TOLERANCE OF SELECTED MAIZE (*Zea Mays L.*) AND SOYABEAN (*Glycine Max* L. Merr.) CULTIVARS TO SOIL ACIDITY

By

CHIPO MUSHARO

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Department of Soil Science and Agricultural Engineering

Faculty of Agriculture

University of Zimbabwe

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Abstract

Soil acidity is the most important growth-limiting factor especially in the tropics and sub-tropics. Increased acidity in Zimbabwe's smallholder agricultural soils has been attributed to use of acidifying fertilizers without liming. Low input farming in some areas also contribute to increased soil acidification. Aluminium and Mn toxicity together with low P, Ca, Mg, K, N and Zn affect plant growth on acid soils. However, tolerant cultivars may allow for economic crop production under these conditions. The aim of this study was to develop a protocol for screening maize and soyabean cultivars for tolerance to Al and soil acidity and to assess response to lime by these cultivars on light and heavy textured soils. Soil samples (100) and 90 soil amendment samples (80 cattle manure, 5 ash and compost and 5 termitaria) were sampled from Chendambuya smallholder farming area (SFA) to determine the fertility status and the extent of soil acidity. Five maize (SC 403, SC 517, CZH 00013, CZH 00017 and DK 8031) and 3 soyabean (Magoye, Safari and Solitaire) cultivars were screened for tolerance to Al in modified 1/5 Steinberg solutions with 0, 4, 8 and 16 mg L^{-1} Al. Maize (SC 403, SC 513, SC 517, PAN 413 and PHB 30G97), and soyabean (Magoye, Safari, Solitaire and Storm) cultivars were grown on limed and unlimed acid sandy and red clay soils in Chendambuya SFA and at Domboshawa Training Centre for two seasons. Soils from Chendambuya had low pH (averaging 4.43, *sem* 0.08) and only 19% were heavier soils comprising mainly red clay soils (21 – 40% clay) with over 4 times higher Ca and Mg compared to lighter textured sandy soils (0 –5% clay). About 89% of the interviewed households applied cattle manure annually at an average rate of 5.3 t ha^{-1}, while ash and compost were applied once in 3 – 4 years in low quantities, and termitaria was only spread on the ground in the first year of ploughing to level the field. The manure was of poor quality (84% containing < 1.5% N), low liming value averaging 37%, and high soil content (averaging 56%). Aluminium reduced shoot dry matter yield (SDMY) for all maize cultivars (65%, 84%, 82%, 74% and 77%reduction for SC 403, SC 517, CZH 00013, CZH 00017 and DK 8031, respectively, at 16 mgL^{-1} Al). Root responses varied across cultivars and were thus more appropriate in screening maize for Al tolerance. The Al tolerance index (ATI) showed that CZH 00017, CZH 00013, SC 403 and DK 8031 were more tolerant to Al (ATI of 3.1, 3.4, 4.7 and 5.0 respectively) compared to SC 517 (ATI of 1.0). Tolerant cultivars responded positively to low Al concentrations (4 mgL^{-1}) and were more efficient in nutrient uptake and utilization. At 4 mgL^{-1}, Al resulted in an increase in soyabean root and shoot dry matter yield. Magoye and Safari (ATI of 5 and 2.51 respectively) were relatively more tolerant to Al compared to Solitaire (ATI of 1). Nutrient (P, Ca and Mg) translocation was reduced in all soyabean cultivars. Differential cultivar tolerance to Al was observed with both maize and soyabean. Tolerance to Mn and determination of tolerance mechanisms are still areas to be researched on. Lime reduced maize stover (up to 39%) and grain yield (up to 56%) on sandy sites except at Mudzengerere site with much lower Ca and K contents (0.70 and 0.09$cmol_c kg^{-1}$ respectively) where yields were increased (up to 43% and 92% for stover and grain respectively). Up to 69% grain yield increases were realised on red soils. Cultivar PHB 30G97 was recommended for acid soils as it yielded higher grain (6.18 tha^{-1} and 6.67 tha^{-1}) than the Al tolerant SC 403 (5.29 tha^{-1} and 5.83 tha^{-1}) on acid red and on Domboshawa sandy soils, respectively. Nodule numbers and weights were increased by lime especially in the second season. Lime increased grain yield for Magoye and Safari in the two seasons and for Solitaire in the second season only. Soil acidity in Chendambuya SFA was high on both heavy and light textured soils. Cattle manure availability and quality was too low to have a fertilising and liming effect on soils. Aluminium tolerant cultivars can be selected for acid soil conditions using the ATI. Although liming is profitable on heavy textured soils, liming on light textured soils may result in reduced maize yields due to possible micronutrient deficiencies and nutrient imbalances in poorly buffered soil.

Dedication

This work is dedicated to my parents (Esther and Justin Musharo). You are a pillar of strength in my life.

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Chapter 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The smallholder farming areas (SFAs) cover about 50% of total land area of Zimbabwe. The majority of these SFAs are located on coarse-grained sandy soils derived from granitic parent material, with low organic matter content, low cation exchange capacity, low buffering capacity and low N, P and S (Thompson and Purves, 1981). In areas receiving 500-800 mm annual rainfall, fersiallitic soils (Ferrallitic Cambiasols / Arenosols – FAO or Oxic Pleustalf/Ustropept – USDA) are widespread while paraferrallitic (Haplic Lixisols / Gleyic Luvisol – FAO or Typic Kandiustalf / Udic Kandiustalf – USDA) and orthoferrallitic (Ferric Acrisols - FAO or Ultic Pleustalf - USDA) soils occur where annual rainfall is over 800 mm per annum and where altitude is high (900 meters above sea level) (Nyamapfene, 1991).

Soil management practices are generally poor in SFAs and soils are generally acid with Al toxicity problems experienced at pH ($CaCl_2$) < 4.2 (Dhliwayo and Mukurumbira, 1999; Nyamangara and Mpofu, 1996). According to Grant (1971) and Dhliwayo, *et al.* (1998), acidic smallholder (SH) area soils have Al saturation >20%. Nutrient deficiencies are high in these soils. Progressive increase in soil acidity in Zimbabwe's high rainfall SFAs has been reported (Mashiringwani, 1983; Nyamangara and Mpofu, 1996) and has been attributed to failure to use lime coupled with the increased use of acidifying fertilisers (from 27 113 tonnes in 1979/80 season to 110 953 in 1989/90;Humphery, 1991) resulting from better access to credit schemes by farmers (Dhliwayo and Mukurumbira, 1999). Unlike non-ammonium based fertilisers such as urea that cause acidification only when they are leached, all ammonium fertilisers cause acidification whether they are leached out or not. Super phosphates cause acidification indirectly by improving plant growth. When plant growth is enhanced, removal of cations from the soil system increases leading to acidification as Al and H replace the absorbed base metals on exchange sites (Mugwira and Nyamangara, 1998).

In a study focusing on lime requirement for Zimbabwe SH area soils, Nyamangara and Mpofu (1996) noted gradual increase in soil acidification with the majority (62% in 1982 - 84 and 75% in 1992 - 94) being sandy soils and loamy sands. A potential Al toxicity problem and P deficiency was predicted in 43% of soils with pH of 4.5 or less (0.01M $CaCl_2$). A possibility of soil pH decline was predicted with implications of becoming a major soil fertility constraint to crop production as a result of reduced fertilizer effectiveness, P and micronutrient deficiency and Al toxicity. The authors recommended liming, rotations and intercropping as soil acidity amelioration measures.

The majority of Zimbabwe's SH farmers are resource poor and their farming activities are usually for subsistence purposes. Results of a survey conducted in a related study in Chendambuya communal area showed that farmers in the area use locally derived fertilsers such as cattle manure, leaf litter and termitaria. The majority of households (94%) owned cattle with an average head of 9 per household. Other livestock owned include goats (65%), sheep (4%) and chicken (86%) with an average of 5, 3 and 10 per household. Households have permanent arable fields, some near the homesteads (home fields) and others located away from the homesteads (out fields). Grazing is communal with arable fields also communally grazed after harvesting.

Smallholder farmers in Zimbabwe mainly grow maize (*Zea mays L*), the staple crop. Crops such as soyabean (*Glycine max L. Merr*), cowpea *(Vigna anguiculata L. Walp)*, sugar bean (*Phaseolus vulgaris L.*) and other legumes, and small grains such as millet (*Panicum decompositum*) are grown in rotation or intercropped with maize on a small scale in selected areas. Recently, efforts by the Soyabean Promotion Task Force (coordinated at the University of Zimbabwe) to promote soyabean cultivation in the SH areas led to an increase in area under soyabean production. Farmers have since realised the benefits of soyabean through soil fertility improvement, high economic returns and high nutritive value (Rusike *et al*., 2000). Some farmers are however restricted to continuous maize monocropping because of shortage of land as most SFAs are relatively densely populated (>50 persons per km^2; Campbell *et al*., 1994). In Chendambuya, a study carried out in November 2002 showed that 96% of farmers grow maize (*Zea mays*) and 76% of these farmers grew maize in rotation with groundnuts (*Arachis hypogea*) (Matokwe, unpublished data).

The white maize variety is the most commonly grown although the yellow varieties are also grown in selected areas. Maize grows well in areas too dry for rice and too wet for wheat thus fitting into a niche between the two. Maize in Zimbabwe is the major cereal grown mainly for human consumption and for animal feed, especially poultry and cattle.

Soyabean (*glycine max L. Merr*) is a leguminous cash crop with three varieties (yellow, green and black). The yellow variety is widely grown in Zimbabwe. Soyabean accounts for 40% of the national edible vegetable oil and seed cake output in Zimbabwe (Whingwiri, 1996). On average a 100g of soyabean contains 1700 KJ energy, 40g protein, 20g fat, 20g carbohydrates and 10g water (Gardner, 1985; Zharare, 1996). Soyabean contains lysine, methionine and cystine (amino acids lacking in cereal protein) making it essential in supplementing the maize-based staple diet in Zimbabwean households (Mpepereki *et al.*, 1996; Kasasa 1999). Soyabean can also be used as animal feed.

Soyabean forms a symbiotic relationship with *rhizobium* (a gram negative root nodule bacteria) to form nodules on plant roots, which enables it to fix atmospheric nitrogen in the soil. On average soyabean can fix 40 –120kgha^{-1} N in a season (Gardner *et al.*, 1985), estimated to be half of the total N required for its growth thus easing the burden on farmers to apply large quantities of inorganic N (Wynch and Rains, 1978). The residual N and the improved soil structure enhance the performance of a following maize crop in a rotation (Kasasa *et al.*, 1998). Like all grain legumes, soyabean stover has a low C: N ratio so it decomposes rapidly and release N to benefit subsequent crops (Giller and Wilson, 1991). This is important especially in SFAs where N is the most limiting nutrient to maize production and use of inorganic fertilizer is limited due to cash constraints and unreliability of benefits under the variable dryland conditions (Shumba, Chisenga and Ndebele, 1992).

Soil acidity is a complex soil fertility problem characterised by Al toxicity and nutrient (Ca, Mg and P) deficiencies. Manganese toxicity is also common in acid soils derived from parent materials with high Mn content. Farmers in Chendambuya cited stunted crop growth, depressed yields and abnormal leaf colour and prevalence of witch weed as signs and symptoms of soil acidity (Matokwe, unpublished data). Liming (the addition to the soil of any Ca or Ca and Mg containing compound (Tisdale *et al.*, 1985)) acid soils reduces possibilities of Al and Mn toxicity, improves microbial activity and soil physical properties such as soil structure. Symbiotic nitrogen fixation is improved as lime regulates the growth of rhizobia and its ability to nodulate. According to Roychaudhuri *et al.* (1998), liming increases nodule weight, grain yield and N and P uptake. Increase in nodule weight results from an increase in rhizobium colonies while Ca uptake increase due to enhanced root penetration and a normal distribution of nodules on the taproot and lateral roots as a result of lime (Roychaudhuri *et al.* (1998). Liming forage fields improves forage palatability (Mugwira and Haque, 1993). Neutralisation of Al by lime has a marked effect on the response of plants to additions of fertilizer P.

Most studies conducted to promote crop production on acid soils have been focused on the use of lime to raise soil pH to desired levels. Liming in the tropics is usually only aimed at preventing Al toxicity by raising pH to about 5.5 (Pearson, 1975). Although lime is a cheap source of Ca and Mg, it can lead to Bo and Zn deficiency in soils containing just adequate amounts while P availability may not be increased (Helyar, 1998). Correcting soil acidity is usually not feasible especially in subsistence agriculture and in areas where subsoil acidity is a problem because lime is highly immobile and incorporating it in the deeper horizons is expensive (Bookin, 1996; Bianchi- Hall *et al.*, 1998). A survey done by Dhliwayo *et al.* (1998) and a survey conducted in November 2002 showed that although smallholder farmers were aware of the need for lime, they did not rank it among the first priority inputs. The use of lime is also limited by its unavailability in local shops in SFAs, the large threshold tonnage required when purchasing from the manufacturer and lack of information on lime requirement (amount and frequency of application) (Nyamangara and Mpofu, 1996). Lime is bulky and is required in large quantities making its transportation from manufacturer too expensive for smallholder farmers (Nhamo, 2002) although lime itself is relatively cheap. Although cattle manure can ameliorate the acidifying effects of ammonium fertilizers, the quantity and quality of Zimbabwe SFA manure is low (Mugwira and Mukurumbira, 1986; Avila, 1987; Chikowo, 1998).

There is therefore need to pursue alternative methods for productive farming under acid conditions. Among these alternatives is the breeding and screening of cultivars for tolerance to problems associated with soil acidity. Although some researchers have regarded forgoing liming in favour of use of acid tolerant cultivars as a temporary or short-term solution as soil acidification will continue with continuous cultivation, it is worthwhile where subsoil acidity is a problem and where farmers are able to maintain but cannot raise pH from current levels.

There is evidence that differential acidity tolerance exist among crop species and among varieties of the same species. Dual tolerance to low P and Al toxicity has been reported (Malama *et al.*, 2000). The use of acidity tolerant cultivars allows for crop production without liming in soils where production would be impossible or uneconomic. It offers an ecologically clean, energy conserving and cost effective way to increase crop yields in acid areas thus permitting sustainable cropping systems to be established on savanna, forest and hillside acid lands (Malama *et al.*, 2000).

Deterioration of fragile agricultural lands is reduced, easing pressure to cut down tropical rain forests to obtain additional more suitable (in terms of acidity) farmland (Pandey *et al.*, undated).

1.2 OBJECTIVES AND HYPOTHESES

The main objective of this study was to develop a protocol for screening maize and soyabean cultivars for tolerance to soil acidity and aluminium toxicity and to assess the effect of liming on the performance of different cultivars of these crops under acid field conditions.

The study focused on the following specific objectives:

i) To determine the extent of soil acidity in granitic sands and dolerite derived red soils in Chendambuya SFA;

ii) To assess the use of lime and manure in Chendambuya SFA;

iii) To determine the quality of manure used by farmers in Chendambuya SFA as a liming material and fertiliser;

iv) To screen local cultivars of maize and soyabean for tolerance to Al toxicity under greenhouse conditions;

v) To test the performance of maize and soyabean cultivars under acid field conditions in the high rainfall SFAs of Zimbabwe;

vi) To assess the effect of lime on different soils and varieties of maize and soyabean.

The following hypotheses were tested:

i) The extent of soil acidity in Chendambuya is variable depending on soil type;

ii) The use of lime and manure is limited in Chendambuya SFA;

iii) Manure in Chendambuya SFA is poor both as a liming material and as a nutrient source;

iv) There are no maize and soyabean crop and varietal differences in tolerance to Al toxicity;

v) There is no maize and soyabean cultivar differences in performance under acid soil conditions;

vi) Liming effects do not depend on soil type, crop or variety.

Chapter 2

LITERATURE REVIEW

2.1. SOIL ACIDITY

Soil acidity is a major growth-limiting factor for some plant species in many parts of the world especially in tropical and subtropical countries. Thirty percent of the worlds land area and 43% of the world's tropical land area comprising 27% of Tropical Africa is acidic and it is on these soils that production constraints are intense. (Pandey *et al.,* 1994). Jones (1975) and Copeland (1976) concluded that low soil pH was the number one growth-limiting factor and that most fertility problems in the tropics are associated with low pH.

Acidity is expressed as pH on a scale of 1 – 14 where pH is the $-\log_{10} [H^+]$ with acid soils containing high concentrations of H^+ ions in solution. In Zimbabwe, the $CaCl_2$ method is used to determine soil pH. This method gives pH values 0.5-1.0 units lower than the conventional water method (Dhliwayo and Mukurumbira, 1996). Acid soils, according to the Zimbabwe soil classification, are soils with a pH ($CaCl_2$) less than or equal to 5.5 (Table 2.1). This classification is used in lime recommendations, where liming is required for soils with pH $\leq$ 5.0 for most crops (Nyamangara and Mpofu, 1996). The water range, given in the table, was obtained by adding 1 unit to the $CaCl_2$ range (Landon 1991). Soil pH measurements in $CaCl_2$ are preferred as the concentration of the test solution is more representative of the salt concentration in the natural soil. The effects of natural variations in pH for a soil due to differences in properties such as moisture content are effectively swamped when the $CaCl_2$ method is used.

Table 2. 1: Soil pH classification used for crop production in Zimbabwe.

0.01M $CaCl_2$ scale	H_2O scale	pH Status
Above 7.5	Above 8.5	Strongly alkaline
6.5-7.5	7.5 -8.5	Alkaline
6.0-6.5	7.0- 7.5	Neutral
5.5-6.0	6.5- 7.0	Slightly acid
5.0-5.5	6.0- 6.5	Medium acid
4.5-5.0	5.5- 6.0	Strongly acid
Below 4.5	Below 5.5	Very strongly acidic

(Dhliwayo and Mukurumbira, 1996)

2.2. EFFECTS OF SOIL ACIDITY ON NUTRIENT AVAILABILITY

The effects of low pH on plant growth are nutritional and indirect (Thompson and Toeh, 1978). Acid soil toxicity is a complex of factors that affect plant physiological and biochemical processes. Acidity per se is not harmful to plants except in extreme cases (Mengel and Kirkby. 1979). The problems of plant growth on acid soils are largely due to the large amounts of Al, Fe and Mn (Giller, 2001). Plants grown in nutrient solution under pH of 3 with no Al, managed to grow normally as opposed to plants grown in soil with 1ppm Al (which occurs at pH 5) (Thompson and Toeh, 1978).

At low pH, organic matter mineralisation rate decreases resulting in reduced availability of N, P and S. Nitrification is significantly retarded as bacterial activity is reduced. The survival and function of rhizobia, mycorrhizae and other microorganisms such as nutrient fixers, decomposers and nutrient recyclers is also reduced (Landon 1991).

Deficiencies of P, Ca and Mg are common on acid soils. Calcium and Mg deficiencies are due to leaching while Al and Fe bind P in acid soils (Care, 1995). According to Heylar (1998), Ca and Mg deficiencies are limited to acid soils although they are of secondary importance after Al and Mn toxicities, except in very low CEC sandy soils. All micronutrients, except Mo, become more available in acid soils. Molybdenum exists in the soil as MoO_4^{2-} and is held like P on Al and Fe hydroxides, making it unavailable for plant uptake at low pH (Giller, 2001). Manganese toxicity may become a problem on red soils.

Leaf sufficiency content ranges from 10-50mg Mn per kg of the dry matter of mature leaves depending on the environment and plant species, and Mn toxicity varies from 20-50 mg/l at pH 4.8 (Jones, Wolf and Mills, 1991). Since Fe and Mn compete at cellular level, increases in Fe concentration may decrease Mn toxicity (Marschner, 1995). Manganese toxicity can however induce Fe deficiency because it serves as an oxidising agent converting ferrous iron to insoluble ferric form.

2.3. EFFECTS OF SOIL ACIDITY ON PLANT GROWTH

Aluminium toxicity is related to Ca and Mg deficiency. Calcium is important for the maintenance of cell membranes and cell wall integrity. In legumes, Ca is important especially under acid conditions because it enhances the appearance and development of nodules (Graham, 1992). The function of Ca in nodulation is not well understood but its role in the initial stages of rhizobial cell attachment to the root hair tips has been shown. The proteinaceous cell surface component of *Rhizobium leguminosarum* biovar *viciae* which is believed to be required for rhizobial attachment to the root is dependant on Ca (De Carvalho *et al*., 1991). According to Lodeiro (1995), both Ca and Mg are involved in the specific tight binding of rhizobia to roots of the host legume in the early stages of infection. Calcium also acts as a secondary messenger in Nod factor transduction in root hairs (Niebel *et al.*, 1999). Magnesium acts as an enzyme activator and as a constituent of chlorophyll (Thompson and Troeh, 1978).

Maize yields are severely restricted by acidity in the tropics (Grant, Tanner and Madziva 1973; Horst, 1998). The primary effect of soil acidity is Al inhibition on root growth resulting in shoot growth reductions and an ultimate decrease in grain yield. Maize plants growing on acid soils often experience an induced drought stress shown by wilting of plants. This results from the compromised exploitation of water supplies in the soil as root growth is inhibited by Al toxicity (Management of Soil Acidity in Agricultural Land Farmnote 80/2000). The visual symptoms associated with Al toxicity on cereals are poor and stunted growth and orange-yellow to white interveinal chlorosis of leaves. Yellow to white mottling of interveins is followed by tip death and leaf margin scorch. During severe toxicity, necrosis of chlorotic areas occurs (International Rice Research Institute, 2002).

There has been contradicting ideas about the susceptibility of legumes to soil acidity factors. According to Parker (1985), legumes have the same nutrient requirements as other crops in about the same quantities except for Mo and Co. Other researchers have however concluded that legumes have greater requirements for water and nutrients and are more sensitive to Al and Mn toxicity with nodulation and N_2 fixation being more sensitive to Mn than host plants (Cassman *et al.,* 1981; Clark and Mgema, 1993).

Russel (1978) showed that soyabean required 20-25ppm available P while cereals require 10-16ppm (Adeoye and Agboola, 1985). Symbiotically dependant soyabean requires 50% more P than when N is provided (Cassman *et al.*, 1981). Adequate P is essential for the energy relations of the fixation process (Mullen *et al*., 1988). Low P conditions experienced under acid conditions delay the infection of the primary root and inhibit nodulation even when numerous compatible and effective bacteria are present (Keyser *et al*., 1979). Some root nodule bacteria, which are able to produce phosphatase especially in the alkaline form are however tolerant to low P conditions (Mullen *et al*., 1988).

The symptoms of Al toxicity in legumes include yellowing of leaves and reduced root growth. Graham (1992) concluded that the legume symbiosis can withstand proportionally more exchangeable H than Al but very few rhizobial strains can grow under acidic conditions of below 4.5 (Graham, 1992). This is because aluminium toxicity is a severe stress component in acid soils even for some rhizobial strains that can tolerate an acidic pH of 4.5 (Keyser and Munns, 1979a,b). High aluminium levels cause severe root stunting consequently affecting nodulation, while high manganese levels inhibit calcium uptake reducing both nodulation and N_2 fixation (Davis, 1986). In soyabeans, excess Mn has been associated with an increase in leaf temperature and stomatal closure leading to disruption in gaseous exchange, an important process in photosynthesis (Suresh *et al.,* 1987). Acid soils cause ineffective nodulation due to low Ca and Mg, P and Mo content. Phosphorus is important for protein synthesis and

Mo is important in the nutrition of rhizobium and N-fixation. The rhizobial cell has a specific requirement for Ca for its cell wall development (Roychaudhuri *et al.,* 1998). An Al saturation of 33% can completely stop nodulation (Adeoye and Agboola 1985). Mugwira (1980) showed that Al toxicity decreased Ca and Mg, and increased K and Al uptake by black pepper (*Piper nigrium L.)*. In rice (*Oryza sativa L.)* Ca, Mg, K, Mn and Si were decreased, and N and P increased.

2.4. ALUMINIUM TOXICITY

Aluminium often accumulates in the roots leading to root damage and increasing cell wall rigidity. Aluminium toxicity is often expressed as P deficiency because Al strongly fixes P into insoluble compounds making it unavailable to plants. Under acid conditions it is difficult to separate detrimental effects of Al and those of low available P (Malama *et al.*, 2000). Addition of phosphate fertilisers can temporarily alleviate Al toxicity but with time the insoluble compounds formed between Al and phosphorus may be dissolved as P preferentially bonds with free iron, releasing Al (Vega, Calisay and Hue, 1992). The initial bonding between Al and P can result in the reduction of P availability for plant uptake and utilisation. This is why the upper parts of Al toxic plants are frequently low in P (Vega, *et al*., 1992).

Reduced Mg availability under acid conditions is probably due to antagonism of both Al and H^+ on Mg uptake, particularly when the percent Al saturation is high in relation to Ca and Mg. High concentrations of Al, like all other cations, results in the replacement of Mg on the root CEC and this may have a direct negative consequence for the uptake of Mg (Keltjens, 1995). According to Huang *et al.* (1993), Al inhibition of Ca uptake is instantaneous. The amount of Ca needed to promote good root growth is dependent on Al concentration in solution.

The initial step in the interaction between Al and Mg probably takes place in the root apoplast (Keltjens, 1995). Competition between Al and Mg and /or Ca does not depend only on Al concentration but also on speciation, which is directly related to pH. Maximum competition occurs when Al is present as Al^{3+} and it decreases with decreasing valence (Keltjens, 1995).

Rufty *et al.* (1995) showed that nitrate and ammonium uptake by soyabean decreased when aluminium concentration was increased from 10 – 50µM while Keltjens (1995) indicated an increase in NH_4^+ uptake and H^+ release in Al sensitive sorghum cultivars. Nitrate uptake reduction leads to the acidification of the rhizosphere (Horst, 1998). Nitrate is generally the main anion balancing cation uptake. In N fixing plants therefore cation uptake exceeds anion uptake and in order to balance the equilibrium, protons are expelled into the rhizosphere thus acidifying it (Israel and Jackson, 1978). Research by Durieux *et al.* (1993), showed a significant decrease in nitrate uptake in 8 day old corn seedlings within 30 minutes of Al exposure. The authors concluded that Al restricted the activity of NO_3^- transporters to a greater extent than it prohibited intercellular NO_3^- transporter synthesis or induction.

2.5. SOIL ACIDITY TOLERANCE BY PLANTS

2.5.1. Plant Tolerance to Soil Acidity

Tolerance to soil acidity is a complex character involving not only tolerance to low pH but also Al toxicity, and in some cases Mn and Fe toxicity and P, Ca and Mg deficiencies. The difference between varieties or species in terms of Al tolerance seem to be positively correlated with differences in P translocation rates in the presence of Al (Malama *et al.*, 2000).

According to Moustakos *et al.* (1992), Al toxicity tolerance differs between plant species and cultivars. Clark and Mgema (1993) noted that Al generally reduced P, Ca, Mg, Fe, Zn, Mn and Cu uptake in sensitive maize cultivars than in tolerant ones. Uptake of nutrients such as Ca, P, Mg, K, Fe, Zn and Cu was reduced in sensitive maize cultivars than in tolerant ones (Mugwira, 1980). Differential uptake and utilisation of Ca and P by wheat have also been associated with sensitivity to Al (Mugwira, 1980). Foy *et al.* (1967) showed differential tolerance to Al and soil acidity between varieties of wheat and barley with sensitive cultivars having a higher root CEC and induced lower rhizosphere pH compared to tolerant ones. Aluminium and P in the roots were higher and concentrations of Ca in tops lower in sensitive than in tolerant cultivars. Differential tolerance to Al in rye grass, wheat, barley and alfalfa has also been shown (Foy *et al*., 1967). Foy *et al.* (1995) showed that durum wheat (T*riticum durum*) was more sensitive to Al in acid soils than hexaploid wheat (*Triticum aestivum*). Large differences in tolerance to toxic effects of acid soils have also been observed between species of pasture legumes (McFarlane *et al*., 2003; de

Calvalho *et al*., 1981). Phytohormone imbalances resulting from Al toxicity have been reported on sensitive plants (International Rice Research Institute, 2002).

