

**SCREENING GROUNDNUT (*Arachis hypogaea* L.)
GENOTYPES FOR TOLERANCE TO SOIL ACIDITY**

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DECLARATION

I, Ntandoyenkosi Happiness Shezi, certify that the material reported in this thesis represents my original work, except where acknowledged. I further declare that these results have not otherwise been submitted in any form for any degree or diploma to any university.

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Signature _____

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ABSTRACT

Groundnuts (*Arachis hypogaea* L.) are an important subsistence and cash crop for smallholder farmers in Southern Africa. They require well drained light textured soils. However, most light textured soils are acidic and inherently infertile, and therefore require supplementary nutrients and amelioration with lime. In addition to application of a basal fertilizer, groundnut production also requires Ca. This increases the inputs required to produce the crop, particularly for smallholder farmers. The study examined two options for smallholder farmers, outside the classical lime application, for ameliorating soil acidity, i.e., evaluating the response of different groundnut genotypes for tolerance to soil acidity and low-cost liming alternatives. Initially ten groundnuts genotypes were screened for tolerance to soil acidity. Following this, three genotypes classified as tolerant and susceptible were used to evaluate the effect of high acid saturation on germination, emergence and seedling establishment. Thereafter, selected cultivars were used to compare calcium silicate, as an alternative to dolomitic lime, for ameliorating soil acidity and supplying calcium to developing pods. All three studies were conducted under controlled conditions: $25 \pm 5^{\circ}\text{C}$ and $20 \pm 3^{\circ}\text{C}$ day/night temperatures, 65% RH. Results measured as plant height, leaf area, yield, concentration and uptake of selected macro-and micro-nutrients showed that different groundnut genotypes differed in their response to soil acidity. Genotypes like Billy, Selmani, Rambo and JL 24 had low Al uptake and high Ca and P uptake and were classified as tolerant to acidity. In addition, these genotypes also had a higher leaf area and high number of nodules compared with Anel, Harts, Sellie, RG 784 and Robbie. With the exception of JL 24 all other tolerant genotypes (Billy, Selmani and Rambo) were large seeded. In the early establishment stage especially, root development was susceptible to soil acidity, but Rambo appeared to perform better than Jasper

and Harts. Calcium silicate reduced soil acid saturation and provided enough calcium for pod development, suggesting that it may be used as an additional source of calcium. Soil acidity increased grain protein concentration and reduced its oil content, however, amelioration with either lime source reversed this trend. Thus, growing groundnuts in acid soils has implications for the commercial value of the product in terms of oil or protein supply. Overall, the study suggests that a combination of application of a cheap liming source like calcium silicate and growing tolerant cultivars, like Rambo, Billy and JL 24 might provide a window of opportunity for smallholder farmers to produce groundnuts possibly with only a fraction of the costs associated with ameliorating soil acidity.

TABLE OF CONTENTS

SCREENING GROUNDNUT (<i>Arachis hypogaea</i> L.) GENOTYPES FOR TOLERANCE TO SOIL ACIDITY	1
DECLARATION	I
ACKNOWLEDGEMENTS	II
ABSTRACT	III
TABLE OF CONTENTS	V
List of Figures	VII
List of Tables	VIII ^{VIII}
CHAPTER 1	1
1.0 INTRODUCTION	1
CHAPTER 2	3
LITERATURE REVIEW	3
2.1 Botany	3
2.2 Origin and distribution	4
2.3 Ecological requirements	5
2.4 Groundnut production in South Africa	6
2.5 Economic importance	7
2.6 Problem of acidity in soil forms conducive to groundnut production	8
2.7 Causes of soil acidity	9
2.8 Soil acidity and the effect of excess aluminium on nutrient availability	11
2.9 Aluminium toxicity	12
2.10 Important nutrients in groundnut production	16
2.11 Effect of soil acidity on crop growth and production	18
2.12 Amelioration of acid soils	21
REFERENCES	25
CHAPTER 3	37
Evaluation of the Tolerance of Ten Groundnut (<i>Arachis Hypogaea</i> . L) Genotypes to Soil Acidity	37
ABSTRACT	37
INTRODUCTION	38
MATERIALS and METHODS	40

RESULTS	45
DISCUSSION	61
CONCLUSION.....	65
REFERENCES	66
CHAPTER 4	72
Effect of Soil Acidity on Germination, Emergence and Seedling Establishment of Groundnut Seeds	72
ABSTRACT.....	72
INTRODUCTION	73
METHODS and MATERIALS	75
RESULTS	787778
DISCUSSION	867786
CONCLUSION.....	887788
REFERENCES	897789
CHAPTER 5	937793
Comparison of Dolomite and Calcium Silicate for Soil Acidity Amelioration in Three Selected Groundnut Genotypes	937793
ABSTRACT.....	937793
INTRODUCTION	947794
METHODS and MATERIALS	967796
RESULTS	987798
DISCUSSION	11077110
REFERENCES	11377113
CHAPTER 6	11677116
GENERAL DISCUSSION	11677116
RECOMMENDATIONS.....	11977119
REFERENCES	12077120
APPENDICES	12277122
Appendix 1: Protein Standard Curve.....	12277122

List of Figures

Figure 2. 1: World groundnut production in 2009 (Agrostat, 2009).	5
Figure 2. 2: Groundnut production figures for South Africa from the 1998/99 season to 2007/08 as reported by the National Department of Agricultural (2009).....	7
Figure 3. 1: Shoot height of different genotypes in response to different soil acidity treatments.	46
Figure 3. 2: Effect of 20% and 80% soil acid saturation on number of seeds per pod.....	50
Figure 3. 3: Effect of soil acidity on shoot Al concentration of 10 groundnut genotypes.....	53
Figure 3. 4: Mean shoot Fe concentration of 10 different groundnut cultivars grown in acid soils.....	55
Figure 3. 5: Effect of soil acidity on shoot Cu concentration	55
Figure 3. 6: Correlations between shoot dry matter (DM) and macro-nutrients N, P, K and Ca uptake of groundnut.	59
Figure 3. 7: Nutrient use efficiency of groundnut genotypes, as determined by agronomic use efficiency, in response to lime application at A (40% acid saturation) and B (20% acid saturation).	61
Figure 4. 1: Effect of Al concentration on percentage germination of three groundnut cultivars. Means are representatives of 25 seeds germinated at 25°C for 5 days.....	807780
Figure 4. 2: Effect of Al concentration on root length of three groundnuts cultivars (Harts, Rambo and Jasper) measured on day 3 and 5.....	817781
Figure 4. 3: Effect of Al concentration on seedling roots, left seedling in control treatments with distilled water and right seedlings in 200 µM Al. Top Figure shows seed at 1 Day After Sowing (DAS), while the bottom shows 3 DAS.	827782
Figure 4. 4: Effect of soil acidity on emergence of three groundnut cultivars (Harts, Jasper and Rambo) from day 1 to 10 days after sowing.....	837783
Figure 4. 5: Seedling roots grown in limed soil, right: seedling roots of no lime treatment with 80% acid saturation.....	847784

Figure 5. 1: Shoot height of three groundnut cultivars grown under no lime, dolomitic lime and CaSiO ₃ treatments from week one to five after sowing.....	997799
Figure 5. 2: Comparison of dolomite and CaSiO ₃ with respect to shoot Al and Mn concentration.....	10277102
Figure 5. 3: Effect of dolomite and CaSiO ₃ on Al and Mn shoot concentration of three groundnut cultivars	10277102
Figure 5. 4: Effect of application of lime to three groundnut cultivars on phosphorus, potassium, calcium and magnesium uptake.....	10377103
Figure 5. 5: Aluminium uptake by three groundnuts cultivars planted in control without ameriolation (80% acid saturation) and limed soil using dolomite and calcium silicate slag (20% acid saturation).....	10477104
Figure 5. 6: Effect of calcium silicate and dolomite application on Al and Mn uptake by groundnut plants	10477104
Figure 5. 7: Effect of soil acidity on seeds protein concentration of three groundnut cultivars (Harts, Kwarts and Rambo) in soil limed with dolomite or calcium silicate compared with no lime.	10677106
Figure 5. 8: Effect of soil acidity on oil content (%) of three groundnut cultivars (Harts, Kwarts and Rambo) in soil limed with dolomite or calcium silicate compared with control (without lime).	10777107
Figure 5. 9: Effect of applied dolomite and calcium silicate on soil acid saturation and pH.	10877108
Figure 5. 10: Effect of application of dolomite and calcium silicate on soil Ca, Mg, and K levels at the end of the study.....	10977109

List of Tables

Table 3. 1: Some known characteristics of the 10 groundnut cultivars that were used in this study as described by Table 3. 1 Van der Merwe and Vermeulen, (1977); Van der Merwer, (1988); Van der Merwe and Joubert, (1995); Swanevelder, (1998). Genotypes largely studied for tolerance to diseases rather than to soil acidity.	41
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Table 3. 2: Chemical characteristics of Inanda soil form used in the study	42
Table 3. 3: Response of shoot dry mass, nodule number, leaf area and photosynthetic efficiency of groundnut genotypes to soil acidity.....	48
Table 3. 4: Yield and yield components of ten genotypes subjected to different levels of soil acidity.....	49
Table 3. 5: Shoot nutrient concentrations of 10 groundnut genotypes grown at 80%, 40% and 20% soil acid saturation.....	52
Table 3. 6: Manganese concentration of 10 groundnut genotypes grown at 80, 40, and 20% acid saturation.....	54
Table 3. 7: Effect of varying acid saturations on nutrient uptake per DW plant of 10 groundnuts genotypes.....	58
Table 3. 8: Tissue concentration of Al, Ca and physical appearance of ten groundnut genotypes grown at 80% acid saturation and possible tolerance/susceptibility classification criteria.....	60
Table 4. 1: Effect of different Al concentrations on seed germination, germination velocity index and mean germination time of three groundnut cultivars.....	797779
Table 4. 2: Effect of soil acidity on emergence and seedling growth of 3 groundnut cultivars grown in no lime, 50% required lime (40% AS) and 100% required lime (20% AS).	847784
Table 4. 3: Effect of differential soil acidity on seedling establishment measured at 21 DAS	857785
Table 5. 1: Comparison of CaSiO ₃ and dolomite on vegetative growth of 3 groundnut cultivars measured by dry mass and leaf area.....	997799
Table 5. 2: Nutrient concentration of above ground parts of three groundnut cultivars grown with no lime, dolomite lime and calcium silicate.....	10177101
Table 5. 3: Effect of applied dolomite and calcium silicate on yield components of three groundnut cultivars.	10577105

CHAPTER 1

1.0 INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is the 13th most important food crop and 4th most important oil seed crop in the world (FAO, 2010). Groundnut seeds have a high nutritive value and contain high amounts of edible oil (45- 55%) and protein (25- 28%) and therefore have many domestic and industrial uses. Although the crop is mainly produced in China, India and USA, several African countries e.g. Nigeria, Sudan, Senegal and South Africa produce it on a large scale (FAO, 2010). In South Africa, it contributes approximately 1.1% of the gross value of field crops (NDA, 2009) and is an important subsistence and cash crop for smallholder farmers (Sparks, 2010).

The crop grows best in well-drained, light textured soils ranging from coarse fine sand to sandy clay loam (Heiming *et al.*, 1982). Most light textured soils are, however, highly weathered and characterized by high soil acidity, low nutrient levels, phosphorus fixation and aluminium toxicity (Foy 1984; Beukes, 2000; Truter, 2002). Since soils conducive to groundnut production in South Africa are inherently infertile due to high acidity (Swanevelder, 1998), yield is low when sufficient liming material and fertilizers are not applied. The problem of acidification is more severe in smallholder farms because of continuous monoculture without the use of soil amendments. Acid soil infertility is therefore a major constraint to groundnut production by smallholder farmers.

Fageria (1994) reported that the best way to increase yield on acid soils was to apply lime. Despite the obvious impact of lime on ameliorating soil acidity, most smallholder farmers in South Africa do not use it due to high costs and logistical constraints, including transport and actual application of lime in the field. Alternate low cost options need to be investigated if these farmers are to improve yields. Among these options are the uses of cultivars tolerant to acid soils or inexpensive industrial by-products, which contain some calcium, in place of the well-established liming materials like calcitic and dolomitic lime. These options may help farmers with limited capital, to increase yield.

The aims of the study were therefore to:

- a) Evaluate groundnut genotypes for tolerance to soil acidity and assess responses of some growth stages to soil acidity.
- b) Evaluate a low-cost alternative liming material, calcium silicate, for use in ameliorating soil acidity during groundnut production.

These would probably offer solutions for farmers with limited capital in order to allow for improved yields on acid soils.

Scope of work

The study comprised three greenhouse experiments and one field trial. However, only the results of the greenhouse experiments are reported in the main body of the thesis as the field study was invaded by black ants feeding on seeds.

CHAPTER 2

LITERATURE REVIEW

The literature is reviewed in different sections. The first section covers taxonomy, origin, distribution, and description of groundnut. The second gives a broad overview of groundnut production in South Africa that includes areas of production, its importance, and production constraints faced by farmers. The third section focuses on the problem of soil acidity in soil forms conducive to groundnut production, the cause of soil acidity and its effects on soil nutrient availability and aluminium toxicity. The fourth section discusses the effects of soil acidity on crop growth and development, as well as the amelioration of acid soils.

2.1 Botany

The cultivated groundnut (*Arachis hypogaea* L.) belongs to the genus *Arachis* of the Fabaceae family (World geography of the peanut, 2004). Members of this genus are known for their unique characteristic of flowering above the ground and producing pods underground (Holbrook and Stalker, 2003). Groundnut is a self-pollinating annual herbaceous legume with an indeterminate growth habit (Melouk and Shokes, 1995). The crop is erect or prostrate and grows up to a maximum height of 50 cm (Smartt, 1994). After fertilization an intercalary meristem is activated below the ovary, and this meristem pushes the ovary to grow, forming a peg (Smartt, 1994). The peg bears the fertilized ovule at its tip (Smith, 2006). The growth of the peg is positively geotropic, up to a soil depth of 10 cm, after which it becomes diageotropic (Smartt, 1994). After the peg penetrates into the soil, the tip begins to swell and groundnuts develop, absorbing moisture, calcium and boron directly from the soil (Smartt, 1994; Melouk and Shokes, 1995).

Groundnut is divided into two sub-species *hypogaea* and *fastigiata* (Jennings and Cock, 1977; Stalker, 1997). The sub-species *hypogaea* consists of two varieties (*var. hypogea* and *var. hirsuta*) while the sub-species *fastigiata* has three varieties (*var. fastigiata*; *var. Valencia* and *var. Spanish*) (Simpson, 1994; Smartt, 1994). Varieties are classified according to the location of flowers, pattern of reproductive nodes on the branches and pod morphology (Krapovickas and Gregory, 1994).

The sub-species *hypogea* possess dark-green foliage with branches crawling either partially or completely on the surface of the soil. The sub-species *hypogea* does not produce flowers on the main stem (Smartt, 1994). In addition, it has a high water requirement, and can be grown successfully under irrigation. Also, it produces large pods with oblong, brownish seeds and matures late (180 days after sowing), yielding higher than the bunch types (Smartt, 1994; Kamburona, 2007). The sub-species *Fastigiata*, on the other hand, grows erect, possessing light-green leaves and produces flowers on the main stem (Smartt, 1994). This species has a relatively low water requirement and produces small seeds with a light-rose (red) testa. The small pods, which rarely have more than two seeds, are produced in clusters at the base of the plant and mature very early (120 to 150 days after sowing) (Smartt, 1994; Kamburona, 2007).

2.2 Origin and distribution

The crop is believed to have originated in South America (Weiss, 2000) because of the large genetic diversity in that region. Groundnuts are cultivated in all subtropical, tropical and warm temperate regions of the world between latitudes 35° North and 40° South (Encyclopaedia of Agriculture Science, 1994). In terms of global production, groundnut is the 13th most

important food crop and the 4th most important oil seed crop. It is mainly produced in China, India, USA, and several African countries (FAO, 2003; Agrostat, 2009) but only to a small extent in South Africa (Fig 2.1).

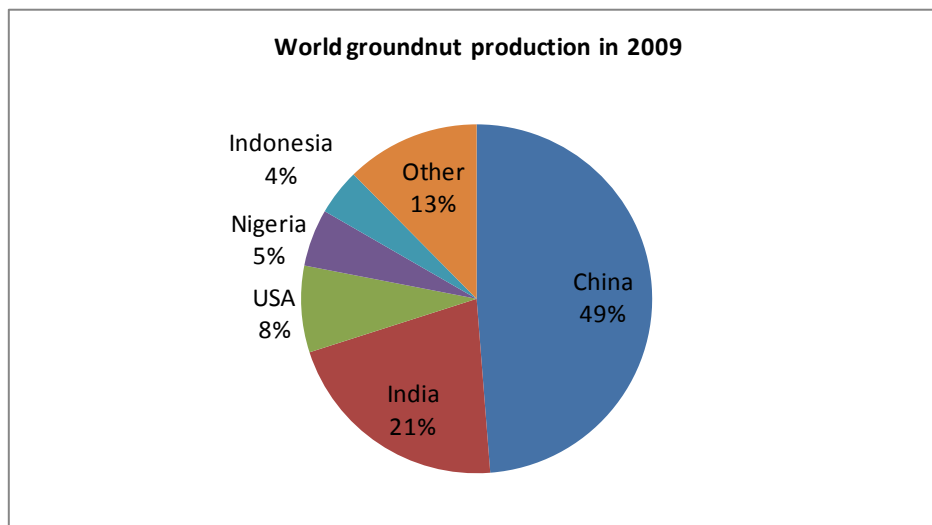


Figure 2. 1: World groundnut production in 2009 (Agrostat, 2009).

2.3 Ecological requirements

Since groundnut originated from a tropical region (Weiss, 2000), it requires warm growing conditions. It grows best at mean temperatures ranging from 25°C to 30°C (Smith, 2006). Rainfall is one of the major climatic factors limiting dryland production of groundnut in Southern Africa (Swanevelder, 1998; Mathews *et al.*, 2007). Chamberlin and Diop (1999) reported that low rainfall during crop growth reduced average yield. For good yields (3 t ha⁻¹) under dryland production, groundnut requires mean rainfall amounts ranging from 500 to 700 mm during the growing season (Smith, 2006). The crop is adapted to well-drained, deep-medium textured soils with a clay content of less than 25% to enable the peg to penetrate the soil easily and avoid pod discoloration (Smith, 2006).

2.4 Groundnut production in South Africa

The most commonly cultivated varieties in South Africa are those of the *vulgaris* (Spanish) and *fastigiata* (Valencia) types (Swanevelder, 1998). Groundnut cultivation in South Africa started in the former Natal Province (KwaZulu-Natal), spreading to the Transvaal (Mpumalanga) (Herselman, 2003). The Spanish cultivars were introduced by Portuguese traders along the East Coast of South Africa. This germplasm established into one of the well-known cultivar, Natal Common, which has served as parental material for most of South Africa's genotypes (Herselman, 2003).

After a long period of dominance by Natal Common, another cultivar, Sellie, was released in 1974. Sellie was the result of crossing Natal Common and Narmark, a landrace from Kenya (Van der Merwe and Vermeulen, 1977). From there onwards, many other varieties were developed and released with tolerance to leaf and pod diseases. The *hypogea* varieties (Virginia and runner) are not commonly grown because they require a long growing season and irrigation (Swanevelder, 1998).

Commercially groundnuts are produced in the Free State, North West and Northern Cape provinces. They are also grown by smallholder farmers in the Limpopo province, northern KwaZulu-Natal and the Lowveld of Mpumalanga (Swanevelder, 1998; Smith, 2006; Mathews *et al.*, 2007). Groundnut production in RSA is estimated to about 100 000 tons per annum with 80% being produced by commercial farmers (Swanevelder, 1998). Between 1970 and 1982 annual production averaged 204 000 tonnes decreasing to about 94 000 tonnes from 1982 to 1994 (Swanevelder, 1998). The observed reduction of approximately 50% between 1970 and 1982 was due to an epidemic of web blotch caused by *Phoma arachidicola* and

black pod rot caused by the fungus *Chalara elegans* (Swanevelder, 1998). Irregular rainfall and harvest problems also added to the rapid yield reduction (Mathews and Beck, 1994; Swanevelder, 1998). Production started to increase again from 1998 to 2000/01 due to an increase in area planted (NDA, 2009). However, from 2002/03 groundnut production has been fluctuating with lowest production recorded between 2004 and 2006 (Fig 2.2). Major production constraints are foliar diseases and drought at pod formation (Mathew and Beck, 1994).

