CHAPTER 2

FIELD AMELIORATION OF ACID SOIL INFERTILITY IN SANDY SOILS OF ZIMBABWE USING LIME, GYPSUM AND SUPER PHOSPHATE

2.1 INTRODUCTION

Various authors have emphasized acid soil infertility as a constraint to crop productivity on Zimbabwean soils (Grant, 1970, 1981; Grant *et al.,* 1973; Tanner, 1976; Mashiringwani, 1983; Mukurumbira, 1997; Dhliwayo *et al*., 1998). High acidification rates of light textured sandy soils under crop production in the smallholder areas of Zimbabwe have been reported by Nyamangara & Mpofu (1996). Dhliwayo *et al.* (1998) observed that more than 60% of the sandy soils in the smallholder sector were in the extremely acidic to very strongly acidic range (pH 4.15 to 4.5). Thus, soil acidity is a major crop production constraint in the smallholder sector of Zimbabwe. A majority of the smallholder farmers are aware of the acidity status of their soils, but their poor-resource base is a major socio-economic constraint that limits the extent to which they can invest in large amounts of liming materials. In view of this situation, practical and cheap options for soil acidity amelioration are a prerequisite.

Groundnut (*Arachis hypogaea* L.) is one of the most important crops in the smallholder-farming sector of Zimbabwe. In this sector, Spanish cultivars with a growing period of 100-130 days are largely grown. As a protein source, groundnut is an important component in the diet of the rural population, and the demand for it by the oil expressing industry and for confectioneries makes it a cash crop of significance to the economy of Zimbabwe. The bulk of the crop is produced on light textured soils ranging from coarse and fine sands to sandy clay loams. These soils are highly weathered, and have low Ca, Mg, P and Zn status (Grant, 1971; Mashiringwani, 1983; Tagwira *et al*., 1993). In addition, the soils are usually acidic (Grant, 1971; Mashiringwani, 1983), resulting in high hydrogen ion (H^+) concentrations as well as toxicities of aluminum (Al) and manganese (Mn) (Mukurumbira, 1997). Consequently, productivity of groundnut on these soils has declined

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despite the recent genetic and disease resistance improvements to the crop, with pod yields averaging only 0.5 t ha^{-1} (CSO, 2001).

Acid soil infertility in highly weathered tropical soils is in general a major constraint for cultivation of legume crops whose nodulation, growth and yield are reduced (Munns, 1978; Lie, 1981; Marziah *et al.,* 1995). As mentioned in Chapter 1 (section 1.2), the infertility problems of acid soil are associated with proton toxicity, nutrient deficiencies (Ca, Mg, Mo and P) and the presence of phytotoxic concentrations of Al and Mn (Awad *et al.,* 1976; Coventry & Evans, 1989). Liming may ameliorate some of these factors (Haynes, 1984; Foy, 1992), but the maximization of the benefits of liming acid soils requires a thorough knowledge of lime reactions with soil and of crop responses to lime application. Furthermore, because of the complexity of acid soil infertility, it is imperative to firstly identify the factors that are reducing plant growth in order to select the most effective measures of correcting acid soil infertility (Dolling *et al.,* 1991).

Amelioration of acid soils is generally accomplished by the application of calcitic or dolomitic limes. In addition to alleviating toxicities (Haynes, 1984), these two liming materials also supply Ca (calcitic and dolomitic limes) and Mg (dolomitic lime). The levels of these two nutrients, together with that of P, are usually low in acid soils of the tropics (Sanchez, 1976). Alternative ameliorants that supply calcium include superphosphate (Mongia *et al,* 1998) and gypsum (Shainberg, *et al,* 1989; Sumner, 1993; Carvalho & van Raij, 1997). Studies have shown that liming benefits groundnut productivity on acid soils mainly because of improved Ca nutrition (Snyman, 1972; Reid & Cox, 1973; Walker, 1975; Blamey & Chapman, 1982; Blamey, 1983; Gani *et al*., 1992; Rosolem & Caires, 1998; Macció, 2002). However, because of the many factors involved in acid soil infertility and because of the often-inconsistent response of the crop to lime application on different soils, interpretation of liming benefits of acid soils with respect to groundnut has been difficult (Blamey & Chapman, 1982).

The major goals of this study were to elucidate the cause(s) of poor groundnut yields on acid light textured soils of Zimbabwe and to identify a practical soil acidity amelioration option conducive to improved groundnut productivity in the smallholder-farming sector. The specific objectives of the study were to assess the effects of lime, gypsum and phosphate application on (1) soil pH and nutrient status (2) plant nutrient composition and (3) vegetative and reproductive performance of Spanish groundnut cultivar *Falcon* on acid light textured soils of Zimbabwe.

2.2 MATERIALS AND METHODS

Field experiments with groundnut (Spanish type *cv. Falcon*) were established for three consecutive cropping seasons (1999/2000 to 2001/02) on acid sandy soils at the Horticulture Research Centre (HRC) located in agro-ecological region II (750 – 1000 mm rainfall), and at Makoholi Experiment Station (MES) located in agro-ecological region IV (450 – 600 mm rainfall) of Zimbabwe. The soils at both sites are derived from granite and belong to the 5G (Fersiallitic order). They are moderately shallow, grayish brown, coarse-grained sands (particle size >0.02mm; silt + clay <15%), with low pH, low cation exchange capacity (CEC) and low amounts of several cations (Thompson & Purves, 1981).

The four Ca materials evaluated in the experiments were calcitic lime (CL), dolomitic lime (DL), gypsum (G) and single superphosphate (SSP). Samples of the Ca materials were analysed by the Chemistry and Soils Research Institute in Harare to determine their chemical nature (Table 2.1).

Table 2.1 Characteristics of the Ca sources used in the experiments

Source	% Ca	% Mg	Neutralizing value (%)
Calcitic lime ($CaCO_3$) Finely ground limestone passed through a 200-mesh (0.074mm) screen.	23	7.2	107
Dolomitic lime ($CaCO_3.MgCO_3$) Finely ground dolomite passed through a 200-mesh screen	18	11	102
Gypsum ($CaSO_4$) In powder form - passed through a 200-mesh sieve.	20	0.5	25
Single Superphosphate [$Ca(H_2PO_4)_2.CaSO_4$] In granular form and contains 18.2% P_2O_5.	12	4.3	Not determined

In the 1999/2000 cropping season the treatments were calcitic lime (CL) applied at 2000 and 4000 kg ha^{-1}, dolomitic lime (DL) applied at 2000 and 4000 kg ha^{-1}, gypsum (G) applied at 200 kg ha^{-1} single superphosphate (SSP) applied at 250 kg ha^{-1}. These materials were applied either alone or in combinations, thus totaling ten soil amelioration treatments (Table 2.2). In the

2000/01 and 2001/02 cropping seasons, the experiment was repeated with minor changes; the treatments with low rates of Ca (Treatments 1, 5 and 7) were repeated each year, whereas residual effects of the other treatments were observed.

Table 2.2 Treatments applied at Horticulture Research Centre (HRC) and Makoholi Experiment Station (MES) in the 1999/2000 cropping season

Trt. No.	Treatment (kg ha^{-1})	Code
1.	Gypsum (200)	G-200
2.	Calcitic or Dolomitic lime (2000)	L-2000 †
3.	Calcitic lime (4000)	CL-4000
4.	Dolomitic lime (4000)	DL-4000
5.	Single super phosphate (250)	SSP-250
6.	Gypsum (200) + Calcitic Lime (2000)	G + CL
7.	Gypsum (200) + SSP (250)	G + SSP
8.	SSP (250) + Calcitic Lime (2000)	SSP + CL
9.	SSP (250) + Gypsum (200) + CL (2000)	SSP + G + CL
10.	Control (no amendment)	Control

†Due to the low exchangeable Mg status of the MES soil, CL was replaced with DL in the case of treatment 2. Thus, L-2000 = CL at HRC, DL at MES.

The lime was broadcast by hand and disced into the soil a month before planting while super phosphate and gypsum were banded in the row at planting. The treatments were in four replicates arranged in a randomized complete block design. The plots were maintained for the duration of the experiments. Gross plot size was eight rows of groundnut spaced at 0.45m apart and 5m long (18m^2), while the net plot comprised of four rows spaced at 0.45 m apart and 4m long (7.2m^2).

In the first and third seasons, the groundnut was planted immediately after the first effective rains in November at both sites. In the second season, the trials had to be established with irrigation at both sites due to lateness of the rains. In all three seasons, the rainfall amount was typical for the respective ecological zones, but distribution in all three seasons was poor. As is the practice with smallholder farmers, the groundnut seed was not inoculated with *Rhizobium*. All plots received a starter nitrogen application of 20 kg N ha^{-1} as NH_4NO_3. Fungicides (Mancozeb and Benomyl) were applied as required to minimize *Cercospora* infection. No groundnut disease or pest problems were observed in all the three seasons. The crop was kept weed-free by hand hoeing throughout the growing season.

Soil samples (one from the middle of each plot in 1999/2000; four cores per plot, mixed and subsampled in 2000/01) were taken from the pod zone (0-10 cm depth) and from the root zone (20-30 cm depth) at peak flowering and at harvest. The soils were air dried, sieved to <2mm 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 & 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 ($NO_3^- + NH_4^+$) was determined by the semi-micro Kjeldal procedure followed by steam distillation (Bremner & Mulvaney, 1982). In the third season, the soils were analyzed for pH only, due to budget constraints. The Soil Productivity Research Laboratory (SPRL) and the Chemistry & Soils Research Institute, Department of Research and Specialist Services, Zimbabwe conducted all the analyses.

The plants were separated into pods (if present), shoots, roots and nodules, and the fresh weight of these plant parts and the number of nodules per plant were determined before they were dried in an oven at 80° C for 48 hrs to determine dry mass. At peak flowering stage quadrants were thrown onto each plot and ten representative plants per plot were harvested to determine the effects of the treatments on leaf nutrient composition in relation to vegetative growth of the groundnut. The same procedure was repeated at physiological maturity. The youngest fully expanded leaves (YFEL) inclusive of petioles were sampled to determine uptake of N, P, K, Ca, and Mg. The plant shoots were oven-dried at 80° C for 48 hrs to determine dry mass. The total number of nodules per plant was recorded, and the dry weight of nodules determined. At physiological maturity all plants in the net plot were harvested by hand, the nuts were hand picked, placed in mesh bags and dried to 10% moisture. Haulm, pod and kernel yields as well as quality characteristics were determined. Nutrient concentrations in the kernels were also determined. A nitric perchloric acid (HNO_3:$HClO_4$) digestion of the plant material was used to prepare all the plant samples for analysis.

Data were analyzed as randomized complete block designs with four replicates using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS Institute Inc. Cary, NC, USA 1996 Copyright). Duncan's least significant difference (LSD) test was used to separate treatment means, and differences at the $P\leq 0.05$ level of significance are reported. In addition, data on kernel yield and some of its parameters were subjected to regression analysis. Emulating the methodology used by Blamey (1983) to investigate the mutual associations between kernel yield and yield components, simple correlation coefficients between kernel yield, yield components and soil parameters were computed.

2.3 RESULTS AND DISCUSSION

Before the application of the ameliorants, the soil pH ($CaCl_2$) values ranged from medium acid (pH 4.8 – 5.1) at HRC to strongly acid (<4.4) at MES, but the Al^{3+} levels were very low (Table 2.3). The pH was generally higher in the pod zone (0 - 10 cm depth) than in the root zone (20-30 cm depth). The soils at both sites were low in N, and in the basic cations (Ca, Mg and K) in both the pod zone and the root zone.

Table 2.3 Soil analyses before application of amendments to acid soils at HRC and MES

Site	Soil depth (cm)	pH ($CaCl_2$)	Al^{3+} (mg kg^{-1})	Mineral N (mg kg^{-1})	P (mg kg^{-1})	Exchangeable cations (mg kg^{-1})		
						K	Ca	Mg
HRC	0 – 10	5.1	0.00	11	25.1	23.5	105	22.5
	20 - 30	4.8	0.002	13	26.6	27.4	100	29.8
MES	0 - 10	4.4	0.001	14	25.0	19.5	46	12.2
	20 - 30	4.3	0.003	18	27.9	19.5	52	12.8

2.3.1 EFFECT OF AMENDMENTS ON SOIL CHEMICAL PROPERTIES

Pod zone pH changes in the 1999/2000 cropping season

At the peak flowering period of groundnut the mean pH values in the pod zone were 4.6 in the control plots at HRC (Figure 2.1) and 4.1 at MES (Figure 2.2). Application of 2000 kg ha^{-1} lime increased the pH to 5.6 at HRC, and to 5.7 at MES, while application of 4000 kg ha^{-1} CL or DL increased the pH to values >6.0 at both sites. Combining gypsum and/or SSP with 2000 kg ha^{-1} CL did not affect soil pH differently than applying the lime alone. By contrast, gypsum and SSP alone or in combination had very little effect on soil pH. The response trends at the end of the cropping season were similar to those observed at peak flowering, but with gypsum and SSP inducing some increase in soil pH (Appendix Table A2.1).

Root zone pH changes in the 1999/2000 cropping season

In the root zone (20-30 cm soil depth layer), mean pH values in the 1999/2000 cropping season were 4.7 in the control plots at HRC (Figure 2.1) and 4.0 at MES (Figure 2.2). At both sites, the largest increases in pH were recorded from plots on which 4000 kg ha^{-1} CL was applied, with mean pH values for this treatment being 5.2 at HRC and 5.6 at MES. Dolomitic lime applied at the same rate achieved similar increases at HRC (pH 5.2) and at MES (pH 5.1). Relatively small pH increases (up to 0.4 and 0.6 units at HRC and MES, respectively) were obtained when limestone was applied at 2000 kg ha^{-1} alone, or in combination with SSP and/or gypsum. Similar treatments effects were observed at physiological maturity (Appendix Table A2.1).