Tolerance to soil acidity in root nodule bacteria has also been reported. Dilworth *et al*. (2001) has shown that acidity resistance in gram-negative bacteria, which includes root nodule bacteria, is associated with the medium in which cells were grown (ATR-Adaptive Tolerance Response). Normally rhizobial strains that can tolerate low pH have the ability to regulate their internal pH to near neutral. Sensitive strains have higher membrane permeability as compared to tolerant ones and thus high concentrations of H ions enter their cytoplasm (Chen, Richardson and Rolie, 1993). The slow growing rhizobia are generally more tolerant to acid and low P conditions than fast growing ones because of their ability regulate their internal pH under acid conditions (Graham 1992; O'Hara, 2001).

2.5.2. Plant Tolerance Mechanisms

Mechanisms of tolerance pertain to the uptake of the toxic element. Two groups of plants have been observed. One group has a symplasmic tolerance mechanism where Al is accumulated in the symplasm. The symplasmic Al is either chelated and/ or sequestrated within an internal compartment such as the vacuole (Schaffert *et al*., *2003*), and in woody species it is dumped in the unused xylem vessels and in cell walls. The sequestrated Al does not interfere with processes in the plant cell.

The other group has an exclusion tolerance mechanism. These plants either release chelating ligands in the rhizosphere, induce higher rhizosphere pH so as to make Al less available, bind Al in the cell wall or decrease the permeability of the plasma membrane to Al (Schaffert *et al*., *2003*). Secretion of organic acid**s** and alteration of the media pH in order to reduce fixation of plant nutrients by Al has been documented (Foy *et al.*, 1965).

Delhaze (1999) has shown that Al tolerance in wheat is correlated with the ability to secrete malate from root tips. The Al-tolerant line secreted 5-10 fold more malate than the corresponding near-isogenic sister line when root tips were exposed to Al. His hypothesis was that the secreted malate confers tolerance by binding Al^{3+} into a non-toxic complex.

In maize, Menossi (1999) observed that increasing levels of Al induced the release of malate at similar velocities by roots of both tolerant and susceptible varieties. However the exudation of citrate, a stronger Al-binding compound, was 3.7-fold higher in the Al-tolerant line. Kamh *et al.* (2001) observed wide differences in exudation rates of malate and citrate by 8 maize cultivars. Research by Kidd *et al.* (2001) showed that maize root exudation of flavenoid-type phenols was also linked to apoplasmic detoxification of Al.

Huang, Gruns and Kochian (1993) associated Al tolerance in certain wheat and barley cultivars with the ability to resist Al induced Ca deficiency or Al induced inhibition of Ca uptake. The proposed mechanisms of soil acid tolerance include root cation exchange variation, ion uptake and exclusion mechanism and organic acid secretion. Plants with a high root cation exchange capacity tend to be more susceptible to aluminium toxicity than those with a low root CEC. This is because a high root CEC results in a larger capacity to absorb cations. Organic acids have negative charges on carboxyl groups making them good cation chelates and solubiliser of anions (Lopez-

Bucio *et al*., 1999). Increase in root surface area by vesicular arbuscular mycorrhiza enhances the effectiveness of these mechanisms (Howeler, 1995). Foy, Fleming, Burns and Armiger (1967) suggested that variability in Al tolerance in plants of the same species could be a result of zones of differential pH existing around the roots of different varieties. He also suggested that sensitive varieties absorb more Al than tolerant varieties at the same pH.

Large differences in sensitivities to the toxic effects of acid soils have been observed between species of tropical pasture legumes. In some species where nodulation is by direct infection, lateral root formation reduction due to acidity results in reduction in the number of possible infection sites (de Calvalho *et al.*, 1981).

Manganese tolerance also does not always imply exclusion during uptake. Some Mn tolerant varieties of wheat always contain higher concentrations of Mn than sensitive varieties (Foy *et al.*, 1981; Foy *et al.*, 1995). In such cases tolerant varieties have an internal tolerance mechanism where the chemical state of Mn in the shoots is compartmentalised into less available forms (Weil, Foy and Coradetti, 1997). Manganese affected seedlings generally produce few and shorter brown roots and chlorotic leaves (Zhang, Jessop and Ellison, 1998). In another study, Brown, Hills and Krants (1968), showed that sugar beet could tolerate up to 5,590 ppm Mn in their leaves.

Applications of P and K fertilizer on acid soils can double the amount of N fixed by legumes and also increase the percentage of N derived from the symbiosis, (Liya *et al*, 1998). Mugwira (1980) found no consistent differences in Al effects on Ca absorption by different plant species. Some crops, such as cotton, groundnuts and potato are tolerant to soil acidity but sensitive to Ca deficiency and can therefore be grown in acid soils with sufficient fertiliser application (Sapra, Mugwira, Choudry and Hughes, 1978).

2.5.3. Screening of Plants for Tolerance to Acidity

Aluminium tolerance is a prerequisite for increased crop production in acid soils (Horst, 1998). Visual assessment of plant growth has been used as a preliminary in screening plants for tolerance to Al toxicity, before assessment of the plant's chemical composition. The use of hydroponic cultures with low ionic strength nutrient solution is standard procedure for the study of Al toxicity and Al tolerance at seedling level. Inhibition of root elongation in hydroponics is a sensitive short-term response of maize seedlings to Al (Horst, 1998). The most common parameters used in screening experiments include root lengths, dry matter yields (both shoots and roots), total leaf area and leaf area index (Sapra *et al.,* 1978; Mugwira 1980; Bennet, 1998; Tang *et al*., 2003). Nutrient uptake and exudation of organic acids and phenolics have also been used (Durieux *et al.,* 1995; Menossi, 1999; Kamh *et al.,* 2001; Kidd *et al.* 2001).

In legumes, selection of both a tolerant host and a tolerant bacterial strain may be necessary to maximise the symbiosis (Dilworth *et al*., 2001). Sometimes the rhizobium fails to nodulate because of its inability to multiply under acid conditions. It is interesting to note that not all symbiotically acid tolerant *rhizobia* can form nodules with the host plant under acid conditions. Sometimes even when the host rhizosphere contains enormous numbers of viable infective rhizobia, low pH can prevent infection of the host plant (Keyser *et al.,* 1979). Determining the effectiveness of the symbiosis formed between rhizobia and the host plant is often used to assess Al tolerance in legumes (Roychaudhuri *et al.* (1998). Parameters such as nodule numbers, nodule effectiveness and weight are common parameters together with dry matter and grain yield Roychaudhuri *et al.* (1998).

2.6. SUMMARY OF LITERATURE REVIEW

Literature shows that smallholder-farming areas are continuously becoming acid either due to use of acidifying fertilizers without liming or continuous cultivation with low inputs. Crop production on these soils is limited by Al toxicity and deficiency of nutrients such as Ca, Mg and P. Although breeding of maize and soyabean has mainly been focused on high yields, drought tolerance and disease tolerance, it has become necessary to select and breed cultivars for tolerance to acidity. Differential tolerance to acidity and specifically to Al toxicity has been shown with crops such as wheat and rye. Tolerance mechanisms identified include exclusion of the toxic element during uptake or seqestration or chelation of absorbed elememts into less harmful components.

Chapter 3

CHEMICAL FERTILITY STATUS OF SOILS AND MANURE QUALITY IN CHENDAMBUYA SMALLHOLDER AREA

3.1. INTRODUCTION

Soils in high rainfall SFAs of Zimbabwe are generally sandy and acid, and requiring lime to correct pH. Nutrients are also easily lost through leaching as soils have comparatively higher infiltration rates compared to clayey soils. Nitrogen is the most limiting nutrient together with P and S in most of these soils (Grant, 1981). Apart from having poor chemical properties, the soils have poor physical properties such as water holding capacity and structure. Addition of organic matter does not always lead to a build up of soil organic matter because these soils are well aerated and organic matter is easily decomposed (Mpepereki, 1994).

Grant (1981) noted that no lime was necessary on smallholder soils before and during the early 80s. This was due to the limited use of acidifying fertilizers as farmers used manure, which had a liming effect on the soils. Studies in the mid 90s showed a gradual development of soil acidity in SFAs (Nyamangara and Mpofu, 1996; Dhliwayo *et al*, 1998) resulting from increased use of inorganic fertilizer as farmers got access to input credit schemes (Humphery, 1991). The severe droughts of 1982/3, 1992/3 and 2002/3 that destroyed a lot of cattle in the smallholder areas resulted in limited amounts of manure being available to SH farmers to produce significant liming effects on acidic soils (Dhliwayo *et al.,* 2000). This crisis is worsened by the fact that although lime is relatively inexpensive, it is not affordable to the resource poor smallholder farmers who also have to purchase other inputs such as seed and fertilizer (Nhamo, 2002). Recent studies have shown that the cost of agricultural inputs have escalated to such levels that Zimbabwe SH farmers are applying lower than recommended rates of inorganic fertilisers (Nyamangara, 2001). They were reported as applying an average rate of 53 kg ha^{-1} compared to 705 kg ha^{-1} inorganic fertiliser applied by large-scale commercial farmers in the 1989 – 90 growing season (Humphery, 1991).

Cattle manure is an integral component of soil fertility management in many regions in the sub Saharan Africa (Giller *et al*., 1998). Organic resources play a critical role in both short-term nutrient availability and long-term maintenance of soil organic matter providing a wide range of plant essential nutrients and non-essential but beneficial nutrients such as Co, Se, Si and Na (Velthof *et al*., 2000). The authors showed that the relatively stable carbon sources in cattle manure are effective in the long-term supply of nutrient and maintenance of soil organic C (carbon sequestration). Soil organic matter influences nutrient storage and turnover, water holding capacity, soil structure, soil stability and vulnerability to erosion. It increases soil pH by adding bases to the soil, chelation of Al by organic acid anions and ammonification (Nhamo, 2002; Chikowo, 1998). The commonly used organic fertilizers in Zimbabwe are cattle manure, leaf litter and household refuse or ash compost.

The quality of cattle manure largely depends on the quality of cattle feed and the method of manure collection and storage (Mugwira, 1984; Mugwira and Shumba 1986; Giller *et al*., 1998). Mugwira and Mukurumbira (1984) also attributed differences in manure quality to differences in animal condition and age. Manure from Zimbabwe's SFAs is low in nutrients, particularly P, compared to feedlot manure (Mugwira and Mukurumbira, 1984). In SFAs, cattle feed on grass and crop residues. The systems are characterised by nutrient cycling between the animal and crop component of the farming systems. According to Powell (1996), cattle manure in the dry season has a low N content compared to during the early rainy season when the quality of the diet improves.

The quality of organics is often defined in terms of N content because N availability is the prime factor governing crop yields on sandy soils. Plant response to addition of these resources is also an important quality determining parameter (Tanner and Mugwira, 1984). Cattle manure has also been shown to improve P availability in soils that tend to fix P (Murwira and Mawoneke, 1996).

The C: N ratio gives an indication of an organic amendment's decomposability and its effectiveness as a source of nutrients. Some of the N in cow dung from tannin rich diets such as A*cacia anguistissma* or *calliandra* is very resistant to mineralisation and addition of such manure can lead to an initial negative N phase (Tanner and Mugwira, 1984). Carbon from high lignin manure cannot be readily utilised by microbes in the soil (Tanner and Mugwira, 1984).

Anthill soil, although not an organic material, is used in the same manner and alongside other organics and has high $CaCO_3$ that is important for reducing soil acidity. Studies in Zimbabwe have shown that anthill soils have high clay and soil organic carbon contents and high pH (Nhamo *et al*., 2002). The quality of anthill soil depends on the parent material it is derived from, its position on the catena and its age (Nhamo *et al*., 2000).

The Chendambuya smallholder-farming system is characterized by mixed cropping combined with animal farming. The animals (mainly cattle) are fed on crop residues and also naturally grazed in summer while they provide draught power and produce manure for fertilising crops. Farmers grow mainly maize and small grains such as millet and sorghum with a few farmers on red clay soils also growing legumes such as soyabean, sugar bean and cowpea on a small scale as a sole crop or intercropped with maize (Nyamangara, 2005, Personal communication). The system, like most smallholder farming systems in Zimbabwe, is characterized by high soil nutrient mining with little nutrient additions. Farming activities are mainly rain fed in fields but in gardens, which are usually located near streams, production continues all year round under irrigation. Activities on these gardens are usually production of horticultural crops such as onions, tomatoes, potatoes and leafy vegetables.

Although farmers use locally derived fertilisers (e.g. leaf litter, manure or termitaria), they fall short of satisfying crop requirements because of their low quality and declining availability (Mapfumo and Giller, 2001). It is increasingly evident that declining soil fertility is the most widespread limitation to maize (*Zea mays L.*) yields in Southern and Eastern Africa (Kumwenda et al, 1996).

A survey conducted in a related study showed that 97% of farmers in Chendambuya SFA were aware of soil acidity and lime but did not apply lime mainly because of cash constraints. Although lime itself is relatively cheap, transportation to farmers' field is expensive because lime is bulky and is required in large amounts. Lime is also usually unavailable in local outlets in communal areas implying that farmers would need to transport it from far away towns. Soil acidity has thus become a major problem affecting crop production in these areas. The aim of the survey was to determine the extent of soil acidity and to assess the use and quality (as fertiliser and liming material) of locally derived fertilisers used by farmers in Chendambuya SFA. This chapter also sought to assess the liming value of organics used in the area given that use of lime was limited. It was hypothesised that the extent of soil acidity in Chendambuya SFA is variable depending on soil type. It was also hypothesized that manure used by farmers in Chendambuya SFA is of poor quality both as a nutrient source and as a liming material.

3.2. MATERIALS AND METHODS

3.2.1. Farmer awareness of soil fertility issues.

A structured questionnaire (Annex 2) covering a range of issues related to soil fertility management was developed. The questionnaire was administered to 100 smallholder farmers in Chendambuya smallholder farming area in September 2002. Farmers were selected using a wealth ranking based on cattle ownership developed with the assistance of Agricultural Extension Officers in the area. Farmers were grouped into 3 groups, the poor (with no cattle), the average group (with no more than 4 cattle) and the rich. The interviewed farmers were 25% poor, 50% average and 25% rich based on the proportion of each group in the area. The aim of the survey was to determine the extent of soil acidity, lime and fertilizer management practices, and the level of awareness on the problems of soil acidity, if any, in the study area.

3.2.2. Soil Sampling and Analysis

Soils (0 – 15cm) were sampled from fields of interviewed households in Chendambuya SFA. A total of 100 composite soil samples comprising both red soils and sandy soils in the area were collected. Each composite sample comprised 10 sub-samples taken randomly for each farmer's field using a bucket auger. These samples were thoroughly mixed, air-dried and passed through a 2mm sieve. The soil fertility status was assessed by characterisation for texture, pH, cation exchange capacity (CEC), organic C and exchangeable bases.

Texture was determined using the hydrometer method (Gee and Bauder, 1986). The soil was dispersed using sodium hexametaphosphate (calgon solution). The silt, clay and sand sieving contents were then estimated by determining their settling time in water using a hydrometer. Using the USDA textural triangle the textural class of each soil sample was determined.

Soil pH was determined using a suspension of 0.01M $CaCl_2$. A 1: 5 (w/v) soil: water suspension was made (Anderson and Ingram, 1993) and the pH of the suspension was determined using a PW 9420 Phillips pH meter. Cation exchange capacity (CEC) was determined by saturating the soil with 1M CH_3COONH_4 (Ammonium acetate) buffered at pH 5.2. The extract was retained for total exchangeable bases determination. Exchangeable Ca and Mg were determined using atomic absorption and Na and K using emission spectrophotometry (Anderson and Ingram, 1993).

Organic C was determined by the modified Walkley Black method (Houba *et al.*, 1989). Organic matter was oxidised to CO_2 with acidified potassium dichromate at

130^{o}C. Excess dichromate was quantified by back titration with ferrous ammonium sulphate. Only about 75 % of carbon is estimated as oxidized with this method (Page *et al*., 1982). A correlation factor of 1.33 was used to calculate total organic carbon.

Exchangeable Al was determined using the KCl method. This method involves the displacement of exchangeable Al and H by K using 1M KCl. The displaced Al and H are then quantified in solution by titration with NaOH (Page *et al.*, 1982).

The soils were classified into 4 groups (A-D) according to clay content (Class A, 0 – 5% clay, B, 5 – 10% clay, C, 10 – 20% clay, D with 20 – 40% clay). Differences in fertility status between these classes were quantified.

3.2.3. Sampling and Analysis of Soil Amendments

Manure, anthill soil and ash and compost used by farmers as soil amendments were sampled from the interviewed farmers in Chendambuya SFA. The type of amendment sampled depended on the amendments used by each farmer. Where farmers did not use any organic amendment no samples were taken. A total of 90 samples (80 samples of cattle manure, 5 ash and compost and 5 termitaria) were collected. The samples were air-dried, passed through a 2mm sieve and analysed for total nutrients (Ca, Mg, K, P), organic C (Nelson and Sommers, 1982) and total N (Stevenson, 1982).

The soil and ash content in cattle manure was determined by ignition overnight in a muffle furnace at 550^{o}C. The loss in weight represents organic matter while the remaining weight represents inorganic material (ash and soil). Ash was dissolved in

HCl and separated from the soil by filtration. The soil was oven dried and weighed (Nyamangara, 2001).

The amendments were classified and ranked according to N content (Mugwira and Mukurumbira, 1986). Twenty samples representing the different ranks of total N contents (5 from each group) were further analysed for neutralizing value using the $CaCO_3$ equivalence method (Nhamo *et al*., 2002).

3.2.4. Statistical Analysis

Farmer responses were coded and analysed using SPSS (LEAD Technologies 1991-2000, version 8). The data was analysed for case summaries (mean, median and range) and frequency distribution. Results of this analysis are discussed in a related study (Matokwe, M., unpublished data. Soil and amendment characterisation data was summarised using Genstat 5 for windows statistical package (Lawes Agricultural Trust, 1997). The data was analysed for case summaries (mean, median and range) and the standard error of means was used to separate means.

3.3. RESULTS

3.3.1. Soil Characterisation

The majority of soils sampled were sandy (37%) and loamy sands (29%). Of the sampled soils only 15% were sandy loam and 19% were sandy clay. Soils had low % clay content ranging from 1 – 39%. The soils were predominantly acid, with an average pH ($CaCl_2$) of 4.43. Base saturation was relatively low (63.86%) showing evidence of moderate leaching of bases. On average, the Ca and Mg contents ranged from 0.30 to 12.90 $cmol_c\ kg^{-1}$ averaging 2.90 $cmol_c\ kg^{-1}$ for Ca and 0.10 $cmol_ckg^{-1}$ to 4.60 $cmol_ckg^{-1}$ averaging 0.93 $cmol_ckg^{-1}$ for Mg (Table 3.1).

Table 3. 1: Chemical Properties of Soils sampled from Chendambuya SFA in 2002.

Soil Property	Range	Mean	S.E.M
pH ($CaCl_2$)	3.2 – 6.9	4.43	0.08
Exchangeable Ca ($cmol_ckg^{-1}$)	0.30 – 12.90	2.90	0.25
Exchangeable Mg ($cmol_ckg^{-1}$)	0.10 – 4.60	0.93	0.10
Exchangeable Na ($cmol_ckg^{-1}$)	0.02 – 0.20	0.07	0.004
Exchangeable K ($cmol_ckg^{-1}$)	0.03 – 0.72	0.19	0.01
TEB ($cmol_ckg^{-1}$)	0.50 – 17.00	4.12	0.35
CEC ($cmol_ckg^{-1}$)	1.40 – 23.50	6.45	0.52
BS (%)	24.00 – 95.00	63.86	1.65

SEM - standard error of means
CEC – cation exchange capacity
BS – Base saturation
TEB- Total base saturation

Group D soils (21 – 40% Clay content) had almost 4 times higher concentrations of Ca and Mg compared to Group A soils with 0-5% clay soils (average of 6.9 $cmol^{c}kg^{-1}$ Ca and 2.5 $cmol^{c}kg^{-1}$ Mg compared to 1.6 $cmol^{c}kg^{-1}$ Ca and 0.4 $cmol^{c}kg^{-1}$ Mg) (Figure 3.1).

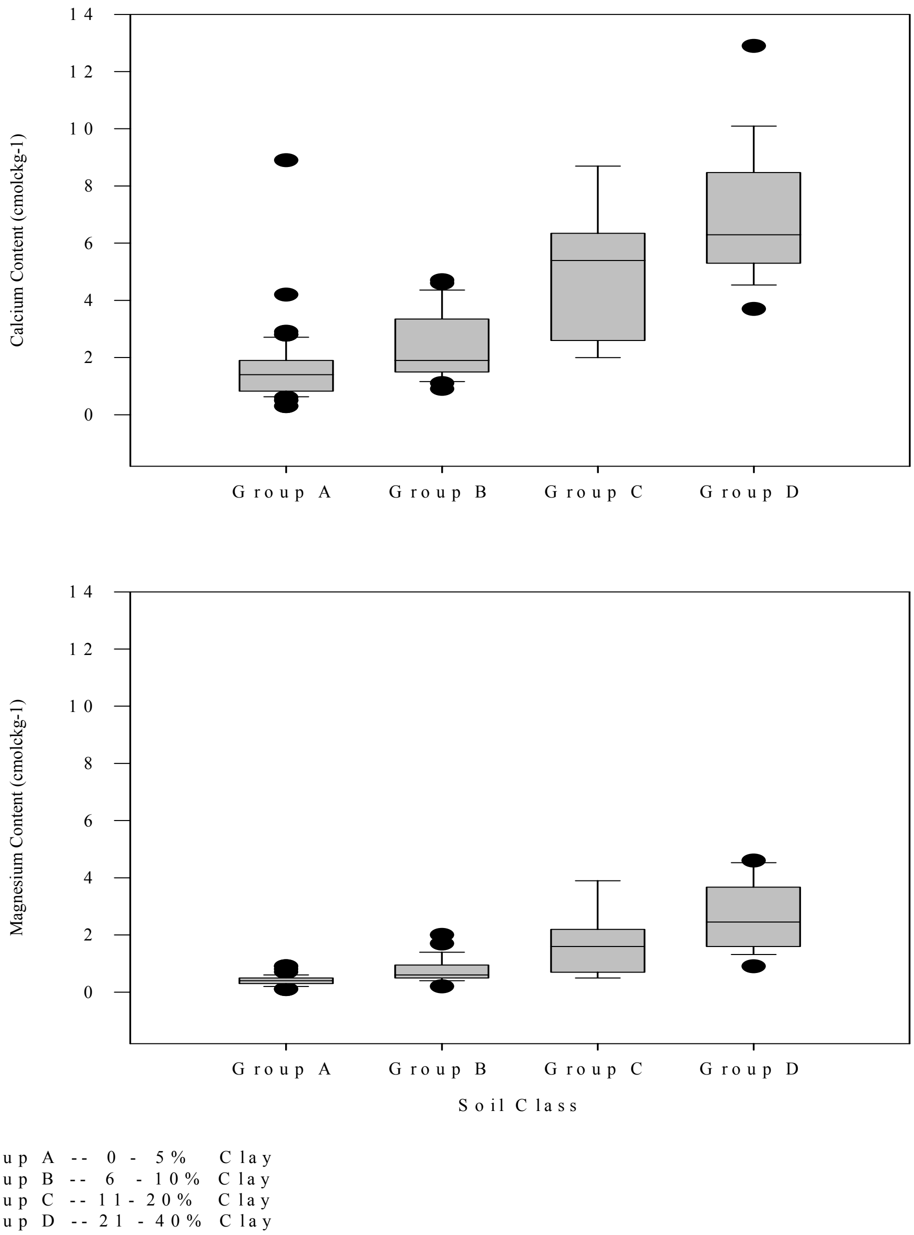

Figure 3. 1: A comparison of Ca and Mg content in the 4 soils classified according to clay content at Chendambuya SFA in 2002.

However, the 4 groups did not differ much in terms of base saturation (Table 3.2). Base saturation averaged 63.63% on group A soils and 64.50% on group D soils.

Table 3. 2: A summary of properties of soils at Chendambuya SFA.

Soil Property	Soil Class	Range	Mean	S.E.M
% Clay	A	0 – 5	3.89	0.15
	B	6 – 10	7.72	0.31
	C	11 – 20	15.11	1.40
	D	22 – 36	27.56	1.13
pH ($CaCl_2$)	A	3.2 – 6.9	4.35	0.13
	B	3.5 – 7.1	4.56	0.21
	C	3.9 – 4.8	4.44	0.09
	D	3.7 – 6.1	4.71	0.16
CEC ($cmol_c kg^{-1}$)	A	1.4 – 10.8	3.42	0.19
	B	2.2 – 14.0	5.02	0.50
	C	4.2 – 17.6	10.87	1.70
	D	8.6 – 23.5	15.36	0.97
BS (%)	A	24 – 100	63.63	2.84
	B	44 – 100	69.84	3.24
	C	42 – 79	63.44	3.45
	D	45 – 86	64.50	2.76
TEB	A	0.5 – 9.6	2.19	0.18
	B	1.4 – 6.9	3.39	0.31
	C	2.8 – 12.9	6.74	1.09
	D	5.1 – 17.0	9.94	0.79

SEM – standard error of mean
CEC – cation exchange capacity
BS – Base saturation

The light textured soils (group A) had a lower TEB (averaging 2.19) and CEC (averaging 3.42) compared to the heavy textured soils (group D) (average 9.94 and 15.36 for TEB and CEC respectively) (Table 3.2). The pH of heavy textured soils was higher than for light textured soils (pH of 4.35 for light textured soils compared to 4.71 for heavy textured soils (Table 3.2).

3.3.2. Soil amendment characterization

The majority (89%) of the sampled households used cattle manure as a soil amendment while the use of composts and ash (5%) from rubbish pits and anthill soil (5%) was limited. Ash and compost was applied less frequently compared to cattle manure because of its limited availability. Ash and compost was applied once every 3-4 years as compared to the annual application of cattle manure while anthill soil was only spread on the first ploughing season to level the field (Matokwe, unpublished data).

The majority of the sampled amendments had low to medium N content (81.11%) (Table 3.3). Cattle manure was superior (averaging 1.15 % N) compared to 0.66 % and 0.69% for composts and termitaria, respectively (Figure3.2).

Table 3. 3: Soil amendments classified according to nitrogen content

Quality	V. Low	Low	Medium	High
% N	≤ 0.5	0.51 – 1	1.1 – 1.5	> 1.5
% Cattle Manure	2.5	34.6	46.9	16.1
% Ash	20	70	10	0
% Termitaria	20	60	20	0

(Classification adopted from Mugwira and Mukurumbira, 1986)

The organic carbon content of the amendments was determined in order to assess their ability to improve physical properties of the predominantly sandy soils in the area. Termitaria and ash and composts had low organic matter content averaging 1.02% and 1.58%, respectively, while cattle manure, had higher %OC (averaging 21.48%).

However compost contained higher concentrations of Ca (averaging 4.2%) compared to termitaria (average 1.2%) and cattle manure (average 0.78%) Ash and compost also had higher concentrations of P compared to cattle manure (Figure 3.2).