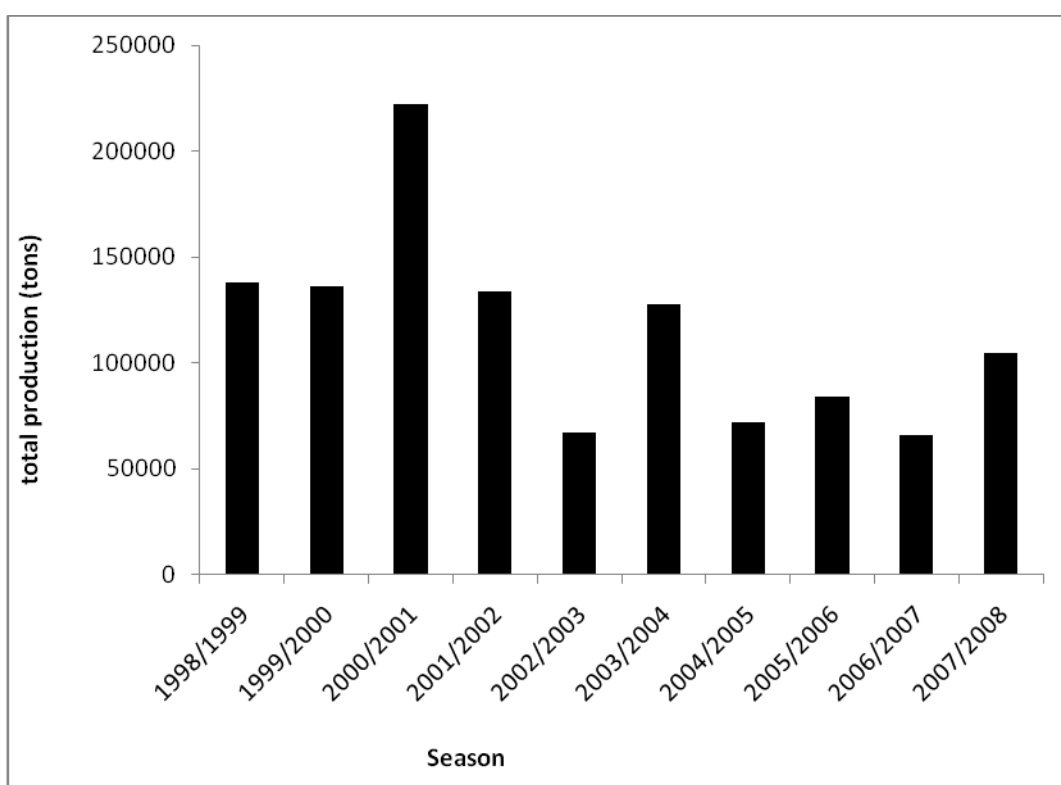


Figure 2. 2: Groundnut production figures for South Africa from the 1998/99 season to 2007/08 as reported by the National Department of Agricultural (2009).

2.5 Economic importance

Its high oil and protein contents make groundnut an important food crop for both humans and animals. Groundnut shell, skin, haulm and hay are good sources of fodder for animals and the

cake is an important animal feed, as well as manure for soil improvement (Pimrathch *et al.*, 2004; Paik-Ro *et al.*, 1991). It is also an important cash crop even for smallholder farmers who depend on it as a source of income and subsistence (Mathews *et al.*, 2007). Boiled peanuts are popular in Africa as a snack (Smartt, 1994). Groundnuts are also used in industry as raw materials for products such as soap, detergent and cosmetics (Smartt, 1994). Being a legume, the crop is able to fix atmospheric nitrogen, thus improving soil fertility, and is useful as a rotational crop (Smartt, 1994).

2.6 Problem of acidity in soil forms conducive to groundnut production

Soils suitable for groundnut production in RSA belong to the Avalon, Bainsvlei, Clovelly, Hutton, Pinedene and Glencoe forms (Swanevelder, 1998). These soils are light-textured, well-drained and suitable for both irrigated and dryland production. The soils consist of an orthic A horizon with less than 1.8% carbon and are red or yellow-brown in colour. These soils are usually non-calcareous, with clay dominated by kaolinite, implying a low cation exchange capacity (CEC) and light texture (Soil classification working group, 1991). Non-calcareous soils are classified into three soil families; eutrophic (slightly weathered), mesotrophic (moderately weathered) and dystrophic (highly weathered). This classification is based on the degree of leaching, which is an indicator of their weathering status (Truter, 2002). The classification is determined by the sum of exchangeable calcium (Ca), magnesium (Mg), potassium (K) and molybdenum (Mo) present in the soil (Soil classification working group, 1991).

In South Africa, 15% of soils available for crop production are classified as dystrophic (Beukes, 2000; Truter, 2002). Dystrophic soils are characterised by low soil acidity, low

nutrient status, phosphorus fixation and aluminium toxicity (Truter, 2002). Infertility of dystrophic soils results in yield instability in some parts of RSA due to shallow root development associated with soil acidity. As a consequence of the shallow rooting, crops grown on such soils become susceptible to mid-summer drought (Truter, 2002).

2.7 Causes of soil acidity

Most soil acidification is due to natural factors as well as certain agricultural practices (Foth, and Ellis, 1996).

2.7.1 *Natural factors*

The parent material is the primary factor affecting soil acidity (Rowell, 1994) because it determines the original supply of nutrient elements that will be released by weathering as well as the balance between nutrient loss and retention (Anderson, 1988; Rowell, 1994). Sandy soils acidify more rapidly because they have a low cation exchange capacity and high leaching potential. Soils become acidic due to cations (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) being leached from the soil profile faster than they are released by mineral weathering, resulting in hydrogen and aluminium becoming more dominant on the exchange surface (White, 1979). The loss of base cations is caused by the uptake of nutrients by plants or leaching after heavy rains (Helyar and Porter, 1989; Beukes, 2000).

Leaching and weathering result in a deficiency of base cations and trace elements like zinc and boron (Truter, 2002). Acidification during crop production is a problem in most subsistence

farming systems because of intensity of production without application of remedial nutrients (Jansen van Rensburg *et al.*, 2009; Mafongoya *et al.*, 2006).

2.7.2 Acid rain

Increased industrial activity and use of vehicles result in the burning of coal and other fossil fuels and this contributes substantially to soil acidification (Wang *et al.*, 2000; Truter, 2002). When fossil fuels are burnt, carbon, hydrocarbons, sulphur and nitrogen are released into the atmosphere and react with oxygen and moisture resulting in acid rain, as illustrated by the following equations (Truter, 2002; Wang *et al.*, 2000);



2.7.3 Agricultural practice

Soil acidification is low under natural conditions (Helyar and Porter, 1989) but is accelerated by certain agricultural practices. Application of ammonium fertilizers and animal manure tends to increase soil acidity (Wallance, 1994). Acidification is high in well-drained soils because of the rapid nitrification rate. Ammonium fertilizers are oxidised to form nitrate and H^+ ions as per the equation:



2.8 Soil acidity and the effect of excess aluminium on nutrient availability

Soil acidity can be determined by the amount of hydrogen ion activity in the soil solution (Blinkley and Richter, 1987). Although its effects can be measured as changes in pH, its implications are related to both increased H^+ and exchangeable Al^{3+} ions, leading to toxicity in susceptible plants and a decrease in exchangeable Ca^{2+} , Mg^{2+} and K^+ . Measuring soil acid saturation is another method of determining soil acidity; it includes both H^+ and Al^{3+} ions held within the diffused layer and able to move easily. The pH includes only H^+ ions. In acidic KwaZulu-Natal soils, exchangeable Al^{3+} ions rather than adsorbed H^+ ions have been shown to be a main source of acidity (Moberly and Meyer, 1975; Truter, 2002). Measuring soil acidity as percentage acid saturation in KwaZulu-Natal acid soils is more accurate than soil pH because it provides an index of the Al activity levels in the soil. Soil acid saturation is calculated by difference between the soil acidity and sum of exchangeable basic cations (Foth and Ellis, 1996). Hence, acidity is measured as percentage acid saturation i.e. Acid saturation = (Acidity / Total cations)* 100.

Aluminium toxicity is the main factor affecting plant growth in acid soils because it interferes with transfer of nutrients and water through root cell membranes (Rowell, 1994). Excess Al^{3+} and Fe^{2+} ions in the soil solution cause a problem of phosphorus fixation, hence, in acid soils, phosphorus may be present in the soil, but is not readily available for use by crops (Fageria, 1994). High concentrations of Al^{3+} further increase soil acidity because Al^{3+} ions attract hydroxyl ions, thus removing them from soil solution and increasing the concentration of H^+ in the soil, as exemplified in the following equation (Foth and Ellis, 1997):



2.9 Aluminium toxicity

Aluminium toxicity is widely considered to be the most important limiting factor to plant growth in acid soils (Foy, 1984; Horst, 1995; Rowell, 1997). According to Plank (1989) shoot concentrations of Al and Mn must be usually less than 200 mg kg⁻¹ but generally values of 50 – 300 mg kg⁻¹ are acceptable. The inorganic monomeric octahedral hexahydrate Al (H₂O)₆³⁺ or Al³⁺ which predominates soil solutions when the pH is below 4.5 is considered to be toxic to plants (Kinraide, 1993). The monohydroxy Al species Al(OH)³⁺, Al(OH)⁺ and Al(OH)⁻ which are present in soil solution between 5 and 6.2 pH are non-toxic to plants (Kinraide, 1997). Aluminium interferes with absorption, transport and use of essential nutrients including Ca, Mg, K, P, Cu, Zn, Mn, and Fe (Roy *et al.*, 1988; Baligar and Fageria, 1997). The antagonism between Ca and Al is the most important factor affecting Ca uptake by plants (Foy, 1992). Kochain (1995) reported that aluminium inhibited calcium uptake in sensitive plants but had little effect on calcium uptake in tolerant plants. Soil with high acid saturation might be a problem in groundnut production as the crop requires more calcium during the reproductive stage.

2.9.1 *Effect of Al toxicity in crops*

A primary symptom of Al toxicity is inhibition of root growth; high Al concentration inhibits cell expansion and elongation resulting in reduced cell division (Kochian, 2004; Panda and Matsumoto, 2007). The site of aluminium toxicity is localised at the root apex in the apoplast and some in the symplast (Lazof *et al.*, 1996; Taylor *et al.*, 2000; Kochain, 2004). Aluminium toxicity results in a variety of symptoms including, but not being exclusive to the three discussed below.

2.9.1.1 Callose formation and lignin deposition

Callose is a polysaccharide consisting of 1 β -glucan chains, which are formed naturally by cells in response to wounding (Barker and Pilbeam, 2007). An early symptom of Al toxicity is the formation of callose in roots. This symptom is used to screen seedlings for sensitivity to Al toxicity (Wissenmeier *et al.*, 1987). Lignins are complex networks of aromatic compounds that are a distinguishing feature of secondary plant cell walls. Aluminium induced lignification is a marker of Al injury and is associated with inhibition of root elongation (Barker and Pilbeam, 2007).

2.9.1.2 Suppression of photosynthesis

A further aluminium toxicity symptom is leaf necrosis, which was reported to be accompanied by decreasing chlorophyll concentration and photosynthetic rate (Shi, 2004; Lindon *et al.*, 1999). Different studies have reported that low levels of aluminium have no significant effect on chlorophyll concentration, photosynthetic rate and lipid peroxidation or antioxidant enzyme activities. Aluminium is toxic only when the concentration reaches a certain threshold (Kidd and Proctor, 2000; Ying *et al.*, 2007; Zhang *et al.*, 2007), where it affects photosynthesis by lowering chlorophyll concentration and reducing electron flow in leaves (Lindon *et al.*, 1999). The threshold differs with different plant types (Zhang *et al.*, 2007).

2.9.1.3 Abnormal root morphology

Symptoms of Al toxicity include coralloid root morphology with inhibited lateral roots formation and thickening of the primary root (Clarkson, 1965). A damaged root coupled with

reduced root length is expected to result in decreased water and nutrient uptake (Barker and Pilbeam, 2007).

2.9.2 Aluminium tolerance of crop plants

There are two mechanisms by which plants can tolerate high Al concentrations; firstly, by exclusion of Al from the symplasm and, secondly, by internal tolerance of Al in the symplasm (Taylor, 1991; Kochian, 2004). On the basis of the tolerance mechanism, plant species can be divided into two groups, i.e., Al excluders and Al accumulators. Most crop plants are aluminium excluders while only few are aluminium accumulators. Aluminium accumulators are plants with ≥ 1000 mg Al kg⁻¹ in the dried leaves (Barker and Pilbeam, 2007). Aluminium sensitive plants absorb more Al than Al tolerant plants, thus, exclusion mechanisms of Al from the root apex is the major mechanism of tolerance (Jorge and Arrunda, 1997; Ma, 2000). This mechanism of Al tolerance includes Al-activated exudation of organic acids (OA) from roots. Al-activated organic acids released are localized in the root apex (Kochian, 1995). The release of OA is activated by aluminium and activation occurs at the protein not at gene level (Kochian, 2004).

A continuous exudation of organic acids increases their concentration in the layer at the surface of the root apex to a level sufficient to chelate and detoxify a fraction of the Al in contact with the root tip or preventing Al from entering the root (Kochian, 2004). The organic acid exudation continues as roots grow through the soil in order to maintain the chelating barrier around the root apex as they encounter new regions of acid soil (Kochian, 2004). Aluminium activated organic acids are crop specific. Aluminium-activated malate exudation characterises Al exclusion in wheat, while Al-activated citrate exudation is utilized by maize,

sorghum, oat, soybean and tobacco (Jorge and Arrunda, 1997; Magalhase, 2002). Some species, like rye and oilseed rape, use both citrate and malate (Kochian, 2004).

Amelioration of Al toxicity by application of lime is not economical on smallholder farmers. The use of high Al tolerant cultivars is often the most effective strategy for improving production on acid soils. Plant species differ in their Al tolerance; some are inherently more tolerant to high Al concentrations than others, i.e., cassava, cowpea, groundnut, pigeon pea, potato, rice and rye (Mugwira et al., 1978; Little, 1988; Taylor, 1991; Hede *et al.*, 1996).

Amelioration of Al toxicity by silicon is due to formation of an aluminosilicate compound in the root apoplast (Cocker *et al.*, 1997; Hodson and Sangster, 1999). Internal detoxification of aluminium involves chelation of Al in the cytosol and subsequent storage of OA complexes in the vacuole (Kochian, 2004). After absorption, Al undergoes an exchange from Al-oxalate to Al-citrate when it is transported into the xylem and exchanged back to AL-oxalate when transported to leaves for storage in the vacuole (Shen *et al.*, 2002). Once in the vacuole, Al³⁺ ions cannot adversely affect the cytoplasm metabolism (Ma *et al.*, 2001; Kochian, 2004).

2.10 Important nutrients in groundnut production

2.10.1 Calcium

Calcium is a major nutrient in groundnut production because the crop requires large quantities of this element during pod development for production of high quality seeds. Root absorbed calcium is not translocated to developing pods; after the pegs have entered the soil, they absorb moisture, calcium and boron directly from the soil (Brandy, 1947; Heiming *et al*, 1982; Smartt, 1994). One of the major reasons for poor groundnut yield in acid soils is the unavailability of calcium at the pod development stage. Calcium deficiency results in poor seed formation or empty shells (called ‘pops’); under conditions of limited Ca supply, seeds develop a dark plumule (Melouk and Shokes, 1995). The viability of seeds, including those that do not have a black plumule, depends on calcium concentration in the soil (Porter *et al.*, 1984). Calcium deficiency has been associated with hypocotyl failure resulting in poor field establishment of groundnuts (Cox *et al*, 1976). Calcium deficiency can be improved by applying gypsum. Amelioration of soil with lime also provides sufficient calcium for pod development. A calcium level of 600 to 800 mg/kg of soil in the podding zone is considered adequate for good kernel development (Sumner *et al.*, 1988).

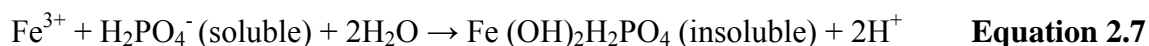
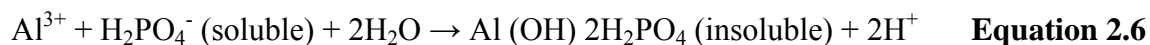
2.10.2 Magnesium

Magnesium is one of the cations that cannot permanently bind to the cation exchange site. As such it is easily replaced by stronger cations and leached through the soil profile. Magnesium is required in stems of groundnuts for its role as a phosphorus carrier during oil formation and its positive effect on seed viability (Smith, 2006).

2.10.3 Nitrogen, phosphorus and potassium

Groundnut is a leguminous crop, capable of fixing atmospheric nitrogen in association with Rhizobium bacteria; when these bacteria are present the crop does not depend on nitrogen fertilization (Swanevelder, 1998) to accelerate growth. Acid soils lack appropriate levels of N to support healthy plant growth (Truter, 2002). Rhizobium bacteria can be completely inactive in acid soils therefore, supplementary N fertilization is required if soil nitrogen is less than 20 mg/kg (Swanevelder, 1998).

Phosphorus in acid soils reacts with Al^{3+} and Fe^{2+} ions to form insoluble compounds;



Applying too much lime may cause P to be fixed;



Soil P levels required for growing groundnuts are generally lower than for other crops (Cope *et al.*, 1984). Phosphorus fertilizer is recommended only when groundnuts are grown in soils with P concentration less than 20 kg ha⁻¹. (Swanevelder, 1998)

Groundnut requires sufficient levels of potassium (K) for normal development. Since K is deficient in acid soils, it must be applied when the soil potassium level is less than 80 mg/kg (Swanevelder, 1998). Kayode (1987) reported that oil and protein percentage as well as yield

responded positively to 15 kg K ha⁻¹ but yield responded negatively to higher K application rates

2.10.4 Micro-nutrients

Molybdenum becomes deficient when soil pH is less than 4.8 because it is strongly adsorbed by hydrous Fe oxide and hydroxides (Melouk and Shoke, 1995). Molybdenum is important for normal plant growth and nitrogen uptake. Deficiency may lead to reduced plant growth, number of pods, seed size, both number and size of nodules, and total nitrogen and protein content in seeds (Porter *et al*, 1984; Swanevelder, 1998). Boron (B) is another important micro-nutrient required for groundnut production but it is highly leached in acid soils. It is essential for germination of pollen grain, growth of pollen tube, seed and cell wall formation (Fageria, 2008). Boron reduces pod abortion, thus increasing pod number. It also improves seed germination and vigour. In seeds, B deficiency results in internal nut damage called hollow heart which reduces the quality of seed (Smartt, 1994; Swanevelder, 1998; Barker and Pilbeam, 2007; Fageria, 2008). One kg ha⁻¹ of B must be applied with or after planting on B deficient soils (Swanevelder, 1998).

2.11 Effect of soil acidity on crop growth and production

2.12.1 Crop establishment

Successful crop establishment involves germination and emergence of seedlings which grow and develop vigorously. Soil acidity does not affect germination but after radicle protrusion, it acts by inhibiting root elongation, as observed in numerous crops e.g. wheat (Jamal *et al.*, 2006), common bean (Rangel *et al*, 2007) and groundnuts (Murata, 2003). Reduction in seedling emergence is attributed to aluminium toxicity which interferes with radicle growth.

The effect of aluminium toxicity on seedlings is marked by callose formation which has been reported to be a sensitivity marker for Al stress (Wissenmeier *et al.*, 1987). Callose synthesis is mostly induced by Al stress rather than stress caused by high concentration of Cadmium (Cd), Mn and Zn (Wissenmeier and Horst, 1995). Hypocotyl collapse and dark plumule in seedlings of groundnuts have been associated with Ca deficiency, a common phenomenon in most acid soils (Cox *et al.*, 1976; Zharare, 1997).

2.12.2 Vegetative growth

Leaf surface area is very important for light interception, radiation use efficiency and consequently plant growth (Melouke and Shokes, 1995). Both leaf area and dry matter contribute towards pod yield in groundnuts. Groundnut productivity depends on its capacity to convert radiant energy to chemical energy by the process of photosynthesis and the effective translocation of photosynthates to the underground pods (Phakamas *et al.*, 2008). Aluminium toxicity does not affect photosynthesis by reducing leaf size and number but rather by lowering the leaf chlorophyll content and reducing electron flow (Roy *et al.*, 1988; Shi, 2004). Acid soils cause nutrient imbalance in meristems resulting in anatomical damage to plant parts, thus reducing plant biomass which is intimately related to yield. In groundnut, vegetative development regulates reproductive capacity (Awal and Ikeda, 2003) since pod number is strongly influenced by crop growth rate around flowering. Growth rate is a function of a crop's ability to capture light, nutrients and water and use them efficiently (Phakamas *et al.*, 2008). Nutrient deficiency in acid soils has been reported by Blamey and Chapman (1982) to negatively affect groundnut growth rate thus limiting crop growth and development.