In the 1999/2000 season, application of lime significantly increased soil pH at both sampling periods, and the higher the lime rate, the greater the increase in soil pH. The increases in pH when equal rates of CL and DL were applied were higher with calcitic lime. Although this effect was observed on both soils, it was more pronounced on the MES soil that initially had lower pH values than the HRC soil. At both sites, lime treatments raised pH more in the pod zone than the root zone. These differences can be attributed to the generally slow movement of lime through the soil profile because of the low dissolution rate, compared to gypsum (McCray & Sumner, 1990). At both sites, there were notable decreases in pH values in the root zone at physiological maturity, compared to the flowering period. A probable explanation is that since the groundnut plants obtain most of their nitrogen through N_2-fixation, and therefore take up more cations than anions, extrusion of H^+ from their roots acidifies the root zone (McLay *et al.*, 1997). In a split pod / root solution culture experiment, Zharare (1997) observed that a massive K uptake by groundnut in the root environment that started at peak podding was accompanied by an intense acidification of the root's culture solution.

In contrast to the effect of lime, application of gypsum alone did not have any effect on soil pH. The low rate of gypsum application (200 kg ha^{-1}) as well as the fact that it was banded in the row at planting explains this. In addition, it is known that increases in pH after gypsum application are due to ligand exchange, and are regulated by zero point charge on the colloidal surface (Sumner, 1993). Thus SO_4^{2-} adsorption on soil surfaces neutralizes the positive charge present in the acid soils, and generates a negative charge until the surface reaches a new zero point charge, where no further adsorption of this anion takes place. That is why the effect of gypsum may be a decrease, increase or no change in the soil pH, depending on how close the soil pH was to zero point charge when gypsum was applied (Mora *et al.,* 1999). In this study, the lack of alteration in soil pH due to gypsum application may imply that a low positive charge was initially present in the soil. Therefore, with the small amount of gypsum applied, there was limited exchange between the SO_4^{2-} and (OH^-) ions, hence the small effect on pH.

Pod zone pH changes in the 2000/01 and 2001/02 cropping seasons

In the second and third cropping seasons, the pH in the pod zone at peak flowering generally decreased successively with time, with slight changes being observed in the gypsum and SSP plots where the ameliorants were applied annually. Mean pod zone pH values in the plots treated with both rates of CL at HRC had decreased by up to 0.54 pH units in the second cropping season; in the DL-4000 treatment the pH had decreased by 0.32 units (Figure 2.1). In the SSP and gypsum plots, there was no change in the pod zone pH as the seasons progressed. The trends observed in the second season were generally maintained in the third season. At MES, the decline in soil pH in the second season was of a lesser magnitude than that observed at HRC (Figure 2.2). Like at HRC, there were hardly any changes in soil pH in the gypsum and SSP plots. In the third season, large decreases in soil pH were observed in all the plots in which residual effects of lime were being monitored, especially the CL-4000 and DL-4000 treatments.

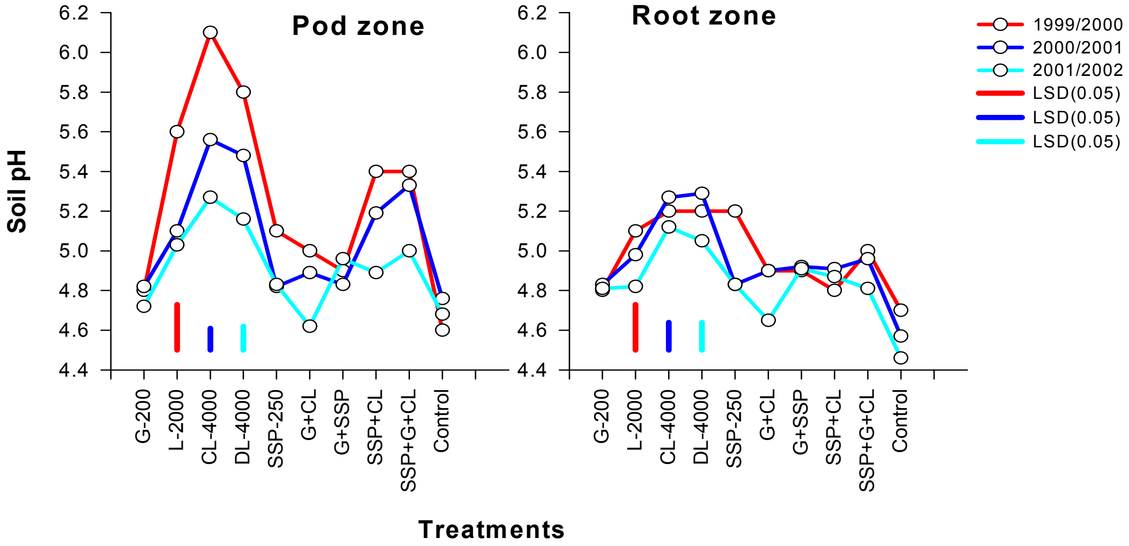

Figure 2.1 Changes in soil pH at peak flowering in 1999/2000, 2000/01 and 2001/02 cropping seasons after application of Ca materials at HRC

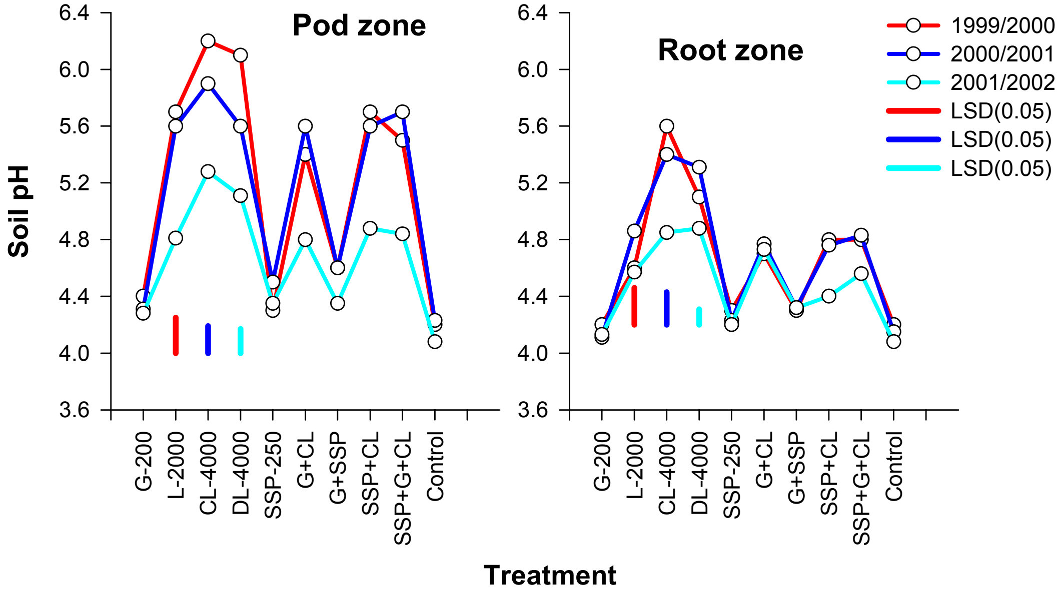

Figure 2.2 Changes in soil pH at peak flowering in 1999/2000, 2000/01 and 2001/02 cropping seasons after application of Ca materials at MES

Changes in the soil pH of the control treatments can be attributed to seasonal variations in the reactions that neutralize H^+ as well as produce H^+ (Conyers *et al.,* 1995). Soil pH undergoes cycles of decrease and increase (Friesen, *et al.,* 1985; Skyllberg, 1991) because of alkali-producing reactions (ammonification, reduction of Mn-oxides, oxidation of organic anions, SO_4^- adsorption) or acid-producing reactions such as nitrification, oxidation of Mn^{2+}, oxidation of organic S (Conyers *et al.,* 1995).

Root zone pH changes in the 2000/01 and 20001/02 cropping seasons

In the 2000/01 cropping season, the pH values in the root zone at both sites tended to be similar to those observed in the 1999/2000 cropping season (Figures 2.1 & 2.2). Plots treated with 4000 kg ha^{-1} CL or DL maintained the highest soil pH levels in the 2000/01 cropping season at both sites. In the 2001/02 cropping season, the soil pH values decreased considerably, resulting in soil pH levels similar to those observed in the first cropping season. The soil pH levels remained highest in plots treated with 4000 kg ha^{-1} lime.

While the pH decreased with time at both sites, soil pH levels in the pod and root zones in plots treated with 4000 kg ha^{-1} lime were still above pH 5.0 in the third season. At the HRC site, the plots treated with either 2000 kg ha^{-1} lime alone or in combination with gypsum and SSP also had soil pH levels above 5.0 in the third season. In the rest of the treatments, the soil pH was slightly higher, but not significantly different from that of the original unlimed soil. Even when gypsum and SSP were added annually, they did not improve soil pH with time. Scott *et al.* (1999) found that the rate of pH decline in the 0-10 cm soil depth depended on the pH increase achieved one year after lime application; the higher the pH increase, the faster the rate of decline and *vice versa.* Similarly in the present study a considerable decline in pH was observed in treatments that attained the highest soil pH values, and this was more pronounced at MES where initial increases in pH of >2.0 units had been observed, followed by a decline of 0.99 units in the third season.

CHANGES IN EXCHANGEABLE SOIL CA LEVELS

Pod zone Ca levels in the 1999/2000 cropping season

Concomitant with the observed increases in soil pH in the 1999/2000 cropping season, exchangeable Ca levels in the soil were also improved. Mean Ca levels in the pod zone of the control plots at HRC were 125 mg kg^{-1} at peak flowering, and application of CL was the most efficient in increasing soil Ca level by 92% to 125% (Figure 2.3). In the plots with 4000 kg ha^{-1} DL, increases in Ca levels were 51%, whereas gypsum or SSP applied alone increased Ca levels by 26% and 9% respectively. Combining gypsum or SSP with 2000 kg ha^{-1} lime did not increase Ca levels more than applying lime alone. At the MES site, the mean exchangeable Ca levels in the control plots were 43 mg kg^{-1} at peak flowering, and application of calcium materials increased the Ca levels up to 418 mg kg^{-1} with 4000 kg ha^{-1} CL (Figure 2.3). Overall, the responses were similar to those observed at HRC, and the treatment effects were highly significant.

At the physiological maturity stage of the groundnut, the pod zone Ca levels in the CL and DL treatments and their combinations tended to be higher than at the flowering stage at HRC (Appendix Table A2.2). Application of CL had increased Ca levels from the initial 167 to 233 mg kg^{-1} with 2000 kg ha^{-1}, and up to 332 mg kg^{-1} with 4000 kg ha^{-1} at HRC. Dolomitic lime applied at 4000 kg ha^{-1} increased Ca levels up to 282 mg kg^{-1}, while combinations of lime with SSP or gypsum did not result in higher Ca levels than lime alone. Similar response trends were observed at MES (Appendix Table A2.3), although the Ca levels were somewhat lower at physiological maturity than at peak flowering for most of the treatments. The Ca levels in plots treated with 4000 kg ha^{-1} CL had increased from 64 to 277 mg kg^{-1}.

Root zone Ca levels in the 1999/2000 cropping season

In the root zone at HRC, the Ca content at peak flowering and at physiological maturity was less affected by application of Ca-materials than in the pod zone, but the response trend was similar (Figure 2.3; Appendix Table 2.2). At MES, the Ca content at peak flowering was significantly increased from the initial 48 up to 209 mg kg^{-1} with application of 4000 kg ha^{-1} CL. Combining lime with gypsum and/or SSP also significantly improved the root zone Ca levels. At physiological maturity, the root zone Ca levels were less affected by treatments than in the pod zone, but the response trend was similar (Appendix Table A2.3). Contrary to the observations made at HRC, the Ca levels in the root zone at MES were somewhat lower at physiological maturity than at peak flowering for most of the treatments. Overall, the increases in Ca levels due to application of ameliorants were higher (up to 335%) at MES than at HRC (up to 77%) with application of CL.

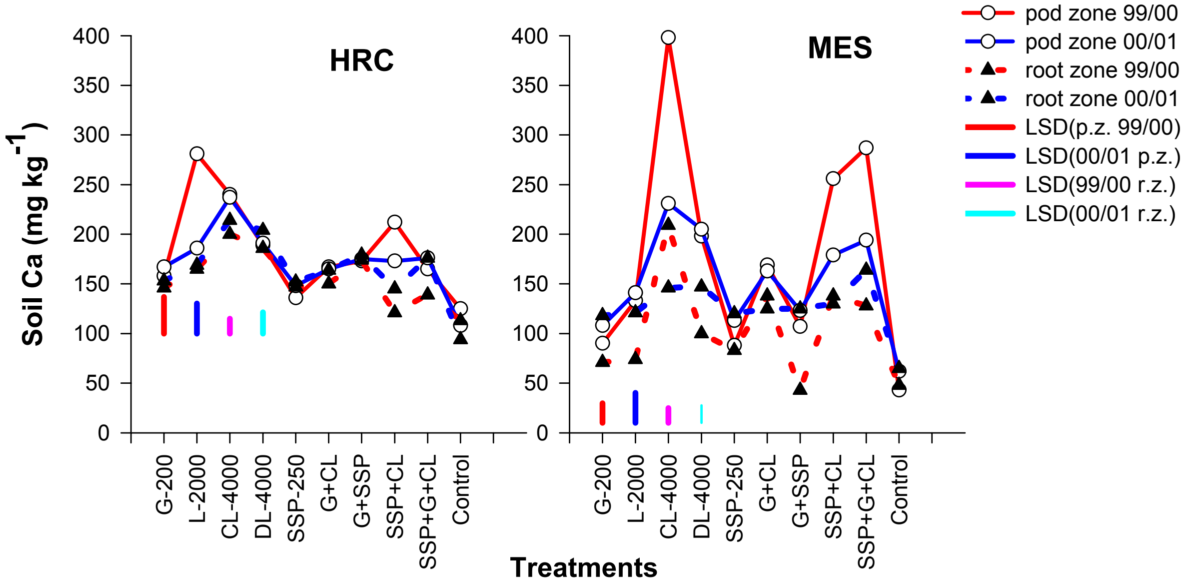

Figure2.3 Changes in soil exchangeable Ca levels at peak flowering in 1999/2000 and 2000/01 seasons after application of Ca materials at HRC and MES.