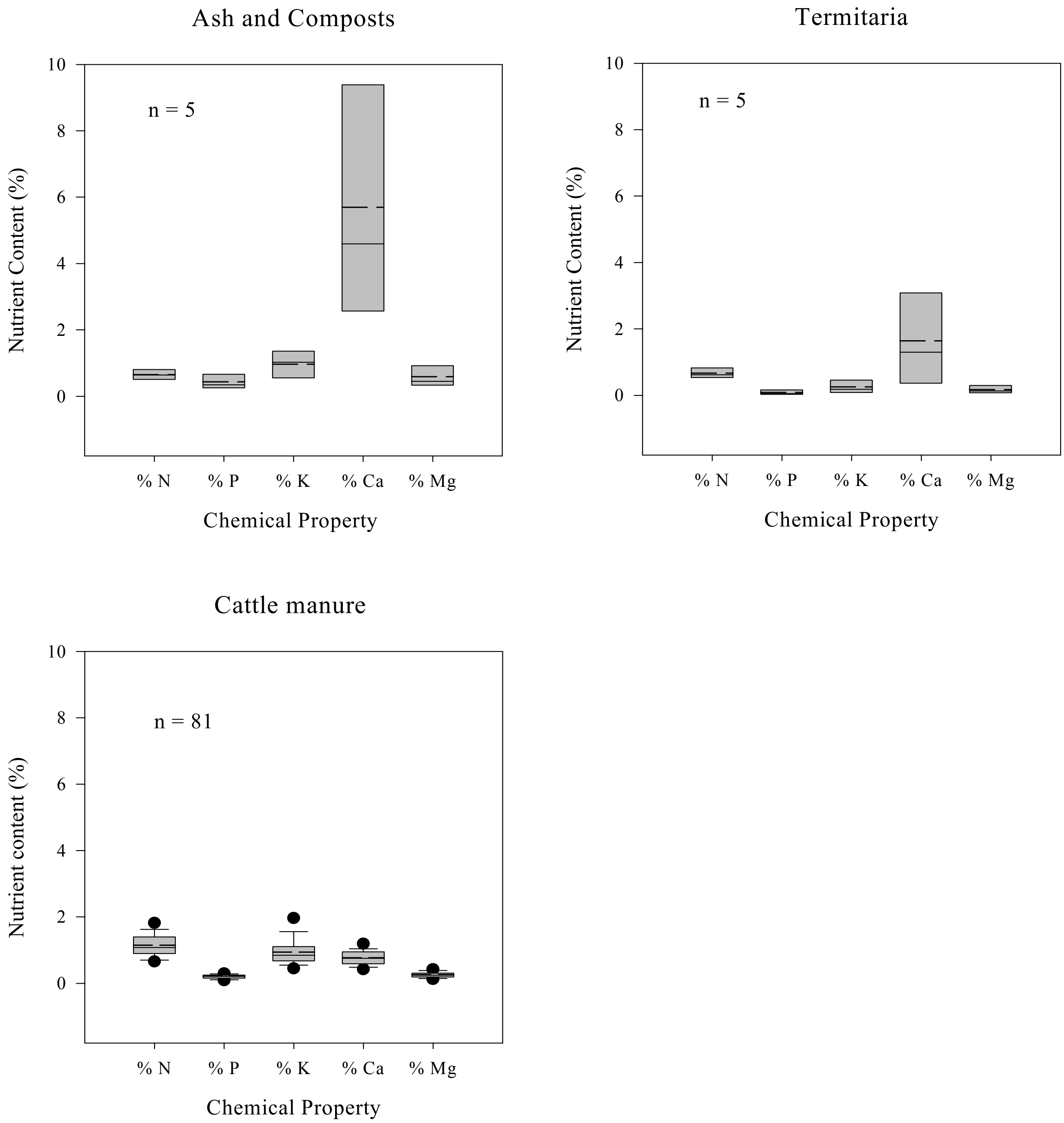

Figure 3. 2: The 25th and 75th Percentile, median and mean nutrient content of the different organic fertilisers sampled in Chendambuya smallholder area.

The lower upper boundaries of the box represent the 25th and 75th percentiles respectively while the continuous line in the box is the median and the broken line in the box represents the mean nutrient content). Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles.

On average, cattle manure applied to the field contained 56% (ranging from 4 - 90%) soil (inorganic material). The manure had an average C: N ratio of 28.9 (4.37 – 124.82).

Only 7% of the interviewed farmers used lime and 37% of these farmers were not aware of lime at all (Matokwe, unpublished data). The cattle manure neutralising value (compared to $CaCO_3$) averaged 36.7 % (6.2 – 75.9%). The neutralizing value of ash and compost averaged 37.5 % (14.01% – 60.96%) and for termitaria it was 37.6 % (16.58 - 58.59%).

3.4. DISCUSSION

The majority (75%) of soils sampled in Chendambuya were sandy derived from granite. Although base saturation was equal for light and heavy textured soils, light textured soils were characterized by lower fertility (averaging 1.82 $cmol_c kg^{-1}$ Ca and 0.51 $cmol_c kg^{-1}$ Mg) than heavy textured soils (averaging 6.06 $cmol_c kg^{-1}$ Ca and 2.28 $cmol_c kg^{-1}$ Mg). However the Ca and Mg contents for light textured soils were not in the critical range according to Landon (1991).

The problem of soil acidity is common across the different soil types in the area (pH averaging 4.38 and 4.57 for light and heavy textured soil, respectively). The expression of detrimental effects of acidity however depends on soil type and is more pronounced on sandy soils because of their low inherent fertility (Heylar, 1998). The difference in CEC (13.65 $cmol_c kg^{-1}$ for heavy textured soils and 3.98 $cmol_c kg^{-}1$ for light textured soils) shows that the heavier soils, which had a higher CEC, can be fertilised more effectively compared to light textured soils where application of fertiliser may not be economic as nutrients are prone to leaching. The CEC for the heavy textured soils was relatively low according to Landon (1991). The Na and K contents for the two soils were not limiting for production of most crops (Landon, 1991). Sandy soils (group A) have poor buffering capacity compared to heavier soils (group B) and liming on these soils will need to be done more frequently though not as heavy as would be required for clay soils.

Although cattle manure is a common amendment in Chendambuya results from a related study have shown that the average herd size is small (averaging 9 animals per family) with several farmers owning as few as 3 animals (Matokwe, unpublished data). This coupled with the scarcity of land for grazing results in farmers having very little amounts of manure available for application on fields.

Most manure samples from this area were poor N sources (Table 3.2). A high proportion (84%) of manure had N content ranging from 0.5% - 1.5%. Supplementing manure from this area with inorganic sources of N may be necessary. Giller *et al*. (1998) and Palm *et al*. (1995) noted potential benefits in combining low quality organic fertilisers with inorganic ones. Apart from effects of low quality grazing in communal areas, the low N contents of manure sampled can imply poor management by farmers resulting in N loss though leaching or volatilization. Improving pastures by planting legumes may also improve the manure quality. Farmers can also be encouraged to use stover to absorb urine (an important source of N) (Tanner and Mugwira, 1984). Studies by Nzuma *et al*. (1998) showed that pit composting unlike heaping produces higher quality (N content) manure. Aerobically composted manure (heaped) due to the high oxygen partial pressures usually has higher pH (8 – 9) thus stimulating N volatilization while on the other hand anaerobically composted manure with low oxygen partial pressure produces organic acids thus induce lower pH. Exposure of manure to sunlight and rain also contribute significantly to N loss through volatilization (Dhliwayo and Mukurumbira, 1996) while Co-composting inorganic and organic fertiliser has been recommended to improve nutrient supply by manure (Dhliwayo and Mukurumbira, 1996). Nitrogen has been described as one of the most limiting nutrients in Zimbabwe SFAs and according to Kirchmann (1985) 8 – 40% of N losses from cattle manure occurs during storage. Minimising these losses can significantly improve the efficiency of communal manure as N sources.

Cattle manure had high OC contents (ave. 21.48%) while termitaria and ash and composts had low %OC (ave. 1.02% and 1.58% respectively). The organic carbon content gives an indication of the organic matter content, which in turn is important for improving the activity of microorganisms in the soil. It also improves the soil water holding capacity, hydraulic conductivity and infiltration rate (Grant, 1967a, 1970; Murwira, *et al*., 1995). However, building soil organic matter on sandy soils and managing nutrient release is difficult as decomposition occurs rapidly (Giller *et al*., 1998).

The amount of inorganic material in cattle manure ranged from 4 - 90% implying that some farmers merely transfered soil from the kraal to their fields. These results also show variability in manure management in the area. The high ash and soil content measured in some of the cattle manure results from manure mixing with sand during trampling by cattle, when manure is dug from the kraals and from direct ingestion by animals during grazing (Nyamangara, 2001). Khombe, *et al,* (1992) showed that trampling of manure by penned cattle can result in exceptionally high sand contents of over 50%.

Samples with undecomposed maize stover had C: N ratios as high as 120. Application of these manures may result in a net N immobilisation (Tanner and Mugwira, 1984). Although manure with high C: N ratios may not improve N availability in soils, Grant (1967b) showed that these manures are important for soil fertility improvement as a result of progressively increasing CEC, exchangeable bases and pH. The large differences in C: N ratios (4.4 – 124.8) show the differences in management of manure in Chendambuya SFA.

The manure neutralising value (compared to $CaCO_3$) was low (ranging from 6.2 – 75.9%, averaging 36.7%) compared to 70±7% regarded as the lower limit for agricultural liming material in Zimbabwe (Farm feeds, Fertilisers and Remedies Act, 1993). Calcium and Mg contribute to manure liming value because of their ability to replace H^+ ions from exchange sites thus increasing base saturation (Nhamo *et al.,* 2002).

3.5. CONCLUSIONS

Soil acidity is a major fertility problem in Chendambuya SFA. Cattle manure from the area is of low quality as a nutrient source and liming material. Light textured soils are more acid than heavy soils but due to their low buffering capacity will require less lime to neutralize the acidity. Low fertilizer applications are also required for light textured soils compared to heavy textured soils because of the low CEC.

Chapter 4

RESPONSE TO ALUMINIUM BY SELECTED MAIZE AND SOYABEAN CULTIVARS

4.1 INTRODUCTION

Aluminium has not been described as a plant nutrient although Foy (1984) noted benefits of low Al levels on plant growth and mineral uptake. Excess Al decreases root respiration, interferes with nutrient uptake, transport and use (Pandey *et al.,* 1994). Plant species differ in their tolerance to Al toxicity. Non-legumes tend to be more tolerant to Al than legumes (Adeoye and Agboola, 1985).

Aluminium solubility is strongly pH dependent. When pH is less than 4.2, Al is released from granitic and red soils leading to toxicity. Aluminium toxicity often occurs in ultisols and oxisols with high exchangeable Al. In such cases it often occurs together with Mn toxicity. It is also common in acid sulphate soils and in flooded soils with pH <4 before Fe toxicity symptoms appear (Marschner, 1995).

The primary expression of Al toxicity is the drastic inhibition of root growth presumed to be a result of Al binding to nuclear DNA thereby reducing its replication (Maustakos, 1992). Aluminium interferes with cell wall expansion thereby increasing cell wall rigidity. As root cell division is inhibited and cell membranes are damaged, root systems become stubby, thickened and distorted (Helyar, 1998). Root growth retardation results in reduced exploitation of water and nutrient supply in the soil. Reduced water exploitation leads to premature closure of stomatal cells and plants experience an induced drought stress.

Calcium and Mg imbalances due to Al toxicity have been reported (Clark, 1997). Huang *et al.* (1993) showed that Ca transport in wheat was inhibited well before inhibition of root and shoot growth implying that Ca translocation probably plays an important role in the mechanisms of Al phytotoxicity. These mechanisms may involve Al alteration of root Ca status of Al sensitive cultivars. Depression of Ca uptake may result in depressed Ca translocation from roots to shoots in order to maintain root cell homeostasis. The toxic effect of Al on the root apex could inhibit the production of certain plant hormones affecting Ca translocation in plants. Pietraszewska (2001) concluded that Al inhibition of Ca transport is involved in the initial phase of Al toxicity as it alters the properties and architecture of the membrane lipid layer.

Phytohormone imbalances due to Al toxicity have been reported on sensitive plants (International Rice Research Institute, 2002). The visual symptoms associated with Al toxicity are poor and stunted growth and orange-yellow to white interveinal chlorosis of leaves. Yellow to white mottling of interveins is followed by tip death and leaf margin scorch. During severe toxicity, necrosis of chlorotic areas occurs. Stunted and deformed roots are common Al toxicity symptoms in susceptible cultivars (International Rice Research Institute, 2002).

Screening cultivars that are tolerant to growth limiting factors associated with acid soils such as Al toxicity have been focused mainly on crops such as wheat, barley and rye (Huang *et al*., 1993; Mugwira, 1980; Taylor and Foy, 1985). Research on cultivars of maize and legumes such as soyabean and cowpea that are commonly grown in Zimbabwe's smallholder farming areas has been limited. Maize is the main crop grown in the SFAs of Zimbabwe and in order to secure the general household food security in these areas maize production needs to be improved. Soyabean and cowpea are important legumes because of both their soil fertility enhancing capacity and as a rich source of nutrients for communities.

The aim of this study was to screen five maize cultivars (CZH 00013, CZH 00017, DK 8031, SC 403 and SC 517) and 3 soyabean cultivars (Magoye, Solitaire and Safari) for tolerance to Al under greenhouse conditions. Shoot and root dry matter yield, total root length and taproot length together with nutrient uptake and translocation were used as screening parameters.

4.2 MATERIALS AND METHODS

Maize and soyabean hybrids bred and grown in the Southern African region were selected. The experiment was laid out in a completely randomised block design (CRBD) with 2 treatments (cultivar and Al concentration). Blocking was done by position in the greenhouse and the 4 blocks used in the experiment also acted as replications for each treatment.

4.2.1 Treatments

The treatment combinations for this experiment were as follows

- Four Al concentrations
- 5 maize cultivars (SC 403, SC 517, DK 8031, CZH 00013 and CZH 00017) for the maize experiment and 3 soyabean cultivars (Magoye, Safari and Solitaire) for the soyabean experiment.

The experiment was laid out in a completely randomized block design where blocking was by position in the greenhouse.

Pre-germinated seed of SC 403 (Seed-Co Zimbabwe), SC 517(Seed-Co Zimbabwe), DK 8031(MONSATO), CZH 00013 and CZH 00017 (MZ00B-1269-3/4 Mozambique) maize cultivars, and Magoye (Zambia), Safari and Solitaire (Zimbabwe) soyabean cultivars were transplanted into 12L 1/5 Steinberg nutrient solution (Foy *et al.,* 1967) with 0, 4, 8 and 16 mg L^{-1} Al added as $AlK(SO_4)_2.12H_2O$ (Foy *et al*., 1967). The chemical composition of the nutrient solution in mg L^{-1} was: 50.8 Ca, 6.6 Mg, 56 N (51.9 as $N0_3^-$ and 4.1 as NH_4^+), 3.8 S (as SO_4^{2-}), 29.4 K, 0.01 Na, 3 P, 0.34 Cl, 0.13 Mn. 0.07 B, 0.04 Zn, 0.01 Cu and 0.005 Mo. Iron was added separately at 1 mg L^{-1}, (50% as FeEDTA and 50% as $FeSO_4$). At planting the solutions were adjusted to pH 4.8 ± 0.2 using dilute HCl and dilute NaCl and were not adjusted thereafter. Each treatment was replicated 4 times and 2 seedlings were planted in each pot. The plants were grown in the greenhouse for 25 days (Mugwira, 1980; Mugwira *et al.,* 1981). At harvest the final solution pH was determined.

4.2.2 Determination of RRE and ATI.

Root lengths were measured every 2 days during the course of the experiment. For purposes of this study Relative Root Elongation (RRE) was calculated using root lengths at 4 days and at 20 days after transplanting as follows (Bennet. 1998):

$RRE = (RE_{xAl} / RE_{0Al}) * 100$

Where $RE = RL_{20d} – RL_{4d}$

RE is root elongation (change in root length)

RE_{XAl} is change in root elongation at x Al concentration

RE_{0Al} is change in root elongation at o Al concentration

RL_{4d} is average root length at 4 days after transplanting

RL_{20d} is average root length at 20 days after transplanting.

Root length measurements at 4 days and 20 days were used because at 4 days it was assumed that all cultivars would have stabilized and effects of seed size on root growth would have been minimized and by the 20^{th} day root elongation would have stabilized.

After 25 days the length of the longest root in each pot was measured and roots were rinsed with distilled water. Roots and shoots were separated and packed in khaki bags.

Total root length was determined by the line intercept method, based on the Buffons needle principle (Anderson and Ingram, 1993). Roots were spread out on a glass plate (25 cm x 25 cm) with 1 cm x 1cm grid lines. Horizontal (H) and vertical (V) intersections between roots and grid lines on the glass were counted and added to give a number (N). Total root length (L) was calculated as

$$L = \pi ND/4$$

Where D is the grid size set at $40/\pi$

Therefore $L=10N$

The Aluminium Tolerance Index was calculated using total root length measurements as follows:

ATI = Each RL – Lowest RL x AC + 1.0

Where Relative Root Length (RL) = (TRL at 16ppm Al)/ (TRL at 0ppm Al)

Adjustment Constant (AC) = 4 / (Highest RL – Lowest RL)

And TRL is total root length (Sapra *et al.,* 1978).

The ATI is given on a scale of 1-5 where 1 is highly sensitive and 5 highly tolerant. This index mitigates subjectivity in scoring from visual observations (Sapra *et al.,* 1978).

4.2.3 Determination of root and shoot dry matter yield

The roots and shoots were oven dried at 60 ^{O}C and weighed. Relative dry weights (RDW) were calculated in order to determine the relative decline in shoot and root dry matter yields at the different Al concentrations. Relative dry weights were calculated as follows:

RDW = x Al / No Al

Where x Al is dry weight at x Al concentration

No Al is dry weight at 0Al concentration.

4.2.4 Nutrient uptake Determination

The dried roots and shoots were ground and analysed for total P, Ca, and Mg. Samples were dry ashed overnight at 450^{0}C in a muffle furnace. The samples were then digested in aqua regia solution. Total P was determined calorimetrically by the Murphy-Riley method using a Milton Roy Spectronic 301 spectrophotometer at 880 nm (Anderson and Ingram, 1993). Total Ca and total Mg were determined using atomic absorption spectrophotometry (Anderson and Ingram, 1993). In order to determine whether Al affects uptake or translocation of nutrients and in an attempt to assess plant nutrition independent of Al effects on root growth, nutrient translocation ratios were determined. The nutrient translocation ratio is the fraction of absorbed nutrient that is translocated to shoots.

4.2.5 Statistical Analysis

Data on shoot and root growth and nutrient uptake was analysed for variance of treatment means using the Genstat 5 for windows statistical package (Lewis

Agricultural Trust, 1997). Least Significant Differences (lsd) were used to separate treatment means.

4.3 RESULTS

4.3.1 The Effect of Al on Maize Root Growth

There were significant differences in mean total root lengths (TRL) for the tested cultivars (P <0.001) (Figure 4.1).

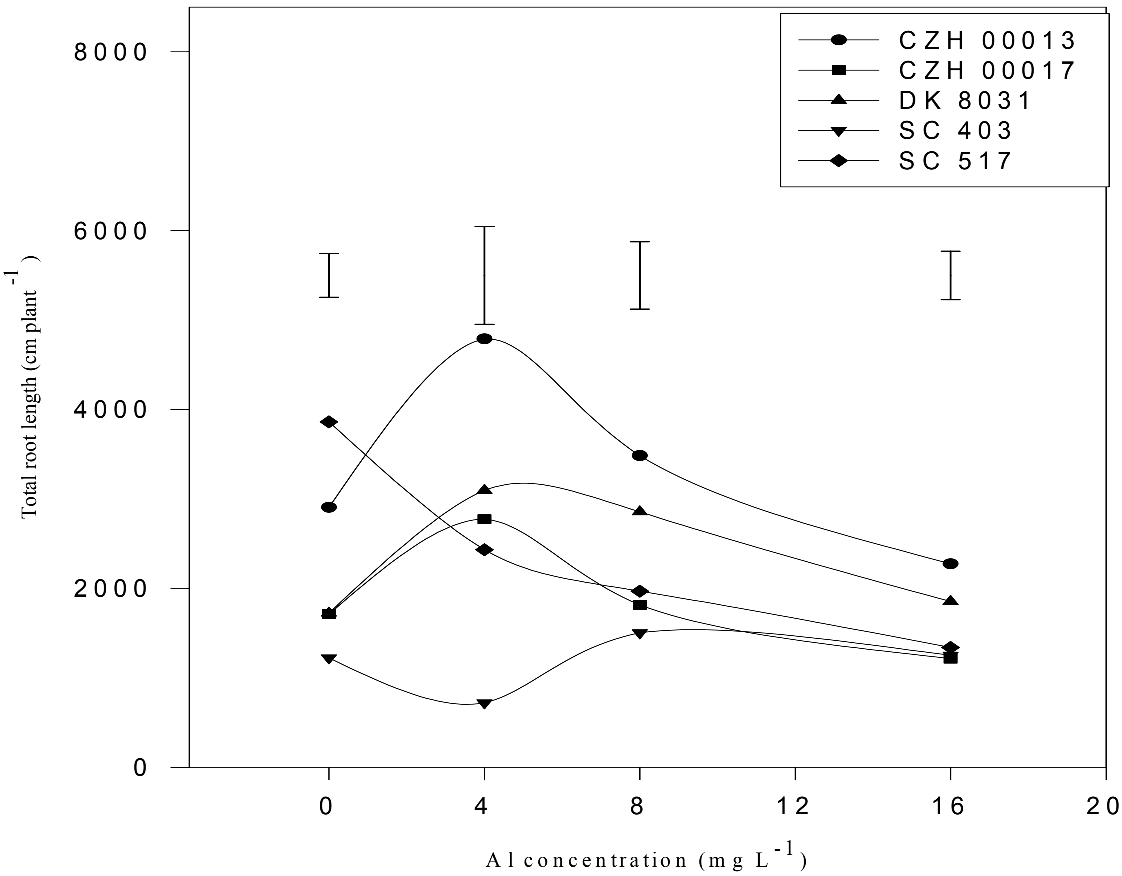

Figure 4. 1: The effect of Al concentration total root length for five maize cultivars grown under greenhouse conditions. (Error bars represent standard error difference at 95% confidence).

Addition of small quantities of Al (4 mg L^{-1}) significantly enhanced root growth for CZH 00013, CZH 00017 and DK 8031 as shown by a rise in TRL (LSD = 507.5). CZH 00013 had the highest TRL while SC 403 had the least TRL at 4 mg L^{-1} Al (Figure 4.1). Addition of higher concentrations of Al significantly reduced TRL for CZH 00013 and CZH 00017 but TRL reduction for DK 8031 was not significant. For SC 517, addition of small amounts of Al (4 mg L^{-1}) significantly reduced TRL. Total root length for SC 403 was not significantly affected by Al (0 – 16 mg L^{-1}) addition (Figure 4.1).

Aluminium tolerance indices showed that DK 8031 was the most tolerant variety while SC 517 was the least tolerant to Al (Table 4.1).

Table 4.1 Aluminium Tolerance Indices for 5 maize cultivars. (Indices were calculated using total root length data at 0 and 16 mg L^{-1} Al concentration).

Cultivar	Root length (cm)		ATI (Al tolerance Index)	
	0mg L^{-1} Al	16 mg L^{-1} Al		
CZH 00013	2906	2275	3.39	
CZH 00017	1713	1215	3.09	
DK 8031	1724	1854	5.00	(Most tolerant)
SC 403	1223	1253	4.72	
SC 517	3863	1339	1	(Least tolerant)

Cultivars SC 403, CZH 00013 and CZH 00017 showed significant taproot elongation as concentration of Al was increased (Figure 4.2). Taproot elongation for DK 8031 was highest at 8mg L^{-1} and then decreased, while that for SC 517 was variable significantly increasing at 4 mg L^{-1} and decreasing at 8 and 16 mg L^{-1} relative to the control.

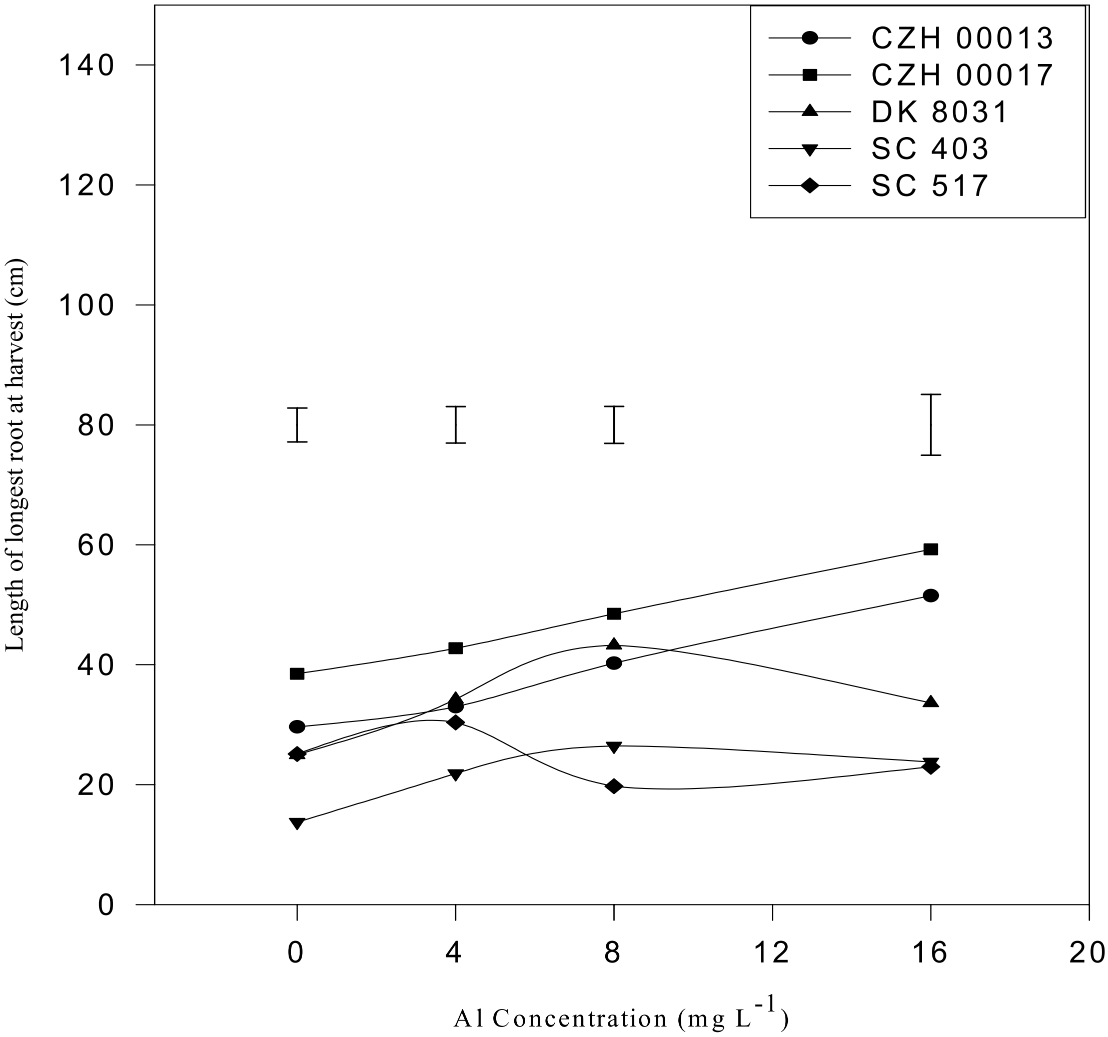

Figure 4. 2**:** The effect of Al concentration on final taproot length of selected maize cultivars after 25 days of growth in a nutrient solution. (Error bars represent standard error difference of means at 95% confidence).

