. Shelling percentage in the gypsum treatment was better than in the CL and DL treatments. Application of SSP on its own had no effect on shelling percentage, but combining it with CL or gypsum increased the shelling percentage. For all Ca sources, increasing the application rate from 115 to 690 kg ha^{-1} Ca did not result in significant improvements in the shelling percentage.



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or G @ 690 kg ha^{-1}.

Figure 3.7 Effect of Ca source and rate on pod and kernel quality in 2000/2001 season

The effects of Ca sources on the proportion of sound mature kernels (SMK) were highly significant (Figure 3.7). Mean percent SMK in the control treatment was 64%, and application of 690 kg ha^{-1} Ca as gypsum increased it to 84%. With all Ca sources, increasing the Ca application rate increased the proportion of sound mature kernels. Combining SSP with CL improved the percent SMK, whereas combining SSP with gypsum did not. Overall, the proportion of sound mature kernels in the gypsum treatment was higher than in the CL and DL treatments. Application of SSP on its own did not increase the proportion of sound mature kernels.

Total poor quality kernels (shriveled, rotted and discolored) were affected by the Ca source used, with gypsum reducing the proportion of poor quality kernels by a greater magnitude compared to CL and DL (Figure 3.7). While the number of rotted and discolored kernels was not significantly influenced by application of Ca sources, shriveled kernels were (Appendix Table A3.4). A high percentage of shriveled kernels were recorded in the control and SSP treatments, and when Ca was applied at 115 kg ha^{-1}. For all Ca sources, increasing the rate of Ca application significantly reduced the number of poor quality kernels. Since a high percentage of poor quality kernels results in the downgrading of groundnut on the market, application of the Ca sources would be beneficial in ensuring that a high proportion of high quality nuts are produced.