When equal rates of lime were applied, Ca levels in the pod and root zones were highest in plots where CL was applied probably due to the higher Ca concentration in CL (23%) than in DL (18%). The pod zone Ca levels in the CL and DL treatments, and their combinations, at HRC tended to be higher at the physiological maturity stage of groundnut than at the flowering stage, which could be an indication that lime may provide more Ca in solution late in the season, as a result of the low solubility and/or slow mobility. The different observation made at MES could be ascribed to uncontrollable variations due to sampling and analytical procedures. Observations that the Ca content in the root zone was less affected by treatments than the pod zone could probably be ascribed to the depth of incorporation, and to the solubility and/or mobility of the materials.

Pod zone Ca levels in the 2000/01 cropping season

In the 2000/01 cropping season, the exchangeable Ca levels in the pod zone at HRC were either similar or slightly lower than those observed in the previous season for most treatments (Figure 2.3). The Ca levels in the control plots had declined to 108 mg kg^{-1}, and remained highest (221-237 mg kg^{-1}) in plots treated with 4000 kg ha^{-1} CL or DL. At MES, the Ca levels in the pod zone also tended to be similar or lower than those observed in the previous season (Figure 2.3). Overall, the highest Ca levels were observed in the plots with 4000 kg ha^{-1} lime and in plots treated with lime in combination with SSP and gypsum. At both sites, the response trend at peak flowering was similar to that observed at physiological maturity. Data for the physiological maturity sampling dates are presented in Appendix Tables A2.2 & A2.3.

Root zone Ca levels in the 2000/01 cropping season

In the root zone, the exchangeable Ca levels at both sites generally showed slight increases compared to those observed in the previous season (Figure 2.3). The mean Ca values in the control plots at peak flowering were 94 mg kg^{-1} at HRC and 48 mg kg^{-1} at MES, and residual effects of 4000 kg ha^{-1} CL increased the levels to 244 mg kg^{-1} at HRC, whereas at MES residual effects of lime in combination with SSP and gypsum increased the levels to 164 mg kg^{-1}. Like in the pod zone, the highest Ca levels were observed in the plots with 4000 kg ha^{-1} lime and in plots treated with lime in combination with SSP and gypsum. At both sites the response trends at physiological maturity were similar to those observed at peak flowering (Appendix Tables A2.2 & A2.3).

The movement of Ca below the depth of initial incorporation could explain the observed higher levels of Ca in the second season in the root zone. Similar interpretations were made by Scott *et al.* (1999) who detected significant increases in Ca in the 10-15 and 15-20 cm soil layers after application of 1000 kg ha^{-1} lime in the previous year. However, the Ca increases could be overestimated if undissolved lime remained in the soil and the extraction of exchangeable cations resulted in the dissolution of some undissolved lime (Aitken *et al.,* 1998).

CHANGES IN EXCHANGEABLE SOIL MG LEVELS

Pod zone Mg levels in the 1999/2000 cropping season

At both sites the exchangeable Mg levels in the pod zone at the peak flowering period of groundnut were increased due to application of CL and DL. At HRC, the exchangeable Mg increased by 183% to 68 mg kg $^{-1}$ in the plots treated with 4000 kg ha^{-1} DL (Figure 2.4). Gypsum and SSP applied alone or in combination did not affect exchangeable Mg levels. At the MES site, the treatments had a similar effect on Mg levels as that observed at HRC (Figure 2.4). Application of 4000 kg ha^{-1} DL increased the Mg content from an initial 11 mg kg^{-1} to 63 mg kg^{-1}, an increase of 473%. Reactions in soil exchangeable Mg levels at physiological maturity of groundnut were similar to those observed at peak flowering at both sites (Appendix Tables A2.2 & A2.3). Generally, significant increases in the levels of exchangeable Mg were found on limed plots. The exchangeable Mg levels at both sites were generally lower at physiological maturity than at peak flowering, the only exception being the DL 4000 kg ha^{-1} treatment at HRC that registered a 34% increase in exchangeable Mg levels.

Root zone Mg levels in the 1999/2000 cropping season

In the root zone, the treatment effects on exchangeable Mg were similar to those observed in the pod zone at both sites, though less prominent (Figure 2.4). At both sites, the gypsum and SSP treatments had no effect on the Mg content of the soil. When they were applied in combination with lime, non-significant increases in Mg content were observed. As expected, plots treated with DL were higher in soil Mg levels than other plots throughout the groundnut growing season, and the higher the application rate, the larger the increase in soil Mg content. This is attributable to the higher Mg content of dolomite (10.9%) compared to that of CL (7.2%), SSP (4.2%) and gypsum (0.5%).

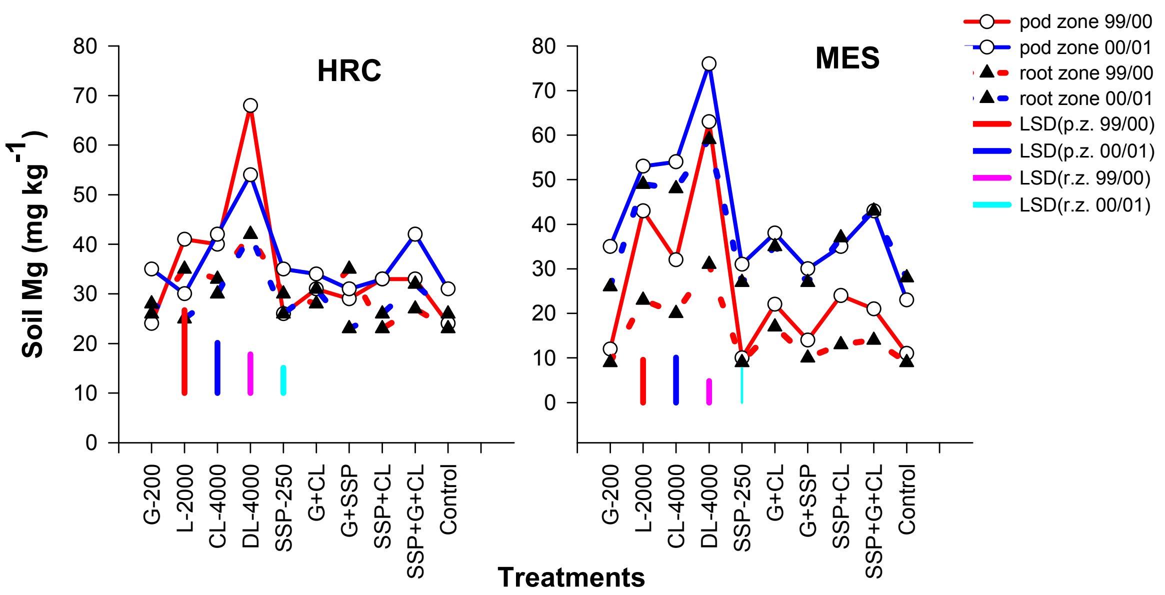

Figure2. 4 Changes in soil exchangeable Mg levels at peak flowering in 1999/2000 and 2000/01 seasons after application of Ca materials at HRC and MES

Pod zone Mg levels in the 2000/01 cropping season

Levels of exchangeable Mg in the pod zone at HRC were similar to those observed in the previous season for all treatments (Figure 2.4). The lowest Mg levels were in the control plots (31 mg kg^{-1}) while the highest (54 mg kg^{-1}) were in plots treated with 4000 kg ha^{-1} DL. Mg levels considerably higher than the control were also observed in plots treated with 4000 kg ha^{-1} CL and where lime was combined with gypsum and SSP. At MES, the Mg levels in the pod zone tended to be higher than those observed in the previous season (Figure 2.4). The Mg levels ranged from 23 mg kg^{-1} in the control treatment to 76 mg kg^{-1} in plots treated with 4000 kg ha^{-1} DL. While the response trends observed at peak flowering were maintained at physiological maturity at both sites, somewhat lower Mg levels were observed at the latter stage (Appendix Tables A2.2 & A2.3).

Root zone Mg levels in the 2000/01 cropping season

In the root zone, the exchangeable Mg levels at HRC were not different from those observed in the 1999/2000 cropping season (Figure 2.4), whereas at MES the Mg levels were considerably higher than those observed in the previous season (Figure 2.4). The highest mean Mg values were observed in the plots with 4000 kg ha^{-1} DL at both sites, whereas annual applications of SSP and gypsum did not increase the soil Mg levels. Overall, the residual effects of the applied ameliorants on soil Mg content were more prominent at MES than at HRC.

At physiological maturity of groundnut, the residual effects of the ameliorants on soil Mg content were similar to those observed at peak flowering at both sites (Appendix Tables A2.2 & A2.3). High levels of exchangeable Mg were found on limed plots whereas gypsum and superphosphate had no effect on the Mg status of the soil. At both sites, the Mg levels were generally lower at physiological maturity compared to the peak flowering period.

CHANGES IN SOIL N, P AND K LEVELS

Pod and root zone N levels in the 1999/2000 and 2000/01 cropping seasons

At both sampling periods in the first season (Table 2.4; Appendix Table A2.4), considerable variation in the N status of the pod zone was observed over the plots of the experiment, especially at the peak flowering period, where the levels ranged from 7 to 17 and 5 to 22 mg kg^{-1} at HRC and MES, respectively. Similar variations were observed in the root zone at both sites. While statistically there were significant differences between the N levels observed, no clear explanation for the variations in N-analysis can be offered. Rosolem & Caires (1998) attributed the low N levels observed in their limed plots to increased N uptake, resulting in the depletion in soil N levels.

In the second cropping season, the mineral N levels in the pod zone at the peak flowering period of groundnut were generally improved at both sites, especially in the limed plots (Table 2.5). As observed in the previous season, the treatment effects were in general not significant, but the higher mineral N levels in the lime treatments may be a reflection of the treatment effects on groundnut productivity during the previous season, resulting in more crop residues on some plots. The trends observed in the pod zone were repeated in the root zone. Overall, the soil N levels remained low during the two cropping seasons. Divergent results on the effects of lime on N mineralization have been documented; with some reporters observing improved N mineralization following lime application (Black, 1968; Lyngstad, 1992), while Nyborg & Hoyt (1978) found no correlation between soil pH and the N mineralized per unit of organic N. Lyngstad (1992) observed that the release of N caused by liming was short-lived, and that the direct as well as residual effects of lime on amounts of N mineralized varied among soils.

Pod and root zone P levels in the 1999/2000 and 2000/01 cropping seasons

In the first season, the mean pod zone P levels in the control plots at peak flowering were 39 mg kg^{-1} at HRC, and increased to 46 mg kg^{-1} with application of SSP in combination with gypsum and lime (Table 2.4). At MES, the mean pod zone P levels in the control plots were 20 mg kg^{-1}, and application of 4000 kg ha^{-1} DL resulted in the highest P content of 41 mg kg^{-1} (Table 2.4). Similar treatment effects were observed at the physiological maturity stage (Appendix Table A2.4). In the root zone at HRC, the P levels ranged from 35 mg kg^{-1} in the control plot to 47 mg kg^{-1} in the plot treated with 250 kg ha^{-1} SSP (Table 2.4). At physiological maturity, the P levels were generally lower, ranging from 19 to 29 mg kg^{-1} (Appendix Table A2.4). This trend was also observed at the MES site where high soil P levels were observed even in the control plots (Table 2.4; Appendix Table A2.4).

The pod and root zone P levels at both sampling periods in the second season were similar to those observed in the first season (Table 2.5; Appendix Table A2.5). The soil analysis in this study clearly shows that there were adequate amounts of plant available P present in the soils at both sites. The absence of any treatment effects on soil P content indicates that any observed differences in plant growth could not be related to differences in P nutrition.