Relative root elongations (RRE) were calculated for SC 517 (least tolerant) and DK 8031(most tolerant) using taproot length measurements at 4 and 20 days after planting. Cultivar DK 8031 showed a general increase in RRE with increase in Al concentration while RRE for SC 517 was decreased (Figure 4.3).

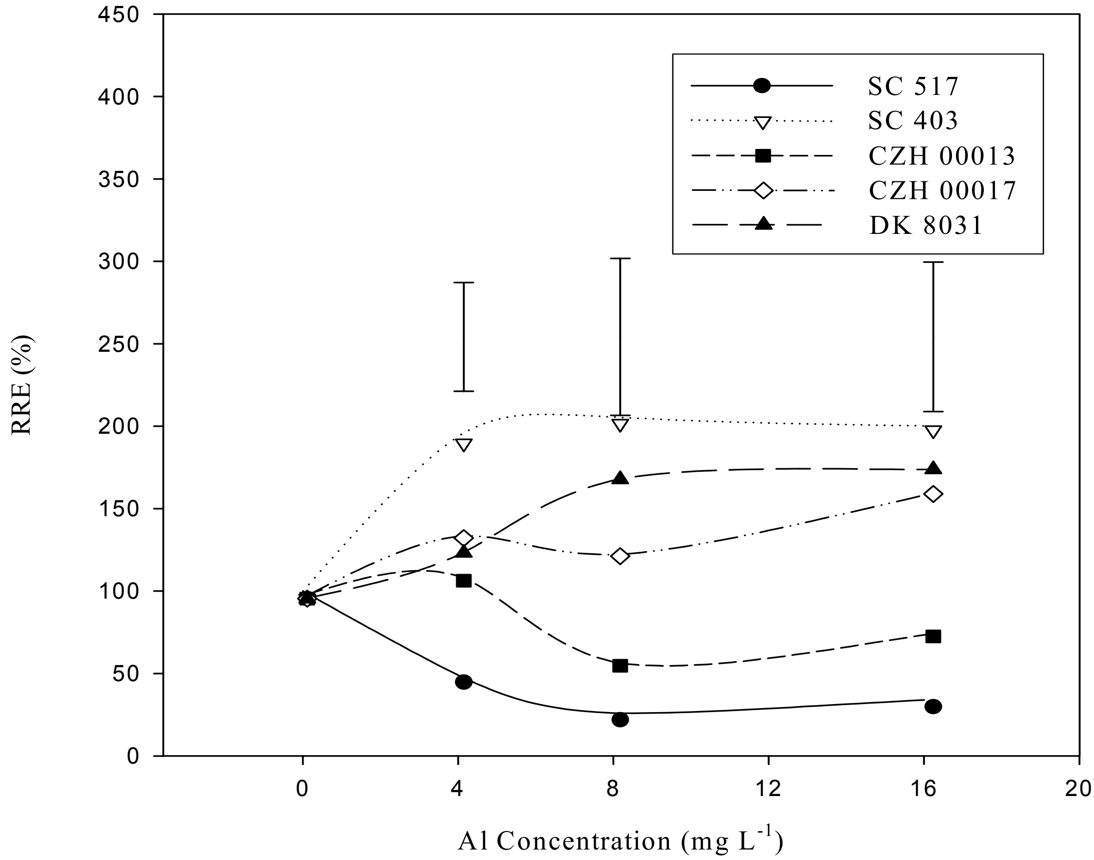

Figure 4. 3 Relative Root Elongations for SC 403, SC 517, CZH 00013, CZH 00017 and DK 8031. (Relative root elongations (RRE) were expressed as a percentage of root elongations at 0mg L^{-1} Al). (Error bars represent standard error difference of means at 95% confidence).

4.3.2 Effect of Al on Maize Root and Shoot Dry Matter Yield

Root dry matter yield (RDMY) and shoot dry matter yield (SDMY) varied inversely with Al concentration in all cultivars. Aluminium toxicity significantly reduced SDMY for all cultivars ($P< 0.001$) (Figure 4.4). At 16 mg L^{-1} Al, an 84% reduction in SDMY was observed with SC 517 while SDMY for SC 403 was reduced by 65%. A 82%, 74% and 77% reduction in SDMY was observed for CZH 00013, CZH 00017 and DK 8031, respectively, at 16 mgL^{-1} Al). Cultivar SC 517 had the highest SDMY at 0 mg L^{-1} compared to the other 4 cultivars (LSD 0.26) but as Al concentration was increased to > 8 mg L^{-1} no cultivar differences were observed. Root dry matter yield for SC 403 was not significantly reduced by Al concentration up to 16 mg L^{-1} while that for DK 8031 was not significantly reduced up to 8 mg L^{-1} Al. Generally the decrease in RDMY was lower compared to SDMY (Figure 4.4).

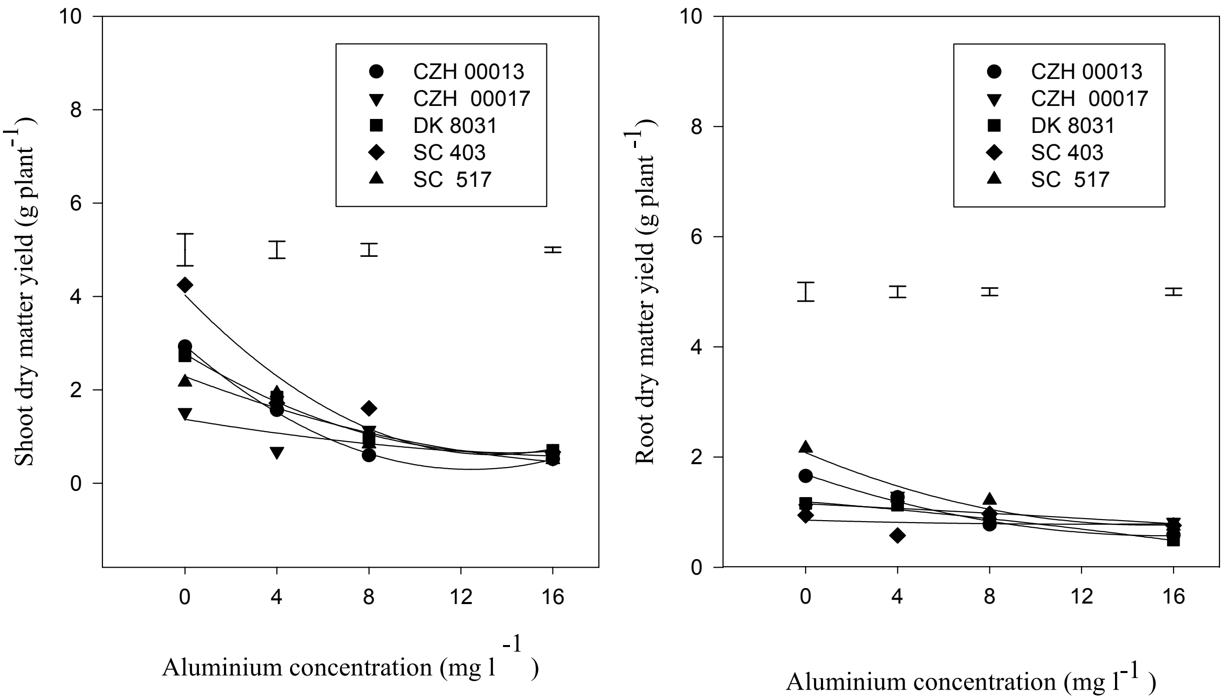

Figure 4. 4: The effect of Al concentration on shoot and root dry matter yield on selected maize cultivars. (Error bars represent standard error difference of means at 95% confidence).

Relative shoot dry matter weight (RSDW) was reduced in all cultivars as Al concentration was increased to 16 mg L^{-1}. At 4 mg L^{-1} Al, RSDW for SC 517 was reduced by 60% while that for DK 8031 was reduced by only 11% of the weight at 0 mg L^{-1} (Figure 4.5). At 8 mg L^{-1} SDW for SC 403 was reduced by 25%, while that of other cultivars was reduced by at least 60%. Shoot dry weights for all cultivars were reduced to less than 40% of the SDW in the control treatment (no Al added) at 16mg L^{-1}. The effect of Al on relative root dry weight (RRDW) was variable depending on variety (Figure 4.5).

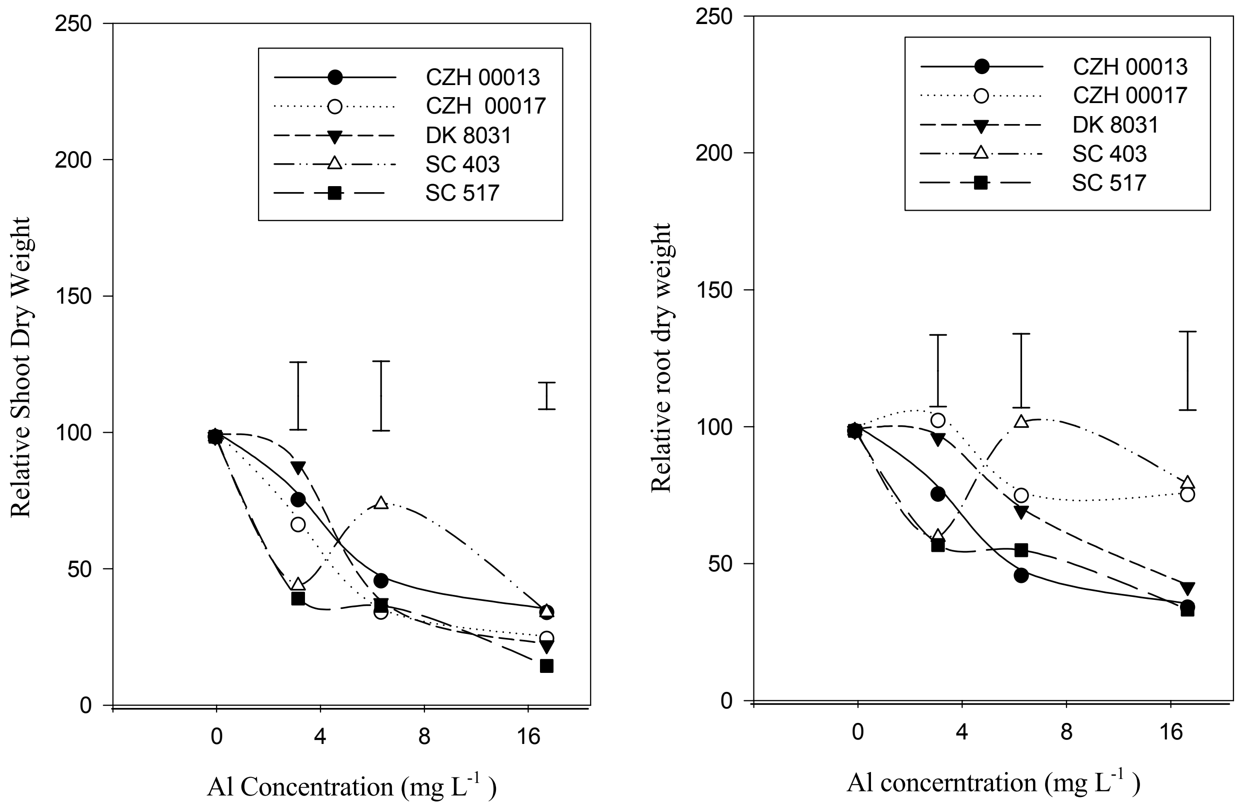

Figure 4. 5**:** The effect of Al concentration on relative shoot and root dry weights of selected maize cultivars. Error bars represent standard error difference at 95% confidence.

4.3.3 Effect of Al on P, Ca and Mg Uptake by Maize

Phosphorus, Ca and Mg accumulation in shoots and roots were significantly reduced in all cultivars as Al concentration was increased (Figure 4.6). Cultivar differences in shoot and root total P were not significant (P = 0.087 and P= 0.094 respectively). Purpling of leaves, a symptom of P deficiency was observed especially with SC 517 where high concentrations of Al were added.

Significant reductions ($P < 0.001$) in Ca translocation (accumulation in shoots) were observed in all cultivars except SC 403 (LSD 3.35). Total Ca in roots was significantly reduced in all cultivars ($P < 0.001$) (Figure 4.6).

At 0 mg L^{-1}, SC 517 generally took up more Mg compared to the other 4 cultivars but as Al was added to 4 mg L^{-1} and above no significant differences were observed (Figure 4.6). Significant reductions in total Mg translocated to shoots (LSD = 0.90) as well as Mg accumulated in the roots (LSD 0.83) were observed in all cultivars as Al concentrations were increased ($P<0.001$).

Calcium translocation ratios varied with variety. In SC 403, Ca translocation ratio increased with increasing Al concentration while in SC 517 no trend was followed (Table 4.2). Calcium translocation ratios for CZH 00013 remained constant while that for DK 8031, remained constant up to 8mg L^{-1} Al then it was reduced at 16mg L^{-1} Al to 44%. Magnesium translocation ratios for the 5 cultivars were not significantly affected by increases in Al concentration (Table 4.3).

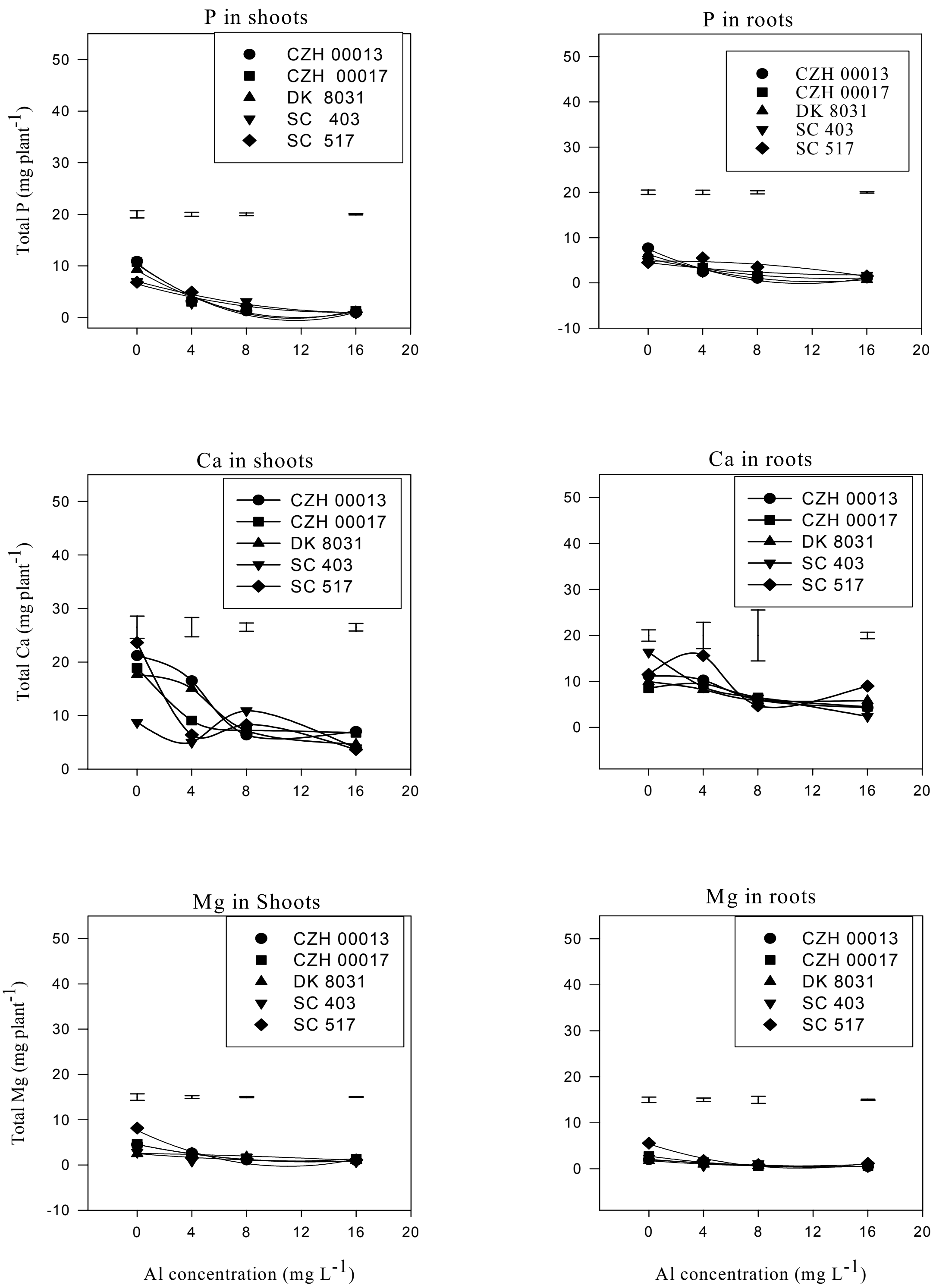

Figure 4. 6**:** The effect of Al concentration on P, Ca and Mg accumulation in roots and translocation to shoots. (Error bars represent least standard error difference of means at 95% confidence).

Table 4. 2: Calcium translocation ratios (the fraction of absorbed Ca that is translocated to shoots) of selected maize cultivars as influenced by Al concentration.

Al concentration (mg L^{-1})	Ca Ratio				
	CZH 00017	CZH 00013	DK 8031	SC 403	SC 517
0	69	62	64	35	67
4	49	62	65	36	29
8	53	51	55	55	64
16	60	62	44	62	29

Table 4. 3: Magnesium translocation ratios of selected maize cultivars as influenced by Al concentration

Al concentration (mg L^{-1})	Mg Ratio				
	CZH 00017	CZH 00013	DK 8031	SC 403	SC 517
0	63	70	58	55	59
4	59	67	72	55	46
8	72	57	72	61	60
16	70	68	51	59	49

4.3.4 Effect of Al on final solution pH

In the control (no Al added) all cultivars except SC 403 increased pH from the initial 4.8 to 5.8 and above. Cultivar SC 403 had a pH of 4.4 in the control treatment. The final solution pH for all the cultivars significantly dropped as 4 mg L^{-1} Al was added. The pH decrease for CZH 00013 and DK 8031 were not significantly different from the initial solution pH. The final solution pH for SC 403 significantly decreased at 4 mg L^{-1} Al. The pH remained constant and was significantly lower than the initial pH of 4.8 with further additions of Al (Figure 4.7). Cultivar SC 517 showed a significant decrease in pH to below initial solution pH as Al was increased to 16 mg L^{-1}.

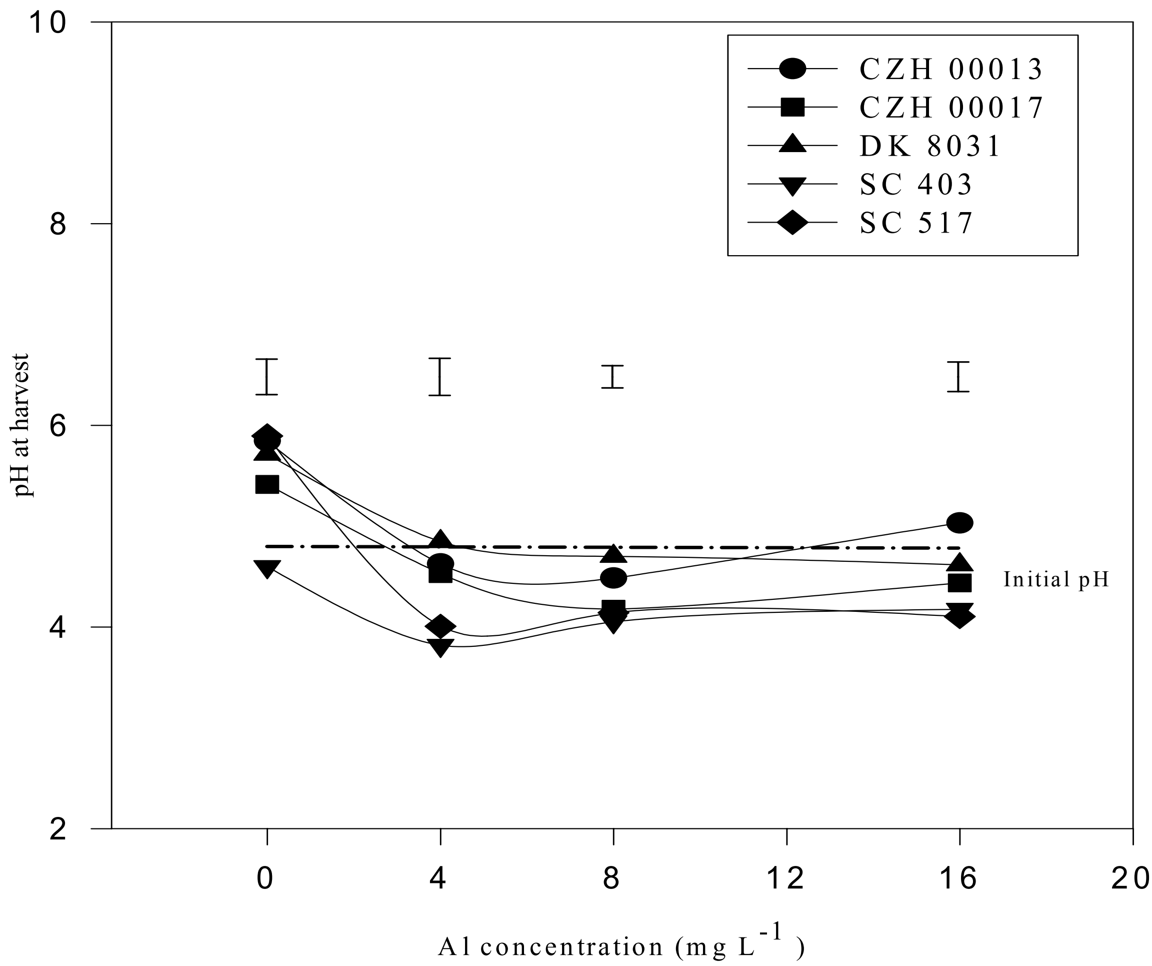

Figure 4. 7**:** Effect of Al concentration on final solution pH. (Error bars represent standard error difference of means at 95% confidence).

4.3.5 Effect of Al on Soyabean Root Growth

Cultivars differed significantly ($P < 0.001$) in terms of total root length (Figure 4.8). Al concentration x variety interaction significantly influenced root growth ($P < 0.001$) with Magoye yielding significantly lower TRL at 0 mg L^{-1} Al and Solitaire yielding lower TRL at 4 mg L^{-1} Al. A significant increase in TRL for Magoye and Safari was observed when Al was added at 4 mg L^{-1} and significant reductions were observed at 8 mg L^{-1}. There was however no significant difference between TRL at 0 and at 16 mg L^{-1} for Magoye while for Safari, TRL at 16 mg L^{-1} was significantly lower than at 0 mg L^{-1}.

A gradual decrease in total root length was observed with Solitaire (Figure 4.8). A significant decrease in TRL was observed when Al was added at 16 mg L^{-1} (LSD = 433.8). Additions of Al at 4 and 8 mg L^{-1}did not significantly reduce TRL.

Aluminium tolerance indices showed that Magoye is the most tolerant while Solitare is the least tolerant (Table 4.4).

Table 4. 4: Aluminium Tolerance Indices of selected soyabean cultivars.

Cultivar	Root length (cm)		ATI (Al tolerance Index)	
	0mg L^{-1} Al	16 mg L^{-1} Al		
Magoye	743	751	5.00	(Most tolerant)
Safari	1597	1034	2.51	(Tolerant)
Solitaire	1760	749	1	(Least tolerant)

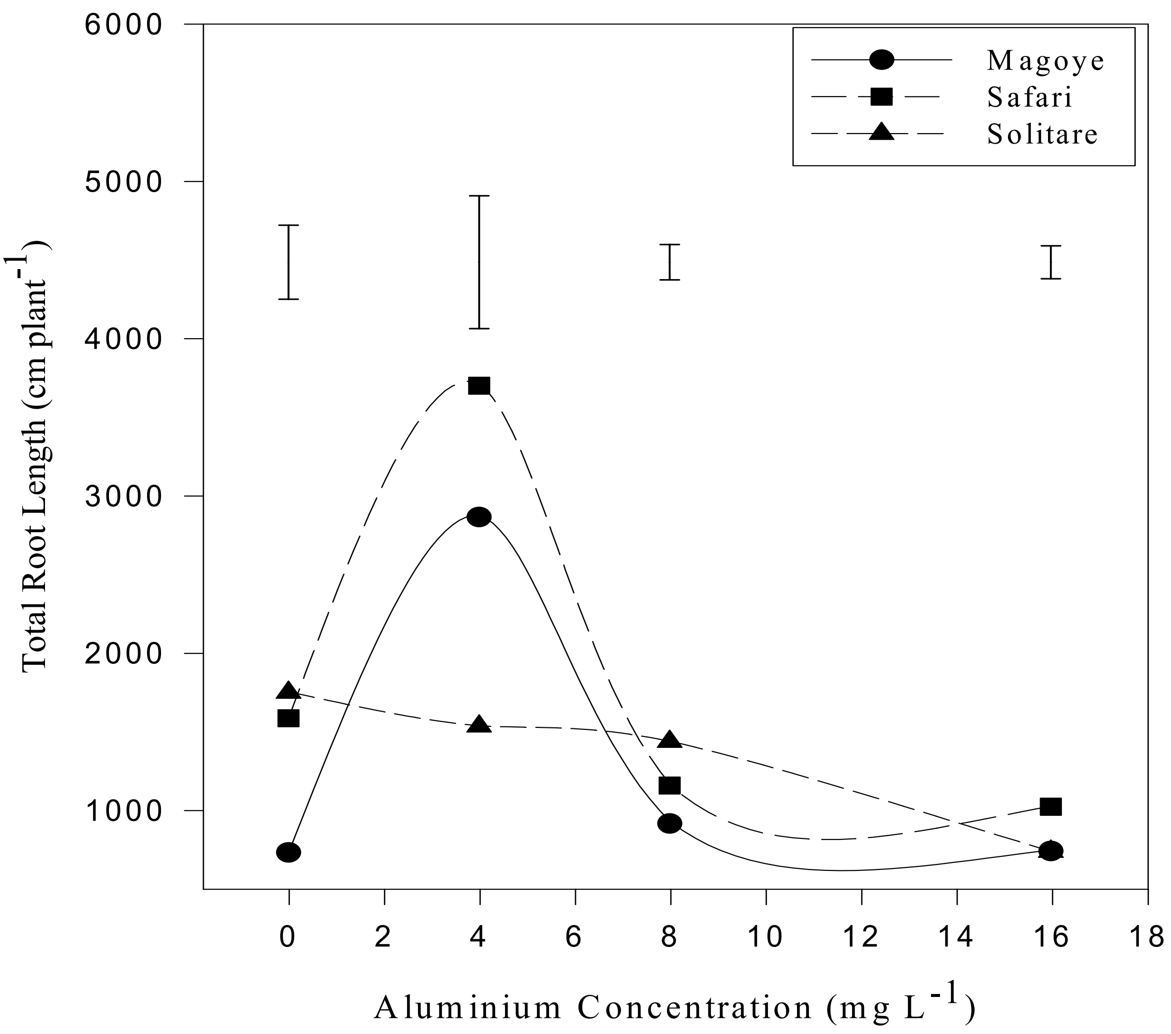

Figure 4. 8**:** The effects of Al concentration on total root length of selected soyabean cultivars. (Error bars represent standard error difference of means at 95% confidence).