2.12.3 Dry matter partitioning

Dry matter partitioning is very important in determining crop yield since potential yield is determined by the efficiency of converting intercepted light to biomass and the subsequent partitioning of biomass to grain yield. The pattern of dry matter accumulation in groundnut is initially slow, increasing rapidly in the late vegetative stage up to the early pod filling stage (Phakamas, 2008). In legumes, tolerance to soil acidity increases as plants grow (Vassileva *et al.*, 1997) thus dry matter accumulation during the reproductive stage ensures sustainable growth in acid soils.

2.12.4 Plant root and nodules

Soil acidity increases the availability of Fe, Mn, Cu, and Al with Al and Mn reaching phytotoxic concentrations in plants (Foth and Ellis, 1996). The most common symptom of excessive Al is reduction in root elongation (Barker and Pilibeam, 2007). Aluminium toxicity inhibits root cell expansion resulting in inhibition of cell elongation and division (Kochain, 1995) thus restricting root growth for exploration of nutrients and water. Stubby roots caused by Al toxicity lead to nutrient deficiency and sometimes drought symptoms may appear, even if water is available down the soil profile (Truter, 2002). Blamey and Chapman (1982) reported that groundnut roots are less affected by soluble Al concentration compared with cotton and sorghum roots. When groundnuts are grown in acid soil they cannot fix sufficient nitrogen because soil acidity limits the number of nodules; hence, soil acidity was found to reduce nodule number and weight in many leguminous crops such as cowpea (Kenechukwe *et al.*, 2007), soybean (Mengel and Kamprath, 1987), common bean (Vassileva *et al.*, 1997), and groundnuts (Shamsuddin *et al.*, 1992; Rossum *et al.*, 1994).

2.12.5 Yield and seed quality

Acid soils are deficient in nutrients required by groundnuts for attainment of high yield and seed quality. Deficiencies of B and Ca in acid soils reduce seed quality. Boron deficiency affects cotyledons and may cause plumule tips to be small and pointed (Porter *et al.*, 1984; Molouk and Shokes, 1995), because it affects the vascular system at the base of the plumule (Harris and Brolmann, 1966). Adams *et al.* (1993) reported that more Ca was required to produce good quality seeds as compared with high yields and sound mature kernels; hence soils used for seed production must be higher in Ca than soils for normal production. Murata (2003) reported that low soil pH results in the production of mostly single seeded pods and, ultimately, reduced yield. Seed produced in Ca deficient soils have low seed vigour because of their low Ca concentration (Adams and Hartzog, 1991). Poor yields in small-scale farming are caused by infertile soil, seasonality of rainfall and poor seed quality (viability and vigour) (Merrey, 2006). Soil fertility is crucial for food production, especially on small-scale farms where fertilizer and lime are not commonly used to ameliorate soil acidity and increase nutrient availability. Poor crop stand in subsistence farming is caused by use of retained seeds with poor quality. Seed quality is affected by the environment and cultural conditions under which seeds develop and mature (Matthews and Powell, 1981).

2.12 Amelioration of acid soils

Liming of acid soils is a common agricultural practice. It is used to ameliorate Al and Mn toxicity as well as to supplement deficient nutrient elements such as Ca and Mg (Leeper and Uren, 1993). Limestone is the main liming material used to neutralize soil acidity (Barber, 1967). The amount of lime required for correcting soil to a desirable acid saturation and

producing good yield is dependent upon the concentration of calcium carbonate equivalent to change a volume of soil (Foth and Ellis, 1996). Lime quantity is also determined by soil properties, quality of liming material and crop species or genotype.

Light textured soils require more lime compared with soils with high clay content. Soils with Mg deficiency require lime containing both Ca and Mg (dolomitic lime). Strongly acidic soils with low buffering capacity can be brought to neutrality easily. Increasing the buffering capacity results in a greater ability of the soil to adsorb cations; therefore, soils with relatively low acid saturation and high buffering capacity need more lime than soils with low buffering capacity (Foth and Ellis, 1996; Fageria, 1998).

2.12.1 Lime material

Gypsum (CaSO_4) contains Ca but has no effect on soil pH because it hydrolyses resulting in a strong base and acid. The base and acid neutralize each other resulting in a neutral soil. As such, gypsum can only be used as Ca source (Fageria, 1998). Calcium carbonate limes change soil acidity because their reaction results in weak acid and strong base as per the equation;



The Ca^{2+} ions replace the adsorbed H^+ ions on soil colloids thus neutralising soil acidity. Calcium carbonate is more effective compared with dolomite because it has higher Calcium Carbonate Equivalent (CCE) and smaller surface area (Fageria, 1998; Shen *et al.*, 2004).

Calcium silicate reacts in a similar manner to calcium carbonates except that it can react faster because of its smaller particles (Shen *et al.*, 2004; Mbakwe, 2008; Ndoro, 2008).

2.12.1.1 Calcium silicate and fly ash

Several studies in which well-known agricultural limes were compared with calcium silicate (produced by steel industries) and fly ash showed that calcium silicate had a high CCE (97%) and high nutrient availability (Shen *et al.*, 2004; Mbakwe, 2008). By contrast, fly ash had a low calcium content and low CCE (10%) (Mbakwe, 2008; Ndoro, 2008). It also contains hazardous element like As and Se in high concentrations (Shen *et al.*, 2004). Both liming materials contain other major elements. Fly ash contains K and Fe while calcium silicate contains Sulphur (S) and Silicon. The element composition study of calcium silicate and lime conducted by Mbakwe (2008) and Ndoro (2008) showed similar nutrient compositions and also increased yield more than other liming materials. Calcium silicate slag contains many additional nutrient elements like Mg, Si, and S. Shen *et al.* (2004) and Mbakwe (2008) reported that Si decreased soil acidity more rapidly than lime and also improved growth and yield of beans. Calcium silicate slag has been used mostly in sugar cane production as Si source because it contains high concentrations of it.

2.12.2 Beneficial effect(s) of silicon

Silicon has beneficial effects on crop growth, development and yield, as observed in maize (Owino-Gerroh and Gascho, 2004), pigeon-pea (Owino-Gerroh *et al.*, 2005), sugar cane (Laing *et al.*, 2006) and wheat (Ahmad *et al.*, 1992). Beneficial effects of Si on crop growth are related to an increased resistance to both abiotic and biotic stresses (Ma and Yamaji, 2006). Silicon is deposited beneath the cuticle to form a Si double layer. This layer blocks

fungal penetration and enhances plant resistance to pests such as stem borer and leaf hoppers. Silicon alleviates abiotic stresses in plants including metal toxicity, nutrient imbalance, and physical stresses like lodging, drought, and high and freezing temperatures (Ma and Tahakashi, 2002; Ma and Yamaji, 2006). Silicon absorbed by plants accumulates in the root apoplast in epidermal cell walls and provides a binding site for toxic metals, resulting in decreased uptake and translocation of toxic elements (Fauteux *et al.*, 2005). Deposition of it into leaves and hull enhances the strength and rigidity of cell walls and decreases transpiration from the cuticle, therefore increasing resistance to low and high temperatures, drought and radiation (Ma and Yamaji, 2006). Silicon improves light interception by keeping leaves erect thereby stimulating canopy photosynthesis (Ma and Takashi, 2002). It also improves lodging resistance by increasing thickness of the culm wall and the size of vascular bundles.

The literature shows that soil acidity has a negative effect on crop growth and yield. This may have serious implications for mostly smallholder farmers who cannot afford lime to ameliorate soil acidity due to cost and logistical constraints. Although soil acidity negatively affects plant growth there are differences in the response to acidity in some plant species; some genotypes within a species may be more tolerant than others. Growing acidity tolerant cultivars is one of the ways for maintaining reasonable production in acid soils. There is also an inexpensive calcium containing industrial by product, calcium silicate, which can be used to ameliorate soil acidity. The combination of using calcium silicate, which is inexpensive, together with acid tolerant genotypes may help farmers with limited capital to increase yield.

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CHAPTER 3

Evaluation of the Tolerance of Ten Groundnut (*Arachis Hypogaea. L*)

Genotypes to Soil Acidity

ABSTRACT

Groundnut (*Arachis hypogaea. L.*) is an important subsistence and cash crop for smallholder farmers. When grown in well-drained, light-textured, acid soils characterised by low nutrient levels, manganese and aluminium toxicity and phosphorus fixation, yields are low. The objective of this study was to examine cultivars for tolerance to soil acidity with the aim of selecting suitable genotypes for smallholder farmers without sufficient inputs for ameliorating soil acidity. The effect of soil acidity was assessed on growth, photosynthesis and yield of 10 groundnut genotypes: Anel, Sellie, Harts, Robbie, JL 24, RG784, Jasper, Rambo, Selmina and Billy. The experiment was carried out in pots in a glasshouse with $25 \pm 5^\circ\text{C}$ day and $20 \pm 3^\circ\text{C}$ night temperatures; 65% RH. Inanda soil was used in the study. Treatments consisted of 80%, 40% and 20% acid saturation, respectively. Measurements of plant height, chlorophyll fluorescence, shoot nutrient concentration and yield components were taken. The results showed highly significant reductions ($P < 0.001$) in leaf area and number of nodules by 80% acid saturation; other vegetative growth parameters were not affected to the same extent by high acid saturation. High acid saturation (80%) had negative effects on number of pods, pod weight, kernel weight and sound mature kernels. Genotypes had different response to high soil acidity. Rambo, Billy, Selmina and JL 24 had low shoot Al and high Ca and P concentrations at 80% acid saturation compared with Anel, Sellie, RG784 and Jasper. Rambo, Billy, Selmani and JL 24 also had high vegetative growth measured as leaf area. Therefore

these genotypes (JL 24, Rambo and Selmani) were classified as more tolerant than Anel, Sellie, RG784 and Jasper..

INTRODUCTION

Groundnuts are grown for their nutritious seeds, with 25% to 32% protein and 42% to 52% oil content fresh weight. They are also a good source of vitamins K and Boron (Robertson, 2003). Their high nutritional content is a possible tool for rural communities in the fight against malnutrition. In RSA groundnuts are grown in Mpumalanga, KwaZulu-Natal and Limpopo, mainly for subsistence purposes (Mathews *et al.*, 2007). They are an important cash crop for both smallholder and commercial farmers. Current production of the crop is estimated at 88 000 tonnes for the 2010/2011 production season (Grain SA, 2011).

Groundnuts are best grown in well-drained, light-textured soils (Heiming *et al.*, 1982; Melouk and Shokes, 1995; Swanevelder, 1998) to enable the pegs to penetrate the soil easily and avoid pod discoloration. Most of these light-textured soils are classified as dystrophic or highly weathered and are associated with high soil acidity characterised by low nutrient levels, manganese and aluminium toxicity (Beukes, 1997; Truter, 2007) and phosphorus fixation (Haynes and Mokolabate, 2001). Acid soils cause shallow root development and as a result, plants may become susceptible to mid-summer drought (Truter, 2002).

When adequate lime is applied for the purpose of reducing soil acidity, it may also provide sufficient calcium for pod development (Sumner *et al.*, 1988). Calcitic (CaCO_3) and dolomitic (CaCO_3 , MgCO_3) limes are commonly used for soil acidity adjustment. Lime reduces soil pH,

increases cations like Ca^{2+} and Mg^{2+} , and also corrects deficiency of phosphorus and molybdenum (Brandy and Weil, 1999) and improves nodulation in legumes (Rossum *et al.*, 1994). Large quantities of lime are required to neutralize the soil compared to the basal fertilizer (NPK) needed to increase soil nutrients to meet crop requirements. Besides the large quantities of lime required, there are also other costs associated with transportation, spreading and soil incorporation that make liming challenging and unaffordable to resource-poor farmers with limited capital.

In order for such farmers to produce satisfactory/acceptable yields in acid soils, they must use other alternatives. Among other alternatives such as manure application and supplementation of deficient nutrients, the cheapest option may be planting of cultivars that are tolerant to soil acidity. A tolerant genotype is one which grows better and produces more dry matter and develops fewer deficiency symptoms than others of the same species when grown at low levels of nutrient elements (Clark, 1976). Different crops and cultivars have different sensitivities to soil acidity. Such differences have been reported in soybean (Foy *et al.*, 1992), barley (Foy, 1996), maize (Smalberger and du Toit, 2001), cowpea (Ezehe *et al.*, 2007) and bean (Lunze *et al.*, 2007). Screening different groundnut genotypes and identification of tolerant genotypes may provide a window of opportunity for farmers with limited resources to produce satisfactory yields in acid soils.

The aim of this study was to examine cultivars for tolerance to soil acidity and select suitable genotypes for smallholder farmers who do not have sufficient inputs for ameliorating soil acidity.

MATERIALS and METHODS

Planting material

Ten groundnuts genotypes: Anel, Sellie, Harts, Robbie, JL 24, RG784, Jasper, Rambo, Selmani and Billy were obtained from the Agricultural Research Council (ARC) – Grain Crop Institute, Potchefstroom, South Africa. These were selected because they are commonly grown genotypes resistant to various pod and leaf diseases and also fall in different classification groups i.e. Spanish (Sellie, Robbie, RG784, Anel, JL 24 and Jasper), Valencia (Harts), Virginia (Rambo and Billy) and Runner (Selmani) types grown in South Africa. Table 3.1 shows the description of genotypes and their characteristics in studies not related to soil acidity.

Soil description

The Inanda soil form was collected from a forest field in Hilton at Pietermaritzburg (29°37'S 30°23'E). The soil consists of a humic A horizon with thick dark brown powdery humic sand clay loam and a red apedal B horizon with dark red porous friable sandy clay loam (Soil Classification Working Group, 1991). The Inanda soil form is one of the acidic soils widely found in the high rainfall regions within KwaZulu-Natal and has a humic A horizon of relative low base status that develops in cool climates in high rainfall areas (SASA, 1999). This soil form has good physical properties but has limited agricultural potential due to aluminium toxicity, calcium and magnesium deficiency and high phosphorus fixation (SASA, 1999). The soil is characterised by low cation levels, i.e., highly weathered soil with high acid saturation (about 80%) and exchange acidity of 2.88 cmol/L (Table 3.2).

Table 3. 1: Some known characteristics of the 10 groundnut cultivars that were used in this study as described by Table 3. 144 Van der Merwe and Vermeulen, (1977); Van der Merwer, (1988); Van der Merwe and Joubert, (1995); Swanevelder, (1998). Genotypes largely studied for tolerance to diseases rather than to soil acidity.

Cultivar	Botanical type and Growth period	Characteristics
Sellie	Spanish (150 days)	Cross between Natal common and Narmark. High percentage of kernel oil.
Harts	Valencia (120 days)	Resistant to black hull and stem rot. Short growing season.
Robbie	Spanish (150 days)	Resistant to Black hull and stem rot.
Selmani	Runner (150 days)	One of two runners grown in RSA. Resistant to Pod nematode, black hull and botrytis stem rot.
Anel	Spanish (150 days)	Drought tolerant. Resistant to pod nematode and black hull.
JL24	Spanish (150 days)	Popular cultivar with small holder farmers but susceptible to leaf diseases.
Billy	Virginia (180 days)	Late leaf spot, Rust and Web blotch. Resistant to pod nematode and black hull
Rambo	Virginia (170 days)	Large seeded type acceptable for oil extractin. High oil content.
RG 784	Spanish(150 days)	Prescribed as acid tolerant by ARC.
Jasper	Spanish (150 days)	Cross between Sellie and Harts. Resistant to pod nematode, black hull, botrytis stem rot and sclerotinia.

Table 3. 2: Chemical characteristics of Inanda soil form used in the study

Property	Composition
pH (KCl)	3.95
Acid saturation	79.5 %
Total cation	3.65cmol/L
Exchange acidity	2.88cmol/L
Phosphorus	17mg/L
Potassium	39 mg/L
Calcium	98.5mg/L
Magnesium	20.5mg/L
Zinc	7.75mg/L
Manganese	8.5mg/L
Copper	2.5mg/L

Experimental Design

The experiment was carried out in a glasshouse set to 25± 5°C day and 20± 3 °C night temperatures 65% RH and natural day length and light, from June to December 2009. The experimental layout was a split plot design with liming treatments as main plots and cultivars as subplot treatments. The treatments were replicated three times.

Liming treatments

The lime source used was calcium hydroxide $\text{Ca}(\text{OH})_2$ with a calcium carbonate equivalent (CCE) of 139 instead of calcitic or dolomitic lime because it reacts faster. Treatments consisted of a control with 80 % acid saturation (no lime), 40 % acid saturation (1.53 g of lime per kg of soil) and 20 % acid saturation (3.2 g of lime per kg of soil). Air-dried soil was thoroughly mixed with calcium hydroxide using a soil mixer. Each 25 cm diameter and 20 cm high pot was filled with 3 kg of the mixture. Fertilizer was applied as 38 mg of ammonium nitrate and 152 mg of potassium phosphate per kg of soil equivalent to 20 kg N ha⁻¹, 20 kg P ha⁻¹ and 85 kg K ha⁻¹ recommended from soil analysis. Magnesium sulphate (MgSO_4) was applied at 260 mg pot⁻¹ to treatments receiving lime to overcome magnesium deficiency. MgSO_4 was not applied in the control treatments. Pots were watered manually and placed in a glasshouse. After two days 4 seeds were planted per pot. Seedlings were thinned to two per pot at 14 days after planting. Soil was kept moist throughout the experiment by daily manual irrigation as necessary.

Pest and disease management

The crop was sprayed with Agromectin[®] (18g/L abamectin) at 6 ml per 10 L against red spider mites at 90 days after planting.

Data collection

Plant height was measured at weekly intervals from 14 days after planting until 50% of plants flowered. One plant per pot was harvested at flowering. These were cut at the base and dried

at 65 °C for 48 h to determine dry weight and dried samples were analysed for N, P, K, Ca, Mg, Al, Fe, Cu, Zn and Mn concentrations.

Nutrient uptake was calculated as nutrient concentration × dry matter.

Agronomic use efficiency was calculated as:

$$AEU = \frac{(Y_l - Y)}{\text{Amount of Lime}} \quad \text{Equation 2.1}$$

Where AUE = agronomic use efficiency,

Y_l = yield with lime applied, and

Y = yield with no lime

Photosynthesis efficiency was measured using a plant efficiency analyser (PEA) (Hansa tech Instruments Ltd, Norfolk, England). The readings were taken in the morning 9h00 ± 30 min, South African time. Young fully-expanded leaves were dark adapted for 30 min before measurement. Measurements of F_v/F_m were then made, where F_v is the magnitude of the variable fluorescence and F_m is the fluorescence emission reached its maximum fluorescence.

Matured plants were harvested and separated into shoots, roots and pods. The shoots were oven dried at 65°C for 48 h to determine dry mass. The nodules were removed at maturity by hand from roots and total number of nodules per plant recorded before drying. The numbers of pods per plant, weight of pods per plant, kernel weight, shelling percentage and sound mature kernels were determined. Soil samples were collected after pod maturity for determination of pH, acid saturation, N, P, K, Ca, Mg, Mn, Fe, and Cu concentrations. The pH

was determined in potassium chloride (KCl) solution, while P, K, Mn and Cu were extracted with NH_4HCO_3 . Exchangeable acidity, Ca and Mg were extracted with KCl.

Data analysis

Data were subjected to analysis of variance (ANOVA) using the GenStat[®] statistical package (Version 12, VSN International Ltd, UK). Least significant difference (LSD) ($P>0.05$) was used to separate treatment means.

RESULTS

Plant growth

Plant height differed significantly ($P<0.001$) between cultivars (Fig 3.1), however there was no reduction ($P>0.05$) in response to increased soil acidity. Selmani and Rambo were the tallest plants at 46.34 and 37.10 cm, respectively. Anel, Billy, and Harts ranged between 32.68 and 35.80 cm; Robbie, JL 24, RG784, and Sellie were the shortest. There was a highly significant interaction ($P<0.001$) between genotypes and treatments as cultivars exhibited distinctive height growth habits. For all genotypes, soil acidity had no significant effect ($P>0.05$) on shoot dry mass. However, dry mass differed significantly ($P<0.001$) between genotypes (Table 3.3). Shoot dry mass of Virginia varieties, Rambo, Billy and Selmani was high ranging between 1.58 g and 1.17 g per plant compared with RG784, Jasper and Robbie ranged from 0.70 g to 0.94 g. There was no significant ($P>0.05$) interaction between genotypes and lime treatments in respect of dry mass.