3.3.8 Shell and kernel Ca, Mg and K content

2000/01 season

Calcium

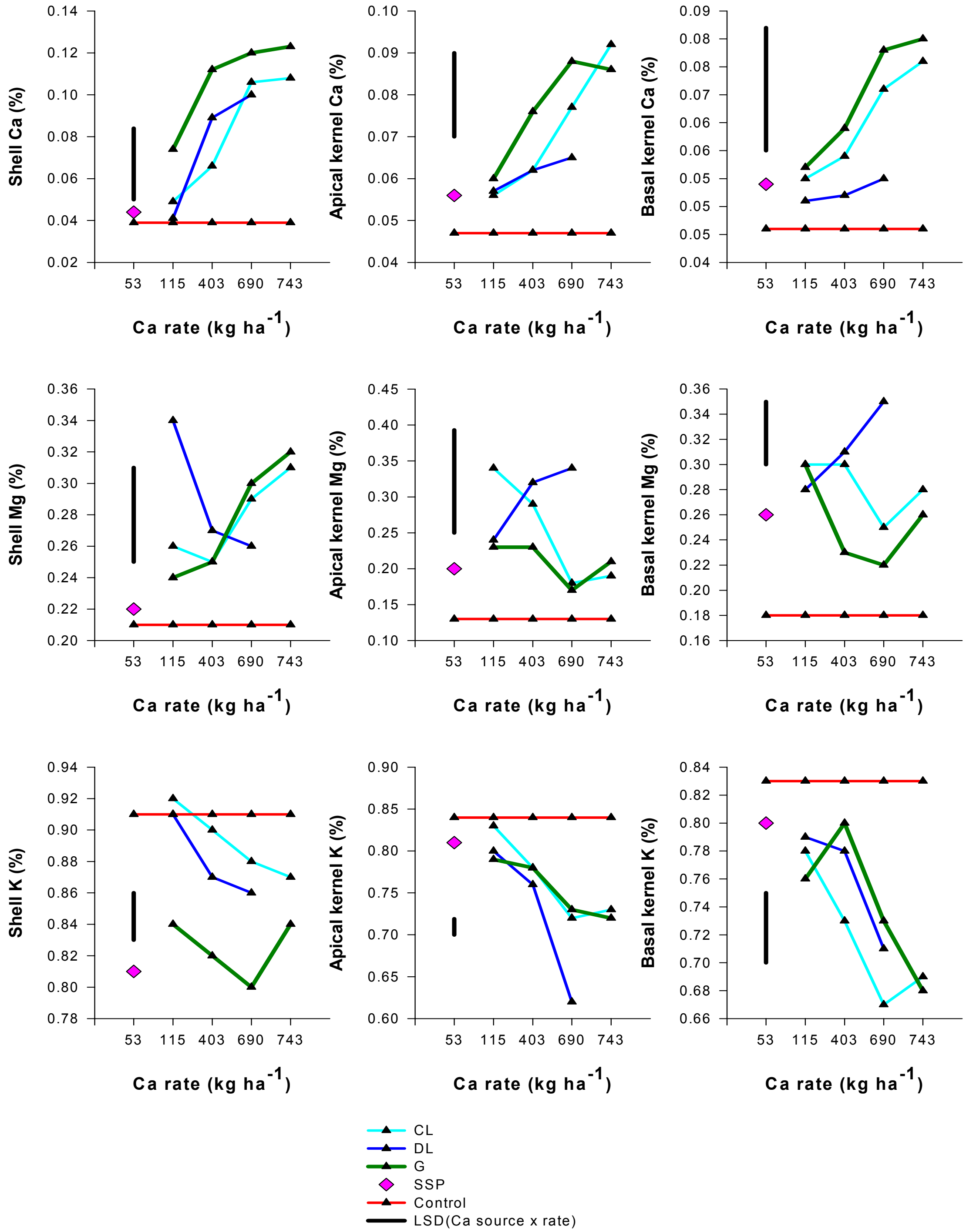
The shell Ca concentrations were significantly influenced by Ca source and rate of application (Figure 3.8). For all Ca sources, significant increases in shell Ca content were observed as the application rate was increased from 115 to 690 kg ha^{-1} Ca. On average, the Ca content was highest in the gypsum treatment, whereas CL and DL treatments had similar shell Ca content. Combining gypsum or CL with SSP was of no benefit in increasing the shell Ca content.

The kernel Ca concentrations in all treatments were adequate (Figure 3.8), the sufficiency values being 0.04 to 0.08% as suggested by Gascho & Davis (1994). The mean Ca concentration in the control treatment was 0.05% in both the basal and apical kernels. Application of gypsum at 690 kg ha^{-1} Ca significantly increased the Ca content to 0.08% in the basal kernels, and to 0.09% in the apical kernels. Combining SSP with CL similarly increased the Ca content in the basal and apical kernels. Increasing the Ca application rate increased the concentration of Ca in basal and apical kernels. Application of SSP also increased the kernel Ca concentration. Overall, the kernel Ca concentrations tended to be higher in the gypsum treatment than in the CL and DL treatments. Slightly higher Ca concentrations in the apical kernels than in the basal kernels were observed, and the reasons for this phenomenon, also observed by Zharare (1997), are not clear.

Magnesium

The shell Mg concentrations increased as the application levels of CL and gypsum increased, but decreased as the DL application rate increased from 115 to 403 kg ha^{-1} Ca (Figure 3.8). Nevertheless, application of 115 and 403 kg ha^{-1} Ca as DL resulted in shell Mg concentrations that were higher than in the CL and gypsum treatments. In the study by Snyman (1972), a significant increase in the Mg content of the shells was observed with increasing levels of CL and DL, whereas gypsum application generally decreased the Mg content.