The length of longest root was significantly influenced by Al concentration ($P = 0.001$) and varietal differences were also significant ($P = 0.031$) (Figure 4.9). Aluminium x variety interaction was significant ($P = 0.016$). Low concentration of Al (4 mg L^{-1}), enhanced root elongation for Magoye and Safari while a gradual decrease in root length was observed in Solitaire with increasing Al. Higher concentrations of

Al (8 and 16 mg L^{-1}), decreased length of longest root for both Magoye and Safari to values lower than at 4 mg L^{-1} but not different from lengths at 0 mg L^{-1} (LSD = 6.15).

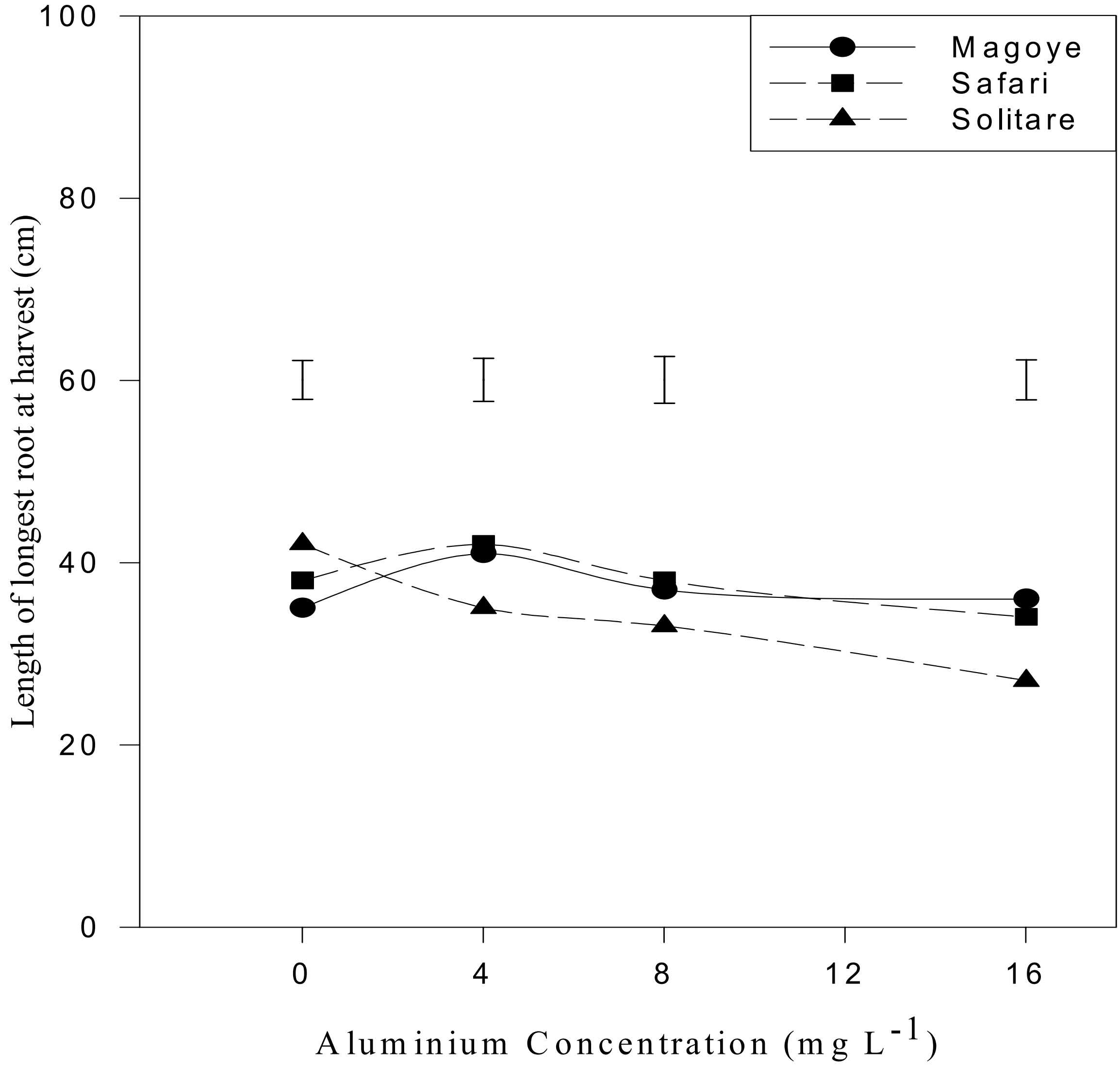

Figure 4. 9**:** The effect of Al concentration on final taproot length of selected soyabean cultivars after 25 days of growth in nutrient solution. (Error bars represent standard error difference of means at 95% confidence).

Relative root elongation (RRE) was reduced in the three cultivars at 4 mg L^{-1}. For Magoye and Safari however, RRE was increased with further increases in Al concentration from 4 to 8 and 16 mgL^{-1}. A gradual decrease in relative root elongation (RRE) with increasing Al concentration was observed with Solitaire with the lowest RRE of 78.66% at 8 mg L^{-1} (Figure 4.10).

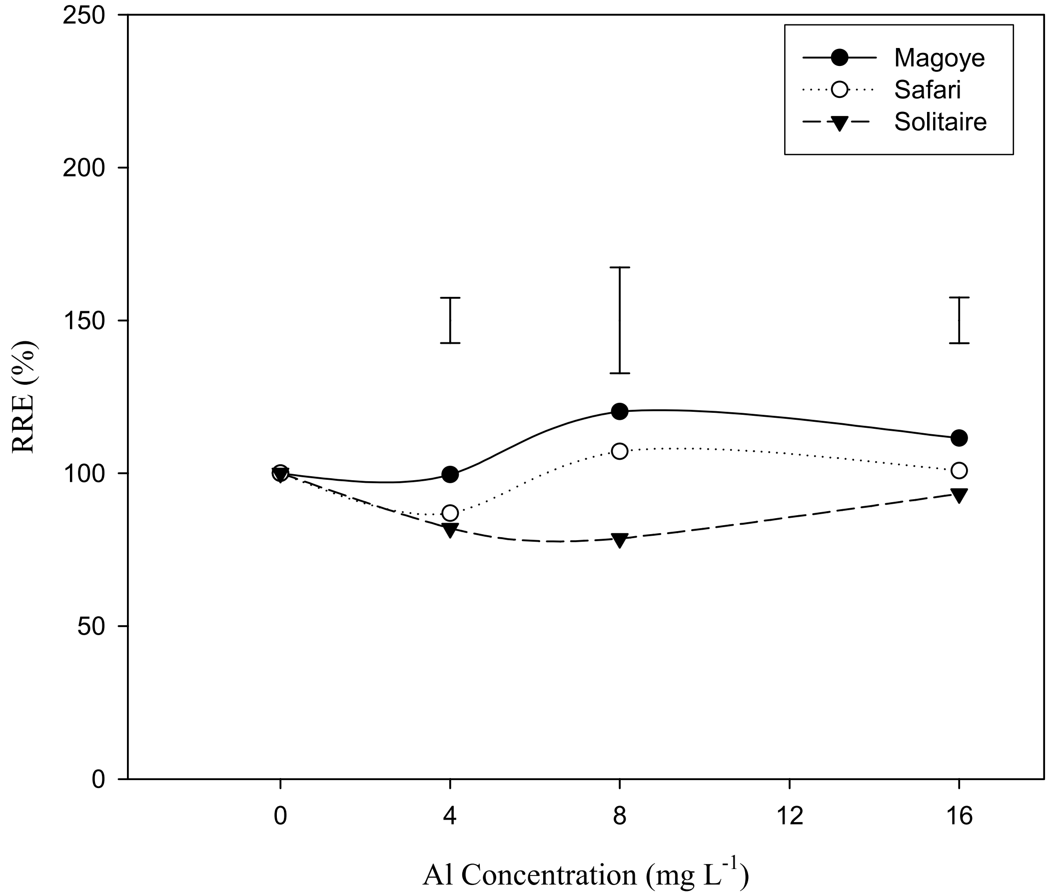

Figure 4. 10: Relative Root Elongations of selected soyabean cultivars. (Error bars represent standard error difference of means at 95% confidence).

4.3.6 Effect of Al on Soyabean Root and Shoot Dry Matter Yield

Shoot dry matter yield varied inversely with aluminium concentration. Shoot dry matter yield reductions were significant in all cultivars ($P < 0.001$) (Figure 4.11). Varietal differences in SDMY were also significant ($P < 0.001$). Safari yielded higher shoot dry matter compared to the other cultivars at all Al concentrations except at 8 mg L^{-1} where SDMY for the three cultivars were not significantly different.

Root dry matter yield for all cultivars, like shoot dry matter yield, was significantly reduced by increase in Al concentration. Cultivar differences were also significant (P = 0.030). Across all Al concentrations, Safari yielded higher root dry matter (0.1988 g $plant^{-1}$) compared to the Magoye (0.1667 g $plant^{-1}$) and Solitaire (0.1673 g $plant^{-1}$) (lsd = 0.027) (Figure 4.11).

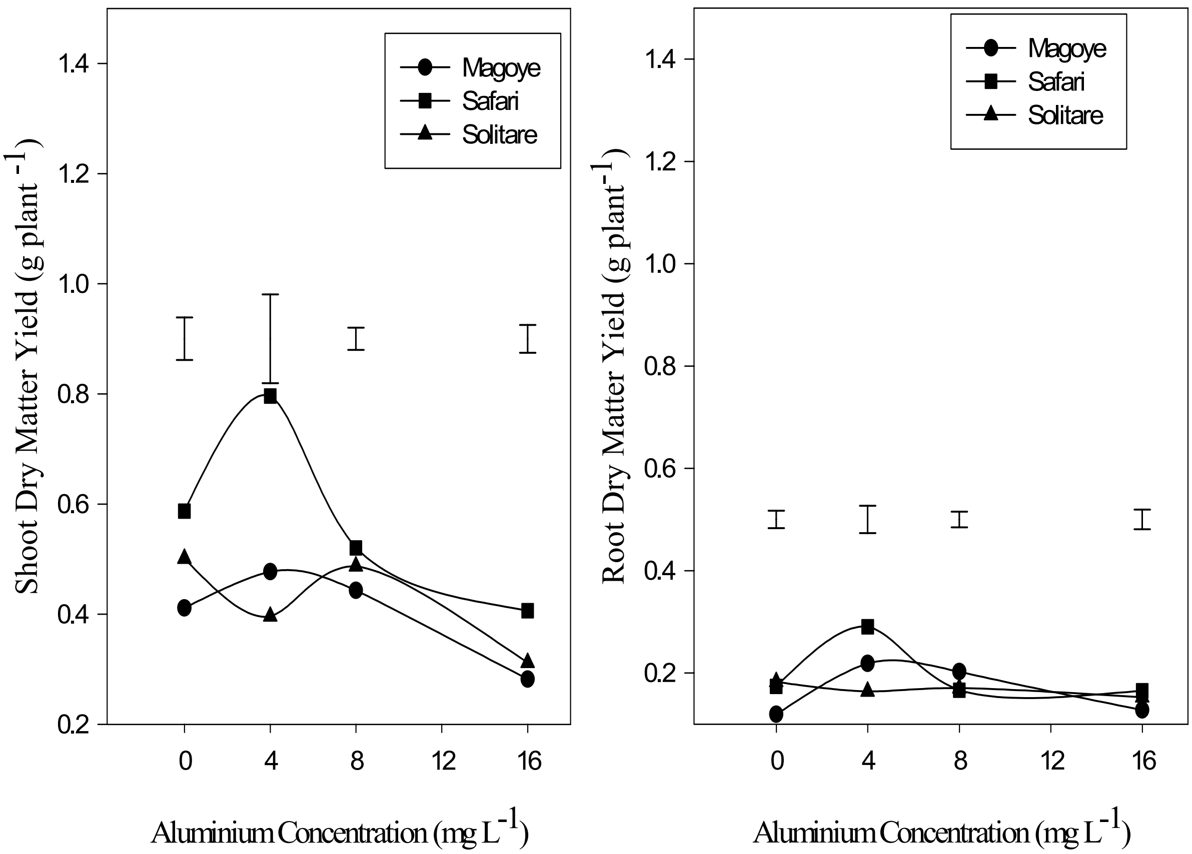

Figure 4. 11: The effects of Al concentration on shoot and root dry matter yield of selected soyabean cultivars. (Error bars represent standard error difference of means at 95% confidence).

Relative root and shoot dry matter yields show that the effect of Al at different levels depended on cultivar (Figure 4.12). Reductions in SDMY were more pronounced compared to RDMY. Shoot dry matter yield for all cultivars was reduced by as much as 30% at 16 mg L^{-1} compared to the control.

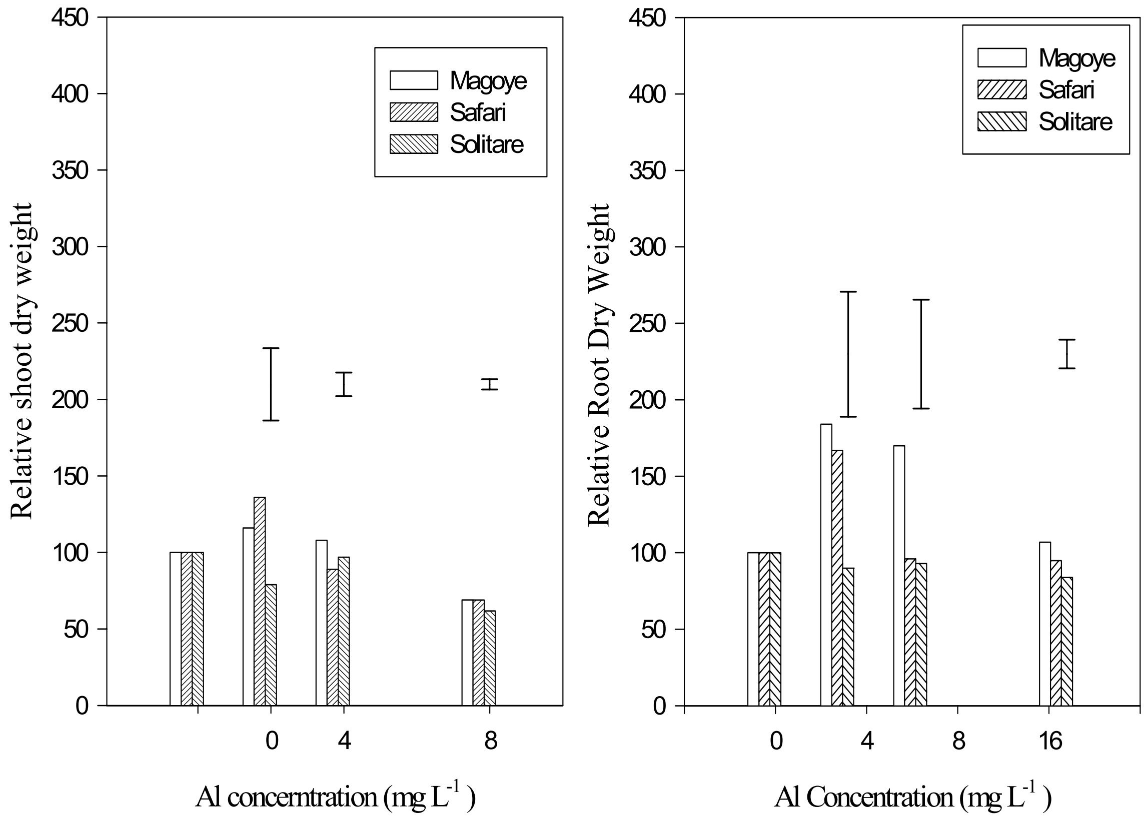

Figure 4. 12: Effect of Aluminium on relative shoot and root dry matter yields of selected soyabean cultivars. Error bars represent standard error difference of means at 95% confidence.

4.3.7 Effect of Al on P, Ca and Mg Uptake

Phosphorus, Ca and Mg uptake and accumulation in shoots and roots were significantly reduced in all cultivars as Al concentration was increased (Figure 4.13). There was significant Al concentration x cultivar interaction effect on total P in shoots and roots ($P < 0.001$ in both cases). Addition of Al in small quantities (4 mg L^{-1}) resulted in significant reductions in total P in shoots and roots for all cultivars.

Significant reductions ($P< 0.001$) in Ca accumulated in shoots were observed in all cultivars. Significant reduction in total shoot P for Safari and Solitaire were observed at 4 mg L^{-1}, while significant reduction for Magoye were observed only when Al was added at 8 mg $L^{-}1$.

In roots, Al significantly reduced P content in Safari (at 16 mg $L^{-}1$) and Solitaire (at 8 mg L^{-1}). Total P in roots of Magoye was not affected by addition of Al. Calcium translocation ratios for the 3 cultivars were reduced slightly by Al (Table 4.5. Aluminium reduced Mg content in both roots and shoots ($P<0.001$). There was no cultivar x Al interaction effects on Mg content in shoots ($P = 0.185$). Aluminium x cultivar interaction effects on total Mg in roots was observed ($P = 0.009$). Reductions in Mg uptake were coupled with reductions in Mg translocation (Table 4.5).

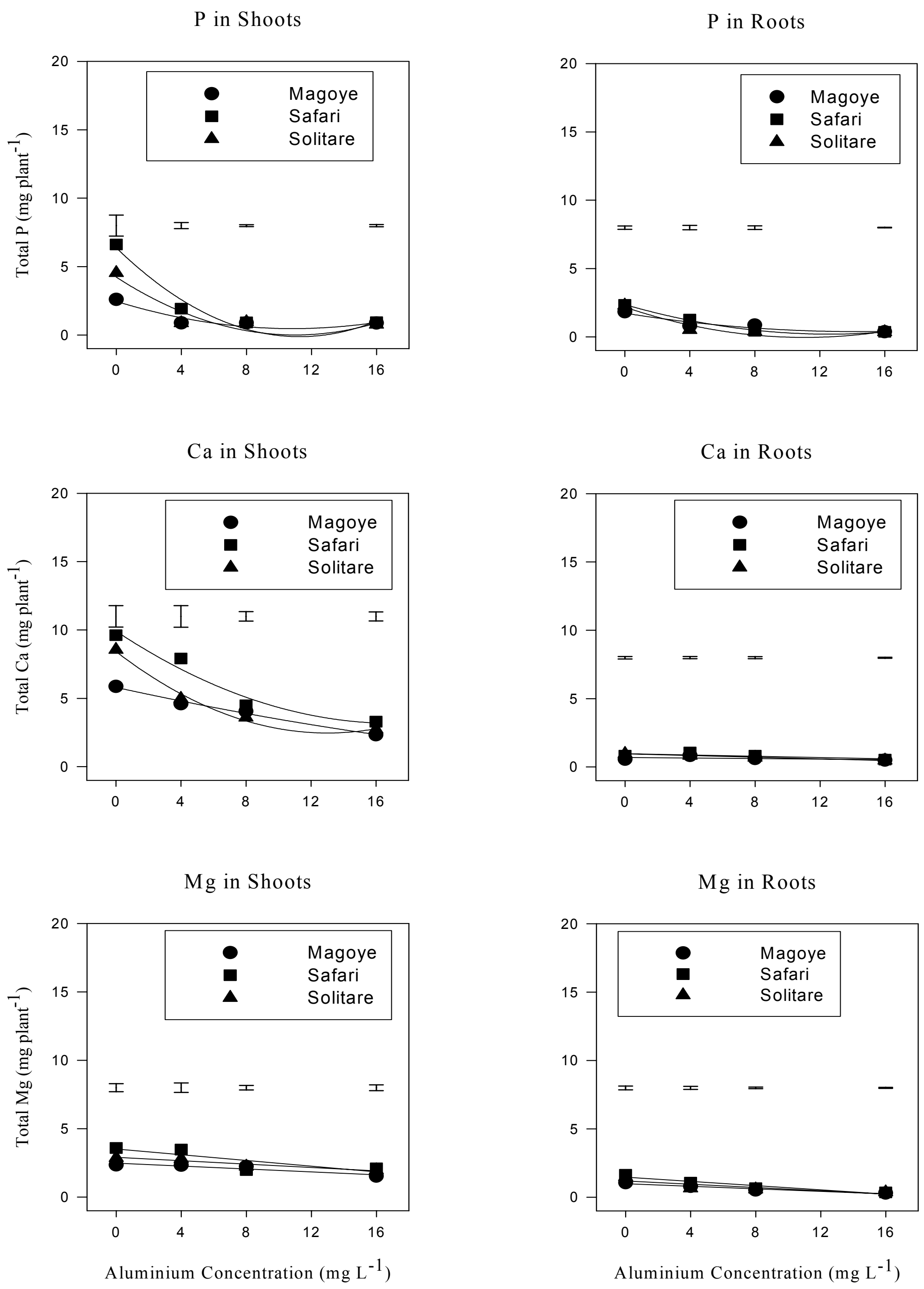

Figure 4. 13**:** The effect of Al concentration on P, Ca and Mg accumulation in roots and shoots of selected soyabean cultivars. (Error bars represent standard error difference of means at 95% confidence).

Table 4. 5: Calcium and Mg translocation ratios for 3 Soyabean cultivars as influenced by Al concentration.

Al concentration (mg L^{-1})	Ca Ratio			Mg Ratio		
	Magoye	Safari	Solitaire	Magoye	Safari	Solitaire
0	91.16	92.11	89.83	69.08	68.54	65.88
4	84.53	88.16	85.64	74.51	76.58	81.00
8	86.74	84.41	83.66	81.03	74.87	79.27
16	82.30	85.92	85.09	83.40	85.63	84.12

4.3.8 Effect of Al on Final Solution pH

All treatments had a higher pH at harvest compared to the pH at planting. There was no Al effect on final pH for Solitaire. For Magoye and Safari, a decrease in final pH was observed with application of Al at 4mgL^{-1} increasing progressively with incremental Al addition ($P < 0.001$). At 16 mg L^{-1}, final solution pH for Magoye and Solitaire were significantly higher than at 0 mg L^{-1} Al while that for Safari was not different (LSD = 0.38) (Figure 4.14).

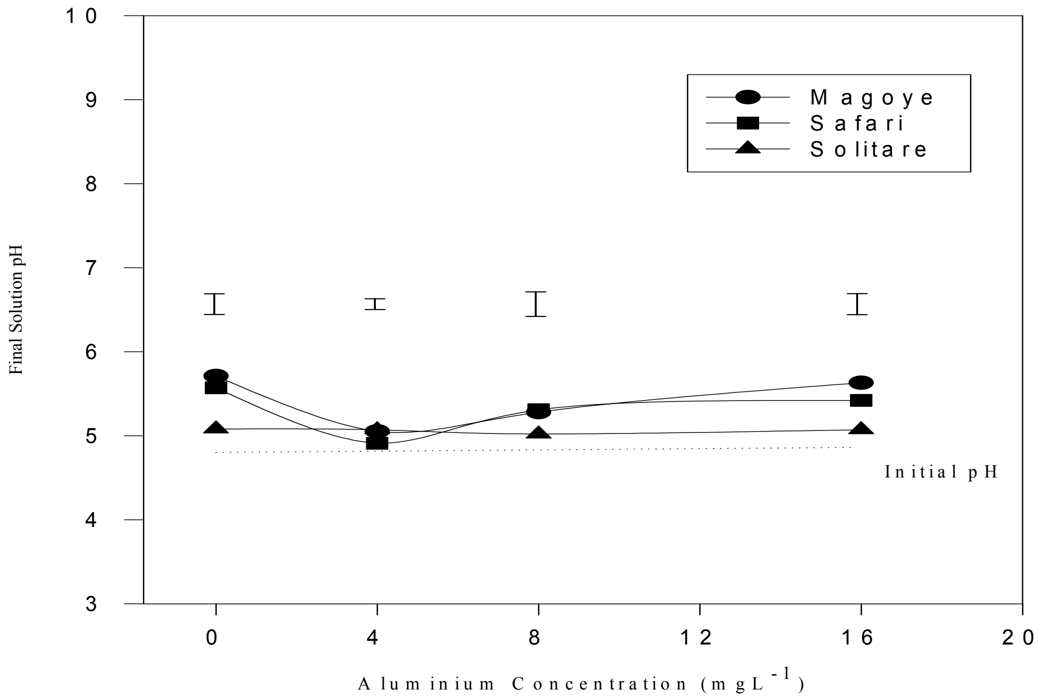

Figure 4. 14**:** Effect of Al concentration on final solution pH for 3 Soyabean cultivars (Magoye, Safari and Solitaire). (Error bars represent standard error of means at 95% confidence).

4.4 DISCUSSION

4.4.1 Effect of Al on Root and Shoot Growth

Aluminium toxicity has been shown to damage root systems particularly of susceptible cultivars thereby inhibiting root growth (Bennett *et al.,* 1987). Total root length and Al tolerance index have been documented as the most reliable growth indicators of Al tolerance (Sapra, *et al.,* 1978). Total root length takes into account the growth of both the lateral fine roots and the taproot. Fine lateral roots however contribute more significantly to TRL measurements as opposed to the tape root.

Relative root elongation on the other hand is a measure of tape root growth and does not account for the proliferation of lateral roots (Anderson and Ingram, 1993). Fine roots are important in enhancing nutrient uptake efficiency by significantly increasing root surface area. Shorter roots resulting from soil acidity results in plants having difficulty getting adequate moisture while reduction in the number of root hairs lowers the plant's capacity to take up nutrients particularly trace elements (Management of Soil Acidity in Agricultural land. Farmnote 80/2000).

Maize cultivars, CZH 00013 and CZH 00017 and soyabean cultivars, Magoye and Safari exhibited a stress avoidance mechanism towards Al toxicity (Bennet, 1998). Their roots grew longer at 4mg L^{-1} Al in an attempt to move away from the source of stress. Root elongation was increased, as roots searched for regions favourable for growth. These cultivars were classified as tolerant based on the ATI. Relative root elongation results show that in relatively tolerant maize cultivars (CZH 00013, CZH 00017, DK 8031 and SC 403) increase in Al concentration to 4 and 8 mgL^{-1} can enhance root growth while in non-tolerant cultivars (SC 517) it can inhibit root elongation. For Safari and Magoye where the total root length increased at low Al (4 mg L^{-1}) but RRE decreased, root growth was mainly directed at production of more lateral roots than tape root elongation. For Solitaire, Al even in low concentrations reduced growth of both lateral and tape roots since both TRL and RRE were reduced.

A total decrease in leaf number and size and a decrease in shoot biomass have been documented as common responses by shoots to Al (Pietrasewka, 2001). In maize, shoots were more sensitive to Al as SDMY was reduced by a larger percentage than RDMY (Figure 4.4). There was however no cultivar differences on the effects of Al on SDMY while the response by roots to Al toxicity varied from variety to variety. This means that roots are more appropriate in screening maize for Al tolerance than shoots since shoot weight variations are similar in all cultivars.

In soyabean, the trend in response to Al for root and shoot dry matter yields was similar. Both were increased at low concentrations of Al (4 mgL^{-1}) but then reduced as Al was increased to 8 and 16 mg L^{-1} (Figure 4.11). Changes in RDMY were more pronounced than SDMY (Figure 4.12) implying that roots are more reliable when screening soyabean cultivars for tolerance to Al. The use of relative figures (relative root lengths and stover yields) reduces possible effects of differences in seed size and nutrient reserves

4.4.2 Effect of Al on P, Ca and Mg Uptake

Aluminium reduced P uptake by maize and soyabean cultivars because Al forms insoluble compounds with P, making it unavailable for plant uptake. The ability of plants to take up P is reduced also as a result of reduced root growth. Roots under high Al concentrations became less able to utilise the nutrients in solution, as they tended to lack fine branching.