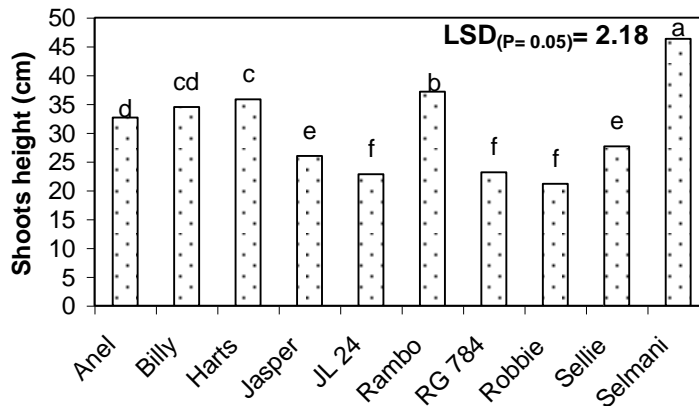


Figure 3. 1: Shoot height of different genotypes in response to different soil acidity treatments.

Nodulation

There was a highly significant interaction ($P < 0.001$) between varieties and soil acidity with respect to nodule development (Table 3.3). High soil acid saturation significantly ($P < 0.05$) reduced the number of nodules per plant. At 20% and 40% acid saturation Rambo, JL 24 and RG784 had the highest number of nodules (Table 3.3). At 80% acid saturation no nodule production occurred in any cultivar.

Leaf area

Leaf area was reduced significantly by high soil acid saturation (Table 3.3). Plants grown at acid saturation of 80% had a leaf area of 96.7 cm^2 compared with 128.5 and 144 cm^2 at 40% and 20%, respectively. Leaf area also differed significantly ($P < 0.001$) with genotypes, with Billy and Rambo having the highest values of 175.1 cm^2 and 158.5 cm^2 , respectively. There was no significant interaction between cultivars and treatments in respect of leaf area.

Photosynthetic efficiency

Chlorophyll fluorescence differed significantly ($P < 0.001$) between genotypes (Table 3.3). Anel had a relatively low CF (0.78) compared with the other genotypes which ranged from 0.81 to 0.83. There was no significant interaction between cultivars and treatments. Different levels of acid saturation had no significant ($P > 0.05$) effect on photosynthetic capacity of groundnut.

Yield and Yield components

There was a highly significant ($P < 0.001$) increase in pod mass per plant, number of pods per plant and kernel weight in response to liming (Table 3.4). However, there was no significant difference ($P > 0.05$) between the 20 and 40% acid saturation levels with respect to yield components. For the yield components measured, there was no significant interaction ($P > 0.05$) between soil acidity and cultivars. Cultivars had significant ($P < 0.001$) differential response to acid saturation in respect of yield components. At 20% acid saturation RG784 had the highest pod mass (9.96 g) while Billy had the lowest (6.66 g). RG784 had a high kernel mass (9.70 g) while Billy had the lowest (5.67 g). At 80% acid saturation plants were stunted with few pods per plant but there were no empty pods (pops) observed. The 40% acid saturation level produced plants with vigorous growth, and few pops were observed in Harts only. At 80% acid saturation 56% of pods were single-seeded and single pods decreased to 28% with liming (Fig 3.2). Anel and Sellie had the most single-seeded pods when grown at 80% acid saturation. Rambo, Billy and RG 784 had double seeded pods at 80% acid saturation (Fig 3.2).

Table 3. 3: Response of shoot dry mass, nodule number, leaf area and photosynthetic efficiency of groundnut genotypes to soil acidity

Treatments	Genotypes	Shoot dry mass (g)	Nodules No./plant	Leaf area (cm ²)	CF (Fv/Fm)
80% acid saturation	Anel	0.69c	No. nodules	88.1b	0.803a
	Harts	1.37ab		128.3ab	0.839a
	Jasper	0.77bc		76.1b	0.836a
	JL 24	0.97abc		135.7ab	0.824a
	RG 784	0.68c		68.7b	0.829a
	Robbie	0.66c		83.9ab	0.827a
	Sellie	1.17abc		129.5ab	0.786a
	Billy	1.32ab		136.6ab	0.788a
	Rambo	0.94abc		132.6ab	0.828a
	Selmani	0.96abc		12.6b	0.836a
40% acid saturation	Anel	1.19abc	20.7e	135.1ab	0.759b
	Harts	1.69a	27.7de	177.5a	0.838a
	Jasper	0.56c	15.3e	74.9b	0.843a
	JL 24	1.31ab	64.3bc	163.8a	0.833ab
	RG 784	0.69c	79.7ab	84.3b	0.825ab
	Robbie	0.64c	13.3e	74.2b	0.810ab
	Sellie	1.03abc	11.3e	120.2ab	0.813ab
	Billy	1.46ab	87.0a	181.1a	0.839a
	Rambo	1.27abc	18.0e	161.7ab	0.793ab
	Selmani	0.97bc	44.7cd	100.1ab	0.828ab
20% acid saturation	Anel	1.33abc	32.0de	148.3abc	0.769ab
	Harts	1.31abc	46.3de	129.8bc	0.761b
	Jasper	1.49ab	14.0e	189.4a	0.8256ab
	JL 24	1.12bc	68.0cd	145.7abc	0.824ab
	RG 784	0.78c	114.0a	103.8c	0.824ab
	Robbie	0.81c	17.5e	74.7c	0.819ab
	Sellie	1.31abc	17.3e	153.9ab	0.819ab
	Billy	1.87a	108a	207.5a	0.827ab
	Rambo	1.36ab	24.7de	181.2ab	0.829ab
	Selmani	1.62a	82.3bc	105.3bc	0.839a
P		0.32	<.001	0.26	0.82
LSD_(P= 0.05)¹		0.40	12.80	43.59	0.04
LSD_(P= 0.05)²		0.22	7.01	23.88	0.02
LSD_(P= 0.05)³		0.67	22.16	75.5	0.08

Note: CF = chlorophyll fluorescence. Values in the same column not sharing the same letter differ significantly at LSD (P = 0.05).

LSD¹ = cultivars, LSD² = treatments, LSD³ = interaction

Table 3. 4: Yield and yield components of ten genotypes subjected to different levels of soil acidity.

Treatment	Genotypes	Pod mass		Kernel	Shelling (%)	SMK (%)
		FW/plant (g)	Pod No./plant	mass/plant (g)		
80% Acid saturation	Anel	6.37	6.33bc	5.24ab	80.72a	97.6a
	Harts	5.67	5.33bcd	4.51ab	79.12ab	68.8bc
	Jasper	3.12	3.33cd	2.23b	69.96ab	60.0c
	JL 24	6.69	6.00bc	5.33ab	78.67ab	91.1a
	RG 784	5.13	4.00cd	3.70ab	70.9ab	84.6ab
	Robbie	6.35	8.17ab	4.61ab	69.18b	96.3a
	Sellie	7.39	10.33 a	5.78a	78.12ab	70.8bc
	Billy	3.91	3.00d	2.87b	67.18b	100.0a
	Rambo	7.07	3.67cd	4.59ab	65.46b	61.1c
	Selmani	5.97	3.33cd	4.78ab	81.23a	100.3a
40% acid saturation	Anel	10.23	10.33a	8.09a	79.19ab	95.6a
	Harts	9.37	9.67a	7.54ab	80.76a	86.0ab
	Jasper	10.32	9.00ab	8.26a	80.8a	89.1ab
	JL 24	9.57	8.67abc	7.83a	82.28a	91.5a
	RG 784	11.26	9.00ab	8.75a	77.63ab	98.2a
	Robbie	8.21	9.00ab	6.50ab	78.95ab	89.9ab
	Sellie	7.62	8.33abc	5.94ab	77.6ab	97.7a
	Billy	6.44	4.00d	4.61b	71.39ab	100.0a
	Rambo	8.82	5.33cd	6.39ab	71.64ab	59.4c
	Selmani	8.87	6.33bcd	5.95ab	68.24b	70.7bc
20% acid saturation	Anel	11.24	11.67ab	9.01ab	79.97a	96.0a
	Harts	11.06	11.33ab	8.63ab	78.46a	92.1a
	Jasper	11.49	9.67bc	8.89ab	77.55a	98.0a
	JL 24	10.43	9.00bc	8.40ab	80.54a	95.6a
	RG 784	12.71	10.33bc	9.78a	76.95a	96.1a
	Robbie	8.91	11.67ab	6.77bc	75.78ab	97.0a
	Sellie	9.92	14.33a	7.44abc	75.05ab	94.1a
	Billy	6.66	5.00d	4.96c	73.79ab	100.0a
	Rambo	9.96	5.33d	6.52bc	64.79b	65.8bc
	Selmani	9.97	8.00cd	7.12abc	70.95ab	82.0ab
P		0.58	0.15	0.49	0.50	0.02
LSD_(P=0.05)¹		2.12	1.90	1.70	6.30	11.18
LSD_(P=0.05)²		1.16	1.02	2.95	3.46	6.12
LSD_(P=0.05)³		3.67	3.23	2.95	10.946	19.36

Note: values in the same column not sharing the same letter differed significantly at LSD_(P=0.05). LSD¹= cultivar, LSD² = treatments, LSD³ = Interaction

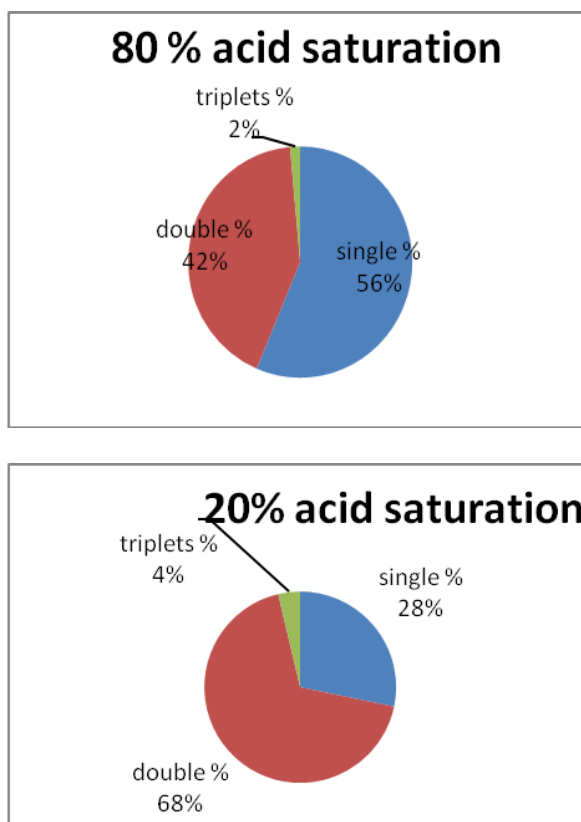


Figure 3. 2: Effect of 20% and 80% soil acid saturation on number of seeds per pod

Shelling percentage and sound mature kernels

Soil acidity had no significant effect ($P > 0.05$) on shelling percentage. However, there were significant ($P < 0.05$) differences among the genotypes (Table 3.4). High soil acid saturation significantly ($P < 0.05$) decreased the percentage of sound mature kernels (SMK). At 80% acid saturation, the average SMK was 83.1%, increasing to 87.8% and 91.7% at 40% and 20% acid saturation, respectively. The genotypes significantly differed ($P < 0.05$) with respect to SMK and at 80% acid saturation, Rambo had the lowest value (61.1%) while Billy had the highest 100%.

Macro nutrients: N, P, K, Ca and Mg concentration in shoots

The P and K concentrations in shoots were reduced significantly ($P < 0.05$) by high soil acidity (Table 3.5). Nitrogen was not significantly affected by application of lime. The response also differed significantly with cultivars. Under 20% acid saturation, Rambo shoots had the highest N concentration (3.36%) while Selmani and Sellie had the lowest (2.6%). Robbie had the highest P concentration (0.15%) while Billy had the lowest (0.08%) with 20% acid soil (Table 3.5). The K concentration was highest in Robbie (1.91%) and lowest (1.16%) in Billy and Rambo (Table 3.5). There was no significant interaction ($P > 0.05$) between cultivars and treatments, with N, P, and K.

Application of calcitic lime resulted in a sharp ($P < 0.001$) increase of Ca concentration in shoots (Table 3.5). Plants grown at 80% soil acid saturation had low Ca concentrations compared to those grown at 40% and 20% acid saturation (Table 2.5). There was a significant difference in Ca concentration ($P < 0.001$) amongst genotypes with Jasper, Harts, Robbie and Selmani having the lowest values (between 1.15 and 1.26%), while other genotypes had higher values between 1.4 and 1.6%. The genotypes with the highest tissue Ca concentration were Rambo and RG784. There was no significant interaction ($P > 0.05$) between genotypes and lime treatments, with respect to Ca concentration (Table 3.5).

The Mg concentration differed amongst the genotypes (Table 3.5) with the lowest values associated with Harts (0.39%), Robbie (0.37%) and Sellie (0.39%), while RG784, Rambo and Billy had highest Mg concentration of 0.48, 0.5, and 0.45%, respectively. There was no significant ($P > 0.05$) interaction between cultivars and treatments with respect to Mg concentration in groundnut shoots.

Table 3. 5: Shoot nutrient concentrations of 10 groundnut genotypes grown at 80%, 40% and 20% soil acid saturation.

Treatments	Genotypes	N %	P %	K %	Ca %	Mg %
80% acid saturation	Anel	3.64	0.09	1.56	0.74	0.42
	Harts	3.00	0.10	0.77	0.84	0.39
	Jasper	2.95	0.09	1.07	1.21	0.47
	JL 24	3.43	0.09	1.40	1.04	0.40
	RG 784	3.26	0.10	1.48	1.11	0.54
	Robbie	2.89	0.09	1.33	1.11	0.40
	Sellie	3.28	0.09	1.35	1.10	0.47
	Billy	3.01	0.08	1.20	1.20	0.52
	Rambo	3.35	0.08	1.27	1.27	0.55
	Selmani	2.41	0.07	1.40	1.40	0.37
40% acid saturation	Anel	3.21	0.10	1.55	1.50	0.41
	Harts	2.69	0.09	1.40	1.34	0.44
	Jasper	2.91	0.09	1.67	1.25	0.41
	JL 24	2.26	0.09	1.24	1.43	0.39
	RG 784	2.96	0.09	1.35	1.75	0.49
	Robbie	2.65	0.16	1.92	1.25	0.36
	Sellie	2.76	0.09	1.37	1.50	0.35
	Billy	3.00	0.10	1.55	1.26	0.44
	Rambo	3.02	0.11	1.01	1.56	0.46
	Selmani	3.06	0.12	1.36	1.62	0.50
20% acid saturation	Anel	3.33	0.10	1.48	1.66	0.37
	Harts	2.89	0.09	1.36	1.60	0.35
	Jasper	2.82	0.17	1.74	1.39	0.44
	JL 24	2.86	0.10	1.60	1.74	0.43
	RG 784	2.93	0.11	1.41	2.07	0.43
	Robbie	3.30	0.15	1.91	1.34	0.35
	Sellie	2.60	0.08	1.24	1.87	0.36
	Billy	2.88	0.08	1.16	1.86	0.40
	Rambo	3.36	0.09	1.16	1.90	0.48
	Selmani	2.62	0.11	1.73	1.39	0.44
P	Genotypes ×AS	<0.001	<0.001	0.025	0.246	0.261
	Genotypes	<0.001	<0.001	0.012	<0.001	0.002
	AS	<0.001	<0.001	<.001	<0.001	0.020
LSD_(P=0.05)	Interacton	0.43	0.029	0.43	0.37	0.11
CV%		8.7	17.4	18.5	16.2	15.4

Note: AS = acid saturation

Aluminium

There was a highly significant ($P < 0.001$) difference in response of genotypes with respect to shoots Al concentration (Figure 3.3). Billy, Rambo and Selmani had the lowest shoot Al concentration ($350\text{-}739\text{ mg kg}^{-1}$), followed by Anel, JL 24 and RG784 (approximately 1800 mg kg^{-1}), while Robbie, Sellie, Jasper and Harts had the highest ($2300\text{ to }3600\text{ mg kg}^{-1}$). Aluminium concentration was significant ($P < 0.001$) reduced by application of lime and there was no significant ($P > 0.05$) interaction between acidity and genotypes in respect of Al concentration.

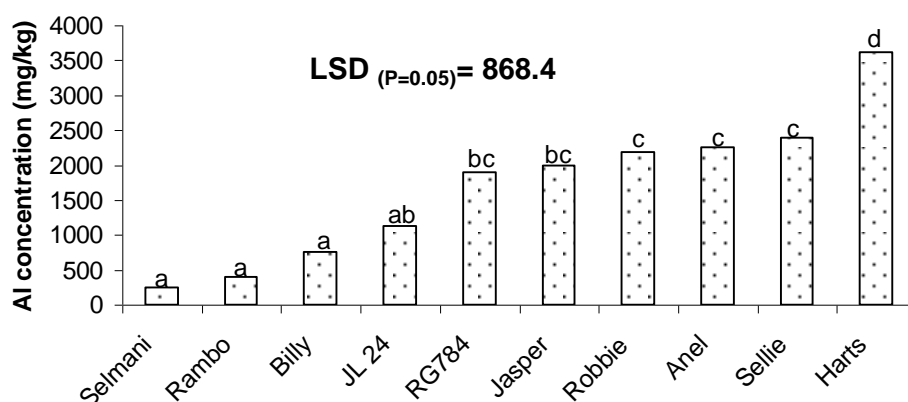


Figure 3. 3: Effect of soil acidity on shoot Al concentration of 10 groundnut genotypes.

Manganese

There was a significant ($P < 0.05$) interaction between cultivars and treatments with respect to Mn concentration. Robbie had the lowest (295 mg/kg) Mn concentration at 80% acid saturation while other genotypes ranged from $462\text{ to }817\text{ mg/kg}$ (Table 3.6). The tissue Mn concentration differed with genotypes. Jasper (392 mg/kg), Rambo (328 mg/kg) and RG784 (326 mg/kg) had the highest Mn concentration compared with Harts (259 mg/kg), JL 24 (230

mg/kg) and Robbie (181 mg/kg). Manganese concentration was reduced significantly by lime application from a mean of 607 mg/kg at 80% acid saturation, to 88 mg/kg at 20% acid saturation

Table 3. 6: Manganese concentration of 10 groundnut genotypes grown at 80, 40, and 20% acid saturation.

Genotypes	80% acid saturation	40% acid saturation	20% acid saturation
Jasper	817	260	99
Billy	780	208	65
Rambo	739	161	85
Sellie	633	187	96
RG784	646	233	98
Anel	595	210	73
Selmani	555	275	72
Harts	544	146	86
JL 24	462	127	101
Robbie	295	140	108
LSD ($P=0.05$) = 182.2 (Interaction)			

Iron and Copper

The Fe concentration was high for all treatments; there were highly significant ($P<0.001$) differences between genotypes (Fig 3.4). Harts (3224 mg/kg), Anel (1816 mg/kg) and Robbie (1703 mg/kg) had the highest Fe concentration, while Rambo (935 mg/kg), Billy (796 mg/kg) and Selmani (553 mg/kg) had the lowest. Concentration of Cu decreased significantly ($P<0.05$) in response to decreasing soil acid saturation (Fig 3.5). There were, however, no differences between the cultivars.

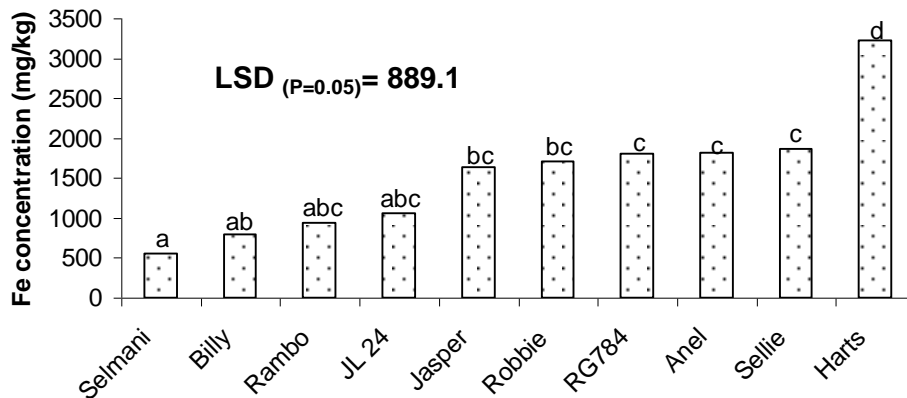


Figure 3. 4: Mean shoot Fe concentration of 10 different groundnut cultivars grown in acid soils.