Table 2.4 Soil N, P and K levels in the 0-10 cm and 20-30 cm soil depth layers at peak flowering period of groundnut at HRC and MES, 1999/2000 season

Treatment	HRC						MES					
	Soil nutrient level (mg kg^{-1})						Soil nutrient level (mg kg^{-1})					
	N		P		K		N		P		K	
	Soil depth layer (cm)						Soil depth layer (cm)					
	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30
G-200	12	10	37	37	23	26	9	23	26	37	11	12
L-2000	8	9	38	37	25	27	11	5	30	36	8	8
CL-4000	10	6	33	37	15	23	7	7	26	51	8	8
DL-4000	17	8	44	40	37	29	6	4	41	49	10	11
SSP-250	7	7	36	47	22	23	5	5	19	41	9	13
G + CL	16	10	36	36	17	22	10	10	20	40	11	18
G + SSP	8	13	35	39	14	23	10	22	27	63	9	9
SSP + CL	11	7	34	37	21	20	9	7	24	47	8	8
SSP + G + CL	11	10	46	41	19	25	5	3	34	22	8	9
Control	8	18	39	35	20	22	22	11	20	61	12	14
Mean	11	10	38	39	21	24	9	10	27	45	9	11
LSD $_{(0.05)}$	3.2	2.8	3.01	4.18	4.57	3.44	4.46	7.68	7.63	10.0	2.08	2.66

Table 2.5 Soil N, P and K levels in the 0-10 cm and 20-30 cm soil depth layers at peak flowering period of groundnut at HRC and MES, 2000/01 season

Treatment	HRC						MES					
	Soil nutrient level (mg kg^{-1})						Soil nutrient level (mg kg^{-1})					
	N		P		K		N		P		K	
	Soil depth layer (cm)						Soil depth layer (cm)					
	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30	0-10	20-30
G-200	12	13	23	15	23	19	13	11	20	34	21	20
L-2000	17	11	24	18	21	14	14	14	20	38	18	17
CL-4000	14	13	27	20	27	18	15	10	26	35	19	15
DL-4000	12	10	25	19	21	13	20	12	27	34	20	14
SSP-250	12	14	29	18	17	14	13	9	21	33	16	14
G + CL	18	15	18	15	27	18	22	14	19	33	22	15
G + SSP	12	13	34	20	17	14	16	10	20	34	17	14
SSP + CL	18	13	27	26	21	14	16	11	23	34	19	16
SSP + G + CL	16	13	35	29	25	15	19	10	25	39	16	13
Control	14	15	18	13	23	16	11	10	17	32	14	16
Mean	**14**	**13**	**26**	**19**	**22**	**15**	**16**	**14**	**22**	**20**	**18**	**15**
LSD $_{(0.05)}$	**5.182**	**2.87**	**5.52**	**5.24**	**6.99**	**5.18**	**3.23**	**2.89**	**5.16**	**5.93**	**3.31**	**2.23**

Pod and root zone K levels in the 1999/2000 and 2000/01 cropping seasons

Potassium levels in the pod zone at HRC ranged from 14 to 37 mg kg^{-1} at peak flowering (Table 2.4) and 12 to 20 mg kg^{-1} at physiological maturity (Appendix Table A2.4). At the MES site, K levels in the pod zone ranged from 8 to 12 mg kg^{-1} at peak flowering (Table 2.4) and 14 to 25 mg kg^{-1} at physiological maturity (Appendix Table A2.4). At both sites, there were no clear soil K responses to application of the Ca-materials. Some plots had lower K levels compared to the control plots, and this may be explained in terms of loss from the soil as a result of consumption by the better growing plants in these plots. In the root zone at HRC, the K values at peak flowering were generally higher than those observed in the pod zone, but were not significantly affected by treatments (Table 2.4). At physiological maturity, the K values in the root zone were similar to those in the pod zone at HRC (Appendix Table A2.4), and lower than those in the pod zone at the MES site (Table 2.4). The high K levels in the pod zone at MES were observed only in plots treated with CL or DL.

In the second season, the K levels were affected by treatments at both sites, and there were no clear response trends (Table 2.5; Appendix Table A2.5). The tendency for lower K levels in some plots compared to the control plots was repeated in the second season. Aitken *et al.* (1998) observed that lime application in acidic soils of south-east Queensland generally did not affect exchangeable K levels, but where the lime effects were significant, the K levels were significantly reduced with application of <4000 kg ha^{-1} lime, and attributed this to the relative ease of displacement of K from the cation complex by Ca. The propensity for generally higher K values in the root zone than in the pod zone at peak flowering, and *vice versa* at physiological maturity, was also repeated in the second season at both sites.

Overall, the soil K levels in this study at both sites are considered too low for production of groundnut, which requires not less than 80 mg kg^{-1} K (Swanevelder, 1998). Therefore, fertilization may be necessary to improve plant available K in the soils used in this study. The observed K levels in the root and pod zones corroborate the observations by Zharare (1997) that at Ca levels that are optimal for pod growth, groundnut plants excrete K through the pods after absorption by the roots, hence the increase in the nutrient in the pod zone, especially at peak pegging and early pod formation stage. More K in the pod zone was observed in plots that generally had high Ca levels. This transfer of K from the root zone to the pod zone has valuable economic implications on the K-fertilization program in cropping systems including groundnut, as groundnut can be sequenced with shallow-rooted crops so that they can utilize subsoil K that would have been recycled to the topsoil by groundnut.

2.3.2 EFFECT OF AMENDMENTS ON PLANT STAND, NODULATION, LEAF NUTRIENT COMPOSITION AND YIELD OF GROUNDNUT

Plant stand

Plant density is an important factor affecting groundnut yield. An assessment of this parameter over the three seasons showed that application of ameliorants significantly improved plant stand at both sites (Figure 2.5). In the first season, the mean plant stand in the control plots at HRC was 77%, and application of lime combined with gypsum and SSP increased the plant population to 94%. Application of 4000 kg ha^{-1} CL or DL achieved a plant stand of 88%. Gypsum and SSP alone or in combination also improved the plant stand compared to the control treatment. Combining lime with gypsum and/or SSP did not influence plant stand differently than applying the lime alone. Similar treatment effects were observed in seasons two and three. Overall, better plant stands were observed in season two, and this can be attributed to better rainfall distribution in that season, coupled with favorable soil pH levels and improved nutrient status.

At MES, the mean plant stand in the control plots in the first season was 71%, and application of lime increased the plant stand to 86% with 2000 kg ha^{-1} CL, and to 90% with 4000 kg ha^{-1} CL. Application of 4000 kg ha^{-1} DL achieved a plant stand of 85%. Unlike at HRC, gypsum and SSP alone did not improve the plant stand, but when applied in combination resulted in a plant stand of 81%. Combining 2000 kg ha^{-1} CL with gypsum and/or SSP did not influence plant stand differently than applying the lime alone. These trends were observed over the three seasons. At this site, plant establishment in the respective treatments was almost similar across the three seasons, despite the improvements in soil pH and soil nutrient status.

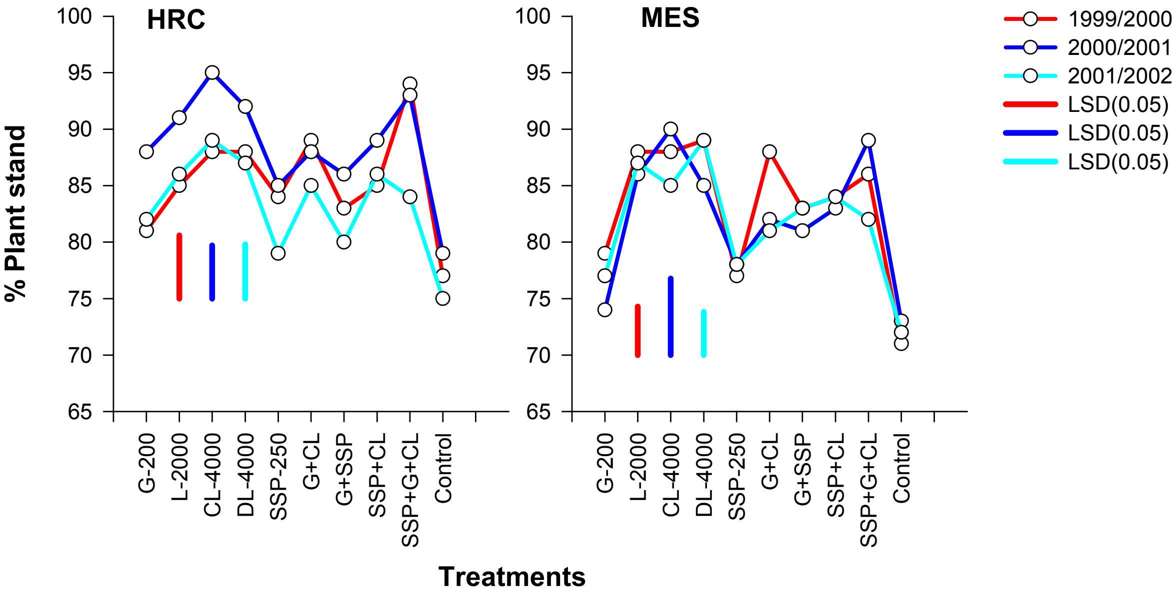

Figure 2.5 **Plant stand (%) at HRC and MES as affected by application of Ca materials**

Nodule number and mass

At HRC, the number of nodules per plant was significantly influenced by application of ameliorants, with an average of 104 nodules per plant being produced with 4000 kg ha^{-1} CL, compared to 32 in the control treatment in the 1999/2000 season (Table 2.6). Nodulation in the gypsum and SSP treatments was not significantly different from the control treatment. Nodule numbers were higher in the DL-4000 treatment than in the CL-2000 treatment. Similar response trends were observed in 2000/01 and 2001/02 seasons, though nodulation was less prolific compared to the 1999/2000 season. Nodule number per plant increased from 32 in the control treatment to 104 following the application of 4000 kg ha^{-1} CL in the 1999/00 season, and similar trends were observed in the second and third seasons. The response of nodule dry mass to ameliorants reflected that of nodule number (Table 2.6). The highest nodule dry mass (0.25 g plant^{-1}) in 1999/2000 season was observed in plots treated with 4000 kg ha^{-1} lime while the lowest (0.07 g plant^{-1}) was in the control plots. A similar effect was observed in the following seasons.

Although nodule number was influenced by application of ameliorants at MES, nodulation was less profuse than at HRC (Table 2.7). The mean number of nodules per plant in the control plots was 10, 35 and 31 in the 1999/2000, 2000/01 and 2001/02 seasons respectively. Application of 4000 kg ha^{-1} lime increased the nodule number per plant to 35 in 1999/2000, 75 in 2000/01 and 56 in 2001/02. The same response trends were observed for nodule dry mass (Table 2.7).

The poor nodulation in the control and gypsum treated plots could be attributed to low pH or low Ca levels, since the process is inhibited by pH levels below 5.0 for most legumes (Jayasundara *et al.*, 1998) and by Mo and Ca deficiency (Munns, 1978). Nodule initiation has been found to be highly sensitive to acidity (Evans *et al.,* 1980), while excess H^+ ions and deficiencies of Ca and P are the acidity factors most detrimental to the nodulation process (Vargas & Graham, 1988; Coventry & Evans, 1989). The pH in the control and gypsum plots was below pH 5.0 in the three seasons while the Ca content in the root zone was low. Hohenberg & Munns (1984) in their work with cowpeas, observed that pH <4.5 reduced early nodule number by as much as 80% compared to nodulation at pH 5.5, and also caused delays in nodulation at low Ca levels. Alva *et al.* (1990) observed that low Ca or pH levels significantly influenced the time to appearance of first nodules, nodule number and nodule dry mass of cowpeas.

Depressed nodulation with gypsum application has been ascribed to probable increased activity of Al-ions in an Al-toxic soil (Blamey & Chapman, 1982), or reduced Mo availability due to the antagonistic effect of sulphate on Mo availability (Reisenauer, 1963). Mengel & Kamprath (1978) observed that in addition to increasing the number of nodules on soybean roots, liming also changed the location and size. Nodules were large and located mainly on the taproot at low pH, and were initiated on the lateral roots as the pH increased, and the mean nodule weight decreased.

Table 2.6 Nodule number and nodule dry mass at HRC as affected by application of Ca materials

Treatment	Nodule number (nodules plant^{-1})			Nodule dry mass (g plant^{-1})		
	1999/00	2000/01	2001/02	1999/00	2000/01	2001/02
G-200	44	43	51	0.079	0.083	0.103
L-2000	68	68	67	0.205	0.173	0.163
CL-4000	104	76	69	0.245	0.128	0.12
DL-4000	96	71	77	0.210	0.105	0.118
SSP-250	38	30	28	0.170	0.083	0.08
G + CL	50	53	88	0.187	0.120	0.133
G + SSP	58	44	48	0.153	0.105	0.095
SSP + CL	39	39	52	0.200	0.083	0.094
SSP + G + CL	73	56	52	0.210	0.123	0.123
Control	32	20	37	0.074	0.048	0.098
Mean	**60**	**50**	**57**	**0.180**	**0.102**	**0.113**
LSD $_{(0.05)}$	**21.33**	**16.377**	**25.177**	**0.043**	**0.025**	**0.031**

Table 2.7 Nodule number and nodule dry mass at MES as affected by application of Ca materials

Treatment	Nodule number (nodules plant^{-1})			Nodule dry mass (g plant^{-1})		
	1999/00	2000/01	2001/02	1999/00	2000/01	2001/02
G-200	15	30	34	0.073	0.095	0.085
L-2000	16	72	43	0.105	0.110	0.143
CL-4000	35	75	56	0.158	0.115	0.105
DL-4000	29	41	47	0.146	0.088	0.123
SSP-250	24	51	41	0.045	0.103	0.085
G + CL	25	45	42	0.143	0.113	0.098
G + SSP	25	55	37	0.100	0.113	0.078
SSP + CL	32	45	48	0.125	0.078	0.098
SSP + G + CL	33	48	49	0.146	0.155	0.110
Control	10	35	31	0.033	0.070	0.058
Mean	**24**	**50**	**43**	**0.107**	**0.110**	**0.101**
LSD $_{(0.05)}$	**8.278**	**14.953**	**14.467**	**0.020**	**0.029**	**0.027**

Leaf nutrient composition

The mean leaf Ca concentrations for the control treatment at HRC were 0.59% in the first season and 0.75% in the second season (Table 2.8). Application of CL at 2000 and 4000 kg ha^{-1} produced a two-fold increase in Ca concentrations in the 1999/2000 season. The other ameliorants also significantly increased the leaf Ca concentrations. However, these increases did not attain the leaf Ca levels of 1.25 – 2.0% indicated to be adequate for good growth of Spanish-type groundnut (Reuter & Robinson, 1986; Gascho & Davis, 1994), indicating the marginal Ca status of the plants. In the 2000/01 season, the treatment effects were similar to those observed in the first season, but the Ca concentrations were higher than in the previous season, probably reflecting the improved availability of Ca.