Aluminium reduced Ca uptake (Ca in shoots + Ca in roots) by SC 403 and to maintain a constant shoot Ca, less Ca was left in the roots when Al concentration was increased and less Ca was taken up from the nutrient solution (Helyar, 1998). Cultivar SC 403 was therefore able to efficiently use the absorbed Ca. In SC 517 and all soyabean varieties where the Ca ratio is almost constant or no trend is followed, the amount of translocated Ca depended on the amount of Ca taken up from the solution. Aluminium affected Ca nutrition at the root level and as Al depressed Ca uptake, translocation of this nutrient to the shoots was also reduced. This might be inorder that root cell Ca homeostasis is maintained (Huang *et al.*, 1993) or it could be a result of inefficiencies in Ca use (Rout *et al*., 2001). The same can be said for Mg in soyabean cultivars.

Magnesium is an important plant nutrient that is closely related to Ca. Aluminium affected uptake of Mg and not translocation in all cultivars except DK 8031, which showed an increased translocation up to 8 mg L^{-1}. Magnesium content in shoots for the other 4 cultivars was reduced because Mg uptake was inhibited and plants continued to translocate a constant percentage of the absorbed nutrient.

Pietrasewka (2001) noted that as roots of wheat become stubby and brittle due to Al toxicity, root caps become thick and inefficient in absorbing Ca and Mg more than other plant nutrients. This is because the atomic size of Al is similar to that of Ca and Mg and thus compete with these two cations on the root CEC than with other cations such as K. Aluminium tolerant cultivars were however reported as being more efficient in uptake and utilization of Ca and P in the presence of Al (Rout *et al*., 2001).

Mugwira (1980) showed that Al affected Ca distribution between tops and roots of triticale and wheat cultivars and that increasing Al concentration in nutrient solution to 12mgL^{-1} severely reduced plant growth, increased Al concentration in plant tops and decreased Ca, Mg and P uptake by plants more than K. In this study, it has been shown that Al toxicity affected uptake of Ca and Mg by maize but cultivars differed in the efficiencies with which the absorbed nutrients were translocated to shoots.

4.4.2 Effect of Al on Final Solution pH

The final solution pH gives an indication of possible tolerance mechanisms that cultivars may have. At 0 mg L^{-1} Al, all cultivars except SC 403, induced a higher pH than the initial solution pH.

The final pH for SC 517 was significantly lower than the initial pH when Al was added at 4 -16 mg L^{-1}. Sensitivity by this variety can be attributed at least in part to greater Al solubility in the root zone. The reductions in nutrient uptake in maize cultivars could thus be attributed to reduced pH in the nutrient solution making nutrients unavailable to plants. For cultivar SC 403 tolerance to Al is not a result of ability to maintain or increase solution pH at 4.8. The cultivar induced lower pH values compared to the initial implying that other tolerance mechanisms such as inactivation of absorbed Al may have been adopted by this cultivar. It would be important to determine Al contents in shoot and roots of this cultivar inorder to ascertain this.

Soyabean grown in nutrient solution relies on supplied N for growth. There is thus no suppression of nitrate uptake normally observed with symbiotically dependent plants. Reduced nitrate uptake is responsible for acidifying the rhizosphere of symbiotically dependant plant (Horst, 1998; Liya *et al.*, 1998). In this study the final solution pH induced by all soyabean cultivars was higher than the initial maybe due to uptake of nitrate.

Mugwira (1980) showed that rye, triticale and wheat cultivars induce a pH of at least 7.0, which is higher than initial of 4.8 with no Al, added but increasing Al in solution significantly decreased plant induced solution pH. Differential uptake of cations and anions by different cultivars has been suggested as the cause of differential pH changes in nutrient solutions by different cultivars (Foy *et al*, 1967).

4.5 CONCLUSION

Differential cultivar tolerance to Al exists with both maize and soyabean. Root growth parameters such as RDMY and TRL can be used to screen maize and soyabean cultivars for tolerance to Al. Tolerant cultivars are more efficient in utilising nutrients such as Ca and Mg and can thus be selected for more economic crop production under Al toxic soils.

Chapter 5

THE PERFOMANCE OF SELECTED MAIZE AND SOYABEANCULTIVARS UNDER FIELD CONDITIONS

5.1 INTRODUCTION

Several maize seed companies in Zimbabwe have been breeding maize mainly for high yield and disease and drought tolerance. Soil acidity constraints symbiotic nitrogen fixation and constitutes a major limitation in legume cultivation by reducing plant growth, nodulation and yield. It limits *rhizobium* survival and persistence in soils thereby reducing nodulation (Graham *et al.*, 1994). In most cases reduction in plant growth as a result of soil acidity corresponds with reduction in nodule number but sometimes nodule number reductions are compensated by increase in average nodule size (Keyser *et al.*, 1979). Soil acidity can also inhibit the function of established nodules depending on host and rhizobial genotype. Both the growth of rhizobia and the process of nodulation are sensitive to nutritional factors associated with acid soils.

Breeding for acid soil tolerance has become important given the increase in soil acidification in most SFAs and the relatively poor lime adoption. There is little information on soil acidity tolerance of maize and soyabean cultivars and how different cultivars respond to lime.

The objective of this study was to determine the effects of soil acidity and liming on growth of selected maize and soyabean cultivars. It was hypothesized that soil acidity and Al toxicity do not influence crop yields in Chendambuya SFA and at

Domboshawa Training Center. It was also hypothesized that liming does not influence grain and stover yields for cultivars of maize and soyabean on both red and sandy soils. It was also hypothesized that lime does not influence nodulation by selected soyabean cultivars.

5.2 MATERIALS AND METHODS

5.2.1 Site description

The research was carried out at two sites in Zimbabwe, Chendambuya (east of Zimbabwe) and Domboshawa Training Centre (30km from Harare).

Chendambuya is located in NR IIb (average rainfall 750-1000 mm annum^{-1}) and is approximately 18^{o} 10' S, 32^{o} 22'E at 1575m altitude. Soils are predominantly sandy derived from granite, and red clay soils derived from dolerite cover only 19% of the area. Domboshawa Training Centre is located in NR IIa (average rainfall 750-1000 mm annum^{-1}) and is approximately 19^{o} 35' S, 31^{o} 14'E at 1474 m altitude. The soils at Domboshawa are classified as Alfisols (USDA) or lixisols (FAO) (Nyamapfene, 1991). Sites were selected based on soil pH, which was determined in a survey done at the beginning of the study. Fields with high acidity (pH_{CaCl2} < 5.0) were selected. In Chendambuya, experiments were therefore laid out on selected farmer fields namely Mudzengerere, Chisuko and Chitsike. In this report, the farmers' names are used to refer to experiments sites on their respective fields. The trials in Chendambuya were farmer-managed while at Domboshawa Training Centre the trials were researcher managed. Soyabean trials were only carried out at Domboshawa Training Centre on the red clay soils while maize trials were conducted on both sites. Research has shown that legumes do not perform well on sandy acid soils due to inhibition of rhizobia proliferation together with host plant root inhibition (Mpepereki, 1994).

5.2.2 Soil sampling and handling

Prior to planting, soil samples were collected from the top 0.15 m at each site to determine soil nutrient status and other soil properties. Using an auger, 10 soil sub-samples were randomly collected from each site. Soil samples were thoroughly mixed, air-dried and sieved through a 2 mm sieve before characterisation.

5.2.3 Soil Characterisation

Soil texture was determined by the hydrometer method (Gee and Bauder, 1986). Soil pH was measured in a supernatant suspension of 1:5 (soil: 0.01 M $CaCl_2$) and 1:5 (soil: water) solution using a glass electrode (Page, *et al* 1982). Exchangeable bases (Ca, Mg and K) were determined by extraction with 1 M ammonium acetate. The amounts of extracted Ca and Mg were determined by atomic absorption spectophotometry and K was determined by flame photometry (Anderson and Ingram, 1993). Available N in soil was determined by extraction, using 0.5 M potassium chloride (Anderson and Ingram, 1993). Available P in the soil was determined by extraction, using alkaline 0.5 M sodium bicarbonate (pH 8.5) (Anderson and Ingram, 1993). Methods used in determining the above soil properties have been described fully in Chapter 3.

5.2.4 Treatments

The performance of 5 maize cultivars and 4 soyabean cultivars was tested in the field in experiments set up in 2002/03 and 2003/04 seasons in Chendambuya and Domboshawa. Some cultivars were selected from those screened in the greenhouse

(Chapter 4) while others were selected from those commonly grown in the country. Cultivars screened in the greenhouse were selected from those bred and grown in the Southern Africa region while in the field cultivars that are more specific to Zimbabwe were selected. The treatment combinations for the experiment were as follows:

- Two lime levels (limed and unlimed)
- Five maize cultivars (PAN 413, PHB 30G97, SC 403, SC 513 and SC 517) for the maize experiment and 4 soyabean cultivars (Magoye, Safari, Solitaire and Storm) for the soyabean experiment.

A split-plot design, with lime as the main plot and crop hybrid as the sub-plot, was used with four replications.

The experiments were established in November 2002 and December 2003. Lime was broadcast on half of each field on the soil surface at 600 $kgha^{-1}$ on sandy soils and 1 000 $kgha^{-1}$ on red soils in the first year just before planting. It was incorporated into the top 0.15 m of the soil using hand hoes. Lime was not applied in the second season.

5.2.5 Maize Trial

Plant spacing was 90 cm between rows and 30 cm between stations on 6m x 5m plots. Two plants were placed at each station and later thinned to 1 plant per station at 2 weeks after germination to achieve a plant population of 37 000 plants ha^{-1}. A basal application of compound D fertilizer (8% N, 7% P, 7% K, 8% S) was spot applied at 350 kg ha^{-1}. Ammonium nitrate (AN) was spot-applied at 150 kg ha^{-1} split at 6 and 8 weeks after planting (WAP). Weed control was done by hand hoeing throughout the cropping season at 2 and 6 WAP on the on station site and when it became necessary on the on farm trials.

Karate (λ-cyhalothrin) was applied at 2WAP in the second season on the on station sandy sites to control maize stalk borer.

5.2.5.1 Grain and Stover Yield Determinations

Stover yield was determined at 6WAP. Three plants were randomly sampled from the net plot area (3 x 4 m centre area of each plot obtained by leaving 1m on all sides of each plot).

Maize grain yield was determined at physiological maturity (ca. 20 WAP) using 40 plants taken from the net plot area. Unshelled net plot cobs were weighed in the field and a sub sample of 4 cobs was taken from each plot for moisture content and shelling percent determination. It is from this sample that cob weight determination was done. Average grain yield per hectare was calculated using net plot cob weight and shelling percentages from the 4-cob sub sample. The grain yield was adjusted to 12% moisture content.

Three maize stalks were sampled from the net plot area after cobs had been removed, for stover yield determination. Total above ground dry matter yield was determined as weight of stalks and shelled cobs.

5.2.6 Soyabean Trial

Experiments were laid out on 5m by 5m plots. Inoculation with *Bradyrhizobium* strain MAR 1491 (USDA 110) (Kasasa *et al.,* 1998) was done in both seasons. A basal application of compound L fertilizer (5% N, 8% P, 8% K, 8% S and 0.25% B) was band applied in rows at 225 kg ha^{-1}.

Inoculated soyabean seed was broadcast into 45cm spaced rows and plants were thinned to 7 cm spacing between plants at 2 weeks after germination to give a plant population of approximately 320 000 plants ha^{-1}. Weed control was done by hand hoeing throughout the cropping season.

5.2.6.1 Assessment of Nodule Numbers and Nodule Effectiveness

Nodulation was assessed at 8WAP by carefully digging up root systems of 10 plants in the row next to the guard row. The roots and shoots were separated and packed. The mean nodule number, nodule weight and shoot and root dry matter yields (SDMY and RDMY) were determined using these plants.

Nodule effectiveness was assessed by noting the nodule internal colour of nodules from 5 carefully dug plants from the row next to the guard row. A red internal colour showed an effective nodule while a pink colour showed a weakly effective nodule. Nodules with a green or white internal colour were classified as ineffective (Zengeni, 2004).

5.2.6.2 Grain and Stover Yield Determinations

Stover yield was determined at 8 WAP. The shoots and roots collected for nodulation determination were used for SDMY and RDMY determinations (Zengeni, 2004).

Grain yield and above ground dry matter yield were determined at physiological maturity (ca. 16 WAP) using net plot plants in the center 3 m by 3 m area of each plot obtained by leaving out two guard rows and 0.5m lengths on either end of each row.

Plant tops were weighed before threshing to give the total above ground dry matter yield. After threshing and winnowing, the separated grain was weighed to get the grain yield. The grain yield per hectare was adjusted to 11% moisture content. Stover yield was obtained by subtracting grain yield from the total above ground dry matter weight (weight of above ground dry matter before threshing). Leaf weight was not included in the stover yield obtained as leaves had fallen to the ground by the time of harvesting.

5.2.7 Statistical analysis

Data on grain and stover yield was analysed for variance using the Genstat 5 for windows statistical package (Lewis Agricultural Trust, 1997). Least Significant Differences (lsd) and standard error of means (SEM) were used to separate treatment means. The effect of lime (the main factor) and cultivar (sub factor) was quantified as well as interaction between the two factors.

5.3 RESULTS

5.3.1 Characterisation of Study Sites

All sites were classified as very strongly acid according to the Zimbabwe classification, except the Chitsike site, which was in the strongly acid range (Table 5.1). Cation exchange capacity was low on all sandy soils with the on station site (Domboshawa sand) having the lowest CEC of 1.8 $cmol_c kg^{-1}$. Base saturation (BS) was relatively low (as low as 27% for Mudzengerere site) an indication of moderate leaching of exchangeable bases by rainfall percolating through the soil (Table 5.1). Domboshawa sand had the highest %BS (75%). This site was however deficient in important cations such as Ca (1.0 $cmol_c kg^{-1}$) and Mg (0.2 $cmol_c kg^{-1}$). Although it had a lower base saturation (59%), the Chitsike site contained higher amounts of Ca and Mg (5.2 and 1.6 $cmol_c kg^{-1}$) (Table 5.1). The Mudzengerere site had lower exchangeable Ca content (0.70 $cmol_c\ kg^{-1}$) and K (0.09 $cmol_c\ kg^{-1}$) compared to the Chisuko site (1.90 $cmol_c\ kg^{-1}$ and 0.17 $cmol_c\ kg^{-1}$ Ca and Mg respectively).

Table 5. 1: Selected properties of soils taken from experimental sites in Chendambuya Smallholder Farming Area and Domboshawa Training Centre trial sites.

	Mudzengerere	Chisuko	Chitsike	Domboshawa Sand	Domboshawa Red
Texture	CLSa	cLSa	mSaCL	cSa	mSaCL
Clay %	5	6	32	2	22
pH ($CaCl_2$/ H_2O)	3.9/4.5	3.7/4.4	3.9/4.5	4.5/5.2	3.9/4.6
CEC ($cmol_c\ kg^{-1}$)	5.1	4.6	12.7	1.8	4.0
Exch. Ca ($cmol_c\ kg^{-1}$)	0.70	1.90	5.20	1.00	2.00
Exch. Mg ($cmol_c\ kg^{-1}$)	0.5	0.5	1.6	0.2	0.5
Exch. Na ($cmol_c\ kg^{-1}$)	0.06	0.06	0.15	0.10	0.14
Exch. K ($cmol_c\ kg^{-1}$)	0.09	0.17	0.52	0.10	0.26
Base Saturation %	27	57	59	79	71
Exch. Al ($cmol_c\ kg^{-1}$)	0.002	0.002	0.002	0.002	0
Avail. P (mg kg^{-1})	2.21	1.76	1.21	4.59	4.86
EC (CEC/100g clay)	101.1	81.3	40.1	80.6	18.1

cLSa –coarse loamy sand mSaCL – medium sandy clay cSa – coarse sand
cSaL – coarse sandy loam Avail. – Available Exch. - Exchangeable

5.3.2 Maize Trial

More farmer managed field sites than reported here were established in the first season of the study and a few of these were selected for sampling at 6 WAP and sampling of stover at harvest. The Mudzengerere site was not selected as priority for sampling but because of the results obtained on effect of lime on grain yield in the first year, the site was then sampled at 6WAP and stover at harvest in the second season.

5.3.2.1 Above ground dry matter yield response to lime on sandy soils

Above ground dry matter yield at 6WAP was increased by lime in all cultivars on the Chisuko site in season 1 ($P = 0.011$) except SC 513 where a 16% reduction (1.930 t ha^{-1} without lime to 1.616 t ha^{-1} with lime) was observed (lsd = 0.3025). PAN 413 had the highest stover yield with and without lime (Table 5.2). Lime x cultivar interaction effect was significant ($P = 0.008$). In the second season however lime did not influence stover yield at 6 WAP ($P = 0.136$).

The Mudzengerere site was sampled in the second season only and lime significantly increased stover yield at 6WAP ($P = 0.045$) with cultivar influencing effects of lime ($P = 0.05$). A 171% increase in stover yield was observed with PAN 413 (Table 5.3).

On the Domboshawa sand site liming reduced above ground dry matter yield in all cultivars at 6WAP ($P = 0.015$ and 0.036 for season 1 and 2 respectively) except PHB 30G97 where no response was observed in the first season. The 8% increase in stover observed with PHB 30G97 in the first season (Table 5.2) was not significant (lsd = 0.41). Lime x cultivar interaction was significant ($P = 0.024$) in the first season. In the second season, PHB 30G97 had significantly higher stover on unlimed plots (P = 0.007). No cultivar differences were observed on the limed plots.

Table 5. 2: Above ground dry matter yield (t ha^{-1}) and response (%) to liming at 6WAP on three sandy soil sites for Season 1 (2002-3). (Negative sign shows a reduction in stover yield due to liming)

Cultivar	Chisuko			Domboshawa		
	- LIME	+ LIME	% Change	- LIME	+ LIME	% Change
PAN 413	2.5	3.6	(46)	2.7	1.9	(-32)
PHB 30G97	2.1	2.4	(14)	1.8	2.0	(8)
SC 403	2.2	3.2	(47)	2.5	1.3	(-45)
SC 513	2.0	1.6	(-16)	2.4	1.7	(-27)
SC 517	2.0	2.5	(29)	2.6	1.8	(-30)
LSD	Lime	Cultivar	Interaction	Lime	Cultivar	Interaction
	0.30	0.40	0.54	0.41	0.38	0.55

Table 5. 3: Above ground dry matter yield (t ha^{-1}) and response (%) to liming at 6WAP on three sandy soil sites for Season 2 (2003-4). (Negative sign shows a reduction in stover yield due to liming)

Cultivar	Mudzengerere			Chisuko			Domboshawa		
	- L	+ L	% Change	- L	+ L	% Change	- L	+ L	% Change
PAN 413	0.3	0.8	(171)	0.9	0.78	(-16)	0.2	0.1	(-32)
PHB 30G97	0.3	0.6	(76)	0.7	0.7	(-6)	0.3	0.2	(-50)
SC 403	0.3	0.8	(145)	0.9	0.7	(-20)	0.3	0.2	(-41)
SC 513	0.3	0.6	(76)	0.8	0.8	(-6)	0.1	0.1	(-12)
SC 517	0.4	0.8	(78)	1.0	0.8	(-19)	0.2	0.2	(2)
$LSD_{0.05}$	Lime	Var	Inter	Lime	Var	Inter	Lime	Var	Inter
	0.35	0.11	0.32	0.19	0.16	0.24	0.06	0.07	0.10

-L --- Unlimed
+L --- Limed

5.3.2.2 Plant and ear heights response to liming on sandy soils

Liming did not influence plant height on the Domboshawa sandy soil site (P = 0.384 and P = 0.237 for season 1 and 2 respectively) but significantly reduced ear height (P = 0.008 and P = 0.022). Varietal differences in plant and ear height were significant with PAN 413 having the lowest average ear height on the limed treatments (Table 5.4).

Table 5. 4: Plant and ear heights responses to liming (%) of five maize cultivars on Domboshawa sandy soil.

Season 1	Plant Height			Ear Height		
Cultivar	No lime	Limed	% Response	No lime	Limed	% Response
PAN 413	1.477	1.388	- 6.03	0.528	0.426	-19.3
PHB 30G97	1.760	1.725	- 1.99	0.659	0.571	-13.4
SC 403	1.723	1.641	- 4.76	0.518	0.483	-7.76
SC 513	1.631	1.598	- 2.02	0.563	0.475	-15.63
SC 517	1.733	1.707	- 1.50	0.604	0.508	-15.89
$LSD_{0.05}$ Lime	0.17			41.6		
Cultivar	0.10			73.6		
Interaction	0.17			96.4		

Season 2	Plant Height			Ear Height		
Cultivar	No lime	Limed	% Response	No lime	Limed	% Response
PAN 413	1.054	1.092	2.48	0.379	0.340	- 10.31
PHB 30G97	1.530	1.390	- 9.15	0.485	0.403	- 16.78
SC 403	1.265	1.173	- 7.27	0.321	0.356	1.46
SC 513	1.210	1.159	- 4.21	0.344	0.365	6.08
SC 517	1.430	1.172	- 18.04	0.453	0.345	- 23.89
$LSD_{0.05}$ Lime	0.22			29.29		
Cultivar	0.13			52.57		
Interaction	0.23			68.80		

5.3.2.3 Above ground dry matter yield at harvest

At the Mudzengerere site lime generally increased stover yield at harvest (P = 0.020) in the second season. A 43 % increase in stover yield was observed with PAN 413

(Table 5.5). Varietal differences in stover yield were also significant ($P < 0.001$). All cultivars responded positively to lime at this site while on the other sandy sites response to lime was either low or negative (Figure 5.1).

At the Chisuko site, stover yield was not influenced by lime in the first season, ($P = 0.553$) but was significantly reduced in the second season ($P = 0.050$). Effects of lime observed in the second season depended on cultivar ($P< 0.001$) (Table 5.5). Lime increased dry matter yield for SC 513 reduced dry matter yield for PAN 413, PHB 30G97 and SC 517 while that for SC 403 was not significantly influenced by lime.

At the Domboshawa site, lime did not affect stover yield in the first season ($P = 0.158$) but significant reductions were observed in the second season ($P = 0.032$). There was significant lime x cultivar interaction effect on stover yield at harvest ($P < 0.001$). Lime reduced dry matter yield for SC 403 and PHB 30G97 while the other cultivars did not respond to lime (LSD = 0.23).

Table 5. 5: Stover yield response (%) to liming at sandy soil sites. (Negative sign shows a reduction in stover yield).

	Season 1 (2002-3)		Season 2 (2003-4)		
Cultivar	Chisuko	Domboshawa	Mudzengerere	Chisuko	Domboshawa
PAN 413	-10	-23	43	-18	3
PHB 30G97	-22	-4	35	-28	-14
SC 403	16	-16	19	8	-39
SC 513	.7	-7	31	18	-1
SC 517	-3	-20	31	-30	-4

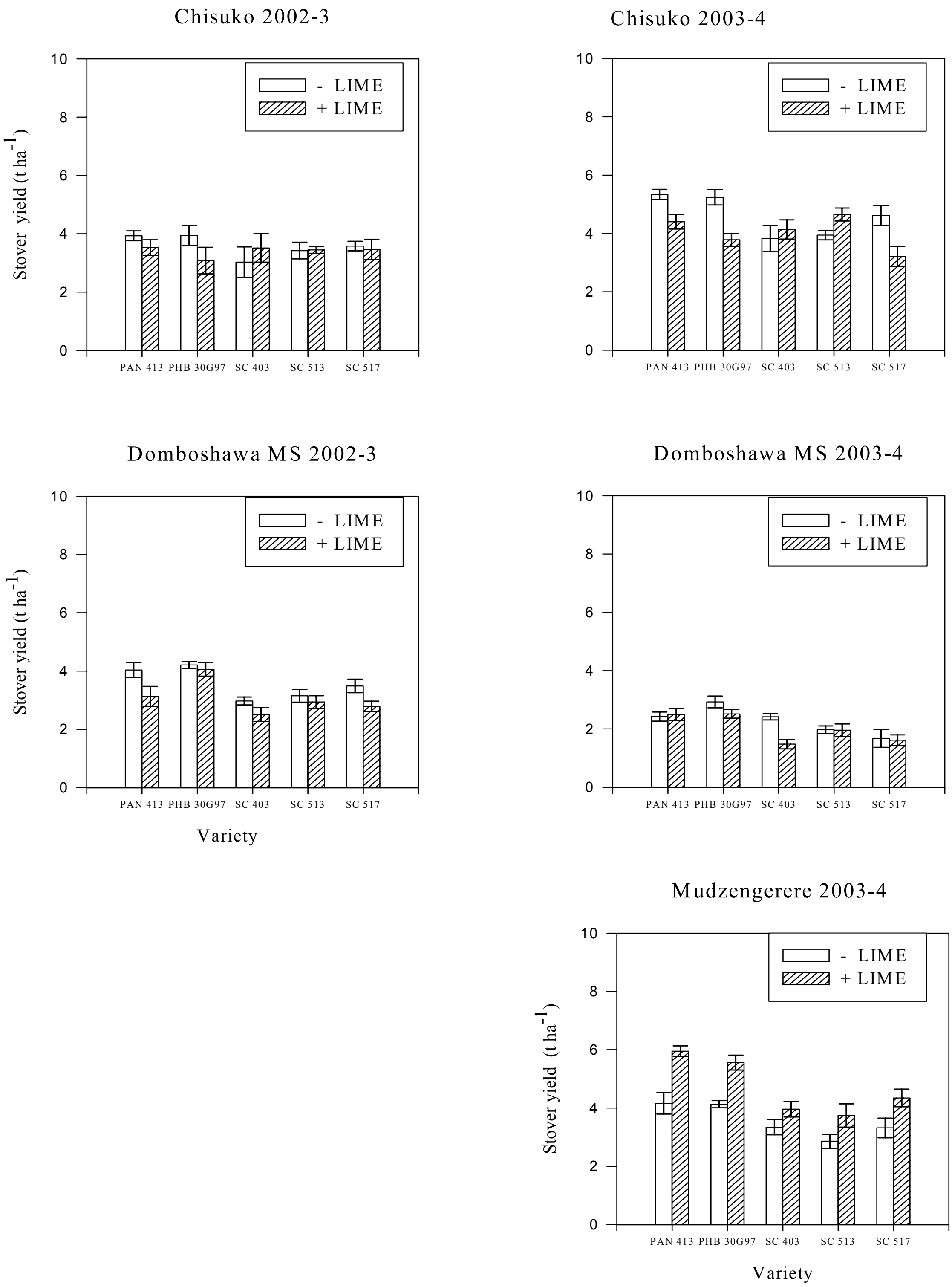

Figure 5. 1: Above ground dry matter yield response to lime at harvest on sandy soils for selected maize cultivars. (Error bars represent standard error of means at 95% confidence).