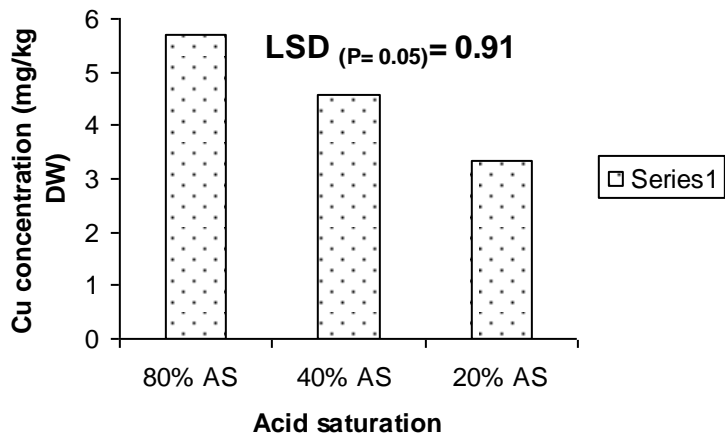


Figure 3. 5: Effect of soil acidity on shoot Cu concentration

Macro-nutrient (N, P and K) uptake

Application of lime had little effect ($P > 0.05$) on N uptake. Nitrogen uptake differed significantly ($P < 0.05$) among genotypes (Table 3.7). Billy, Harts and Rambo had the highest

N uptake from 38.3 to 45.3 mg per plant followed by Anel, Sellie and Selmani which ranged between 31.4 to 35.9 mg per plant and the lowest were Jasper, RG784 and Robbie from 21.00 to 26.10 mg per plant. Most of the genotypes with high N uptake had low Al uptake. There was no significant interaction ($P>0.05$) between genotypes and lime treatments. Phosphorus uptake was not increased significantly ($P>0.05$) as soil acid saturation decreased (Table 3.7). There was no significant difference between the cultivars in respect of P uptake. There was also no significant interaction between genotypes and treatments (Table 3.7). Potassium uptake was not significantly increased ($P>0.05$) in response to reduced soil acidity; at 80% acid saturation K (13.23 mg per plant) uptake had no significant difference as compared to the 40% and 20% acid saturation treatments with 15.34 and 17.64 mg per plant, respectively.

Ca and Mg uptake

Calcium uptake increased significantly ($P<0.05$) with decreasing soil acid saturation (Table 3.7). Calcium uptake was lower (10.22 mg per plant) at high acid saturation but increased to 15.72 mg per plant at 40% acid saturation and 20.43 mg per plant 20% acid saturation, following soil ameliorations. At 20% acid saturation, the genotypes Billy (22.85 mg per plant) and Rambo (18.53 mg per plant) had higher Ca uptake followed by Harts and Sellie (17.9 mg per plant), JL 24 (16.7 mg per plant) and Anel (15.9 mg per plant) while RG784 (11.7 mg per plant) and Robbie (8.5 mg per plant) had the lowest Ca uptake. There was no significant interaction between genotypes and Ca uptake.

Application of lime had no significant ($P>0.05$) effect on Mg uptake (Table 3.7). However, Mg uptake differed significantly amongst the genotypes. Billy, Harts, Rambo and Selmani

had high Mg uptake between 6.8 mg per plant and 5.13 mg per plant on the other had Robbie and RG784 had lowest values between 3.5 and 2.6 mg.

Aluminium and manganese uptake

Aluminium uptake was highest ($P < 0.05$) at high acid saturation (Table 3.7), with significant ($P < 0.05$) differences among genotypes. Harts, Anel, Robbie and Sellie had the highest Al uptake from 2.6 to 5.07 mg per plant, while Rambo and Selmani had the lowest Al uptake of 0.58 and 0.18 mg per plant, respectively. There was no significant ($P > 0.05$) interaction between genotypes and lime treatments, with respect to Al uptake (Table 3.7). Uptake of Mn decreased significantly ($P < 0.05$) with decreasing soil acid saturation (Table 3.6). It also differed with genotypes. Billy (0.47 mg per plant) and Selmani (0.4 mg) had the highest Mn uptake while Robbie (0.118 mg per plant) had the lowest. There was a significant ($P < 0.05$) interaction between cultivars and treatments with respect to Mn uptake.

Correlation between dry matter and yield on N, P, K, Ca, Mg, Mn and Al uptake

There was a highly significant positive correlation between dry matter and uptake of Ca, N, P and K nutrient (Fig 3.6). There was no significant correlation between individual nutrients with respect to yield.

Table 3. 7: Effect of varying acid saturations on nutrient uptake per plant of 10 groundnuts genotypes.

Elements	Genotypes	N mg	P mg	K mg	Ca mg	Mg mg	Al mg	Mn mg
80% saturation	Anel	24.9	0.68	11.14	7.98	2.96	0.94	0.44
	Harts	40.4	1.33	10.31	9.69	5.39	6.41	0.76
	Jasper	22.9	0.68	8.36	6.33	3.62	1.66	0.63
	JL 24	34.3	0.95	15.04	11.69	4.25	1.07	0.51
	RG 784	22.1	0.69	9.93	7.48	3.68	2.21	0.44
	Robbie	23.2	0.73	10.59	8.57	3.23	2.77	0.24
	Sellie	38.4	1.00	15.68	13.91	5.48	3.78	0.73
	Billy	39.7	1.06	16.02	14.22	6.84	1.39	1.02
	Rambo	31.6	0.76	11.98	10.43	5.15	0.45	0.70
	Selmani	39.0	1.19	23.23	11.91	5.96	0.04	0.95
40% acid saturation	Anel	38.4	1.26	18.62	17.56	4.72	3.88	0.24
	Harts	45.6	1.55	23.72	23.21	6.80	3.91	0.23
	Jasper	16.1	0.47	10.02	6.33	2.40	1.51	0.14
	JL 24	30.4	1.41	16.35	19.31	5.20	1.02	0.16
	RG 784	20.5	0.65	9.15	12.16	3.32	1.23	0.16
	Robbie	17.1	1.12	13.33	7.97	2.29	1.53	0.07
	Sellie	28.5	0.91	14.25	15.19	3.58	2.73	0.19
	Billy	42.8	1.36	21.52	20.12	6.23	1.52	0.29
	Rambo	38.8	1.11	13.83	18.92	5.52	1.41	0.19
	Selmani	30.0	1.04	12.60	16.40	5.08	1.36	0.24
20% acid saturation	Anel	44.4	1.35	19.60	22.14	4.85	3.12	0.09
	Harts	37.7	1.14	17.67	20.91	4.59	4.89	0.09
	Jasper	41.0	1.88	25.61	19.34	6.70	1.45	0.16
	JL 24	31.9	1.10	17.75	19.42	4.75	1.94	0.11
	RG 784	23.0	0.84	10.72	15.38	5.77	1.55	0.07
	Robbie	22.8	1.06	13.64	8.94	3.60	1.62	0.05
	Sellie	34.0	1.11	16.16	24.61	2.33	1.79	0.14
	Billy	53.5	1.50	21.81	34.21	7.46	2.10	0.12
	Rambo	46.1	1.15	15.98	25.84	4.57	0.44	0.13
	Selmani	25.2	1.05	17.41	13.46	4.34	3.61	0.02
P		0.673	0.01	0.19	0.51	0.39	0.27	0.02
LSD_(P=0.05)³		21.05	0.82	10.22	11.42	2.81	2.63	0.25
CV%		39.0	45.6	40.3	44.9	36.4	75.5	48.4

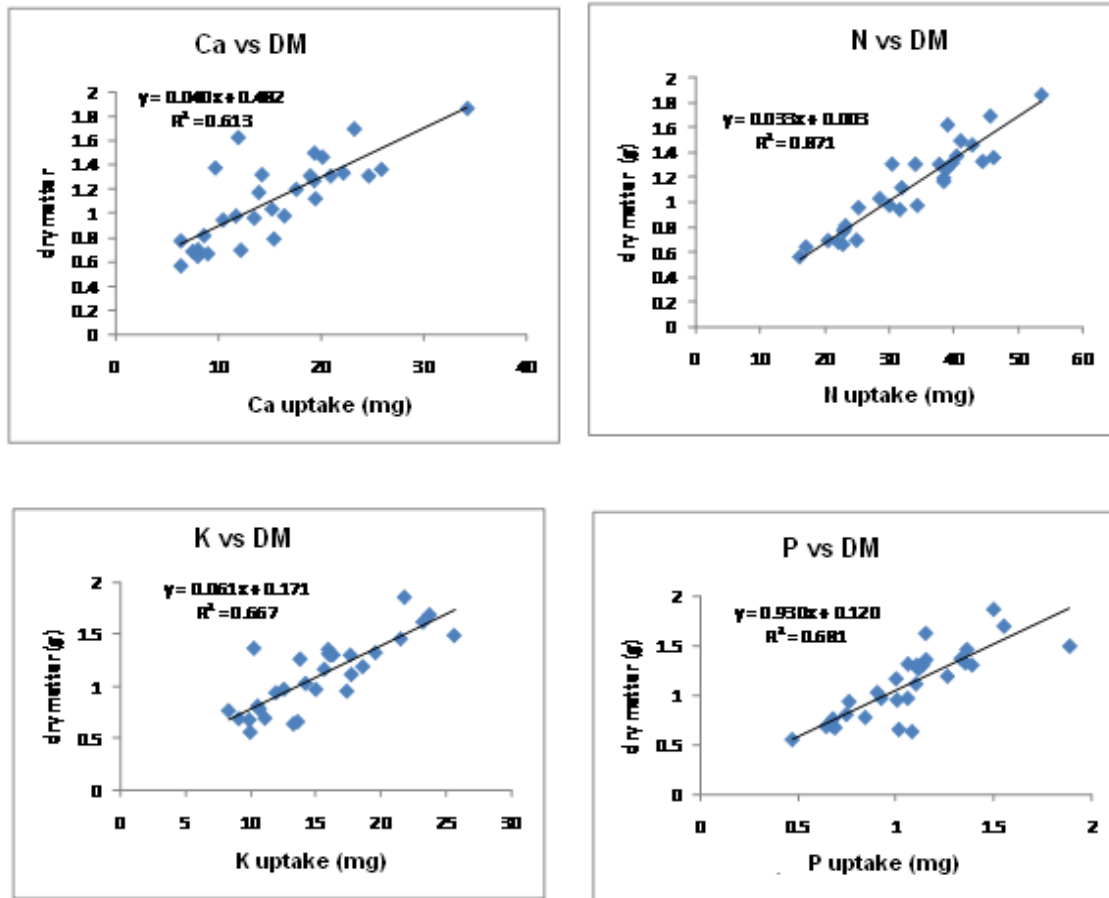


Figure 3. 6: Correlations between shoot dry matter (DM) and macro-nutrients N, P, K and Ca uptake of groundnut.

Differential responses of genotypes to soil acidity

Both Al and Ca concentrations of shoots differed significantly with genotypes. The genotypes with high shoot Ca concentration and lower shoot Al concentration may be tolerant to soil acidity and those with low Ca and high Al shoot concentration may be classified as susceptible to soil acidity. Hence, genotypes like Rambo, Billy, Selmani and JL 24 with high shoot Ca and lower shoot Al concentration may be described as tolerant to soil acidity (Table 3.8). Also the

physical observation of growth characteristics the genotypes may be an indicator of their response to high soil acidity.

Table 3. 8: Tissue concentration of Al, Ca and physical appearance of ten groundnut genotypes grown at 80% acid saturation and possible tolerance/susceptibility classification criteria.

Genotypes	Al concentration (mg/kg)	Ca concentration (%)	Physical appearance	Susceptibility
Harts	3618	0.74	Pale green & older leaves senescence	Susceptible
Jasper	2826	0.84	Few yellow leaves	Susceptible
Sellie	2389	1.21	Leaf senescence	Susceptible
Robbie	2215	1.04	Few pale leaves & leaf senescence	Susceptible
RG 784	1896	1.11	Leaf rust, no brunches	Susceptible
Anel	1722	1.11	Leaf senescence	Susceptible
JL 24	999	1.10	Leaf senescence, vigorous growth	Moderately tolerant
Billy	739	1.20	Healthy leaves	Tolerant
Rambo	417	1.27	Healthy leaves	Tolerant
Selmani	350	1.40	Healthy leaves	Tolerant

Nutrient use efficiency

Nutrient use efficiency was determined as agronomic use efficiency of all cultivars. The response of groundnut genotypes to different lime applications showed that 40% acid saturation supply sufficient Ca compared with 20% acid saturation. (Fig 3.8). Eight of ten genotypes had a high agronomic efficiency.

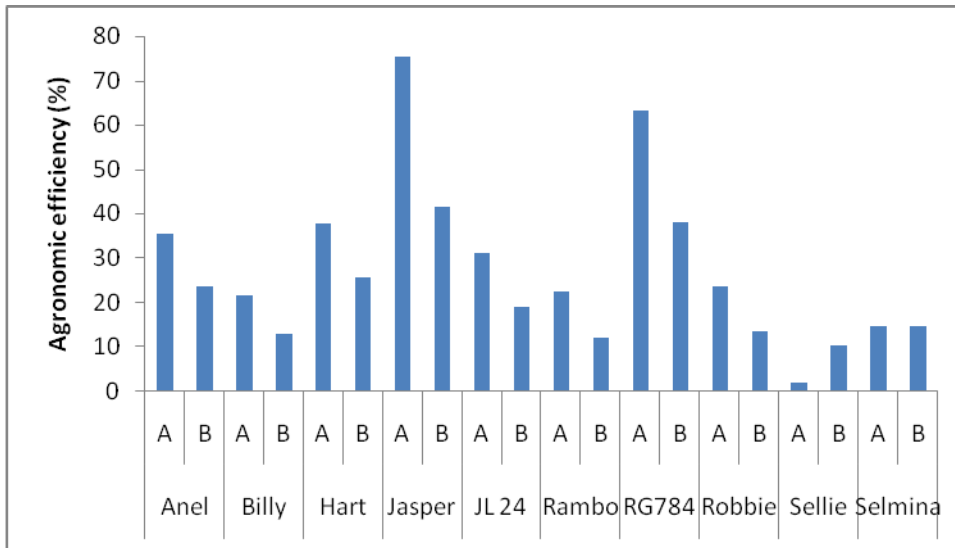


Figure 3. 6: Nutrient use efficiency of groundnut genotypes, as determined by agronomic use efficiency, in response to lime application at A (40% acid saturation) and B (20% acid saturation).

DISCUSSION

There is evidence suggesting that groundnuts are moderately tolerant to soil acidity and aluminium toxicity (Adams and Pearson, 1976; Munns and Fox, 1977; Foster *et al.*, 1980), however, results of the current study suggest that soil acid saturation of 80% significantly reduces groundnut growth as measured by plant height, leaf area and dry matter as compared with soils of 40% and 20% acid saturation. The results are consistent with those of Blamey and Chapman (1982) who reported a decrease in plant height due to nutrient imbalances, especially phosphorus in acid soils. The increased growth observed for three genotypes, JL 24, Rambo and RG784 at 40 and 20%, may have been due to an increase in number of nodules such an increased be dependent upon availability of nutrients especially nitrogen.

Although 80% acid saturation reduced crop growth measured as plant height, the current results show that photosynthesis efficiency of groundnut genotypes, as measured by CF, was not affected by soil acidity. Soil acidity was found to reduce yield components in all genotypes. For most yield components, JL 24 and Anel performed better than the other genotypes. Increase in calcium and nutrients like P and Mg in response to liming was associated with increased yield and yield components in groundnut plants.

Exposure to soil acidity resulted in reduced shoot dry matter which led to formation of fewer pods. Phakamas *et al.* (2008) reported that a reduction in shoot dry matter accumulation resulted in reduced number of pods. Different groundnut genotypes exhibited different growth patterns. High vegetative growth as well as nutrient uptake and reduced shoot Al concentration of Billy, Rambo, Selmani (the Virginia varieties) and JL 24 was observed at 80% acid saturation compared with other Spanish genotypes Jasper, Harts, Anel, Sellie, RG784 and Robbie.. These attributes make these genotypes suitable for consideration as tolerant to acidity. Generally, Virginia varieties (Billy, Rambo and Selmani) have a large canopy, mature late and have higher yields than Spanish varieties JL 24, Sellie, Harts, Anel, Jasper and RG784. (Smartt, 1994) However, in this study, the Virginia varieties did not produce high yields compared with the Spanish types. Pots size (25 cm) might have contributed to reduced yield of Virginia varieties since they produce their pods along the branches not on main stem like the Spanish types. The reduced percentage of sound mature kernel in Rambo, for example, may have resulted from being harvested prior to maturity. Thus, these acid tolerant cultivars may not have been given the opportunity to express their full potential in acid conditions, an artefact of experimental procedure rather than cultivar characteristics. Results of nodule number showed that 80% acid saturation significantly affected nodulation in all

genotypes (Table 3.3). Rossum *et al.* (1994) reported that some *Bradyrhizobium* species may be completely ineffective under acidity stress. The absence of nodules at 80% acid saturation is consistent with reports on soybean (Buerkert *et al.*, 1990) and common bean (Vassileva *et al.*, 1997) that soil acidity reduces nodule development. Genotypes with low Al concentration (Rambo, Selmani and Billy) that are presumably tolerant to acidity had high dry matter and number of nodules. A negative effect of soil acidity on nodule development has been reported in soybean (Mengel and Kamprath, 1978), groundnuts (Shamsuddin *et al.*, 1991; Rossum *et al.*, 1994), common bean (Vassileva *et al.*, 1997) and cowpea (Kenechukwe *et al.*, 2007).

Sufficient nutrient concentration of groundnut shoot at 40 days after planting in percentage of dry matter are reported as: 3.3 – 3.9 N, 0.15 – 0.25 P, 1.0 – 1.5 K, 0.3 Mg and 2.0 Ca (Plank, 1989). According to this baseline, N, K and Mg were adequate for normal groundnut growth in all treatments (Table 3.5). However, Ca and P were deficient in 80% acid saturation with P continued to be deficient even after lime application. Genotypes like Rambo, Billy, Selmani and JL 24 had high Ca concentration at 80% acid saturation compared with others (Table 3.7). Therefore the growth reduction may be due to deficiency of Ca and P. This supported the view that reduced growth of groundnut in acid soil may be caused by deficiency of P as reported by Blamey and Chapman (1982). The highly positive correlation between nutrient uptake and shoot dry mass also emphasis the findings (Fig 3.7).

Soil acidity increases the availability of Fe, Mn, Cu, and Al with Al and Mn reaching toxic concentrations in plants (Foth and Ellis, 1997). High concentration of all these elements in the shoot at 80% acid saturation in this study supports the statement. Aluminium and Mn toxicities are the most important limiting factors to plant growth in acid soils (Foy, 1984;

Baligar and Fageria, 1997). According to Plank (1989) sufficient shoot concentrations of Al and Mn must be less than 200 mg kg⁻¹ and 50 – 300 mg kg⁻¹, respectively at flowering. Virginia and runner genotypes, Rambo, Billy and Selmani had low Al uptake; similar results were also reported by Fageria *et al.* (2009) that large-seeded cultivars appeared to tolerate soil acidity better than small seeded cultivars. The Mn concentration was very high in leaves at 80% acid saturation but decreased after lime addition. Besides N and P deficiency the reduction in vegetative growth at 80% acid saturation might have been accelerated by Mn toxicity observed in all genotypes (Table 3.6). When manganese accumulation in plant shoots exceeds requirements, it interrupts plant metabolism and reduces growth (Kochain, 2004).

Aluminium toxicity is the main limiting factor found in acid soils. There are two mechanisms which plants can resist Al toxicity, the ability to exclude Al toxicity in roots or their ability to detoxify it within the plant (Taylor, 1995; Kochain, 2004). Although groundnuts generally appeared to be tolerant to soil acidity, their response differed with the genotypes because of genetic variability. The genotypes Rambo, Billy, Selmani and JL 24 had lower shoot Al concentration than others, suggesting ability of the former genotypes to exclude Al. Aluminium interferes with translocation of Ca and Mg (Roy *et al.*, 1988), therefore genotypes that had high Ca and Mg uptake under high acid saturation, namely Rambo, Billy and Selmani may be considered as tolerant to soil acidity. A tolerant genotype is defined as one that grows better and produces more dry matter and develops fewer deficiency symptoms than others of the same species when grown at low levels of the specific nutrient elements (Clark, 1976). Cultivars Rambo, Billy, RG784, Selmani and JL24 had adequate nutrient concentrations, lower Al concentration in their shoots and had no nutrient deficiency symptoms under 80% acid saturation and may be suggested as tolerant cultivars compared with Harts, Robbie, Sellie

and Anel. Such genotypes may provide an opportunity for maintaining production in acid infertile soils used by smallholders.