At MES the effect of lime on leaf Ca concentrations was similar to that observed at HRC (Table 2.9). However, the mean leaf Ca concentrations were higher than at HRC, ranging from 0.76 to 1.47% in 1999/2000 season, and from 0.85 to 1.93% in 2000/01 season. The higher concentrations could be a concentration effect due to relatively poor plant growth at this site, rather than the effects of the amendments *per se.* Stunted plants contain higher tissue concentrations of several nutrients because either the nutrients are not efficiently utilized, resulting in their accumulation in leaf tissue (Ali, 1998), or because of lower dry mass accumulation in relation to their uptake rates (Inskeep & Bloom, 1987). Only plants growing in plots treated with 2000 or 4000 kg ha^{-1} lime had adequate leaf Ca concentrations in the 1999/2000 season, whereas in the 2000/01 season, only plants growing in the control treatment and in plots treated with SSP or gypsum were Ca deficient.

In general, increased Ca concentrations were observed in treatments with higher soil Ca concentrations. Bell *et al.* (1989) made similar observations on a number of tropical legumes (cowpeas, groundnut, guar, pigeonpea and soybean) when he noted that leaf Ca concentrations increased with increasing solution Ca concentrations. Rechcigl *et al.* (1986) and Alva *et al.* (1991) also observed increases in leaf Ca content of legumes as solution Ca concentration increased.

Table 2.8 Ca, Mg, N, P and K concentrations in groundnut leaves (YFEL) sampled at peak flowering at HRC

Treatment	1999/00					2000/01				
	Leaf nutrient concentrations (%)					Leaf nutrient concentrations (%)				
	Ca	Mg	N	P	K	Ca	Mg	N	P	K
G-200	0.96	0.38	3.29	0.37	1.54	1.26	0.80	3.55	0.44	1.31
L-2000	1.20	0.43	3.78	0.32	1.48	1.30	0.77	3.56	0.37	1.27
CL-4000	1.25	0.44	3.88	0.28	1.27	2.02	0.79	3.72	0.34	1.24
DL-4000	1.08	0.45	3.88	0.29	1.12	1.73	0.88	3.79	0.37	1.49
SSP-250	1.00	0.39	3.28	0.33	1.34	1.14	0.70	3.63	0.39	1.29
G + CL	1.12	0.39	3.15	0.30	1.53	1.48	0.67	3.64	0.43	1.01
G + SSP	1.05	0.39	3.46	0.33	1.33	1.26	0.66	3.68	0.41	1.46
SSP + CL	1.09	0.40	3.67	0.33	1.41	1.32	0.69	3.65	0.41	1.27
SSP+G+CL	1.13	0.40	3.65	0.25	1.16	1.57	0.77	3.85	0.35	1.11
Control	0.59	0.33	3.07	0.26	0.94	0.75	0.49	3.46	0.45	1.37
Mean	**1.02**	**0.40**	**3.51**	**0.30**	**1.28**	**1.38**	**0.72**	**3.65**	**0.40**	**1.28**
LSD $_{(0.05)}$	**0.232**	**0.019**	**0.211**	**0.03**	**0.124**	**0.115**	**0.082**	**0.121**	**0.033**	**0.155**

Table 2.9 Ca, Mg, N, P and K concentrations in groundnut leaves (YFEL) sampled at peak flowering at MES

Treatment	1999/00					2000/01				
	Leaf nutrient concentrations (%)									
	Ca	Mg	N	P	K	Ca	Mg	N	P	K
G-200	0.78	0.45	2.34	0.38	2.015	0.94	0.33	3.21	0.4	1.37
L-2000	0.71	0.55	3.05	0.27	1.14	1.27	0.52	3.38	0.38	1.015
CL-4000	1.47	0.56	3.34	0.27	0.67	1.45	0.63	3.82	0.36	1.315
DL-4000	1.1	0.42	3.39	0.28	1.08	1.33	0.39	3.4	0.39	1.255
SSP-250	0.76	0.43	2.92	0.385	1.61	0.93	0.35	3.46	0.39	1.135
G + CL	1.11	0.33	2.9	0.26	1.335	1.15	0.57	3.55	0.44	1.015
G + SSP	0.81	0.36	2.46	0.32	1.575	1.1	0.34	3.65	0.37	0.895
SSP + CL	1.18	0.42	2.89	0.315	1.475	1.45	0.46	3.6	0.44	1.225
SSP + G + CL	1.23	0.49	3.06	0.42	1.845	1.93	0.38	3.41	0.38	0.9
Control	0.79	0.3	2.54	0.285	1.615	0.85	0.32	3.52	0.42	1.42
Mean	**0.994**	**0.431**	**2.889**	**0.3185**	**1.436**	**1.24**	**0.429**	**3.50**	**0.397**	**1.155**
LSD $_{(0.05)}$	**0.223**	**0.020**	**0.174**	**0.032**	**0.139**	**0.103**	**0.049**	**0.116**	**0.033**	**0.140**

The ameliorants significantly increased Mg concentrations at HRC in the both seasons (Table 2.8). The highest Mg concentrations were observed in plants from plots treated with 4000 kg ha^{-1} DL. In both years, plants in all treatments exhibited Mg concentrations within the established sufficiency ranges of 0.3 to 0.8% (Jones, 1974), and the concentrations were inexplicably higher in the second season. At MES, the ameliorants significantly affected leaf Mg concentrations in both seasons (Table 2.9). The Mg levels in the control treatment were 0.3% in both seasons, and were doubled with application of 4000 kg ha^{-1} DL. Application of 2000 kg ha^{-1} DL achieved similar increases. Gani *et al. (*1990) observed similar trends, with the direct and residual effects of lime increasing leaf Mg concentrations of groundnut.

The observed high Mg concentrations in treatments with high soil Ca levels are at variance with observations made by other researchers. Alva *et al. (*1991) noted that an increase in solution Ca decreased the Mg concentrations in soybean and cowpea tops. Bell *et al. (*1989) also reported negative effects of increased solution Ca concentrations on the leaf Mg content of five tropical grain legumes. However, Aitken *et al. (*1998) found no consistent trends with respect to the effect of lime on leaf Mg concentrations of maize.

Leaf N concentrations were significantly improved by application of liming materials in the first season at HRC (Table 2.8), with application of 4000 kg ha^{-1} attaining the highest N concentrations of 3.9%. In the second season, there were no differences in the N concentrations between the treatments, with N concentrations above sufficiency levels (3.0 – 4.5 %) according to Jones (1974). Shamsuddin *et al. (*1992) in their study on effects of Ca and Al on nodulation, N-fixation and growth of groundnut in solution culture observed that the leaf N concentrations were little affected by solution Ca concentration. At MES, the lowest N concentrations (2.34 and 3.21%) were in the gypsum treatment whereas the highest were in plots treated with 4000 kg ha^{-1} CL or DL (Table 2.9). The N concentrations were generally below sufficiency ranges in the 1999/2000 season, but adequate in the 2000/01 season.

In general, the P concentration of the leaves was not affected by application of ameliorants at both sites and in both seasons (Tables 2.8 & 2.9). The P concentrations were adequate in all treatments at both sites, and tended to be lower at the high lime rates. The adequate P concentrations of the leaves are a reflection of the soil P status.

The K concentrations were generally deficient in both seasons and at both sites (Tables 2.8 & 2.9). Values for leaf K concentrations were slightly lower in lime treatments at both sites. Bartlett & McIntosh (1969) observed lower soil K and reduced plant uptake of the nutrient on limed soils and attributed it to the reduction in percentage K saturation of the cation exchange complex because of a lime-induced increase in cation exchange capacity. Soils at both HRC and MES experimental sites have an inherently low K status (Table 2.3).

The response trends of the leaf nutrient concentrations generally reflected the soil nutrient status. Soil Ca and Mg levels were improved by application of ameliorants, so were the leaf Ca and Mg levels. The direct as well as residual effects of the applied ameliorants on soil N, P and K were not significant, neither were they significant for leaf N, P and K concentrations with the exception of N levels at HRC in the first season. Bell *et al. (*1989) found that more Ca in solution produced varied effects on leaf concentrations of N, P and K in groundnut and other tropical food legumes.

Haulm, pod and kernel yields

Haulm yields were determined in the first and third seasons only. At HRC, the haulm yields from the control plots were 1857 kg ha^{-1} in the 1999/2000 season, and 1734 kg ha^{-1} in the 2001/02 season (Table 2.10). Overall, application of ameliorants increased the haulm yields, but there were no consistent trends. In the 1999/2000 season, the highest haulm yields (3750 kg ha^{-1}) were from plots treated with 2000 kg ha^{-1} CL combined with gypsum and SSP, whereas the residual effect of 4000 kg ha^{-1} DL resulted in the highest haulm yields (3719 kg ha^{-1}) in the 2001/02 season. The least yield increases were in plots treated with gypsum or SSP alone. In the experiment at MES, the yields were very low in the first season, a result of the poor plant growth caused by acid soil infertility coupled with water stress in the early vegetative stages of the crop. In spite of the water stress, all the lime treatments produced significant increases in haulm yields (Table 2.10). The yields ranged from 957 kg ha^{-1} in the control plots to 2021 in plots treated with 2000 kg ha^{-1} CL combined with gypsum, and in plots treated with 4000 kg ha^{-1} CL. The yields in the third season were highest (2393 kg ha^{-1}) in the treatment in which CL was combined with SSP and gypsum, an increase of 85% compared to the control treatment.

Table 2.10 Haulm and pod yields at HRC and MES as affected by application of Ca materials

Treatment	HRC					MES				
	Haulm yields		Pod yields			Haulm yields		Pod yields		
	1999/00	2001/02	1999/00	2000/01	2001/02	1999/00	2001/02	1999/00	2000/01	2001/02
G-200	1852	2435	1756	1433	1296	1019	1623	80	838	803
L-2000	2401	2790	2708	2062	1672	1620	2585	236	1530	1499
CL-4000	2963	3226	2741	2663	1888	2021	2904	286	2226	1594
DL-4000	2315	3719	2523	2306	1896	1805	2649	262	2306	1543
SSP-250	2847	2097	1978	1389	1200	1095	1854	86	1061	865
G + CL	3425	2727	2263	2058	1798	2022	3111	264	1852	1529
G + SSP	2384	2775	2004	1650	1552	1250	2486	171	1105	1007
SSP + CL	2963	2766	2364	2046	1814	1698	2524	200	1924	1728
SSP+G+CL	3750	3164	2580	2138	1978	1497	2789	164	2365	2017
Control	1857	1734	1846	1150	941	957	1680	69	631	571
Mean	**2676**	**2743**	**2276**	**1890**	**1604**	**1498**	**2521**	**182**	**1584**	**1316**
LSD $_{(0.05)}$	**673**	**431**	**548**	**599**	**449**	**104**	**944**	**34**	**714**	**645**

Pod yields from the control plots were 1846, 1150 and 941 kg ha^{-1} for the three seasons at HRC (Table 2.10). Application of ameliorants significantly increased the pod yields by up to 48% in the first season, and the highest yields were achieved by 4000 kg ha^{-1} CL. In the second season, the residual effects of the applied ameliorants increased the pod yields by 79% with 2000 kg ha^{-1} CL, and by 132% with 4000 kg ha^{-1} CL. Dolomotic lime applied at 4000 kg ha^{-1} increased the yield by 101%. The lowest increase (21%) was attained with application of 250 kg ha^{-1} SSP. Similar treatment effects were observed in the third season, though the yield increases were of a lesser magnitude, ranging from 28% with 250 kg ha^{-1} SSP to 101% with 4000 kg ha^{-1} DL.

Pod yields at MES were 69, 631 and 571 kg ha^{-1} across the three seasons in the control plots (Table 2.10). Application of ameliorants significantly increased the yields in all three seasons, with the highest yield increases of 314% in 1999/2000 and 334% in 2000/01 attained with 4000 kg ha^{-1} CL or DL. In the third season, the highest yield increase of 253% was attained with lime combined with SSP and gypsum. Gypsum or SSP applications did not influence pod yields in the 1999/2000 season, but increased yields by 33% and 68%, respectively, in the 2000/01 season, and by 41% and 51%, respectively, in the 2001/02 season. Combining gypsum with SSP achieved higher yields than applying each ameliorant alone.

Kernel yields in the first season at HRC were 1 247 kg ha^{-1} in the control plots, and application of 4000 kg ha^{-1} CL resulted in the highest kernel yield increase of 78% (Figure 2.6). In the plots treated with gypsum or SSP, the kernel yields were not significantly different from the control treatment. At MES, the mean kernel yield in the control plots was only 43 kg ha^{-1} in the 1999/2000 season, and application of ameliorants increased the kernel yield by 142% to 362. The kernel yield was highest with application of 4000 kg ha^{-1} CL or DL. The kernel yield response to gypsum or SSP was not significantly different from that of the control treatment.

In the second and third seasons, the kernel yield was significantly increased by residual effects of the 4000 kg ha^{-1} CL or DL treatments, and by the treatments that combined lime with gypsum and/or SSP at both sites. By the third season at HRC, the cumulative kernel yield for the control treatment was 2630 kg/ha, and the application of 4000 kg ha^{-1} CL more than doubled the cumulative kernel yield to 5520 kg/ha. By comparison, applying 2000 kg ha^{-1} CL produced a cumulative kernel yield of 4420 kg/ha over the three seaons, a difference of 25% from the 4000 kg ha^{-1} CL treatment. Application of lime combined with gypsum and SSP increased the cumulative kernel yield by 75%, whereas gypsum application resulted in the least increase (23%). Kernel yield increases due to application of lime at MES were of a much higher magnitude compared those at HRC. The cumulative kernel yield of the control treatment was only 819 kg/ha, and application of 4000 kg ha^{-1} DL resulted in the highest cumulative kernel yield of 3374 kg/ha, an increase of 312%. The cumulative kernel yield attained with application of 4000 kg ha^{-1} CL, or with 2000 kg ha^{-1} CL combined with gypsum and SSP was also considerably high, whereas application of 200 kg ha^{-1} gypsum achieved the least cumulative yield increase of 20%.