5.3.2.4 Grain yield response to lime for 5 maize cultivars on sandy soils

The Mudzengerere site showed significant increases in grain yield in all cultivars except PAN 413 where no significant response was observed in both seasons ($P < 0.005$ and $P = 0.01$ for season 1 and 2 respectively) (Figure 5.2). Cultivar differences were significant in the second season ($P < 0.001$) but not in the first season ($P = 0.422$). In the second season, PHB 30G97, SC 403 and SC 517 yielded significantly higher grain on limed plots compared to the other cultivars. Significant lime x cultivar interaction was observed in the second season ($P = 0.026$) with all cultivars responding positively to lime except PAN 413 (Figure 5.2). PHB 30G97 yielded highest on both limed and unlimed plots and the highest positive response to lime (92%) was observed with SC 517 (Table 5.6).

At Chisuko site, grain yield was not significantly influenced by lime ($P =191$ and $P = 0.263$ for season 1 and 2 respectively) (Figure 5.2). Cultivar differences and lime x cultivar interaction were significant in the first season ($P < 0.001$). Significant grain yield reductions were observed with SC 513 and SC 517 while no response was observed with the other cultivars. In the second season, no significant response was observed with all cultivars (lsd = 0.84). Cultivar differences in yield were significant with PHB 30G97 yielding significantly lower than SC 513 (the highest yielding variety) on unlimed plots and PHB 30G97 and SC 517 yielding lower than SC 513 on limed plots (lsd = 0.63).

At Domboshawa grain yield was generally not influenced by lime in both seasons ($P = 0.062$ and $P = 0.179$ respectively). In the first season, SC 517 yielded lower grain on both unlimed and limed plots while PHB 30G97 yielded highest on unlimed plots and SC 513 on limed plots (Figure 5.2). Lime decreased yield for PAN 413 and SC 403 while yields for the other 3 cultivars was not influenced by lime ($P = 0.016$). PAN 413 and SC 403 yielded higher than the other cultivars on the unlimed plots while on limed plots there was no significant difference in yield between cultivars ($P < 0.001$).

Table 5. 6: Grain yield response (%) to lime for selected maize cultivars on sandy soils for season 1 and 2. (Negative sign shows a reduction in stover yield)

	Season 1 (2002-3)			Season 2 (2003-4)		
Cultivar	Mudzengerere	Chisuko	Domboshawa	Mudzengerere	Chisuko	Domboshawa
PAN 413	-8	- 23	- 16	38	- 4	- 53
PHB 30G97	48	- 8	- 29	53	- 15	- 20
SC 403	61	14	- 25	72	- 3	- 56
SC 513	57	- 51	- 12	59	- 3	- 33
SC 517	23	- 34	- 26	92	- 11	91

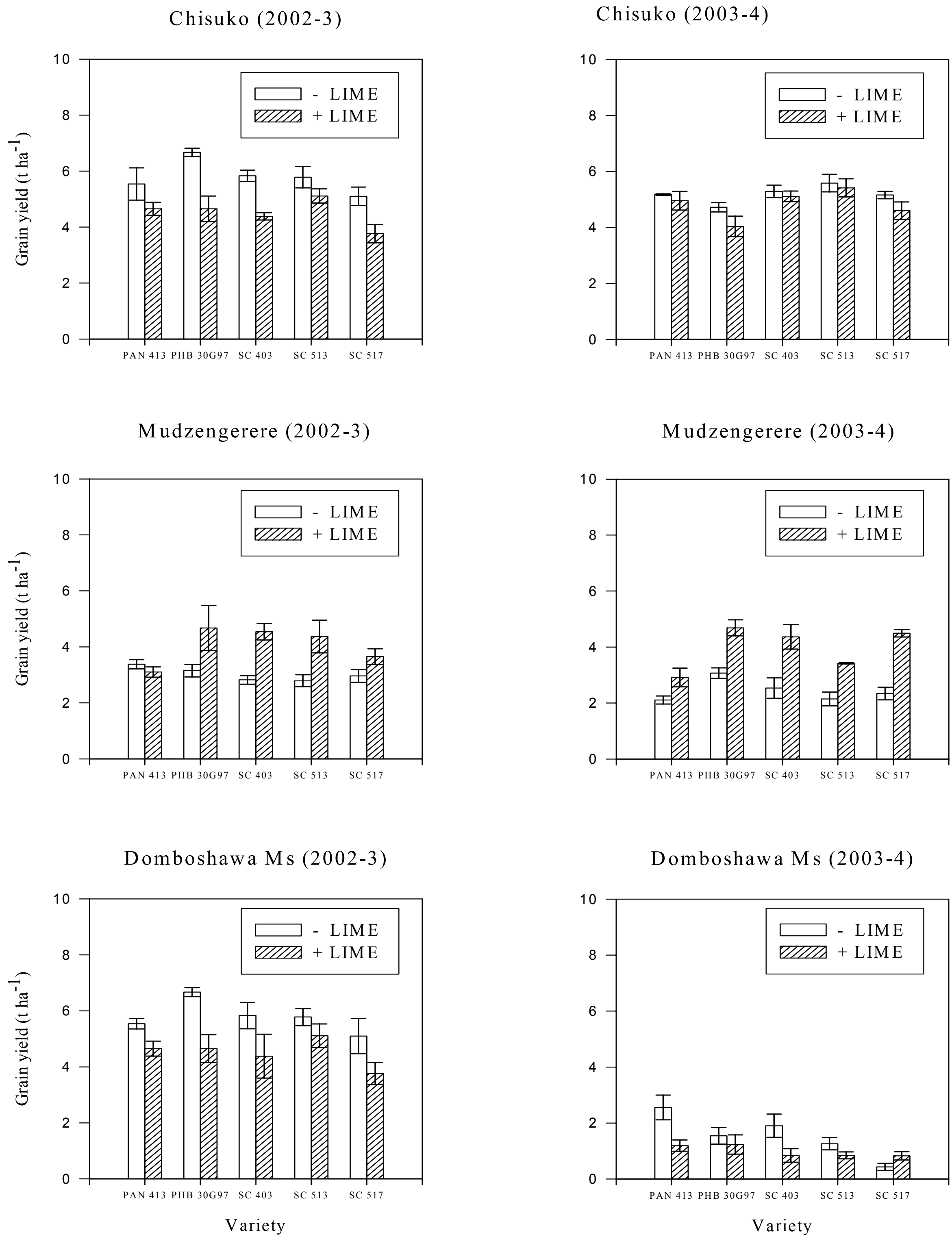

Figure 5. 2: Effect of liming sandy soils on grain yield for selected maize cultivars.

(Error bars represent standard error of means at 95% confidence).

5.3.2.5 Above ground dry matter yield response to lime on red clay soils

At Chitsike site, lime did not influence dry matter production during the first 6 WAP in the first season (P = 0.762). Cultivar differences in stover yield were significant (P = 0.002) and significant lime x cultivar interaction was observed (P = 0.009) with PAN 413 yielding the highest stover without lime and SC 403 responding positively to lime (Table 5.7). In the second season, significant increases (P = 0.040) in stover yield with PAN 413 (154%), SC513 (103%) and SC 517 (55%) were observed (Table 5.7).

On the Domboshawa site liming significantly increased stover yield at 6WAP (P= 0.015 for both seasons 1 and 2) (Table 5.7). Stover yield increases for PHB 30G97 and SC 403 were however not significant in the first season (lsd = 0.751). No lime x cultivar interaction was observed (P = 0.169 and 0.137 for season 1 and 2 respectively) but cultivar differences were expressed at this site (P = 0.02 and P = 0.011 for seasons 1 and 2 respectively).

Table 5. 7: Above ground dry matter yield (t ha^{-1}) and response (%) to liming at 6WAP on two red soil sites for Season 1and 2. (Negative sign shows a reduction in stover yield due to liming)

Season 1 (2002-3)

Cultivar	Chitsike			Domboshawa		
	- LIME	+ LIME		- LIME	+ LIME	
PAN 413	0.2	0.15	(-30)	3.3	6.1	(84)
PHB 30G97	0.15	0.12	(-19)	5.0	5.4	(8.0)
SC 403	0.09	0.10	(5.0)	3.4	4.1	(21)
SC 513	0.08	0.16	(81)	3.4	4.5	(32)
SC 517	0.13	0.17	(24)	4.6	5.6	(22)
$LSD_{0.05}$	Lime	Cultivar	Interaction	Lime	Cultivar	Interaction
	0.03	0.04	0.05	0.75	1.00	1.34

Season 2 (2003-4)

Cultivar	Chitsike			Domboshawa		
	- LIME	+ LIME		- LIME	+ LIME	
PAN 413	0.33	0.84	(154)	0.55	0.61	(11)
PHB 30G97	0.54	0.82	(51)	0.54	0.76	(39)
SC 403	0.55	0.71	(29)	0.29	0.50	(71)
SC 513	0.40	0.82	(103)	0.44	0.56	(26)
SC 517	0.54	0.83	(55)	0.47	0.1	(111)
$LSD_{0.05}$	Lime	Cultivar	Interaction	Lime	Cultivar	Interaction
	0.14	0.19	0.25	0.30	0.22	0.35

5.3.2.6 Plant and ear heights response to liming on red soils

On the red clay sites however, liming did not influence both ear height and plant height in the first season. PHB 30G97, SC 513 and SC 517 had significantly higher average ear heights compared to PAN 413 and SC 403 on both limed and unlimed plots. PAN 413 had the lowest plant height on both the limed and the unlimed plots ($P < 0.001$). In the second season, lime resulted in an increase in both ear and plant height ($P < 0.001$ and $P = 0.031$) (Table 5.8).

Table 5. 8: Plant and ear heights responses to liming (%) by five maize cultivars on the red clay on station site. (Negative sign shows a reduction in height).

Season 1	Plant Height			Ear Height		
Cultivar	No lime	Limed	% Response	No lime	Limed	% Response
PAN 413	1.865	1.846	- 1.02	0.758	0.798	5.28
PHB 30G97	2.205	2.244	1.77	0.892	1.008	13.00
SC 403	2.244	2.353	4.86	0.781	0.881	12.80
SC 513	2.222	2.343	5.45	0.862	0.940	9.05
SC 517	2.172	2.243	3.27	0.885	0.973	9.94
$LSD_{0.05}$ Lime	0.20			127.9		
Cultivar	0.11			73.1		
Interaction	0.20			130.4		

Season 2	Plant Height			Ear Height		
Cultivar	No lime	Limed	% Response	No lime	Limed	% Response
PAN 413	1.751	1.891	8.00	0.657	0.744	13.24
PHB 30G97	2.143	2.314	7.98	0.842	0.963	14.37
SC 403	1.852	2.054	10.91	0558	0.690	23.66
SC 513	1.792	2.167	20.93	0.568	0.910	60.21
SC 517	1.604	1.989	24.00	0.673	0.802	19.17
$LSD_{0.05}$ Lime	0.21			30.5		
Cultivar	0.12			76.3		
Interaction	0.22			98.1		

5.3.2.7 Above ground dry matter yield at harvest response to lime on red clay soils

At harvest stover yield was not influenced by lime on the Domboshawa red soil site in the first season ($P = 0.113$) but significant increases were observed in the second season ($P = 0.006$). Stover yield for PAN 413 was increased by 151%. There was significant lime and cultivar interaction with all cultivars responding positively to lime except SC 403 ($P < 0.001$ and LSD = 1.12).

On the Chitsike site, dry matter yield significantly increased due to liming ($P = 0.020$ and $P = 0.007$ for season 1 and 2 respectively) in all cultivars except SC 403 where no response to lime was observed in the second season. Cultivar differences in stover yield were significant ($P < 0.001$) (Figure 5.3).

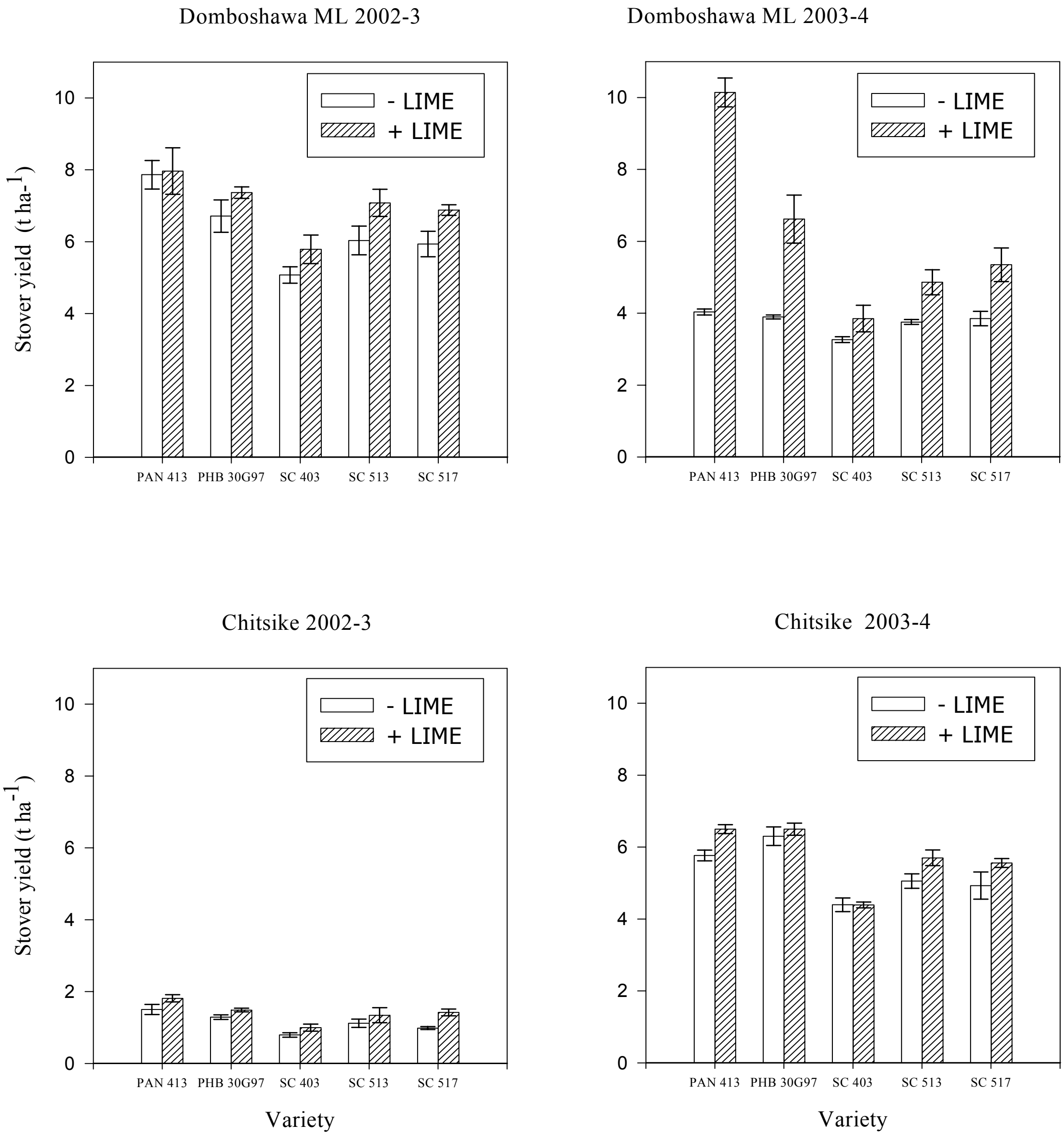

Figure 5. 3: Above ground dry matter yield response to lime at harvest on red soils for five maize cultivars. (Error bars represent standard error of means at 95% confidence).

5.3.2.8 Grain yield response to lime for 5 maize cultivars on red clay soils

Grain yield response to lime on red soils was consistently positive with all cultivars (Figure 5.4)

At Domboshawa liming significantly increased grain yield in the first season (P = 0.032) and second season (P = 0.006) (Figure 5.4). Grain yield was increased in all cultivars except SC 517 in the first season where the increase in grain yield due to liming was not significant at 95% confidence. No lime x cultivar interaction effect was observed (P = 0.301) but cultivar differences in yield were significant in the first season (P = 0.006) with PAN 413 yielding higher on limed plots.

In the second season cultivar differences at Domboshawa were not significant (P = 0.111) and no lime interaction effects were observed. The highest response to lime was observed with PAN 413 (42%) in the first season and SC 403 (52%) in the second season (Figure 5.4).

At the Chitsike site, lime also significantly increased grain yield in the first and second seasons (P=0.004 and P=0.049 respectively) (Figure 5.4). In the first season, grain yield was increased in all cultivars. No cultivar differences in grain yield were observed (P = 0.105) and lime x cultivar interaction effect was not significant (P = 0.984).

In the second season, grain yield increase at the Chitsike site was only significant for PAN 413, SC 403 and SC 517 due to liming. Cultivar differences in yield were not significant (P = 0.192). Significant interaction between lime and cultivars was observed (P = 0.009). The highest response to lime was observed with SC 403 (69%) in the first season and SC 517 (42%) in the second season. In the first season PAN 413 and PHB 30G97 did not respond to lime while in the second season PHB 30G97 and SC 513 did not respond significantly to lime (Figure 5.4).

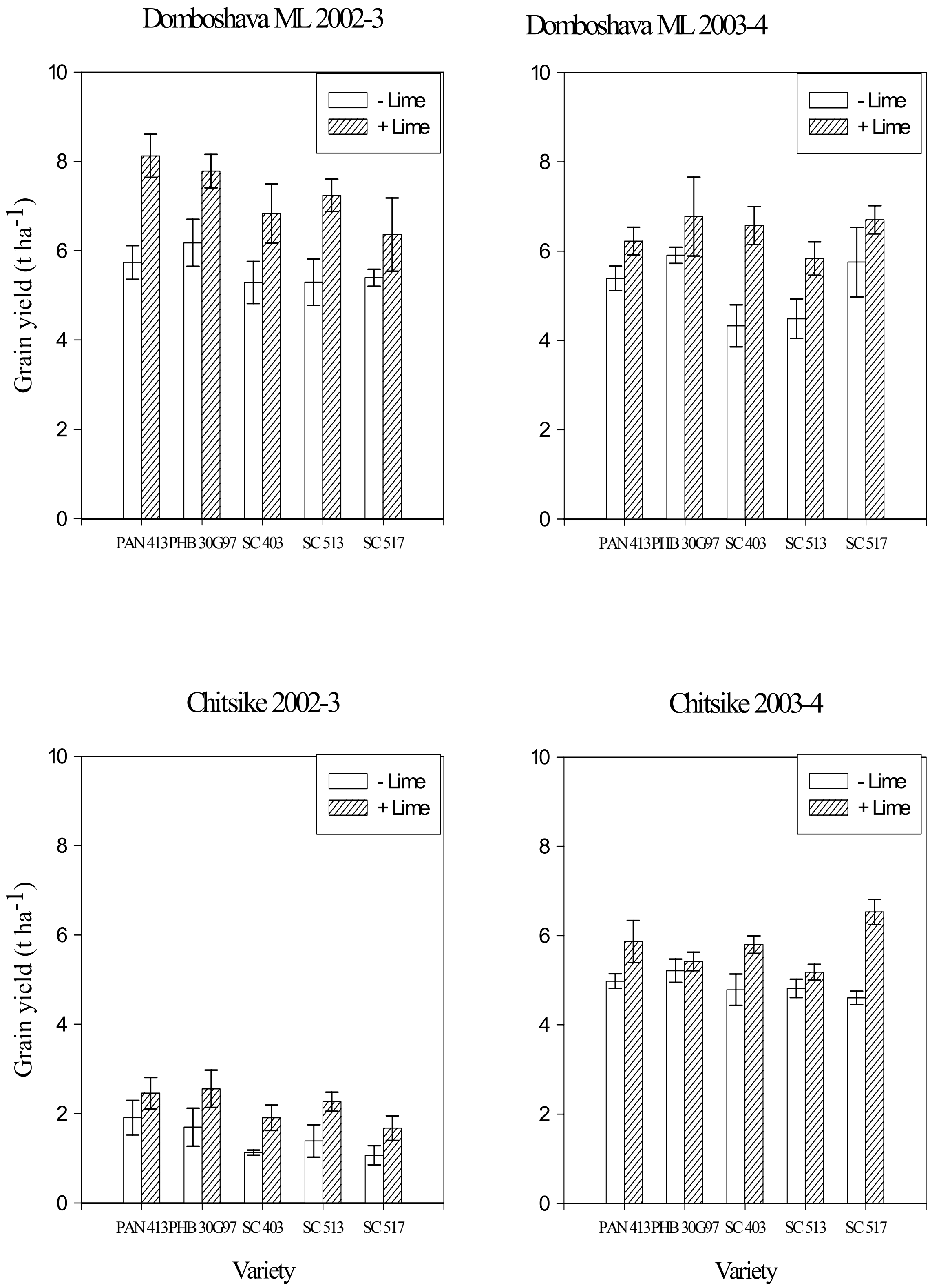

Figure 5. 4: Effect of liming red soils on grain yield for five maize cultivars. (Error bars represent standard error of means at 95% confidence).

5.3.3 Soyabean Trial

The experimental site is the same as that labeled Domboshawa Red in Table 5.1.

5.3.3.1 Effect of Liming and Cultivar on Nodulation

The tolerant cultivars (Safari and Magoye, Chapter 3) responded more to lime compared to the non-tolerant cultivar Solitaire especially in the second season where a 454% and 292% increase in nodule numbers was observed with Magoye and Safari, respectively, while nodule numbers for Solitaire increased by only 57.4% due to lime (Table 5.9).

Nodule Number

Nodule number for all cultivars was not influenced by lime in the first season ($P = 0.206$). Cultivar differences in number of nodules produced were significant ($P < 0.001$) with Safari forming significantly more nodules with rhizobia (92 nodules per 10 plants) compared to the other three cultivars (47, 45 and 58 nodules per 10 plants for Magoye, Solitaire and Storm respectively). With and without lime, Safari yielded the highest number of nodules in the first season. Response to lime in terms of nodule numbers was highest for Magoye (90.6%) in season 1 (Table 5.9). No lime x cultivar interaction was observed ($P = 0.683$).

In the second season significant increases in nodule number due to lime were observed on all cultivars ($P = 0.004$). There were no significant cultivar differences on the unlimed plots (Lsd = 44.43) while on limed plots, Magoye produced the highest number of nodules (454 nodules per 10 plants) while storm produced the least (174 nodules per 10 plant) ($P < 0.001$). Lime x cultivar interaction effect was significant in the second season with Magoye showing the highest increase in nodule numbers (453.7%) due to lime ($P < 0.001$) (Table 5.9).

Table 5. 9: Nodule number (number of nodules/ 10plants) and response (% change in numbers) to liming by soyabean cultivars at Domboshawa (2002/3 and 2003/4 seasons)

	Nodule Numbers / 10 Plants And % Change Due To Lime					
	Season 1			Season 2		
	- Lime	+ Lime	% Response	- Lime	+ Lime	% Response
Magoye	32	61	90.6	82	454	453.7
Safari	87	96	10.3	73	286	291.8
Solitaire	33	57	72.7	122	192	57.4
Storm	52	64	23.1	101	174	72.3
$Lsd_{0.05}$	36.54 (lime)	21.01 (cultivar)	36.84 (interaction)	68.83 (lime)	44.43 (cultivar)	72.76 (interaction)

Although nodule number is an important parameter in estimating plant adaptation and ability to fix N, it does not take into consideration the effectiveness of the nodules.

Nodule Weight

Liming did not have a significant influence on nodule weight in the first season ($P = 744$) and cultivar differences were also not significant ($P = 0.051$). Nodule weights ranged from 0.38 g $10plants^{-1}$ to 0.55 g $10plants^{-1}$ on unlimed plots and 0.31 – 0.58 g $10plants^{-1}$ on limed plots. No significant lime x cultivar interaction effect was observed ($P = 0.191$). Response to lime was highest with Storm in the first season (+47.9%)

In the second season, nodule weight per 10 plants significantly increased with liming (P = 0.025). Significant increases were observed with Magoye and Safari, while for Solitaire and Storm no significant change in nodule weight was observed. On limed plots, weight of nodules produced with Magoye was significantly higher than with the other 3 varieties (lsd = 0.341). Nodule weight for the four cultivars was not significantly different on the no lime plots. Response to lime was highest with Magoye in the second season (+368.3%) (Table 5.10).

Table 5. 10**:** Nodule weight (nodules/10 plants g) response of soyabean cultivars to liming at Domboshawa (2002/3 and 2003/4 seasons)

	Season 1			Season 2		
	- Lime	+ Lime	% Response	- Lime	+ Lime	% Response
Magoye	0.42	0.48	13.7	0.21	0.96	368.3
Safari	0.55	0.58	5.5	0.19	0.55	193.6
Solitaire	0.31	0.42	26.2	0.29	0.45	56.1
Storm	0.38	0.56	47.9	0.17	0.32	92.3
$Lsd_{0.05}$	0.362 $_{(lime)}$	0.133$_{(cultivar)}$	0.334$_{(interaction)}$	0.274$_{(lime)}$	0.241$_{(cultivar)}$	0.346$_{(interaction)}$

Nodule Effectiveness

There was no significant overall influence of lime on nodule effectiveness in both seasons (P = 0.667 and P = 0.963 for first and second season respectively). Nodules produced in the two seasons were highly effective (over 95%).

Cultivar differences in nodule effectiveness were significant (P = 0.004) in the first season with Solitare and Storm producing a higher percent of effective nodules than

Magoye and Safari on unlimed plots. On limed plots the percent of effective nodules produced with Magoye was significantly less than for the other 3 cultivars (Lsd = 3.11). The percent of effective nodules was significantly increased by lime for Safari and Solitaire while for Magoye and Storm it was not.

In the second season no cultivar differences in the effectiveness of nodules formed were observed ($P = 0.620$). Cultivar x lime interaction was also not significant ($P = 0.493$).

5.3.3.2 Root Dry Matter Yield at 6WAP

Significant overall lime and cultivar effects on root dry matter yield ($P = 0.015$ and $P < 0.001$) were observed in the first season. Magoye and Storm however did not show significant increases in RDMY due to liming (Figure 5.5). Lime x cultivar interaction effect was not significant ($P = 0.055$). Solitaire produced more roots on the limed plots compared to the other 3 cultivars (Table 5.11).

In the second season, lime did not influence root dry matter weights ($P = 0.587$) but cultivar differences in RDMY in the second season were significant ($P = 0.010$). Lime x cultivar interaction effect was not significant ($P = 0.086$). Magoye showed significant increase in RDMY (37%) due to liming (Figure 5.5).