Deficiency of Ca in acid soil is the main cause of yield reduction in groundnuts as they require high quantity for seed formation (Smartt, 1994; Adams and Hartzog, 1991). Although groundnuts can grow in soils with low acid saturation, lime is required for good growth and yield stability. Nutrient use efficiency was determined as agronomic use efficiency to assess the genotypes that can produce more with low soil fertility to reduce the cost of production. Agronomic use efficiency showed that amelioration of acid soil to 40% had a high nutrient efficiency in most genotypes used in this study. The yield results suggest that amelioration of soil to 40% acid saturation provided sufficient Ca for seed development.

CONCLUSION

Deficiency of Ca and P are shown to be important factors reducing plant growth and yield in acid soils. Groundnut growth was restricted by P deficiency, Al and Mn toxicity. Yield was also affected by the availability of nutrients. However, the tolerance differed between genotypes. As a result of high nutrient uptake, especially of Ca and P, low shoot Al concentration and better growth at high acid saturation, we conclude that genotypes like Rambo, Selimani and Billy are tolerant, JL 24 is moderately tolerant, and Harts, RG784, Anel, Robbie, Sellie, and Jasper are susceptible to soil acidity.

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CHAPTER 4

Effect of Soil Acidity on Germination, Emergence and Seedling Establishment of Groundnut

ABSTRACT

Research on crop responses to soil acidity has largely neglected the influence of the phenomenon on seedling establishment. The objective of the study was to determine the effect of soil acidity, measured as acid saturation, on germination, emergence and establishment of groundnut seeds. The germination test was used to assess the viability and vigour of 3 groundnut cultivars (Harts, Jasper and Rambo) using different Al concentrations. Seeds were germinated using 4 levels of Al: 0, 50, 100 and 200 μM Al applied as $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$. Seedling emergence was performed in seedling trays using three rates (0, 3 and 6 g) of dolomitic lime per kg soil, representing control, 50% and 100% of the required lime, respectively. The high Al concentration significantly reduced germination of all groundnut cultivars. Germination results were mostly affected by time to maturity therefore they did not give a clear difference between the cultivars. However, Harts and Jasper had a similar behaviour compared with Rambo. There were highly significant differences ($P < 0.001$) in seedling emergence between non-limed and limed soils. Mean emergence time (MET) differed significantly ($P < 0.05$) between cultivars. Harts had a low MET compared with Rambo and Jasper. Root length and root mass of all cultivars were significantly ($P < 0.05$) reduced with no amelioration. The response differed significantly amongst cultivars. In the no lime treatment, Rambo had the highest root dry mass of 0.35 g per plant while Harts had the lowest, 0.23g.

This may be an indicator that Rambo's roots were more tolerant to high soil acidity at the establishment stage.

INTRODUCTION

Crop plants go through different developmental stages, from germination through to maturity. The influence of soil and other environmental factors during the different growth stages can have significant effects on crop growth and yield. Examining the effects of soil and other environmental factors on the different growth stages may help provide an understanding of the relative sensitivity of critical stages of plant growth to these environmental factors (Fageria and Baligar, 1997). Germination and seedling establishment are the first stages of plant growth, the exposure to certain environmental conditions during these stages are important yield determining factors (Rauf *et al.*, 2007) as a poor seedling stand is one of the major limitations to the successful production of grain crops (Ponkia *et al.*, 1991; Cheng and Bradford, 1999). Poor seedling establishment may be attributed to several factors including poor seed quality, soil conditions such as compaction (Ponkia *et al.*, 1991), water logging and water deficit, salinity (Singh *et al.*, 1989), and pH (Anitha and Ramanujam, 1992; Murata, 2003), all of which have been extensively researched. Also, investigations into crop responses to soil acidity have largely neglected the influence of the phenomenon on seedling establishment. Where some studies have been carried out on the effect of acidity on seed germination and establishment these have mostly paid attention to the effect of H^+ ions i.e. pH. The effects of high soil acidity operate through the combined influences of high levels of H^+ and Al^{3+} , i.e. acid saturation. It is important to understand the effect of acid saturation during the early stages of crop development in order to take necessary measures aimed at improving

establishment and ultimately, yield. Under field conditions seeds and seedlings are confronted with high acid saturation rather than soil pH *per se*.

The establishment stage consists of germination, emergence and early seedling growth. When seed is raised in petri-dishes, germination is observed as radicle protrusion but when seed is planted in soil, germination can only be observed as emergence. Murata (2003) reported that low pH did not have a significant effect on groundnut seed germination but a significant effect was shown on emergence and seedling growth in solution culture. Although groundnuts are generally tolerant to soil acidity, poor seedling establishment in acid soil may decrease yield. High acid saturation results in aluminium and manganese toxicity which could affect germination or emergence. A review of the effect of Al toxicity by Kochain (2004) suggested that Al inhibites root elongation within hours of exposure and thus affectes nutrient and water uptake, resulting in poor growth (Ma and Furakava, 2003). Young seedlings are more susceptible to Al toxicity than older plants (Mosor-Pietrazewska, 2001). Examination of responses of different cultivars at this early stage could be a quick screening method for tolerance to acidity.

The objective of the study was to determine the effect of soil acid saturation on germination, emergence and seedling establishment of groundnuts, and using to differentiate between selected cultivars in relation to tolerance to soil acidity.

METHODS and MATERIALS

Three groundnut cultivars, Rambo, Jasper and Harts were used for the study. The cultivars, Harts and Jasper were classified as susceptible and Rambo as tolerant to high acid saturation, In order to control seed-born diseases, seeds were treated with zinc manganese ethylenebisdithiocarbamate (mancozeb) prior to commencement of the study.

Standard germination test

To examine the effect of Al toxicity, seeds were germinated using four levels of Al namely: 0, 50, 100 and 200 μM applied as $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$. The pH of the solutions ranged from 4.3 to 4.8, depending on the amount of $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ used. Five seeds of each cultivar were placed onto filter paper in petri dishes containing 25 ml of the treatment solutions and incubated in a germination chamber set to 25°C for 5 days. The experiment was arranged in a completely randomized design, with 5 replications. Treatment solutions and filter papers were changed at 24 hour intervals to maintain solution pH.

Germination counts were taken daily for seeds showing radicle protrusion. Main root length was measured after 3 and 5 days, from sowing using a digital display calliper ruler (Jida Tools Co., Ltd), a stainless steel horizontal ruler with digital display. Final germination was measured as the percentage of seeds producing normal seedlings as defined by ISTA (1995a) rules. The Germination Velocity Index (GVI) was calculated according to Maguire (1962) as:

$$\text{GVI} = G_1 / N_1 + G_2 / N_2 \dots + G_n / N_n \quad \text{Equation 4.1}$$

Where, GVI = Germination Velocity Index,

$G_1 G_2 \dots G_n$ = number of germinated seeds, and

$N_1 + N_2 \dots + N_n$ = number of sowing days at the first, second ...last count

Mean time to germination (MGT) was calculated according to the formula of Ellis and Roberts (1981):

$$MGT = \frac{\sum Dn}{\sum n}$$

Equation 4.2

Where, MGT = Mean Germination Time,

n is the number of seeds which germinated on day D, and

D is number of days counted from the beginning of germination

Seedling emergence and establishment

The Inanda soil form (Soil Classification Working Group, 1991) was used for the experiment. Soil characteristics are described in Chapter 3 (Table 3.2). Soil fertilizer requirements were calculated based on results of a soil analysis as: 20 kg N ha⁻¹, 20 kg P ha⁻¹, 85 kg K ha⁻¹ and 9 t ha⁻¹ of dolomitic lime. Treatments consisted of 3 rates (0, 3 and 6 g) of dolomitic lime per kg of soil, representing control (no lime), 50% and 100% of the required lime, respectively. Finely ground lime was mixed with soil according to treatment and part of the mixture was put in pots and the rest spread on germination trays, for the emergence and germination studies, respectively. The experiment was arranged in a completely randomized design. Soil was watered and left for 7 days to allow for reaction with the finely crushed lime. Trays were kept

moist by watering twice a day and kept in a controlled temperature growth room (30°C day and 15°C night). Twenty-eight seeds per cultivar (Rambo, Jasper and Harts) with three replicates were sowed at a depth of 50 mm in each 15 cm deep tray and allowed to grow for 10 days. Daily counts of emerged seeds were recorded. Emergence was defined as hypocotyl protrusion from the soil. At 10 days after sowing (DAS) seedlings were harvested and final emergence was determined as the percentage of seeds producing normal seedlings as defined by ISTA (1995) rules. Seedling root and shoot lengths were measured and the shoot: root ratio was calculated by dividing the shoot dry mass by root dry mass.

Mean emergence time was calculated according to the formula by Bewley and Black (1994) as:

$$MET = \frac{\sum fx}{f} \quad \text{Equation 4.3}$$

where MET = mean emergence time,

f = number of newly germinating seeds at a given time (day), and

x = number of days from date of sowing

Seedling establishment

Treatments for assessing effect of soil acidity on seedling establishment were the same as for emergence. After seedlings were harvested at 10 DAS, three seedlings in each treatment, replication and cultivar were transplanted to pots. One plant was grown in each pot and allowed to grow for 21 days. The reafter plants were harvested and root and shoot length

measured. Leaf area was determined using a leaf area meter (LI-3000C, LI-COR[®]). Following this, roots and shoots were oven dried for 48 hours at 65°C to measure dry mass

Data analysis

Data was subjected to analysis of variance (ANOVA) using the GenStat[®] Version 12 (VSN International Ltd, UK). Least significant difference (LSD) ($P>0.05$) was used to separate treatment means.

RESULTS

Standard germination

Results of the germination test showed that high Al concentration significantly ($P\leq 0.001$) reduced percentage groundnut germination, with final germination counts ranging from 92 to 100% with 0, 50 and 100 μM and 88.3% at 200 μM Al (Table 4.1). However, the response was not significantly different ($P>0.05$) among the cultivars. There was no significant ($P>0.05$) interaction between cultivars and Al treatments. Germination velocity index was significantly ($P<0.05$) reduced by high Al concentrations; GVI was about 2.0 at 0 and 100 μM , and 1.63 at 200 μM . There was no significant ($P>0.05$) difference amongst the cultivars. Mean time germination (MTG) was not significantly ($P>0.05$) different amongst the cultivars. Aluminium treatments also had no significant effect on MGT. Also, there was no significant interaction between cultivars and treatment with respect to GVI and MGT. The proportion of germinated seeds increased with time. (Fig 4.1).

Table 4. 1: Effect of different Al concentrations on seed germination, germination velocity index and mean germination time of three groundnut cultivars.

Al conc. (μM)	Cultivar	Final germination%	GVI	MGT (days)
0	Harts	100.0 a	2.07 ab	2.45 cde
	Jasper	90.0ab	2.00 ab	2.52 bcd
	Rambo	95.0ab	2.04 ab	2.50bcde
Means		95.0 ab	2.040 a	2.49 ab
50	Harts	100.0 a	2.24 a	2.25 e
	Jasper	100.0 a	1.99 ab	2.70 abc
	Rambo	100.0 a	1.90 bc	2.36 de
Mean		100.0 a	2.04 ab	2.44 b
100	Harts	95.0 ab	2.01 ab	2.38 de
	Jasper	95.0 ab	1.94 abc	2.45 cde
	Rambo	85.0 b	1.96 ab	2.63abcd
Mean		91.7 b	1.969 ab	2.48 ab
200	Harts	90.0 ab	1.75 bcd	2.53bcde
	Jasper	85.0 b	1.53 d	2.76 ab
	Rambo	90.0 ab	1.62 cd	2.85 a
Mean		88.3 b	1.63 b	2.71 a
P(genotype)		0.39	0.34	0.09
P (Al conc.)		0.02	0.01	0.09
P (Inter.)		0.57	0.84	0.17
LSD_(P=0.05)¹		7.38	0.27	0.24
LSD_(P=0.05)²		12.80	0.33	0.29
CV&		9.50	16.80	11.20

NB: GVI = germination velocity index; MGT = mean germination time

LSD¹=Lime treatments; LSD²= interaction

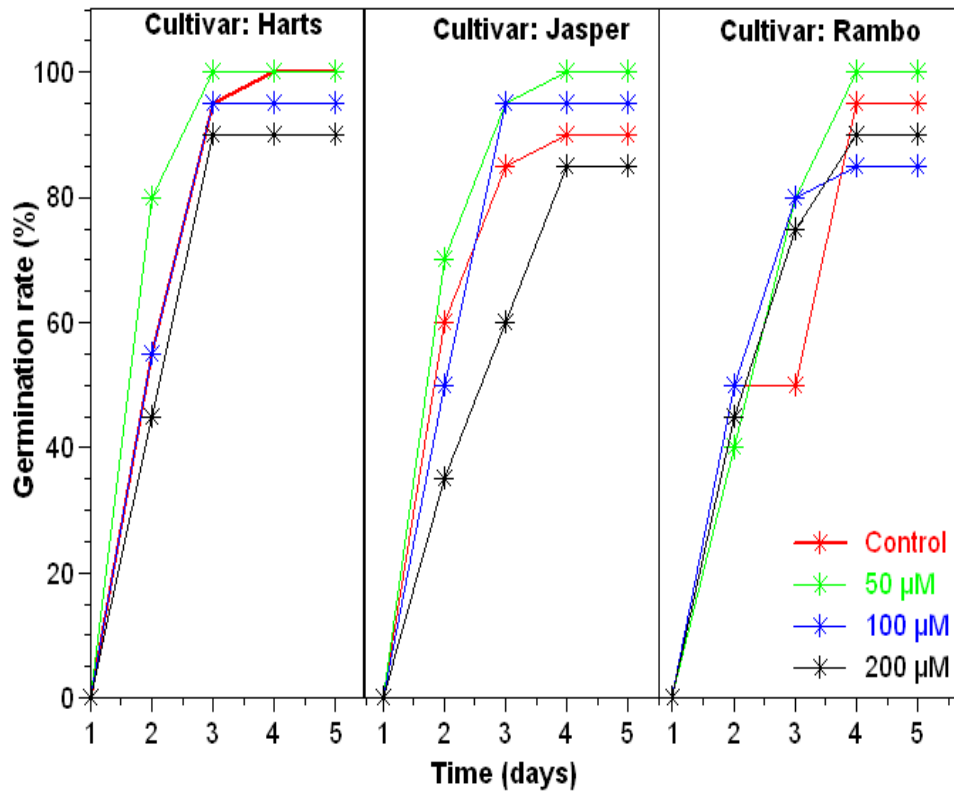


Figure 4. 1: Effect of Al concentration on percentage germination of three groundnut cultivars. Means are representatives of 25 seeds germinated at 25°C for 5 days.

Root length

High Al concentrations, 100 - 200μM, significantly ($P < 0.001$) reduced root length in all cultivars (Fig 4.2). The root length significantly ($P < 0.001$) differed among cultivars. At 3 days after sowing (DAS) the difference between 0 and 200μM was becoming apparent with high Al concentration showing a detrimental effect. At 5 DAS, the root length of control treatments was at least double that of the 200 μM level for Harts and Jasper, while the difference for Rambo was less than this value. In all treatments root lengths of Rambo was slightly lower than those of Harts and Jasper (Fig 4.2). There was no significant interaction ($P > 0.05$) between the cultivars and treatments with respect to root length. In addition to

inhibition of root growth, high Al concentration at 200 μM yielded roots that were particularly thick and brownish (Fig 4.3).

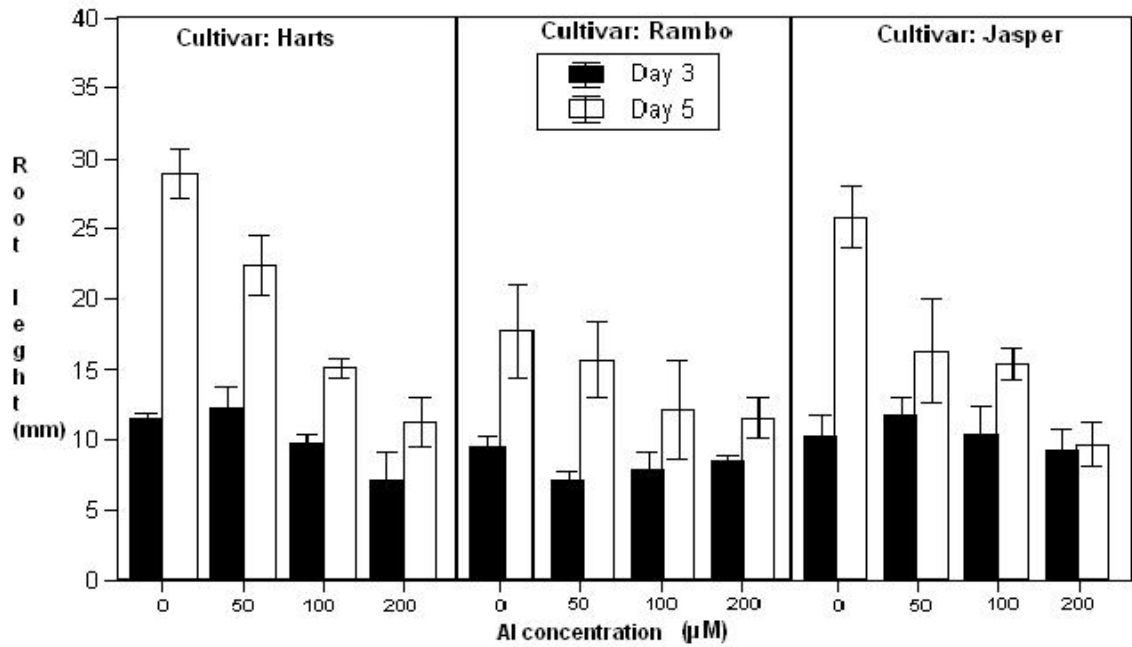


Figure 4. 2: Effect of Al concentration on root length of three groundnuts cultivars (Harts, Rambo and Jasper) measured on day 3 and 5.



Figure 4. 3: Effect of Al concentration on seedling roots, left seedling in control treatments with distilled water and right seedlings in 200 μM Al. Top Figure shows seed at 1 Day After Sowing (DAS), while the bottom shows 3 DAS.

Seedling emergence

The emergence percentage differed significantly ($P < 0.05$) between cultivars (Fig 4.4). Seedlings started emerging by 5 DAS at which time Harts exhibited a high emergence percentage (70%) while Jasper and Rambo showed only 25%. Emergence in both Rambo and Jasper reached 75% at 7 DAS; on day 8 both Harts and Jasper showed 92% emergence while Rambo showed 82% (Fig 4.4). High soil acidity significantly ($P \leq 0.001$) reduced percentage emergence (Fig 4.4). In the no lime treatment, emergence was 88.5% while at full amelioration emergence increased to 98.9%. Mean emergence time was not significantly ($P > 0.05$) affected by liming rate. However, the MET differed significantly among cultivars. Harts had lower MET (5.32) while both Jasper and Rambo had a higher MET (5.65). Root

lengths of all cultivars were significantly ($P<0.05$) suppressed at high soil acidity (Table 4.2). The response was significantly ($P<0.001$) different amongst the cultivars. Root length was higher in Harts compared with Jasper and Rambo for all treatments (Table 4.2). Root mass was also significantly ($P<0.001$) lower when no lime was applied. Shoot dry mass was not significantly affected by varying soil acidity but rather differed significantly amongst the cultivars. Harts had a higher dry mass ($0.25 \text{ g plant}^{-1}$) than Jasper and Rambo ($0.19 \text{ g plant}^{-1}$). In addition, the Ca deficiency symptom of leaf curl was observed in Harts at 80% acid saturation.