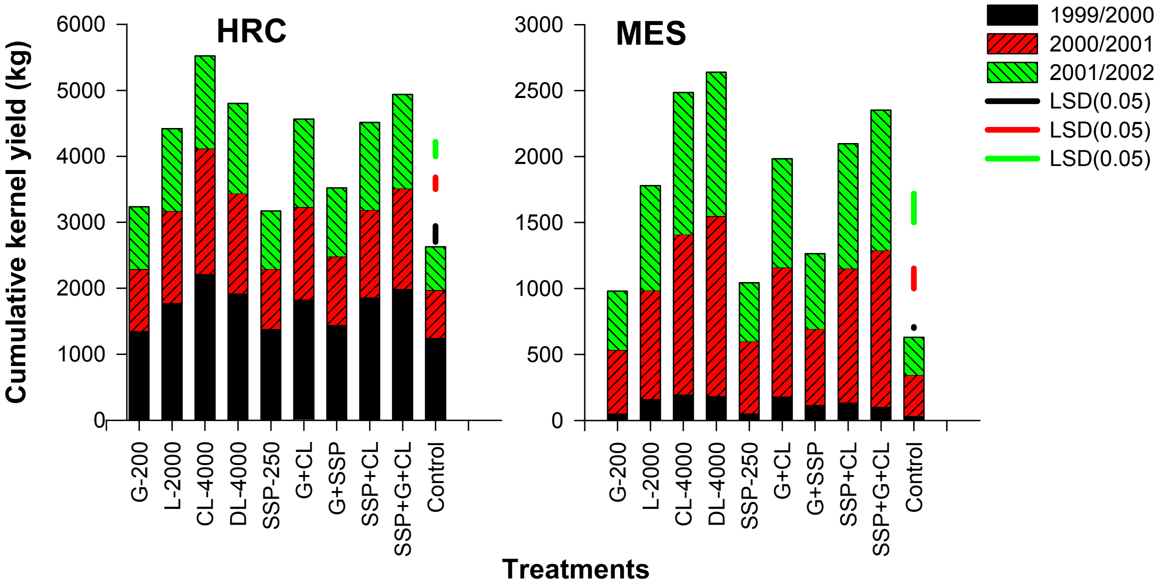

Figure 2.6 Cumulative kernel yields at HRC and MES in 1999/2000, 2000/01 & 2001/02 seasons

The poor kernel yield response to SSP and to gypsum is contrary to the expectation that groundnut production can be improved by SSP and gypsum application through enhanced Ca availability, and through enhanced S availability in the case of gypsum. This poor response is probably a reflection of the lack of effect of the two ameliorants on soil pH, which was not significantly different from the control plots, and the low rates of application. Gypsum application has been observed to have a greater effect on kernel yield in relatively dry seasons (Snyman, 1972; Rajendrudu & Williams, 1987), the reason being that because of its high solubility, it can ensure a continuous supply of available Ca with small amounts of moisture in the pod zone.

Increases in yield due to application of ameliorants were generally higher in the second and third seasons compared to the first, despite the decline in soil pH levels. Reasons for this are not clear, but it is possible that there were additional benefits from application of the ameliorants, and that these benefits would only manifest themselves after some time. For instance, there may be benefits from Mo and P availability or cycling, soil structure, microbial breakdown of organic matter and other spin-offs from application of ameliorants (Scott *et al.,* 1999). In addition to subjection to water stress, the other possible explanation for the small yield increases in the first season at MES could be the sharp increase in soil pH, especially in the high lime treatments. Excessive raising of pH in some highly weathered soils to pH values >6.0 has been known to cause deficiencies of essential nutrients like P, B, Mn, and Zn (Kamprath, 1971; Sanchez, 1976), and to the deterioration of soil structure, thereby leading to yield reductions.

Yields were influenced by application of the ameliorants in a similar manner at both sites, though the magnitude of the effects was not the same. The variations in rainfall amount and distribution could in part explain the differences. Over the three seasons, the kernel yield responses to the applied ameliorants were consistent, with high yields being obtained from the CL or DL treatments and low yields from the gypsum and SSP treatments. It was observed at HRC that applying 2000 kg ha^{-1} CL alone or in combination with gypsum and/or SSP resulted in yields which were statistically on par with the 4000 kg ha^{-1} DL treatment, suggesting that the low lime rate was adequate to reduce the negative effects of soil acidity on kernel yield of groundnut. The residual effects of both rates of lime were still observed in the third season as evidenced by the yield increases over the control treatment. The higher the original application rate, the more effective were the residual effects. The decline in the magnitude of the yield increases by the third season is an indication that another application of the ameliorants was required to boost the yields.

At the time of the experiments, lime at 2000 and 4000 kg ha^{-1} cost Z$29 700 and 59 400 respectively, while 200 kg of gypsum and 250 kg of SSP cost Z$998 and 2 493 respectively. At a grain marketing board producer price of Z$96 000 t^{-1} shelled groundnuts, the cumulative increases in kernel yield due to use of these amendments at HRC represent gross benefits of Z$ 142 140 for lime at 2000 kg ha^{-1}, 218 040 for lime at 4000 kg ha^{-1}, 55 278 for gypsum, and 134 697 for SSP. At MES, the gross benefits were Z$ 80 700 for lime at 2000 kg ha^{-1}, 133 368 for lime at 4000 kg ha^{-1}, 30 702 for gypsum, and 32 265 for SSP. These results show that use of Ca-containing materials, particularly lime, to improve groundnut productivity on acid soils is profitable. The benefits can be substantially higher if consideration is given to premiums paid for superior quality, since the ameliorants improved kernel quality. Consequently, farmers can be persuaded to adopt the liming technology to improve productivity and income on acid soils.

2.3.3 EFFECT OF AMENDMENTS ON KERNEL NUTRIENT COMPOSITION, POD AND KERNEL QUALITY

KERNEL NUTRIENT COMPOSITION

Calcium

In the first season, the kernel Ca concentrations at both sites were significantly influenced by application of ameliorants (Tables 2.11 & 2.12). At HRC, the kernel Ca concentrations were lowest (0.02%) in the control treatment, and were increased to 0.05% with application of either 2000 kg ha^{-1} CL combined with gypsum and SSP, or with 4000 kg ha^{-1} CL. Similarly, at MES, the kernel Ca concentrations were increased from 0.02% to 0.04% with application of 4000 kg ha^{-1} CL. The kernel Ca concentrations in the control, G-200, SSP-250 treatments and their combinations were below the sufficiency ranges of 0.04 – 0.08% (Gascho & Davis, 1994).

In the second season, the mean Ca concentrations in the control treatment were 0.02%, and were increased to 0.06% in the 4000 kg ha^{-1} CL treatment at HRC (Table 2.11). Concomitant with the improved soil Ca levels in the pod zone in the second season, the Ca concentrations were generally improved in the kernels. The kernel Ca concentrations were still below sufficiency levels in the control treatment, and in the G-200 and SSP-250 treatments and their combinations. Similar treatment effects were observed at MES (Table 2.12).

Notwithstanding the significant effects of applied ameliorants on the exchangeable Ca content of the soil, the kernel Ca concentration was not influenced to the same extent, especially at MES. No significant correlations were observed between kernel Ca concentration and soil Ca content (Appendix Table A2.6). Snyman (1972) obtained similar results, and concluded that the shell Ca content was a better indicator of soil Ca status than kernel Ca concentration. Possible reasons for the observed results in this study could be the influence of factors such as variable moisture regimes, or the low (2 – 3%) Ca-fertilizer uptake efficiency of the pods (Keisling *et al.,* 1982). Reduced kernel Ca concentrations have been observed in situations where pod development took place under inadequate moisture conditions (Skelton & Shear, 1971; Cox *et al.,* 1976; Wright, 1989), and attributed to limited solubility and impeded movement of Ca to the pods by mass flow (Gascho & Davis, 1994).

Table 2.11. Effects of ameliorants on Ca, Mg, N, P and K concentrations in groundnut kernels at HRC

Treatment	1999/2000					2000/01				
	Kernel nutrient concentrations (%)					Kernel nutrient concentrations (%)				
	Ca	Mg	N	P	K	Ca	Mg	N	P	K
G-200	0.038	0.19	4.34	0.29	0.70	0.026	0.15	3.45	0.19	0.69
L-2000	0.040	0.24	4.31	0.37	0.70	0.045	0.17	3.37	0.23	0.69
CL-4000	0.043	0.24	4.56	0.35	0.63	0.060	0.16	3.33	0.23	0.55
DL-4000	0.039	0.21	4.51	0.32	0.64	0.040	0.19	3.35	0.21	0.50
SSP-250	0.041	0.19	4.72	0.40	0.70	0.029	0.15	3.66	0.25	0.62
G + CL	0.040	0.20	4.23	0.32	0.69	0.027	0.15	3.42	0.21	0.62
G + SSP	0.036	0.19	4.44	0.40	0.70	0.032	0.14	3.55	0.25	0.60
SSP + CL	0.037	0.19	4.55	0.33	0.63	0.043	0.14	3.69	0.22	0.58
SSP + G+CL	0.046	0.20	4.48	0.41	0.65	0.048	0.15	3.44	0.25	0.58
Control	0.024	0.18	4.06	0.41	0.73	0.017	0.14	3.27	0.26	0.62
Mean	**0.039**	**0.20**	**4.43**	**0.36**	**0.67**	**0.038**	**0.15**	**3.46**	**0.23**	**0.60**
LSD $_{(0.05)}$	**0.006**	**0.01**	**0.11**	**0.04**	**0.02**	**0.007**	**0.01**	**0.10**	**0.03**	**0.01**

Table 2.12. Effects of ameliorants on Ca, Mg, N, P and K concentrations in groundnut kernels at MES

Treatment	1999/2000					2000/01				
	Kernel nutrient concentrations (%)					Kernel nutrient concentrations (%)				
	Ca	Mg	N	P	K	Ca	Mg	N	P	K
G-200	0.028	0.18	3.92	0.36	0.91	0.029	0.12	2.57	0.23	0.65
L-2000	0.039	0.20	4.08	0.38	0.74	0.040	0.15	2.54	0.24	0.48
L-2000	0.043	0.28	3.80	0.41	0.75	0.055	0.13	2.11	0.26	0.49
DL-4000	0.036	0.22	3.96	0.49	0.77	0.049	0.17	2.20	0.29	0.50
SSP-250	0.029	0.19	4.00	0.43	0.88	0.023	0.12	2.78	0.27	0.57
G + CL	0.028	0.17	4.04	0.48	0.78	0.035	0.10	2.55	0.28	0.51
G + SSP	0.035	0.18	3.98	0.47	0.90	0.021	0.11	2.65	0.28	0.58
SSP + CL	0.031	0.18	3.87	0.50	0.74	0.033	0.13	2.83	0.30	0.48
SSP+G+CL	0.035	0.17	3.92	0.40	0.70	0.036	0.12	2.39	0.24	0.46
Control	0.022	0.11	3.85	0.40	0.95	0.020	0.12	2.47	0.26	0.47
Mean	**0.033**	**0.19**	**3.94**	**0.43**	**0.81**	**0.033**	**0.13**	**2.50**	**0.27**	**0.52**
LSD $_{(0.05)}$	**0.003**	**0.033**	**0.117**	**0.036**	**0.023**	**0.005**	**0.008**	**0.140**	**0.018**	**0.038**

Magnesium

The kernel Mg concentration was significantly altered by application of ameliorants at both sites and in both seasons (Tables 2.11 & 2.12). At HRC, the kernel Mg concentration ranged from 0.18% in the control treatment to 0.24% in the CL-4000 treatment in the 1999/2000 season. The kernel Mg levels were adequate in all treatments. The sufficiency ranges are 0.16 – 0.2% (Gascho & Davis, 1994). At MES, the kernel Mg concentration ranged from 0.11% in the control treatment to 0.28% in the CL-4000 treatment, and was adequate in all but the control treatment in the 1999/2000 season.

In the second season, the Mg levels in the kernels were lower at both sites, ranging from 0.14% to 0.19% at HRC, and from 0.10% to 0.17% at MES (Tables 2.11 & 2.12). With the exception of the CL-2000, CL-4000 and DL-4000 treatments, the Mg levels in the kernels were below sufficiency at HRC. Despite the slightly improved soil Mg levels in the second season, the kernel Mg concentrations at MES were inadequate in all but the DL-4000 treatment. No significant correlation between exchangeable soil Mg and kernel Mg concentrations was observed, (Appendix Table A2.6), and no explanation for the seasonal variations in kernel Mg levels can be offered.

Nitrogen, Phosphorus and Potassium

Application of the ameliorants had no effect on the N concentrations of the kernels at both sites (Tables 2.11 & 2.12). The ranges of the N concentrations in the first season were 4.1% to 4.7% at HRC, and 3.8% to 4.1% at MES, respectively. In the second season, the N concentrations were much lower at both sites, and the response to the ameliorants was varied. The N concentrations ranged from 3.3% to 3.7% at HRC, and from 2.1% to 2.8% at MES, and reasons for the variations are not clear.