Application of Ca sources had a significant though varied effect on kernel Mg content (Figure 3.8). Whereas application of DL increased the Mg content as the rate of application increased, the reverse trend was observed with application of CL and gypsum. This trend was observed in apical and in basal kernels. Overall, the kernel Mg content in the apical kernels ranged from 0.13% in the control treatment to 0.34% in the DL treatment. In the basal kernels, Mg content ranged from 0.18% in the control treatment to 0.35% in the DL treatment. Thus, the kernel Mg levels were generally adequate in all but the basal kernels in the control treatment, the sufficiency values being 0.16 – 0.2% as suggested by Gascho & Davis (1994).



** Ca rate of 743 = SSP @ 53 kg ha^{-1} + CL or G @ 690 kg ha^{-1}.

Figure 3.8 Effect of Ca source and rate on shell and kernel Ca, Mg, and K concentrations in 2000/2001 season

Potassium

The K content of the shells tended to be slightly better under conditions of low Ca (control and 115 kg ha^{-1} Ca treatments). Shells in the gypsum treatment generally had the lowest K levels (up to 0.83%) while those in the control treatment had a mean K content of 0.91% (Figure 3.8).

The K concentration in the basal and apical kernels was influenced by application of Ca sources (Figure 3.8). Like in the shells, the K concentrations were highest at the lowest Ca application rate, and in the control treatment. The trend was observed in both basal and apical kernels. Snyman (1972) observed a quadratic response of kernel K to increases in Ca application rate, with significant decreases in K content being recorded at the lower Ca application rates, but insignificant decreases being observed at the higher application rates. Kernels in the gypsum treatment generally had the lowest K levels compared to the CL and DL treatments, and in all the treatments, apical kernels tended to have slightly higher K concentrations compared to basal kernels.

The tendency for the K concentrations in the shells and kernels to decline as the Ca application rate was increased concurs with the assertion that Ca inhibits K uptake. Nevertheless, the K concentrations removal, within the sufficiency levels of 0.62 to 0.89% as suggested by Gascho & Davis (1994) in all treatments impy that the applied Ca rates were not detrimentally antagonistic to K uptake by the pods. However, it may be noted that K may enter the pods via long distance transport in the xylem sap from the roots. Hence, provided that sufficient amounts of K exist in the root zone, deficiencies in the pod tissues may not be experienced.

3.4 CONCLUSIONS

Although a different soil was used, the results of this study concur with those from the field experiments. Application of various rates of calcitic and dolomitic lime produced significant changes in soil pH, whereas gypsum did not, even when equal rates of Ca were applied. Application of single superphosphate at 53 kg ha^{-1} Ca did not influence the soil pH. Following increases in solution pH, concomitant increases in soil exchangeable Ca and Mg levels were observed after application of CL or DL. Gypsum application increased exchangeable Ca levels, but not Mg. The Ca sources had little effect on the soil N, P and exchangeable K content. An increase in soil pH significantly increased concentrations of Ca and Mg in the leaves, kernels and shells of groundnut, but had small or variable effects on N, P and K concentrations. However, the concentrations of N, P and K in the shoots appeared to be adequate for unrestricted growth of groundnut.

Increasing the Ca application rates increased the pH of the soil solution, thereby eliciting positive effects on growth and productivity of groundnut. The observed better yields with intermediate Ca application rates particularly in the CL and DL treatments appear to be consistent with the pH and calcium levels in the soil. Ca application rates above 400 kg ha^{-1} seem detrimental to yield in the sandy soil under consideration.

Even though gypsum application did not change soil pH, the observed plant growth and productivity in that treatment was as good as that obtained with application of CL and DL. Combining SSP with gypsum or CL was generally not beneficial, probably due to the resultant high Ca application rate, which might have induced nutrient imbalances. The magnitude of response to application of Ca sources was generally of the order CL>DL>G for most of the measured parameters. Overall, both lime types were superior to gypsum in improving the vegetative and reproductive growth of groundnut, but when it came to improving pod and kernel quality, gypsum was superior. The similarity of these results to those observed in the field experiments (Chapter 2) implies that pot experiments, which have the advantage of testing as many treatments combinations as possible, can be used to screen a range of soil acidity amelioration treatments before they are tested in the field.