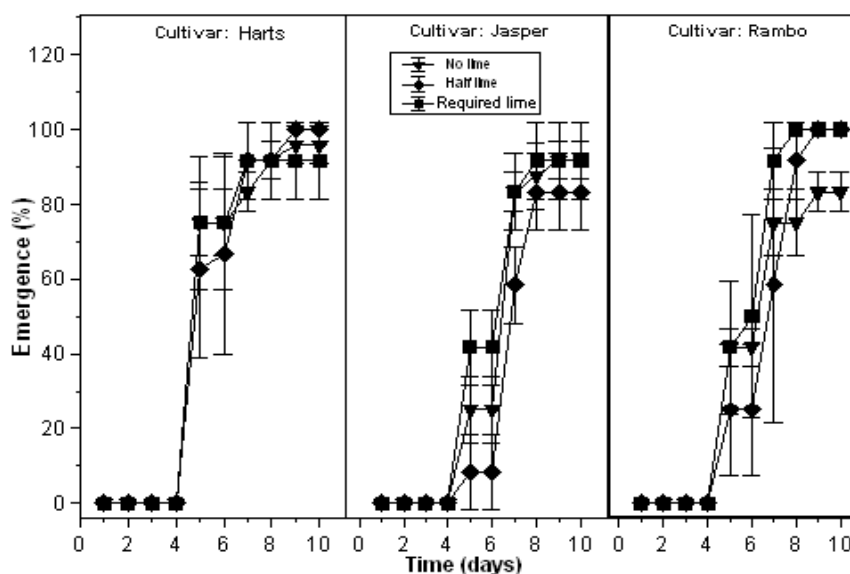


Figure 4. 4: Effect of soil acidity on emergence of three groundnut cultivars (Harts, Jasper and Rambo) from day 1 to 10 days after sowing.

Table 4. 2: Effect of soil acidity on emergence and seedling growth of 3 groundnut cultivars grown in no lime, 50% required lime (40% AS) and 100% required lime (20% AS).

Lime application (g kg ⁻¹ soil)	Cultivar	MET (days)	Shoot height (mm)	Root length (mm)	Shoot mass/plant (g)	Root mass/plant (g)
No lime (80% AS)	Harts	5.10 d	64.2 b	104.0 bc	0.26 ab	0.11 abcd
	Jasper	5.84 ab	66.7 b	62.7 e	0.18 cd	0.08 d
	Rambo	5.62 bc	63.8 b	52.3 e	0.17 cd	0.09 cd
Mean		5.52 a	64.9 b	73.0 b	0.21 a	0.09 b
3 (40% AS)	Harts	5.39 cd	70.2 ab	128.2 a	0.30 a	0.14 ab
	Jasper	6.01 a	73.2 ab	113.8 ab	0.16 d	0.11 abcd
	Rambo	5.55 bc	66.7 b	87.4 d	0.19 cd	0.10 bcd
Mean		5.65 a	70.0 ab	109.8 a	0.21 a	0.12 a
6 (20% AS)	Harts	5.47 bcd	80.1 a	130.6 a	0.19 cd	0.15a
	Jasper	5.69 abc	75.0 ab	122.2 a	0.23 bc	0.10 abcd
	Rambo	5.78 ab	70.7 ab	92.9 cd	0.21 bcd	0.12 abc
Mean		5.65 a	75.3 a	115.2 a	0.21 a	0.12 a
P(treatment)		0.37	0.02	<.001	0.880	0.032
P (inter)		0.14	0.77	0.10	0.007	0.936
LSD_(P=0.05)¹		0.21	7.03	10.07	0.038	0.025
LSD_(P=0.05)²		0.37	12.17	17.44	0.066	0.043
CV%			10.00	10.10	18.10	22.30

NB: MTE= mean time emergence, LSD¹= treatments, LSD²= interaction, AS= acid saturation



Figure 4. 5: Seedling roots grown in limed soil, right: seedling roots of no lime treatment with 80% acid saturation.

Establishment

High soil acidity significantly ($P < 0.001$) reduced groundnut growth as determined by shoot length and dry mass (Table 4.3); the responses differed among cultivars. Harts and Jasper had higher shoot lengths (153.3 and 150.0mm, respectively) compared with Rambo (120mm). However, leaf area was not affected ($P > 0.05$) by differences in soil acidity (Table 4.3). Root dry mass were not significantly increased by lime application. However, root dry mass differed significantly amongst the cultivars with no lime treatment, Rambo had the highest root dry mass of 0.35g per plant while Harts had the lowest, 0.23g per plant (Table 4.3). This may be an indicator that Rambo's roots were more tolerant to high soil acidity at establishment.

Table 4. 3: Effect of differential soil acidity on seedling establishment measured at 21 DAS

Lime application (g kg ⁻¹ soil)	Cultivars	Shoot length (mm)	Root length (mm)	Shoot dry mass (g)	Root dry mass (g)	Leaf area (cm ²)
No lime (80% AS)	Harts	136.7 bc	210.0 ab	1.31 abc	0.23 e	218.9 a
	Jasper	153.3 ab	246.0 ab	1.13 c	0.32 cd	190.4 a
	Rambo	115.0 d	246.7 ab	1.09c	0.35 bcd	214.5 a
Mean		135.0 b	234.2 a	1.18 b	0.29 b	207.9 a
3 (40% AS)	Harts	165.0 a	201.7 b	1.45 ab	0.29 cde	243.8 a
	Jasper	135.0 c	263.3 a	1.25 abc	0.37 abc	203.7 a
	Rambo	121.7 cd	220.0 ab	1.39 abc	0.44 a	247.9 a
Mean		140.6 ab	228.3 a	1.36 a	0.37a	231.8 a
6 (20%AS)	Harts	158.3 a	249.0 ab	1.55 a	0.32 cd	256.6 a
	Jasper	161.7 a	212.7 ab	1.39 abc	0.28 de	259.2 a
	Rambo	123.3 cd	255.7 ab	1.20 bc	0.44 a	209.5 a
Mean		147.8 a	239.1 a	1.38 a	0.35 a	241.8 a
P (treat.)		0.049	0.06	0.017	0.060	0.221
P (inter.)		0.151	13.50	0.61	0.15	0.38
P (cultivars)		<.001	0.06	0.06	<.001	0.31
LSD (P= 0.05)¹		10.030	31.51	0.18	0.048	40.49
LSD (P= 0.05)²		17.370	54.57	0.32	0.084	70.13
CV%		14.400	0.098	14.10	14.40	17.80

NB: LSD¹= treatments, LSD² = interaction, AS = acid saturation

DISCUSSION

The standard germination test is used as a measure of viability (ISTA, 1985) with the objective of gaining information with respect to field planting value of a seed lot (Mabhaudhi and Modi, 2010). Groundnut germination was sensitive to high Al concentrations as germination speed (GVI) decreased with increasing Al concentration in the study. Prolonged germination exposes seeds to soil borne pathogens (Melouk and Backman, 1995); hence, high soil acidity may result in poor seedling emergence. Aluminium concentration between 0 and 50 μ M was shown to have some positive albeit small effect on germination in all cultivars compared with 100 and 200 μ M. Similar results were reported by Rout *et al.* (2001) and Jamal *et al.* (2006) that low concentrations of Al (<20 ppm) enhanced seed germination while the effects were adverse at high (>20 ppm) concentrations. Aluminium toxicity does not only affect seed germination but, after radicle protrusion, it limits root expansion. When roots were exposed to Al toxicity they became stubby and brittle; root tips and lateral roots became thick and turned brown (Fig 4.5).

The increase in MET under low soil acidity also emphasises the effect of soil acidity on root expansion and seedling emergence. Increasing Al in the soil may have inhibited root elongation. Ma (2007) has suggested that the mechanism involved in this inhibition may include disruption of the functions of the membrane, cell wall, Ca homeostasis and signal translocation pathways. Failure of radicle growth may result in poor seedling emergence. Although groundnuts have been previously reported to be moderately tolerant to acid soils, (Adams and Pearson, 1970; Munns and Fox, 1977; Foster *et al.*, 1980), the decline in seedling emergence as observed in this study suggests that this stage may be vulnerable and hence a possible cause for ultimate yield reduction. Poor seedling establishment results in reduced

yield for many crops (Fageria and Baligar, 1997). Harts has a shorter growing season (120 days) compared with Jasper (150 days) and Rambo (180 days). Harts emerged faster and grew more vigorously compared with Jasper and Rambo in limed condition and this may not be a result of tolerance to acid soils but more a function of days to maturity. With high acid saturation the degree of inhibition of rooting in both Harts and Jasper was more pronounced than in Rambo (Figure 4.2 and Table 4.3). Thus in acid soils in field conditions Rambo is less likely to suffer to the same degree in terms of root inhibition and the consequences arising from that, e.g. nutrient and water uptake as discussed below.

Inhibition of root expansion is a major symptom of Al toxicity (Foy *et al.*, 1987; Delhaize and Ryan, 1995; Kochain, 1995) as observed in this study, particularly at acid saturation of 80%. Blamey and Chapman (1982) reported that groundnut roots were less sensitive to low acidity as compared with cotton and sorghum roots. In this study root growth was not significantly affected, but root growth differed with cultivars at germination. Rambo had high root mass, suggesting the possibility of roots tolerant to high acidity compared with Jasper and Harts at establishment. The reduction in root mass may have been the result of a reduction in lateral roots at high acid saturation (Fig 3.5). Aluminium toxicity was reported to reduce crop lateral roots in cowpea (Manzi and Cartwright, 1984) and soybean (Brandy *et al.*, 1993). Lateral roots are involved in nutrient and water uptake. In legumes they are also required for infection by rhizobia for successful nodulation (Brandy *et al.*, 1993). The roots affected by Al toxicity are inefficient in absorbing water and nutrients, thus affecting shoot growth (Jamal *et al.*, 2006). This may explain the reduced shoot growth (shoot length) observed in the zero lime treatment. The observed primary leaf curl a few days after emergence in the zero lime treatments may be associated with calcium deficiency symptoms, since acid soils are known to

be deficient in base cations like Ca, Mg, and K. As seedlings grew, the older leaves dropped and new leaves formed without any sign of nutrient deficiency. This observation concurs with the observations of Vesseleva *et al.* (1997) who found that tolerance of legumes to soil acidity increased as they developed.

CONCLUSION

Groundnut seedlings are susceptible to soil acidity during early establishment; however, the response is genotype specific. Jasper and Harts root growth appeared to have a similar response to high Al concentration compared with Rambo. Germination did not give a clear difference between the cultivars. The observed variations were mainly the result of different growth habits and time to maturity. However, the establishment phase showed that Rambo performs better under acid conditions. The high root mass and absence of Ca deficiency symptoms on Rambo indicates the possibility of soil acid tolerance.

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CHAPTER 5

Comparison of Dolomite and Calcium Silicate for Soil Acidity Amelioration in Three Selected Groundnut Genotypes

ABSTRACT

Application of lime is a common practice in acid soils. Effective amelioration of soil acidity by using well known agricultural limes has been limited by high cost of lime, thereby opening opportunities for research to find alternative ways to ameliorate soil acidity. The aim of the study was to compare calcium silicate and dolomitic lime as liming agents in relation to nutrient availability, vegetative growth, yield and seed quality of groundnuts genotypes. The experiment was a pot study conducted under controlled environment using the Inanda soil form. Treatments consisted of dolomite and calcium silicate applied at 30 and 27 g per kg, respectively representing 9 tons ha⁻¹. Plant height and yield components were measured, Shoot nutrient concentration, soil nutrient levels and seed quality were analysed. The results showed that both lime sources were effective in ameliorating soil acidity.. Shoot concentration and uptake of Ca, K and P were significantly increased by application of both limes. However, application of CaSiO₃ resulted in higher nutrient uptake compared with dolomite. Magnesium concentration and uptake was increased significantly by application of dolomite compared with CaSiO₃. Aluminium and Mn uptake was significantly reduced by application of both liming materials. However, Al uptake was significantly (P<0.05) different among the cultivars. Rambo had low Al uptake compared with Kwarts and Harts. High vegetative growth in all treatments resulted in an increased number of pods in all treatments. Pod and kernel mass was significantly affected by soil acidity; application of either lime

source increased pod and kernel mass but the response also differed with cultivar. Rambo had high pod and kernel mass compared with Kwarts and Harts. High acid saturation increased protein the content of the seeds. Application of either lime source increased oil and decreased protein showing the decrease in acid stress. Therefore application of CaSiO_3 might be an alternative method of ameliorating soil acidity and increasing groundnut yield at low cost.

INTRODUCTION

Most of the communities in rural areas grow groundnuts for subsistence purposes and also as a cash crop. For these communities to produce crops and get stable yields and ensure food security, in conditions of high acid saturation, they must apply lime (Beukes, 1995). For acid soils, application of lime increases groundnuts yield compared with gypsum (Blamey and Champman, 1982). However, lime may be unaffordable to subsistence farmers. As indicated in Chapter 3 alternative options like planting tolerant genotypes, need to be exploited in addition to the use of inexpensive Ca containing industrial by products like calcium silicate.

Calcium silicate is an alkaline material that has the potential to ameliorate soil acidity (Shen *et al.*, 2004; Mbakwe, 2008; Ndoro, 2008). It is produced by steel industries as a by-product called calcium silicate slag or calmasil and has a CCE value of 97% and a calcium/magnesium proportion of 1:4. Although calcium silicate can be potentially used to ameliorate soil acidity, it is mostly used in sugarcane production as a silicon source due to its high silicon content. Silicon is classified as a beneficial nutrient for plants; it helps plants to resist both abiotic and biotic stresses. At the same time it has been reported to alleviate aluminium toxicity in soils,

reduce manganese uptake and improve phosphorus translocation in phosphorus deficient soils (Datnoff *et al.*, 2001).

One ton of calcium silicate costs only fifty Rands (<http://www.pbd-lime.co.za/calmasil>) compared to seven hundred and sixty rands per ton of dolomitic lime. Using calcium silicate may help groundnut farmers to increase yield with less cost by ameliorating soil acidity with this product and also providing Ca for pod growth. It has an additional benefit of reducing incidence of diseases, since it is deposited beneath the cuticle to form a Si double layer that blocks fungal penetration and enhances plant resistance to pests (Savant *et al.*, 1997; Ma and Takahashi, 2002; Ma and Yamaji, 2006; Fauteux *et al.*, 2005).

The present study was undertaken to compare application of calcium silicate and dolomitic lime in relation to nutrient availability, growth, yield and seed quality of groundnut plants, to three groundnut genotypes of contrasting tolerance to acid soils.

METHODS and MATERIALS

The experiment was conducted in a glasshouse at the University of KwaZulu-Natal between January and July 2010. The Inanda soil form (Soil Classification Working Group, 1991) collected from Hilton, Pietermaritzburg, was used in the study. Properties of this soil were described in chapter 3 (Table 3.2). The genotypes used were selected from the 10 tested for acid soil tolerance in chapter 3. Harts and Jasper were classified as susceptible and Rambo was classified as tolerant to soil acidity. Kwarts and Jasper have same genetic background, and as a result of seed shortage Kwarts was used instead Jasper in the experiment.

Experimental design

Treatments were arranged in a completely randomised design with two factors: Cultivars (Harts, Kwarts and Rambo) and different lime sources (calcium silicate, dolomite and no lime) with three replications.

Treatments

Treatments consisted of dolomite applied at 30 g per kg of soil, calcium silicate applied at 27 g per kg of soil. This corresponds to 9 tons ha⁻¹. A control with no lime was also used. Lime was thoroughly mixed with the soil before being placed into pots. Required fertilizer was applied as 38 mg of ammonium nitrate and 152 mg of potassium phosphate per kg of soil, equivalent to 20 kg N ha⁻¹, 20 kg P ha⁻¹ and 85 kg K ha⁻¹. Pots were watered and placed in a glasshouse at 26 ± 5°C under natural light for 7 days to allow the finely ground lime to react with the soil. Thereafter, four seeds were planted per pot and thinned to two seedlings per pot

after emergence. Pots were watered manually on a daily basis throughout the experiment to avoid any water deficits.

Pest and disease management

At 120 days after planting Torque ® (550g/L fenbutatin oxide) at a concentration of 10 ml per 10 litre of water was applied to control red spider mites.

Data collection

Plant height was measured at weekly intervals, starting from 14 days after planting until 50% of plants had flowered. The above ground part of the plant was harvested and dried at 65 °C for 48 h to determine dry weight. Dried samples were analysed for N, P, K, Ca, Mg, Al, Fe, Cu, and Mn concentration. Nutrient uptake was calculated as nutrient concentration × dry matter.

Mature plants were harvested and data for numbers of pods per plant, weight of pods per plant, kernel weight, shelling percentage and sound mature kernels were then collected. Soil samples were collected after harvesting and analysed for pH, acid saturation, N, P, K, Ca, Mg, Zn, Cu, Fe, Mn and Al.

Protein analysis

Seeds were ground to a fine powder using a mortar and pestle and a 0.5 g subsample was added to a test tube containing 5 ml extraction buffer. Total proteins were extracted according to the modified method of Zhang *et al.* (2005). The extraction buffer consisted of 150 mmol/L Tris-HCL (pH 8.9), 2% (w/v) SDS, 10 mmol/L MgCl₂, 10 mmol/L ascorbic acid, 2 mmol/L

EDTA-Na₂, 1 mmol/L PMSF, 0.2% (v/v) 2-mercaptoethanol and 2% (w/v) PVPP. Thereafter the mixture was homogenized and centrifuged at 10 000 rpm for 10 minutes at 4°C. The protein concentration was determined using bovine albumin (BSA) as a standard (Bradford, 1976).

The seed lipid concentration was determined according to Meyer and Terry (2008). A 1 g finely seed tissue was homogenised with hexane and centrifuged at 10000 rpm for 10 minutes at 4°C. The mixture was filtered under vacuum through a filter paper. The extract was dried for 48 h in a Savant Vacuum drier. The recovered oil was weighed and percentage oil calculated [% (w/w)].

RESULTS

Vegetative growth

There was no significant effect ($P>0.05$) of lime sources on vegetative growth measured as dry mass and leaf area per plant (Table 5.1) although both sources were better than the no lime control. Plant height was significantly ($P\leq 0.001$) reduced by high soil acidity and both lime treatments resulted in taller plants compared with the no lime treatment (Fig 5.1). There was no significant difference between the two liming materials. However, plant height differed significantly between cultivars. Harts was tallest (193.3 mm) followed by Rambo and Kwarts with 169.4 mm and 169.6 mm respectively.

Table 5. 1: Comparison of CaSiO₃ and dolomite on vegetative growth of 3 groundnut cultivars measured by dry mass and leaf area.

Treatments	Cultivars	Dry mass (g)	Leaf area (cm ²)
No lime	Harts	4.62	483
	Kwarts	4.95	509
	Rambo	4.39	507
Mean		4.65	500
CaSiO ₃	Harts	7	645
	Kwarts	6.34	654
	Rambo	6.66	743
Mean		6.67	681
Dolomite	Harts	6.07	575
	Kwarts	6.08	646
	Rambo	5.10	519
Mean		5.75	580
P		0.953	0.79
LSD_{p=0.05}¹		2.78	259.3
LSD_{p=0.05}²		1.61	149.7
CV%		28.20	25.5

Note: LSD¹ = interaction, LSD² = treatment

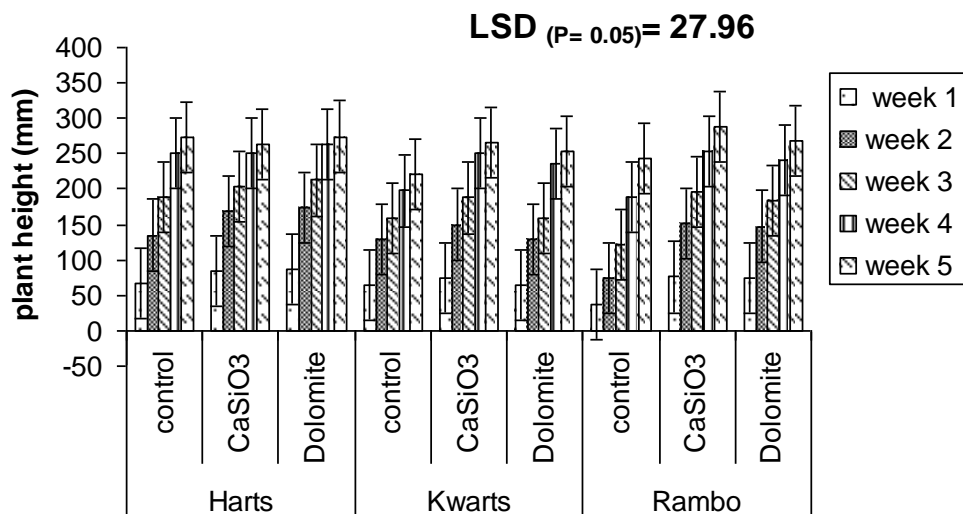


Figure 5. 1: Shoot height of three groundnut cultivars grown under no lime, dolomitic lime and CaSiO₃ treatments from week one to five after sowing.