The effects of ameliorants on P concentration in the kernels were not significant at both sites, and this could partly be attributed to the inherent high P levels in the soils, and the fact that the ameliorants did not influence the soil P levels (Tables 2.11 & 2.12). The mean P concentrations in all the treatments were, however, within the sufficiency ranges of 0.17– 0.47% (Gascho & Davis, 1994) at both sites and in both seasons.

The Ca sources had no effect on K concentration in the kernels, which tended to be higher in the control and gypsum treatments at both sites in the first season (Tables 2.11 & 2.12). The trend was observed again in the second season at MES. At HRC, the 2000 kg ha^{-1} lime treatment had the highest kernel K concentrations. Snyman (1972) observed significant increases in kernel K concentrations due to applications of lower rates of Ca, but a considerable decrease in kernel K concentrations as the Ca application rate increased. The overall insignificant effect of applied ameliorants on kernel N, K and Mg can be ascribed to the preferential absorption of Ca over Mg, K and N as proposed by Csinos & Gaines (1986).

PROPORTION OF MATURE PODS

At HRC the proportion of mature pods was significantly affected by the ameliorant treatments (Figure 2.7). In the first season, the control treatment had a low proportion of mature pods (65%), whereas the application of 4000 kg ha^{-1} CL increased the proportion of mature pods to 74%, the highest among the treatments for the season. Combining lime with gypsum and/or SSP also increased the proportion of mature pods to more than 70%. The proportion of mature pods was low (64 %) in plots treated with 250 kg ha^{-1} SSP. Similar treatment effects were observed in the third season where the proportion of mature pods in the control plots was quite low (51%). In the other treatments, the proportion of mature pods generally improved compared to the first season, with the highest value of 79% being achieved with application of 4000 kg ha^{-1} CL. The same response trends were observed at MES (Appendix Table A2.7).

PRODUCTION OF EMPTY PODS (POPS)

The proportion of pops was significantly reduced to 5.3% by application of 4000 kg ha^{-1} CL, from 23.5% in the control treatment (Figure 2.7). The incidence of pops was also greatly reduced in plots treated with gypsum alone or in combination with SSP. Snyman (1972) also observed a highly significant decrease in percentage empty fruit where gypsum was applied, compared to lime application. Overall, application of the ameliorants was beneficial in reducing the percentage of pops, and this trend continued in the third season. Data from the MES site (Appendix Table A2.7) also exhibit response trends were similar to those observed at HRC.

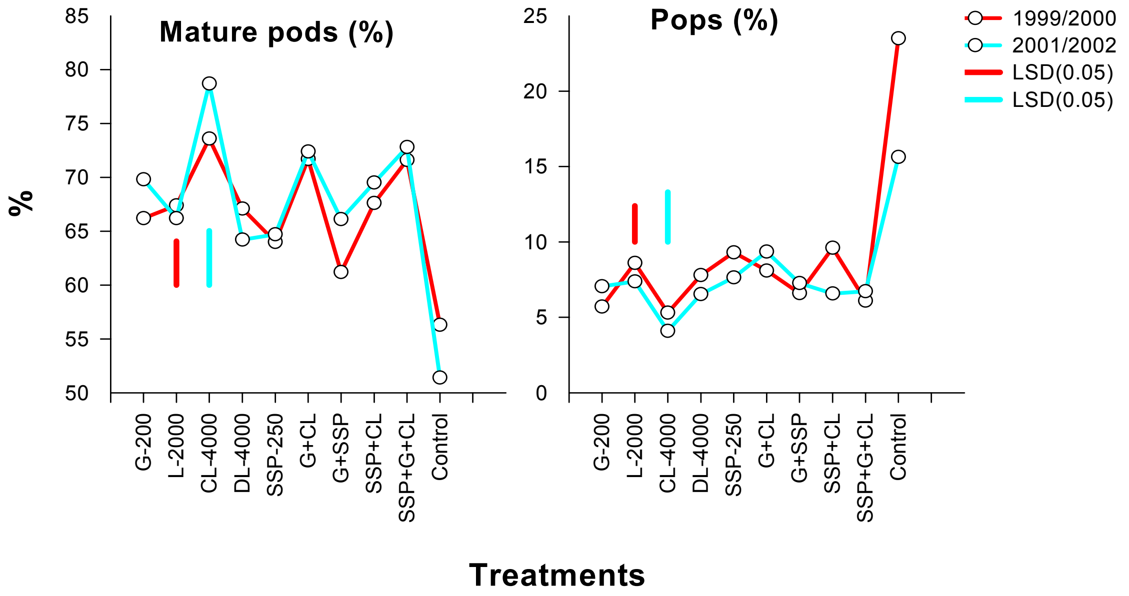

Figure 2.7 Percentage mature pods and pops at HRC as affected by application of Ca materials

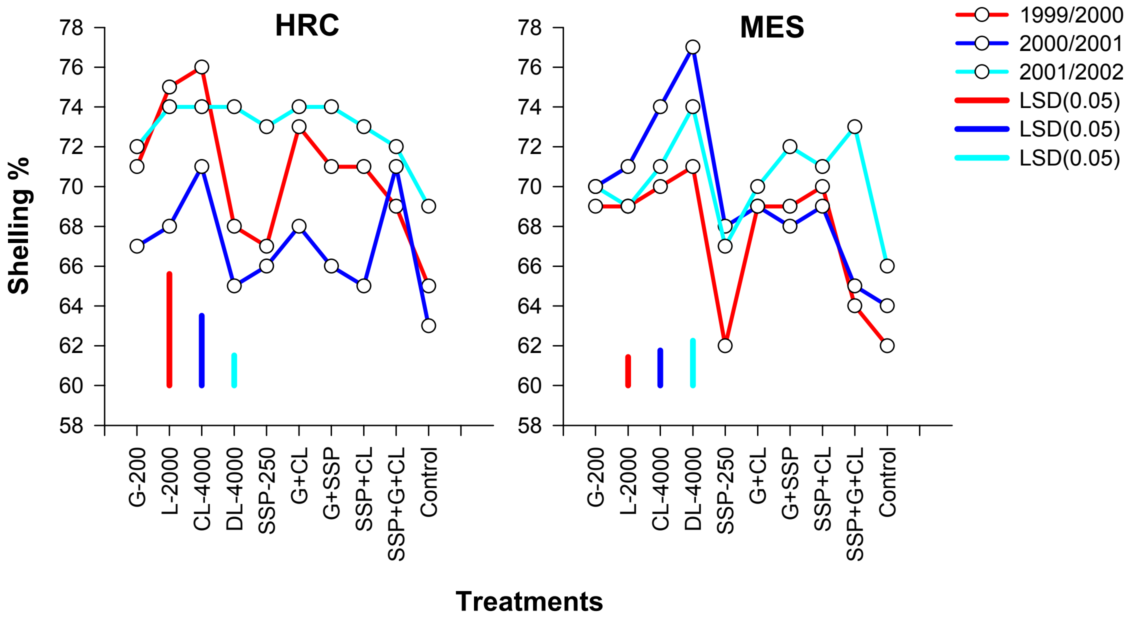

Figure 2.8 Effects of Ca materials on shelling % at HRC and MES

SHELLING PERCENTAGE

At HRC, the shelling percentage values were generally highest in the third season, intermediate in the first season and lowest in the second season, whereas at MES they tended to improve as the seasons progressed from 1999/2000 to 2001/02 (Figure 2.8). The response trends were however similar, with the lowest values being observed in the control treatment, and in the SSP treatment. The shelling percentage values were highest with application of 4000 kg ha^{-1} CL at HRC, and with application of 4000 kg ha^{-1} DL at MES. Combining lime with gypsum and/or SSP also increased the shelling percentage. Shelling percentage provides the most readily available index of Ca deficiency according to Hartmond *et al.* (1994). The significant correlations between the shelling % and exchangeable Ca in the soil (Tables 2.13 and 2.14) support this assertion.

PERCENTAGE OF SOUND MATURE KERNELS

The percentage of sound mature kernels (SMK%) was significantly influenced by application of ameliorants at both sites (Figure 2.9). As with shelling percentage, the magnitude of the treatment effects over the seasons was erratic, and the SMK at HRC tended to decrease as the seasons progressed, whereas a prominent reverse trend was observed at MES. The SMK% in the control plots at HRC ranged from 69% to 74% across the seasons. The highest %SMK values were in the 4000 kg ha^{-1} CL treatment, and averaged 89%. Gypsum application also increased SMK values to 87% on average, while the lowest values (83%) were attained with application of 250 kg ha^{-1} SSP. At MES, the SMK in the control plots averaged 72%, and was highest (80%) with application of 2000 kg ha^{-1} lime. In general, application of ameliorants had similar effects on the proportion of sound mature kernels as on kernel yields.

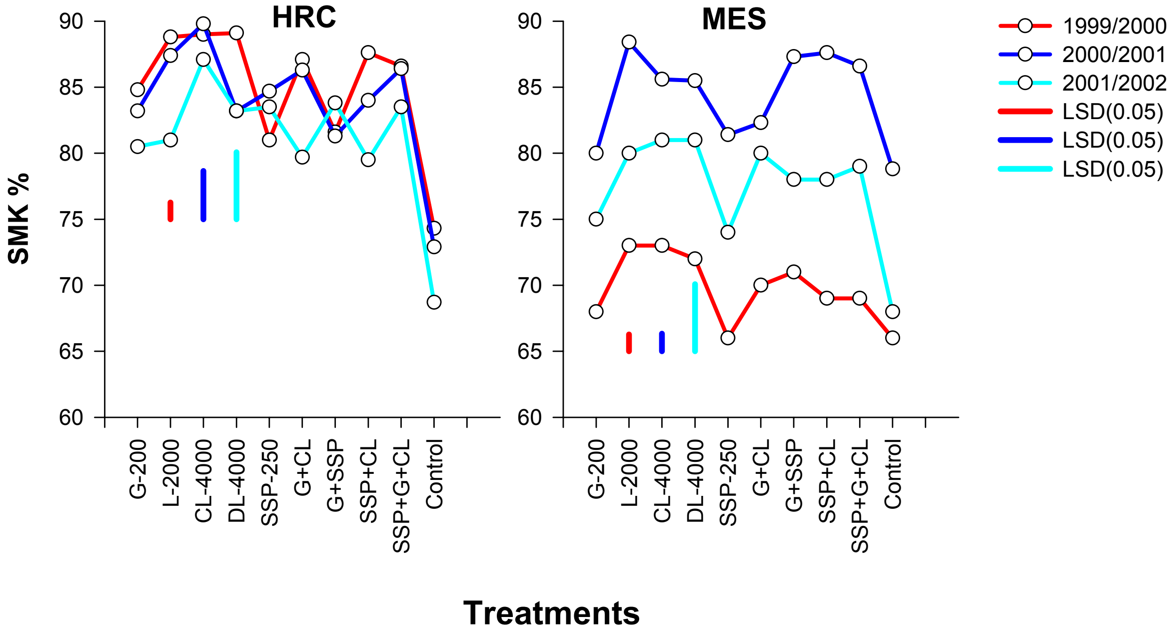

Figure 2.9 Effects of Ca materials on percentage sound mature kernels (SMK) at HRC and MES

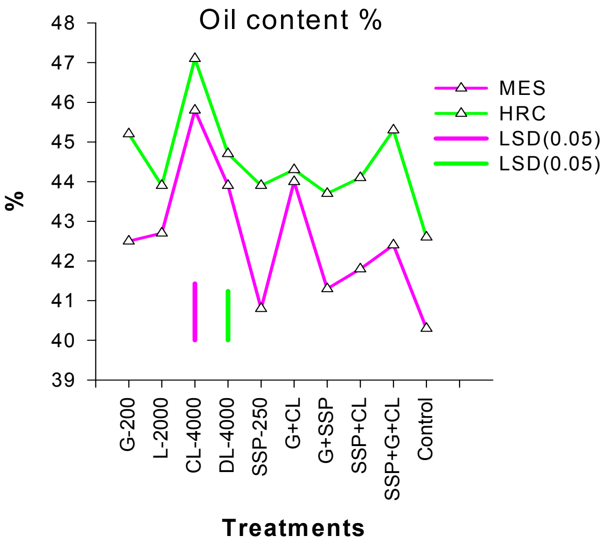

Figure 2.10 Effects of Ca materials on oil content (%) at HRC and MES

OIL CONTENT

The kernel oil content was determined at both sites in the 2000/01 season only. The mean kernel oil content from the control plots was 42.6% at HRC, and 40.3% at MES (Figure 2.10). At both sites, the oil content was significantly increased with application of 4000 kg ha^{-1} CL to 47.1% at HRC and 45.8% at MES. Gypsum and lime applied at 2000 kg ha^{-1} similarly increased oil content, whereas SSP application resulted in smaller increases in oil content. Snyman (1972) observed that kernel oil content was affected more by the source of Ca than by the amount of Ca applied, with CL and DL generally decreasing oil content at high rates of application, whereas gypsum tended to increase the oil content. Taking cognizance of the fact that kernel mass was similarly influenced by application of ameliorants, i.e. higher kernel mass with application of lime and gypsum, then the changes in kernel oil content can be ascribed to treatment effects *per se*.

2.3.4 RELATIONSHIPS OF KERNEL YIELD WITH SOIL PARAMETERS AND OTHER YIELD COMPONENTS

Very often, the elucidation of acid soil amelioration effects on groundnut is confounded by the erratic responses of groundnut to application of ameliorants. In addition, many soil parameters are changed when ameliorating acid soils, thereby making it difficult to isolate the exact cause of the yield responses (Blamey, 1983). In order to overcome the problem, correlation analyses were conducted to examine the interactions between groundnut yield components and soil parameters. At both sites, weak correlations ($r \leq 0.09$) were detected between kernel yield and soil N, P or K levels. At HRC, soil Mg was also weakly correlated ($r = 0.107$) with kernel yield. The soil parameters observed to be highly correlated with kernel yield were pH and Ca at HRC and pH, Ca and Mg at MES. Most of the plant parameters were significantly correlated with kernel yield.