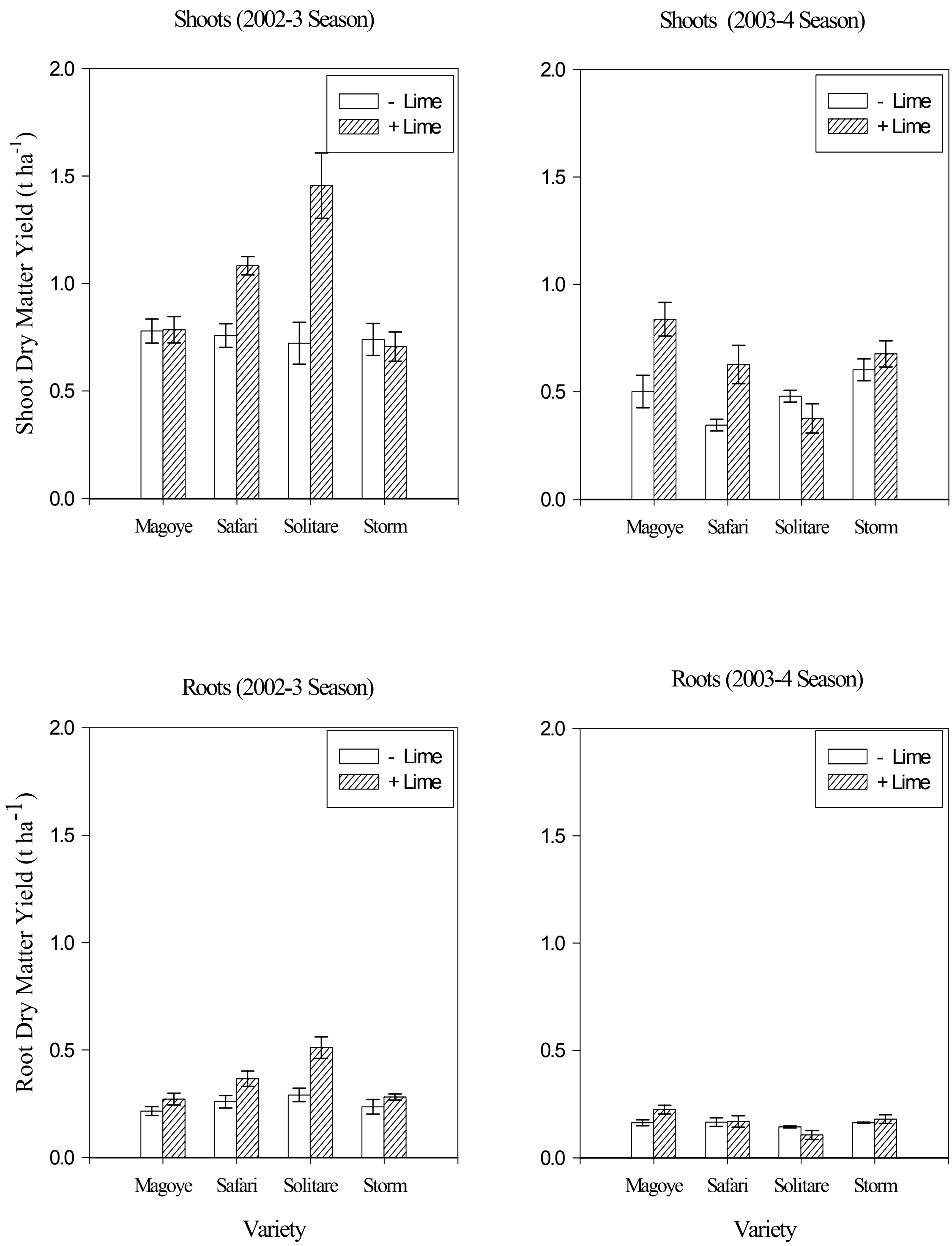

Figure 5. 5: Shoot and root dry matter yield response to liming by 4 soyabean cultivars at 6 WAP in Season 1 and 2. (Error bars represent standard error of means at 95%confidence)

Table 5. 11: Root dry matter yield and differences between four soyabean cultivars in terms of root growth with and without lime at 6WAP

No Lime

Season 1 (LSD = 0.097)		Magoye	Safari	Solitare	Storm
	Means	0.216	0.260	0.291	0.236
Magoye	0.272		b	b	b
Safari	0.367	b		b	b
Solitaire	0.512	a	a		b
Storm	0.282	b	b	a	

+ Lime

No Lime

Season 2 (LSD = 0.0528)		Magoye	Safari	Solitare	Storm
	Means	0.163	0.166	0.144	0.164
Magoye	0.224		a	a	b
Safari	0.170	b		a	b
Solitaire	0.107	b	b		a
Storm	0.181	a	b	b	

+ Lime

a---- cultivars with significantly different means
b---- cultivars with same mean

5.3.3.3 Shoot Dry Matter Yield at 6WAP

Liming significantly increased shoot dry matter yield in season 1 and 2 ($P = 0.021$ and $P = 0.034$). In the first season, lime x cultivar interaction effect on SDMY was significant ($P = 0.003$) showing that cultivars responded differently to lime. Magoye and Storm did not respond to lime while Safari and Solitaire yielded higher with lime than without lime (Figure 5.5).

In the second season, liming increased SDMY for Magoye and Safari while Solitaire and Storm showed no response (P = 0.034). Shoot dry matter yield varied significantly with cultivar (P < 0.001). Safari yielded the least SDMY on the unlimed plots (0.345 tha^{-1}) while Storm yielded highest (0.603 tha^{-1}). On the limed plots Solitaire yielded the least SDMY (0.377 tha^{-}1) compared to the other varieties (lsd = 0.1541). Table 5.12 shows mean separation for the four soyabean cultivars for season 1 and 2.

Table 5. 12: Shoot dry matter yield differences between four soyabean cultivars with and without lime at 6WAP

No Lime

Season 1 (LSD = 0.261)		Magoye	Safari	Solitare	Storm
	Means	0.779	0.758	0.723	0.740
Magoye	0.786		b	b	b
Safari	1.084	a		b	b
Solitaire	1.457	a	a		b
Storm	0.708	b	a	a	

+ Lime

No Lime

Season 2 (LSD = 0.154)		Magoye	Safari	Solitare	Storm
	Means	0.501	0.345	0.480	0.603
Magoye	0.839		a	b	b
Safari	0.628	a		b	a
Solitaire	0.377	a	a		b
Storm	0.678	a	b	a	

+ Lime

a---- cultivars with significantly different means
b---- cultivars with same mean

5.3.3.4 Stover Yield at Harvest

Liming increased stover yield at harvest in the 2 seasons (P = 0.008 and P = 0.036 for season 1 and 2 respectively) with stover yields for Magoye and Safari in the first season and Magoye and Solitaire in the second season increasing significantly due to liming (Figure 5.6). Cultivar differences in yield were significant (P = 0.002 for both seasons). Lime x cultivar interaction effect was not significant in the two seasons (P = 0.711 and 0.258 for season 1 and 2 respectively).

Table 5. 13: Stover yield differences between four soyabean cultivars with and without lime at harvest.

No Lime

Season 1 (LSD =0.495)		Magoye	Safari	Solitare	Storm
	Means	2.751	3.471	3.212	2.788
Magoye	3.171		a	b	b
Safari	3.902	a		b	a
Solitaire	3.302	b	a		b
Storm	2.916	b	a	b	

+ Lime

No Lime

Season 2 (LSD = 1.213)		Magoye	Safari	Solitare	Storm
	Means	3.48	4.79	4.91	5.27
Magoye	5.40		a	a	a
Safari	5.79	b		b	b
Solitaire	6.69	a	b		b
Storm	6.10	b	b	b	

+ Lime

a---- cultivars with significantly different means
b---- cultivars with same mean

5.3.3.5 Soyabean grain yield response to liming

In both seasons, lime increased grain yield (P = 0.046 and P = 0.023 for season 1 and 2 respectively). Cultivar differences in yield were not significant (P = 0.081 and P =

0.143 for season 1 and 2 respectively). Significant lime x cultivar interaction effects was observed in both seasons with Magoye and Safari responding positively to lime in both seasons. Grain yield for Solitaire was only increased in the second season while Storm showed no significant response to lime in both seasons (Figure 5.6).

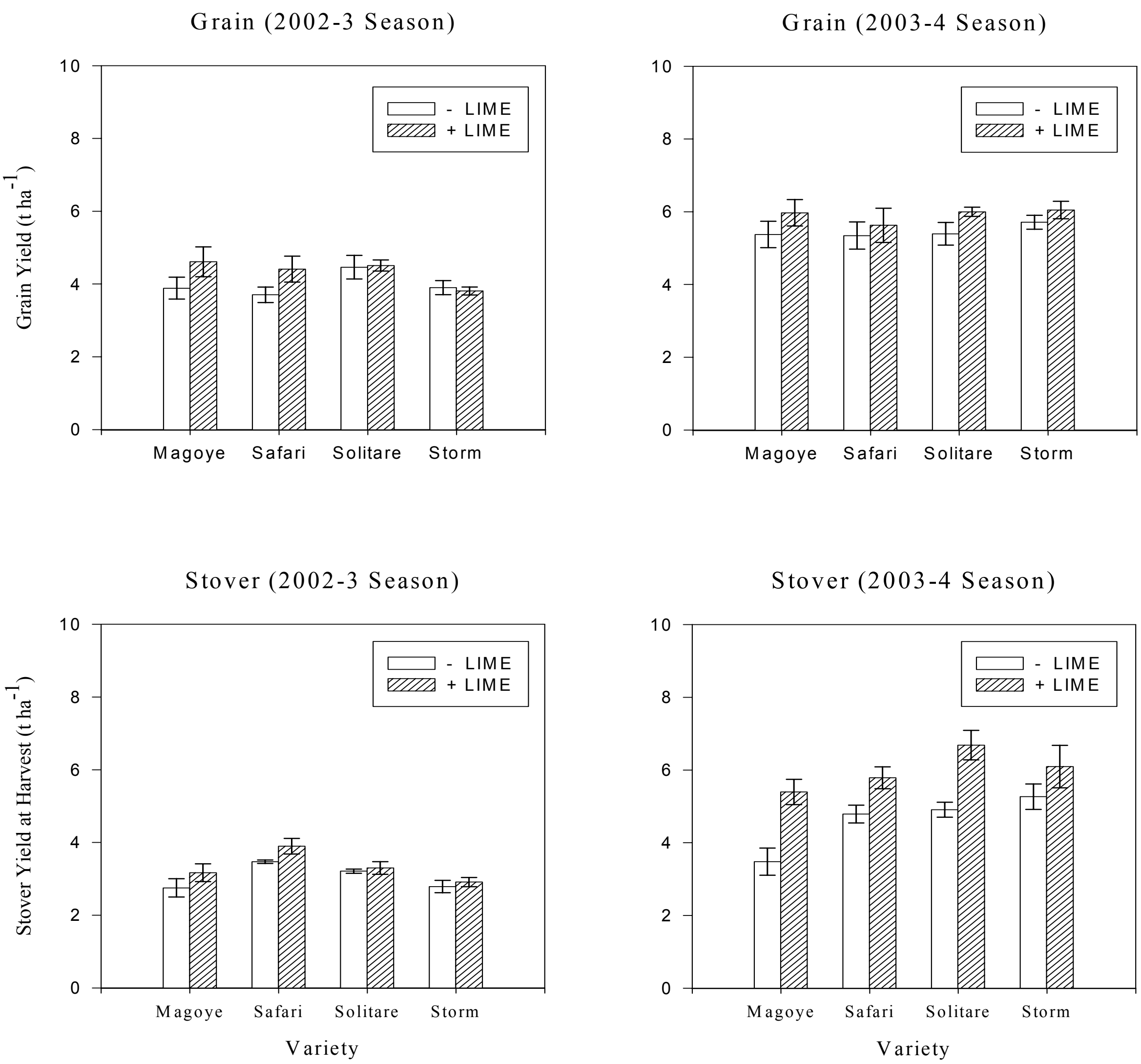

Figure 5. 6: Stover yield at harvest and grain yield response to liming for 4 soyabean cultivars at harvest for Season 1 and 2.(Error bars represent least significant difference of means at 95%confidence).

The highest response to lime was observed with Safari in the first season (19.1%) and Magoye in the second season (27.6%) (Table 5.14).

Table 5. 14: Grain yield response to lime for 4 soyabean cultivars in the 2002-3 and 2003-4 seasons.

	Season 1			Season 2		
	- Lime	+ Lime	% Response	- Lime	+ Lime	% Response
Magoye	3.89	4.62	18.8	5.04	6.43	27.6
Safari	3.71	4.42	19.1	4.96	5.82	17.3
Solitaire	4.47	4.83	8.1	5.40	6.01	11.3
Storm	3.67	4.02	9.5	5.72	6.06	5.9
$Lsd_{0.05}$	0.524 (lime)	0.625 (cultivar)	0.832 (Interaction)	0.584 (lime)	0.437 (cultivar)	0.666 (Interaction)

5.4 DISSCUSSION

The reduced stover and grain yields observed on sandy soils due to liming can be a result of induced micronutrient deficiencies. Sudden pH increases due liming on poor buffering sandy soils with just adequate amounts of Bo and Zn, can induce deficiencies of these important micronutrients while P availability is not increased (Heylar, 1998). The negative effects observed due to lime with some cultivars on sandy soils make liming unprofitable to farmers on such soils.

5.4.1 Effect of Lime on Maize Stover and Grain Yield

Stover yields at harvest for maize in the second season were lower due to late and poor rains experienced in the early stages of the season.

The response to lime on sandy soils was variable depending on soil nutrient status of the different sites and also on cultivar. PAN 413 consistently gave positive response to lime on the on farm sites but on the on station site a negative response was observed in both seasons. This cultivar could be very sensitive to Mg deficiency as the on station sandy site had low Mg content (0.2 $cmol_c kg^{-1}$) compared to on farm sites (0.5 $cmol_c kg^{-1}$ for both Chisuko and Mudzengerere). The addition of calcitic lime on this site could have further induced Mg deficiency leading to reduced yields as uptake of Mg is influenced by relative amounts of Ca and K (Piha, undated).

Positive responses to lime were observed with all cultivars on the Mudzengerere site. This could be because this site compared to the other sandy sites was low in exchangeable Ca (0.7 $cmol_c kg^{-1}$ compared to 1.9 and 1.0 $cmol_c kg^{-1}$ for Chisuko and Domboshawa respectively). The effects of lime could have been a result of the indirect addition of Ca by the calcitic lime.

On the red soils, more time is required for lime to influence soil pH due to their high buffering capacity. The effects of lime on the Chitsike site were not significant in the first 6 weeks of the first season, because lime was applied rather late (at planting). It is recommended that lime be applied at wintertime to allow for equilibration before the onset of the planting season.

The Domboshawa site had lower exchangeable Ca content (2.0 $cmol_c kg^{-1}$) compared to the onfarm Chitsike site (5.20 $cmol_c kg^{-1}$). The site also had lower exchangeable Mg and K compared to the Chitsike site (Table 5.1). Maize on this site responded positively to lime at 6WAP maybe due to the indirect addition of Ca by calcitic lime.

Soyabean trials were only established on the on station red soil site. This is because farmers highlighted that they would prefer to have maize trials on their fields and also because rhizobia survival is poor on sandy soils (Mpepereki, 1994). According to Clarke *et al.* (1993), inadequate amounts of carbon on sandy soils have an adverse effect on BNF.

5.4.2 Effect of liming on nodulation

Nodule numbers and weights

Seed inoculation ensures that an adequate population of effective *rhizobial* strains is available for colonization and infection of legume roots to optimize nodulation and N_2 fixation (Dudeja and Khurana, 1988). Increase in nodule numbers due to lime in the second season showed an increase in rhizobia survival. The number of nodules depends on the number of rhizobial colonies in a soil, which in turn depends on soil acidity (Raychaunduri *et al*., 1997). Watkin *et al*. (1997) showed that liming created favorable conditions for survival and growth of root nodule bacteria by increasing pH. In the first season, the effect of lime was not significant as soils were still reacting with lime. Liming effects on nodulation, according to Raychaunduri *et al.* (1997) are more pronounced in the second season after lime application. This has been shown in this study as lime increased nodule numbers and weights more in the second season than in the first. Nodule number increased by up to 453.7% in the second season (Table 5.9). The insignificant lime influence on nodule numbers in the first season also showed that lime should be applied well before the beginning of the season inorder to get a response. Results of this study show that the infection of legume roots by root nodule bacteria is influenced by soil acidity. Raychaunduri *et al.* (1997)

showed that liming induced a normal distribution of the tape root and lateral roots as a result of increased Ca concentrations.

Increases in nodule weight in the second season where a result of an increase in nodule numbers resulting from an increase in rhizobial colonies especially the effective ones (Raychaunduri *et al*., 1998). Raychaunduri *et al.* (1997) showed that liming increased growth of rhizobium and also nodule weight.

Nodule effectiveness

The symbiosis between the rhizobia strain MAR 1491 and the four soyabean cultivars produced highly effective nodules in this study. This is because the rhizobia strain used was acid tolerant.

In this study, lime increased nodule numbers but not nodule biomass. It can however be assumed that BNF was increased with liming even though nodule biomass was not increased because still the effectiveness of the nodules remained high (95.92% in the first season and 98.13% in the second season). Results on nodule effectiveness showed that the effectiveness of nodules produced was not influenced by acidity as a high percent of nodules produced on unlimed plots were also effective (95.92% in the first season and 98.13% in the second season). This could imply that the acid sensitive part of the soyabean-rhizobia symbiosis is the infection of roots and nodule formation. Once nodules are formed, their function is not influenced by acidity (Keyser *et al.,* 1979).

5.4.3 Effect of Lime on Root and Shoot Dry Matter Yield at 6WAP

The absence of significant lime effects on RDMY in the second season, when lime had resulted in an increase in RDMY in the first season could mean that other factors such as moisture stress were more limiting to root growth other than soil acidity in the second season. Moisture stress was experienced in the first weeks of the second season. This can imply that roots are more sensitive to moisture stress than shoots as there was a significant rise in SDMY in both seasons despite the reduced and late incidence of rainfall in the second season. Results on RDMY can also imply that root harvesting in the second season was poor maybe because more roots were left in the lower soil layers. A study by Raychaunduri *et al.* (1997), showed that liming enhance root penetration into deeper soil horizons and these lime effects are more pronounced in the second season after lime application. It was also observed that for soyabean, Al sensitive cultivars responded less to lime as compared to acid tolerant ones. These results could have been influenced by moisture deficits experienced in the second season (Annex 3). This implies that Solitaire can either be less responsive to lime or it is less tolerant to moisture deficiency.

5.4.4 Effect of Lime on Stover Yield at Harvest and Grain Yield

The effects of lime on stover yield at harvest were only significant in the second season. Equilibration of pH in the first season may not have been achieved since lime was applied at planting. This factor might have influenced results on the effect of liming on general plant growth in the first season.

Magoye is a promiscuous nodulating cultivar bred to obviate the need of inoculation. Although Magoye has been generally classified as a higher stover yielding cultivar that produces less grain compared to more specific cultivars such as Solitaire, Storm and Safari (Tattersfield, 1996; Javaheri, 1981; Zengeni 2004), in this study stover yields at harvest for Magoye and Solitare were not significantly different in first season. In the second season stover yield for Magoye was actually less than that for Solitaire on both limed and unlimed plots. This could imply that in terms of stover yield, Magoye is less tolerant to soil acidity.

Grain yield for Magoye and Solitaire was the same in both seasons, although Solitaire was bred for higher grain yield compared to Magoye. This could imply that Solitaire in terms of grain yield is more sensitive to soil acidity as opposed to Magoye. It was also observed that for soyabean, the cultivar that was classified as most tolerant to Al in Chapter 4 (Magoye) responded more to lime compared to Solitare (which was classified as less tolerant. Response to lime was lower for Solitaire (8.1% and 11.3%) than Magoye (18.8% and 27.6%) for the two seasons. These results are similar to 6WAP results where the tolerant cultivars responded more to lime than the non-tolerant cultivar. This can either imply that the screening criteria for Al tolerance are not adequate in selecting soyabean for acid field conditions as unlike in hydroponics studies where N is supplied under field conditions the plant has to fix atmospheric N through symbiosis with rhizobia. Since the N fixing process is an energy requiring process, factors such as P deficiency also come into play (Woomers *et al*., 1986). These results also show that although both the bacteria and the host plant are acid tolerant, it does not automatically mean that the symbiosis will be tolerant. Studies by (Keyser *et al*., 1979) showed that significant interaction of the two components of the symbiosis influences tolerance of the whole system to acidity. Storm, a variety that was not screened in the greenhouse, can according to these results be classified as non-tolerant since it showed similar stover and grain yield response to lime as Solitaire.

5.5 CONCLUSIONS

Liming on sandy soils may not be profitable and is thus unsustainable as it results in lower stover and grain yield. Selection of acid tolerant cultivars is more profitable than liming on these soils. However on sandy soils with low Ca and K such as the Mudzengerere site and on red soils liming is profitable. PAN 413 and SC 403 did very well under these conditions.

Maize can thus be produced sustainably on acid soils where lime is not available or not economic, by selecting cultivars that can tolerate soil acidity. Results from the sandy sites also did not give convincing benefits of lime on grain yield. This can explain why the survey showed that although farmers were aware of acidity and the need for lime they were reluctant to adopt and apply lime on their acid sandy soils.

Shoot and root dry matter yield together and other root parameters can be used in screening soyabean cultivars for tolerance to soil acidity as significant variation and differences in these parameters across cultivars were observed.

Selection of soyabean plants for acid soils is more complex than selection of cereals such as maize as there are other factors such as tolerance of the bacteria and the symbiosis other than just the host plant to be considered.

Chapter 6

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 The Soil Fertility Status and Manure Quality in Chendambuya Smallholder Area

The majority of communal soils are light textured (81% of arable land in Chendambuya was classified as light textured). These soils have poor nutrient supply capacity. Soil acidity is a major soil fertility problem on both light and heavy textured soils in Chendambuya (pH_{cacl2} averaging 4.43) impacting negatively on crop production. The use of lime is limited because of the limited financial capacity of households in the area and the bulkiness and non-availability of lime on the local market. Crop yields are therefore usually lower than potential yields for each variety.

Although cattle manure is the most commonly used soil amendment in the area, the amounts of manure applied are low averaging 5.3 tha^{-1} (Matokwe, unpublished data) and also of poor quality in terms of nutrient supply (84% of the sampled manure having >1.5% N) and liming capacity (ave.36.7%). The economics of applying manure in Chendambuya SFA is also compromised by the high proportion of inorganic material mainly soil transported from cattle kraals to the fields. An average of 56% of a Chendambuya farmer's manure is soil with some manures having as much as 90% soil (range 4 – 90%). Application of low quantities of poor quality manure makes very little impact on soil fertility and also does not influence pH.

Targeted application of manure by farmers in Chendambuya is necessary for optimal benefits. Some technologies developed by ICRISAT such as application of manure or fertilizer in the planting basin can be implemented. Farmers make planting holes on the same spot year after year applying manure on the stations each time they plant. This will result in a build up of nutrients and increased soil pH on the point where plants grow.

6.2 Effect of Al on Growth of Maize and Soyabean Cultivars

Differential Al tolerance by maize and soyabean hybrids bred in Zimbabwe, Mozambique and Zambia has been shown. Aluminium has been shown to affect primarily root growth and elongation (Maustakos, 1992).

Using the ATI as the screening criteria it was shown that of the five maize cultivars tested in this study, DK 8031 and SC 403 are the most tolerant to Al (ATI of 5 and 4.72 respectively). Inhibition of root elongation by Al on these cultivars was minimal. Maize cultivars DK 8031 and SC 403 can thus be selected for Al toxic soils, as they will show very minimal inhibition by Al. The Mozambique bred CZH 00013 and CZH 00017 showed medium tolerance to Al. Although Al will affect these cultivars, the effect will not be as adverse as will be experienced when SC 517 (the least tolerant cultivar) is grown.

Tolerant cultivars may require less fertilizer for growth to optimal levels than non-tolerant cultivars, as they were more efficient in nutrient utilization. A comparison of the two Seed Co varieties (SC 403 and SC 517) tested in this study showed that SC 403, which was ranked as more tolerant compared to SC 517 using the ATI, was also more efficient in nutrient use. SC 403 is however lower yielding than SC 517 (yield potential of 0-5 $tonha^{-1}$ for SC 403 compared to 2-8 $tonha^{-1}$ for SC 517 (Seed Co seed manual, 2001)). Non-tolerant cultivars may be more yielding, but their nutrient use efficiency is lower than that of tolerant cultivars.

Magoye was the most Al tolerant of the soyabean cultivars tested in this study (ATI of 5.00). Safari showed medium tolerance to Al with an ATI of 2.51. Compared to Magoye, Safari produced more root and shoot dry matter yield especially at 4 mgL^{-1}. Although Magoye is more tolerant (because it showed less reduction in root growth due to Al) than Safari, farmers may prefer Safari a medium tolerant cultivar because of the higher yield potential. Solitare is not suitable for Al tolerant soils, as this cultivar will experience severe root growth reductions under Al toxic conditions.

Nutrient (Ca, Mg and P) uptake by the three cultivars was reduced by Al implying that nutrient use efficiencies for both tolerant and non tolerant cultivars of soyabean was reduced by Al.

Tolerant cultivars of maize and soyabean can be selected, using the ATI, for acid Al toxic soils where liming may not be profitable.

6.3 Response of Maize and Soyabean Cultivars to Soil Acidity

The study has shown that effect of lime application on maize is not consistently beneficial especially on light textured soils such as the Domboshawa sand and Chisuko sites. Maize, both tolerant and non-tolerant grown without lime on these soils yielded the same grain as when lime was applied. In some instances such as when a farmer in Domboshawa with an acid sandy field grows cultivars PAN 413 and SC 403 and when a farmer in Chendambuya on sandy soil grows SC 513 or SC 517, lime will actually depress grain yield. In Chendambuya SFA, about 81% of the soils cannot be limed profitably unless other nutrient limitations are studied and are corrected. Lime is only profitable on light textured soils when exchangeable Ca and K are low such as was at the Mudzengerere site. This is because on these soils Ca and Mg will be limiting to crop growth and indirect addition of these through liming will positively influence crop growth. Where these nutrients are not limiting such as was on other light textured soils, low pH could be the most limiting. Light textured soils have poor buffering capacity and liming to correct pH can actually lead to micronutrient deficiency. A study currently being undertaken in Murewa has shown that Zn deficiency is common on most light textured soils (Zingore, S. Unpublished data). When pH is raised on soils with low micronutrient levels, they may become deficient. Heavy textured soils such as Domboshawa red and Chitsike on the other hand can be profitably limed. The problem of micronutrient deficiency is not common on heavy textured soils, Mn toxicity and maybe Ca and Mg will be most limiting in these cases. Lime applications therefore have to be made considering soil texture.

Farmers in Chendambuya and Domboshawa with heavier soils will be encouraged to select cultivars more suitable for their soils. This is because varietal response to lime on the heavy textured soils differed depending on plant tolerance. Non tolerant maize cultivars such as SC 517 responded more to lime compared to tolerant cultivars such as SC 403 in terms of grain yield.

For soyabean a different trend was observed with non tolerant cultivars responding less to lime. This means that acid tolerant soyabean cultivars may not necessarily produce a tolerant symbiosis with rhizobia. Solitaire, which has been bred for higher grain yield compared to Magoye, may not achieve maximum yield under acid conditions. Selection of higher yielding cultivars such as Solitaire which are not acid tolerant may not produce better yields than lower yielding acid tolerant cultivars such as Magoye if the soyabean is grown under acid conditions.

These field experiments have shown that cultivars and soyabean rhizobia symbiosis differ in their tolerance to acidity. Maize and soyabean cultivars can thus be selected for such marginal conditions.

6.4 Areas for Further Research

This study had to be completed within 2 years, which was too short a period to study other issues related to soil acidity. Future research is required in order to address the following issues

- In order to determine the tolerance mechanisms of the selected cultivars (whether Al is excluded during uptake or whether it is inactivated. This is also important so as to assess if accumulation of Al in seed or stover may be a threat to human and animal health.
- Screening locally available rhizobia strains for tolerance to Al toxicity. It is important that both the host and bacterial sites of the symbiosis be tolerant to nutritional factors experienced under acid conditions in order to maximize the symbiosis.
- Screening of these crops for Mn toxicity, another nutrient disorder experienced mainly on red soils is important. This is so because Mn toxicity is difficult to control as it can occur at higher pH under waterlogged conditions.

- Interaction between Al resistance with factors such as Mn toxicity, P deficiency, and H toxicity need to be considered in improving screening techniques of acid soil tolerance.
- Interaction between liming with micronutrient deficiency especially on sandy soils and also Ca and Mg availability in response to liming.

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