The factors influencing kernel yield were divided into first order (yield parameters) and second order (soil parameters). The first order factors were plant density, number of pods per unit area, mean kernel mass, shelling percentage and proportion of pops. Soil pH and levels of exchangeable Ca were regarded as the second order factors since they strongly affected kernel yield at HRC. At MES exchangeable Mg was also included because of its strong correlation with kernel yield. Significant correlations were then subjected to path coefficient analysis to identify the causes of poor kernel yield in the acid soils in question.

CORRELATIONS AT HRC

Correlations of kernel yield with the first order-factors were generally positive, but not always significant. At HRC, highly significant and positive correlations were found between kernel yield and the first- and second-order factors that influenced the kernel yield (Table 2.13). Pod number was the most important determinant of kernel yield among the first-order factors at HRC, since it achieved a positive correlation of the highest magnitude with kernel yield (r=0.960). By contrast, shelling percentage was the least important determinant of kernel yield (r=0.293). As expected, the proportion of pops was negatively correlated with kernel yield. The proportion of pops was negatively correlated with all the first-order factors, this being more so with kernel mass than with kernel yield. Blamey (1983) found highly significant positive correlations between kernel yield and the first-order factors, which he explained as implying that kernel development was not limited by available photosynthate, as competition for the latter would lead to some negative correlations. It, however, appears that the first-order factors do not always assume the same importance in influencing kernel yield. For example, Tarimo & Blamey (1999) observed that the most important components associated with maximum economic yield in groundnut were pod harvest index, kernel harvest index and the ratio of pod number to peg + pod number; the other parameters like pod number, kernel number per pod, kernel size being less important.

Since the kernel yield correlation was positively stronger with exchangeable Ca than with soil pH among the second-order factors at HRC (Table 2.13), it implies that the kernel yield increases in responses to application of ameliorants can be mainly attributed to improved Ca supply. Nonetheless, the significant and positive correlation between soil pH and kernel yield indicates that the soil pH had a major influence on kernel yield, also. These results, therefore, suggest that soil levels of the two parameters can be used to predict kernel yield responses to application of the ameliorants at HRC.

Table 2.13 Total correlation coefficients between groundnut kernel yield, yield components and soil parameters at HRC

	Kernel yield	Pod No.	Kernel mass	Shelling %	% Plant stand	% SMK	% Pops	pH	Exch. Ca
Kernel yield	1.000								
Pod No.	0.960**	1.000							
Kernel mass	0.648**	0.604**	1.000						
Shelling %	0.293**	0.115ns	0.288**	1.000					
% Plant stand	0.514**	0.529***	0.074ns	0.010ns	1.000				
% SMK	0.414**	0.409**	0.720**	0.245*	0.023ns	1.000			
% Pops	-0.306**	-0.246*	-0.575**	-0.217*	-0.001ns	-0.415**	1.000		
PH	0.274**	0.245*	0.086ns	0.093ns	0.283**	0.042ns	-0.010ns	1.000	
Exch. Ca	0.346**	0.296**	0.254*	0.242*	0.138ns	0.161ns	-0.204*	0.659	1.000

Table 2.14 Total correlation coefficients between groundnut kernel yield, yield components and soil parameters at MES

	Kernel yield	Pod No.	Kernel mass	Shelling %	% Plant stand	% SMK	% Pops	pH	Exch. Ca	Exch. Mg
Kernel yield	1.000									
Pod No.	0.996**	1.000								
Kernel mass	0.288**	0.284**	1.000							
Shelling %	0.371**	0.316**	0.209*	1.000						
% Plant stand	0.254*	0.262*	0.271**	-0.036ns	1.000					
% SMK	0.632**	0.627**	-0.269*	0.285**	0.012ns	1.000				
% Pops	-0.425**	-0.417**	-0.323**	-0.168ns	0.007ns	-0.415**	1.000			
PH	0.534**	0.542**	0.097ns	-0.234*	-0.026ns	-0.628**	0.451**	1.000		
Exch. Ca	0.524**	0.534**	0.135ns	0.222*	0.074ns	0.395**	0.369**	0.599**	1.000	
Exch. Mg	0.689**	0.695**	0.042ns	0.239*	-0.038ns	0.629**	0.446**	0.724**	0.627**	1.000

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

CORRELATIONS AT MES

At MES, significant correlations were found between kernel yield and the yield determining factors (Table 2.14). Among the first-order factors, the kernel yield had the highest positive correlation with pod number (r=0.996) and lowest correlation with plant stand (r=0.254). As at HCR, the proportion of pops was also negatively correlated with kernel yield, being much stronger than that between kernel yield and either shelling percent or kernel mass.

With soil factors, correlation with kernel yield was highest with Mg (r=0.689), followed by pH (r=0.534) and lastly Ca (Table 2.14). The three soil parameters were also significantly correlated between themselves, with Mg being more strongly correlated with soil pH than with Ca. Overall, the observed correlations indicate that the three soil parameters affected kernel yield to varying degrees, and soil levels of the three parameters can be used to predict kernel yield responses to application of the ameliorants at this site.

Path coefficients at HRC and MES

The path coefficient analysis showed that at HRC the direct effects (path coefficients - β) of pod number on kernel yield were much greater than those of any other plant parameter (Figure 2.11). Variation in pod number explained 88% of the variation in kernel yield. Shelling percentage and kernel mass also played a significant role in determining kernel yield, whereas the direct effects of plant stand and the proportion of pops were not significant. In the experiment at MES similar effects of first order yield parameters on kernel yield were observed, with plant stand and the proportion of pops having a non-significant direct influence on kernel yield (Figure 2.12).

At HRC the path coefficients relating Ca to the plant parameters were highest for kernel mass and the proportion of pops, and least for plant stand (Figure 2.11). These results concur with the assertion that Ca has an influence on kernel mass and on pops. At MES, Ca had the largest effect on shelling percentage, but similar effects on pod number and pops (Figure 2.12). As at HRC, the path coefficients relating Ca to plant stand were the lowest, but significant. The positive and significant effects of Ca on the kernel yield components suggest that Ca *per se* influenced kernel yield; the direct effect of exchangeable Ca on kernel yield was high ($\beta = 0.292$), whereas that of soil pH was lower ($\beta = 0.082$), but significant. A regression analysis with kernel yield as the dependent variable and soil pH and Ca as independents showed that variation in the two soil components accounted for 57% of the kernel yield variation observed at HRC.

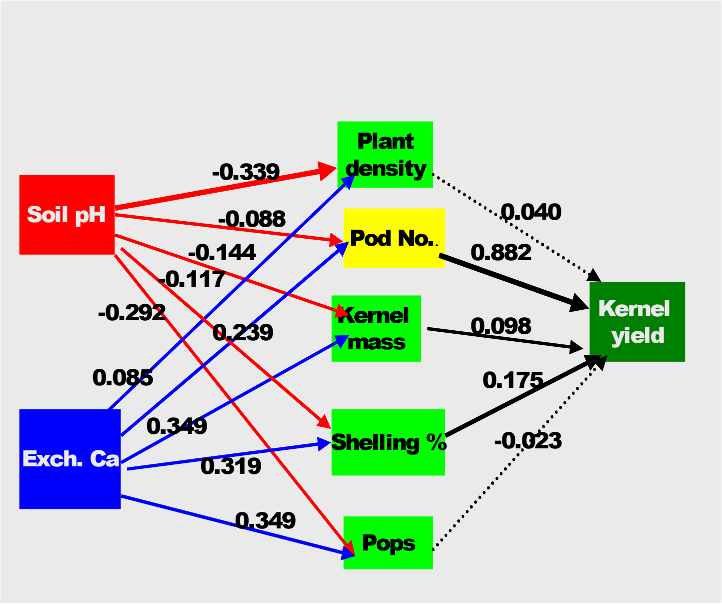

Figure 2.11 Direct effects of the yield components on kernel yield at HRC

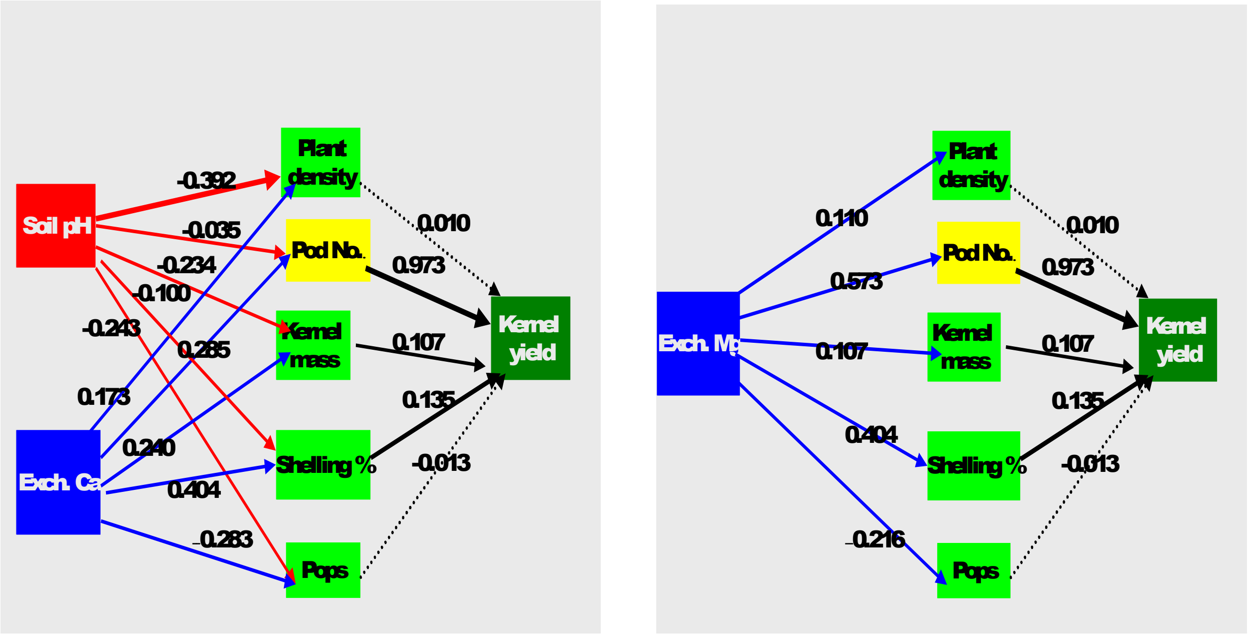

Figure 2.12 Direct effects of the yield components on kernel yield at MES

The direct effects of Mg on the first order yield parameters at MES were greatest on pod number and on shelling percentage (Figure 2.12). Kernel mass was the least affected. At this site, exchangeable Mg appeared to exert a greater influence on kernel yield parameters than exchangeable Ca. Exchangeable Mg also had the greatest effect on the plant parameter that influenced kernel yield most, namely pod number. Given that significant kernel yield increases due to application of dolomite lime were observed at this site, it can be inferred that Mg *per se* directly improved yield. A regression analysis with kernel yield as the dependent variable and soil pH, Ca and Mg as independents showed that variation in the three soil components accounted for 76% of the kernel yield variation. The direct effects of exchangeable Mg on kernel yield were high ($\beta = 0.578$), whereas those of Ca and soil pH were $\beta = 0.245$ and $\beta = 0.129$ respectively.

Path coefficients relating soil pH to the plant parameters showed that the greatest influence of soil pH was on plant stand, and on pops. This observation was made at both sites (Figures 2.11 and 2.12). The direct effects of soil pH on pod number were of a low magnitude at both sites, and non-significant at MES. Since pod number was the plant parameter observed to influence kernel yield most, this result implies that the observed kernel yield responses to application of Ameliorants cannot be attributed to improved soil pH *per se*, but to its indirect effects on other parameters influencing yield. For example, soil pH had a significant direct effect on plant stand, and in turn, the indirect effects of plant stand via pod number on kernel yield were significant ($r=0.249$), in fact higher than the direct effects.

2.4 CONCLUSIONS

The major effects of applying the ameliorants were to increase soil pH and exchangeable Ca and Mg levels. The ameliorants had little effect on the soil N, P and exchangeable K content. In general, application of CL or DL was more beneficial compared to gypsum or SSP and their combinations. Clear increases in yields due to lime application at 2000 and 4000 kg ha^{-1} were observed in the year of application as well as with residual effects. The increases were higher with the higher application rate. 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 to resource poor farmers, as no additional benefits can be expected. Annual applications of gypsum and SSP were not as effective as the traditional liming materials in overcoming soil acidity, but resulted in slight yield improvements over the control.

The residual benefits of application of lime (improved plant stands, better growth, nodulation, productivity and quality) lasted for the duration of the experiments, despite the dissipation of the lime effect on soil pH. After three cropping seasons the soil pH was either lower than or not significantly different from that of the original unlimed soil, except in the high lime treatment. It was concluded that amendments other than lime have no potential for ameliorating acid soils in which nutrient deficiencies and low pH *per se* are limiting groundnut growth and productivity. It is recommended that researchers and extension agents conscientize the smallholder farmers on the benefits of liming, and encourage them to invest in the technology, while policymakers should ensure that the issue of lime availability to the resource-poor farmers is adequately addressed.

Notwithstanding 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. It 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. Because the kernel yield parameters were more directly influenced by soil exchangeable Ca and Mg than with pH, it was concluded that poor groundnut yields on the acid soils at HRC and MES are caused by deficiencies of Ca and Mg primarily, and by low pH *per se*. With the magnitude of the lime responses demonstrated in this study, it is clear that the only practical solution to poor groundnut productivity on acid sandy soils is to apply lime.