Shoot N, P, K, Ca and Mg concentration

The shoot N concentration was reduced significantly ($P \leq 0.001$) by high soil acidity (Table 5.2). Also, the response differed amongst cultivars. CaSiO_3 treatments had a high N concentration (3.26%) while dolomitic lime treatments and control were, 2.82% and 2.51%, respectively. The P concentration was increased significantly by application of both limes, but there was no significant difference between calcium silicate and dolomite (Table 5.2). Application of both limes significantly ($P \leq 0.001$) increased shoot K concentration in all cultivars and there were significant ($P \leq 0.001$) differences between cultivars. Rambo had the highest (3.13%) K concentration followed by Kwarts (2.80%) and Harts (2.26%). Calcium silicate significantly increased the concentration of K compared with dolomite. Application of calcium silicate significantly increased the shoot Ca concentration (Table 5.2) compared with dolomite. However, there were no significant ($P > 0.05$) differences among cultivars. Application of dolomite resulted in to high Mg concentration (0.67%) compared with calcium silicate and no lime treatment with 0.25% and 0.23%, respectively (Table 5.2); however cultivars showed no significant response with respect to Mg concentration.

Table 5. 2: Nutrient concentration of above ground parts of threegroundnut cultivars grown with no lime, dolomite lime and calcium silicate.

Treatments	Cultivars	N%	P%	K%	Ca%	Mg%
No lime	Harts	2.30 a	0.13 a	1.98a	0.69 abc	0.28 ab
	Kwarts	2.53 abc	0.16 ab	2.12 ab	0.53 a	0.16 a
	Rambo	2.70 abc	0.15 ab	2.49 ab	0.59 ab	0.30 abc
Mean		2.510^a	0.14^a	2.20^a	0.61^a	0.25^a
CaSiO ₃	Harts	2.72 abc	0.16 ab	2.80 ab	1.67 d	0.17 a
	Kwarts	3.33 de	0.21 b	3.79 b	1.43 d	0.22 a
	Rambo	3.72 e	0.22 b	4.04 b	1.59 d	0.29 abc
Mean		3.26^b	0.18^b	3.54^b	1.57^c	0.23^a
Dolomite	Harts	2.46 ab	0.14 a	2.01 a	1.02 bc	0.41 abcd
	Kwarts	2.92 bcd	0.17 ab	2.50 ab	1.04 c	0.44 abcd
	Rambo	3.07 cd	0.15 ab	2.86 ab	0.72abc	1.17 bd
Mean		2.817^a	0.17^b	2.46^a	0.93^b	0.67^a
P(interaction)		0.572	0.807	0.47	0.482	0.589
LSD_{p=0.05}¹		0.3135	0.033	0.412	0.2266	0.46
LSD_{p=0.05}²		0.5430	0.058	0.71	0.3924	0.80
CV%		11.0	20.2	15.1	22.0	120.6

Note LSD¹ = treatments, LSD² = interaction

Aluminium and Mn concentrations

There was a highly significant ($P \leq 0.001$) effect of application lime on both Al and Mn shoot concentrations (Fig 5.2). Shoot Al and Mn concentration decreased significantly with application of either lime source but there was no significant difference between the cultivars in respect of Al and Mn concentration. The response of Al also differed significantly amongst the cultivars. Rambo had lower Al concentration compared with Kwarts and Harts (Fig 5.3). However, there was no significant difference between the cultivars in respect of Mn concentration.

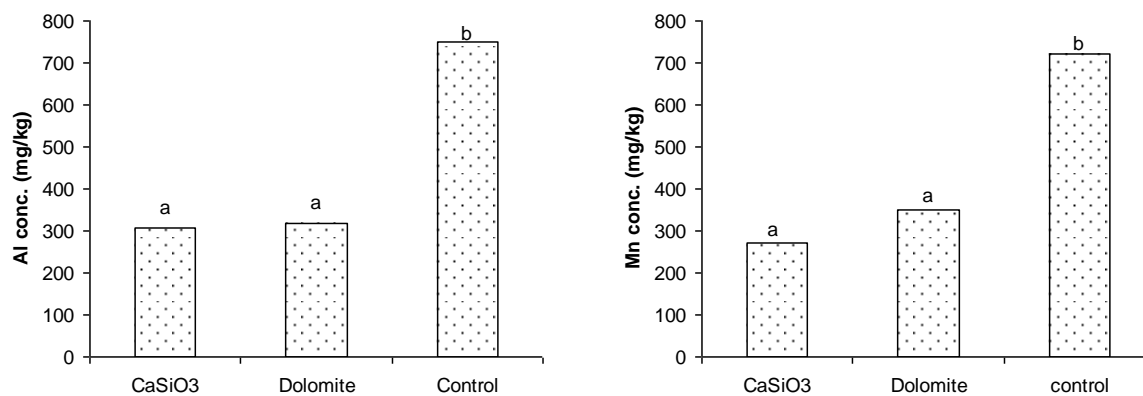


Figure 5. 2: Comparison of dolomite and CaSiO₃ with respect to shoot Al and Mn concentration

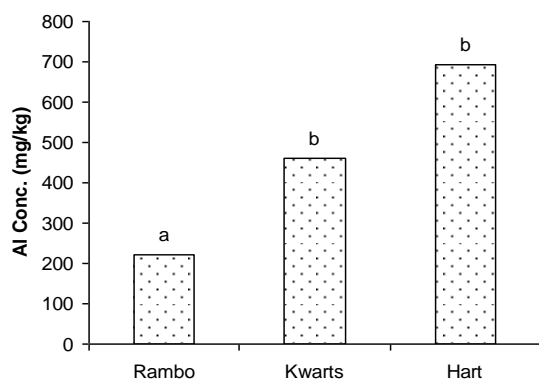


Figure 5. 3: Effect of dolomite and CaSiO₃ on Al and Mn shoot concentration of three groundnut cultivars

Nutrient uptake (N, P, K, Ca and Mg)

Phosphorus, K and Ca were increased significantly by application of calcium silicate as compared with dolomite (Fig 5.4). There was no significant ($P>0.05$) difference between the three cultivars, with respect to P, K and Ca uptake. Application of dolomite resulted in a

higher Mg uptake compared with calcium silicate and control. There was no significant ($P>0.05$) effect of lime sources or in cultivar with respect to N uptake. There was no significant interaction between the cultivars and treatments with respect to any nutrient uptake.

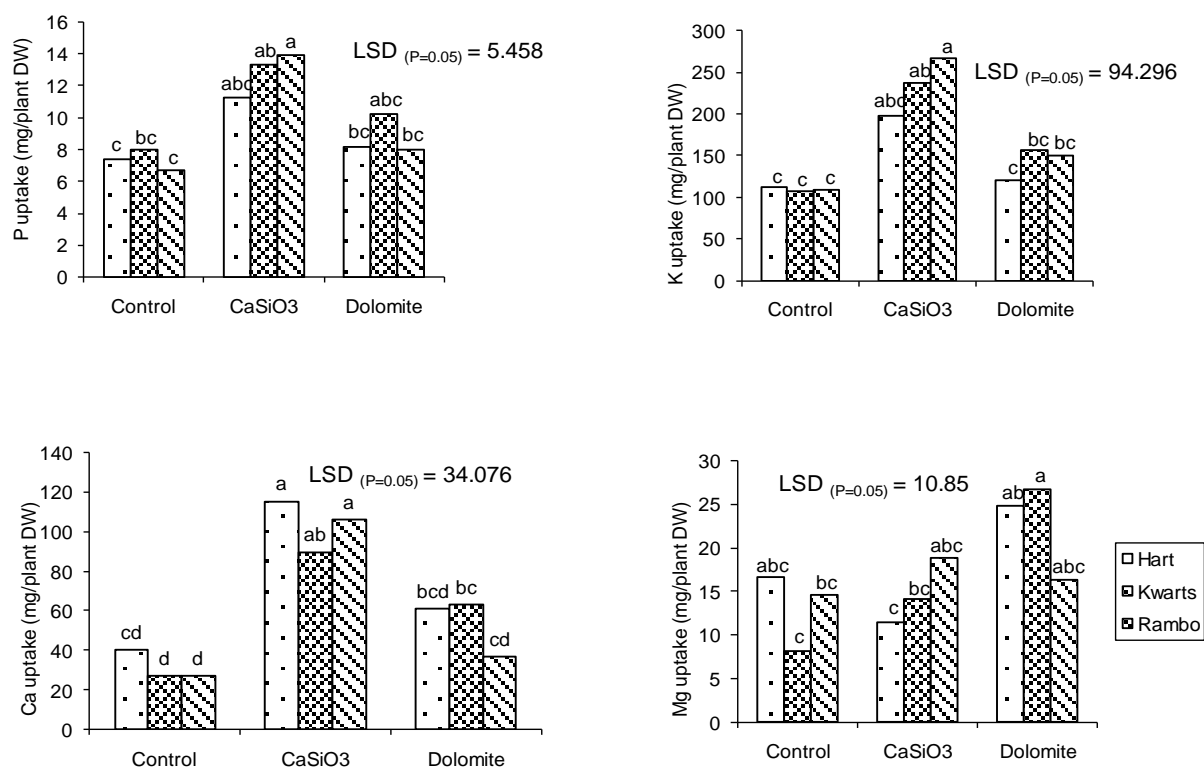


Figure 5. 4: Effect of application of lime to three groundnut cultivars on phosphorus, potassium, calcium and magnesium uptake

Aluminium and Mn uptake

Aluminium uptake differed significantly ($P<0.05$) amongst the cultivars (Fig 5.5). Rambo had low Al uptake (1.07 mg) compared with Kwarts (2.66 mg per plant) and Harts (4.21 mg per

plant) (Fig 5.5). Application of both limes decreased Al uptake and there was no significant ($P>0.05$) difference between dolomite and calcium silicate. Manganese uptake was increased significantly ($P<0.05$) by application of both lime sources (Fig 5.6), however dolomite slightly decreased Mn uptake compared with CaSiO_3 .

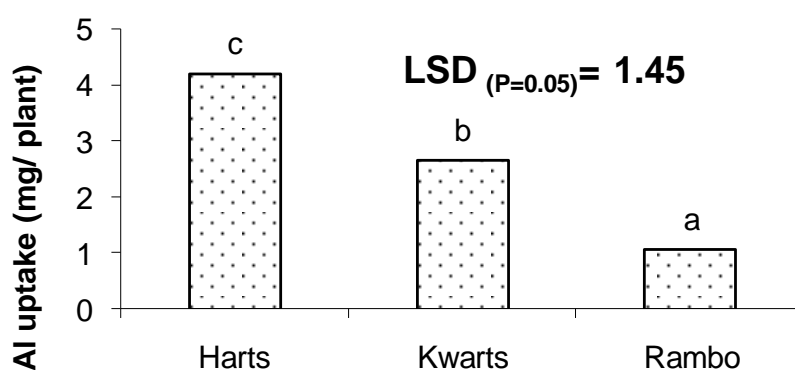


Figure 5. 5: Aluminium uptake by three groundnuts cultivars planted in control without amelioration (80% acid saturation) and limed soil using dolomite and calcium silicate slag (20% acid saturation).

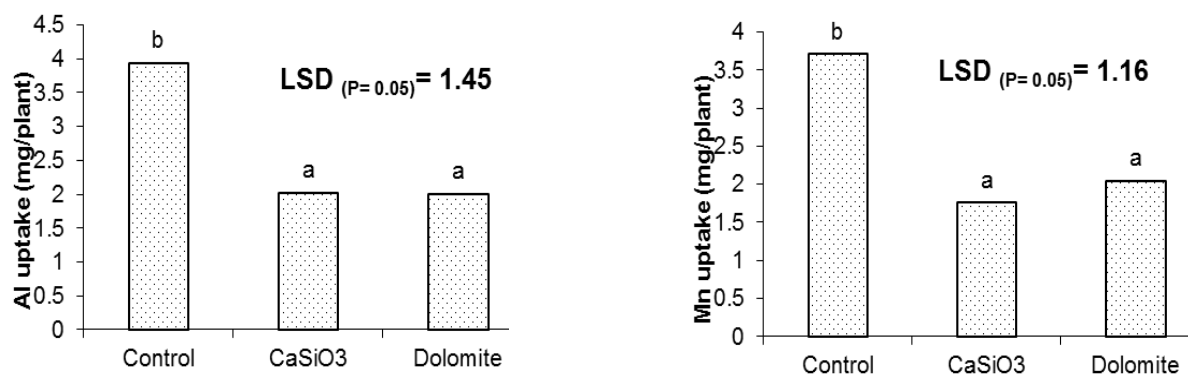


Figure 5. 6: Effect of calcium silicate and dolomite application on Al and Mn uptake by groundnut plants

Yield and Yield components

Pod and kernel mass were reduced significantly ($P < 0.001$) by soil acidity. Without lime application Kwarts had the lowest pod mass (7.50 g), while Rambo had the highest (23.45 g) pod mass. The use of dolomite resulted in a higher kernel and pod mass compared with calcium silicate treatment. There were few pops observed with both the dolomite and CaSO_3 , however incidence of pops were high with no lime treatment. The increase in pop percentage depended greatly on cultivars (Table 5.3). Under high acid saturation Harts had highest pop percentage (90%) followed by Kwart with 79% and Rambo 69%.

Table 5. 3: Effect of applied dolomite and calcium silicate on yield components of three groundnut cultivars.

Treatments	Cultivars	Pod mass/plant (g)	Kernel mass/plant (g)	Pops %	Shelling %
No lime	Harts	10.06 de	3.03 c	90.1 a	30.1 c
	Kwarts	7.50 e	3.87 c	79.0 ab	51.8 b
	Rambo	11.14 cd	6.32 c	65.9 b	52.5 b
CaSiO_3	Harts	13.68 cd	10.81 b	3.5 c	79.0 ab
	Kwarts	12.41 cd	10.45 b	6.2 c	84.2 a
	Rambo	23.44 a	17.45 a	0.0 c	74.5 ab
dolomite	Harts	20.20 ab	16.56 a	9.8 c	81.8 ab
	Kwarts	15.66 bc	12.57 b	5.5 c	79.9 ab
	Rambo	23.45 a	17.56 a	3.0 c	75.1 ab
P(interaction)		0.08	0.15	0.51	0.03
LSD_(p=0.05)		4.72	3.88	18.74	13.76
CV%		17.90	20.40	37.00	11.80

NB: LSD = interaction

Protein and oil content of seeds

The seed protein concentration increased significantly in all cultivars ($P < 0.001$) in response to high soil acid saturation (Fig 5.7). Without lime application the protein concentration was significantly higher in Rambo and Kwarts compared with Harts. Application of either source of lime significantly reduced the protein concentration of Rambo and Kwarts below that of Harts. Oil content was increased significantly ($P < 0.05$) with application of either dolomite or calcium silicate compared to the control. There was no significant difference between cultivars with respect to lime treatments, although a pattern of Rambo > Kwarts > Harts was observed (Fig 5.8).

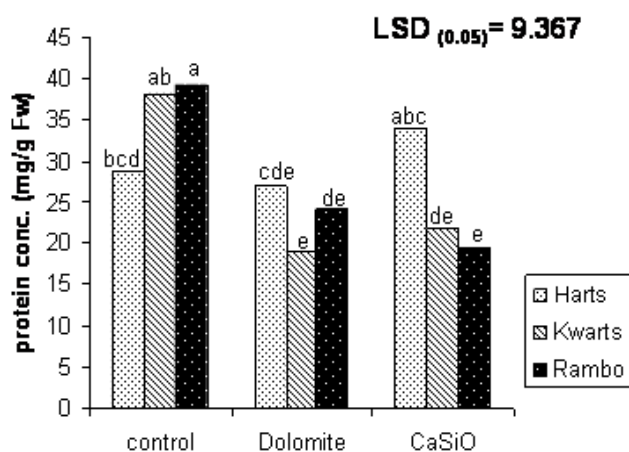


Figure 5. 7: Effect of soil acidity on seeds protein concentration of three groundnut cultivars (Harts, Kwarts and Rambo) in soil limed with dolomite or calcium silicate compared with no lime.

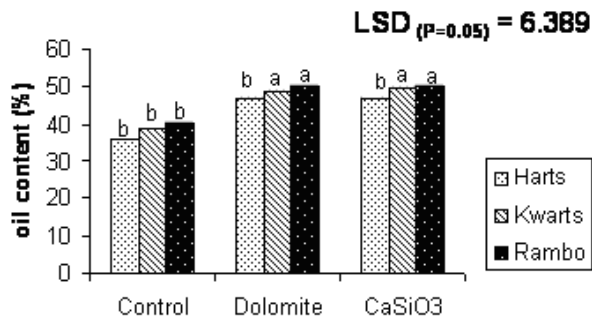


Figure 5. 8: Effect of soil acidity on oil content (%) of three groundnut cultivars (Harts, Kwarts and Rambo) in soil limed with dolomite or calcium silicate compared with control (without lime).

Soil pH and acid saturation

Soil acid saturation was reduced significantly ($P < 0.001$) by application of both limes (Fig 5.9). Application of dolomite decreased soil acid saturation (7.78) compared with (12.44) calcium silicate. Acid saturation differed significantly ($P < 0.001$) with the cultivar planted; where Rambo was planted soil had higher Al concentration compared with where Harts and Kwarts were planted (Fig 5.9). Lime application significantly increased soil pH from (3.86) to (4.27) when soil was treated with calcium silicate and increased to (4.44) following dolomite treatments (Fig 5.9).

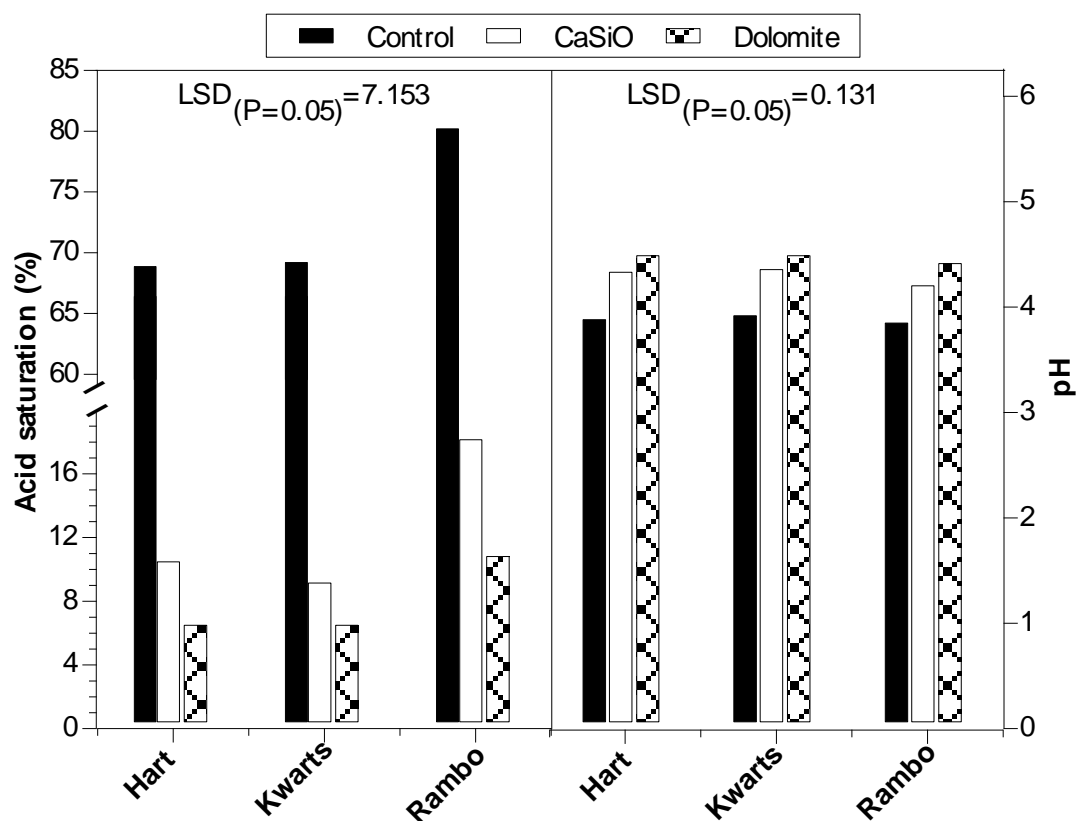


Figure 5. 9: Effect of applied dolomite and calcium silicate on soil acid saturation and pH.

Soil nutrients Ca, Mg and K

The soil Ca concentration was significantly ($P < 0.001$) increased by application of both liming materials (Fig 5.10). Soil limed with calcium silicate had high a Ca levels compared with soil where dolomite was applied. The Mg concentration significantly ($P < 0.001$) increased with an addition of dolomitic lime while the no lime and calcium silicate treatments had similar Mg levels (Fig 5.10). Although K was applied in all treatments,, high soil acidity significantly ($P < 0.05$) reduced K concentration in the soil (Fig 5.10).

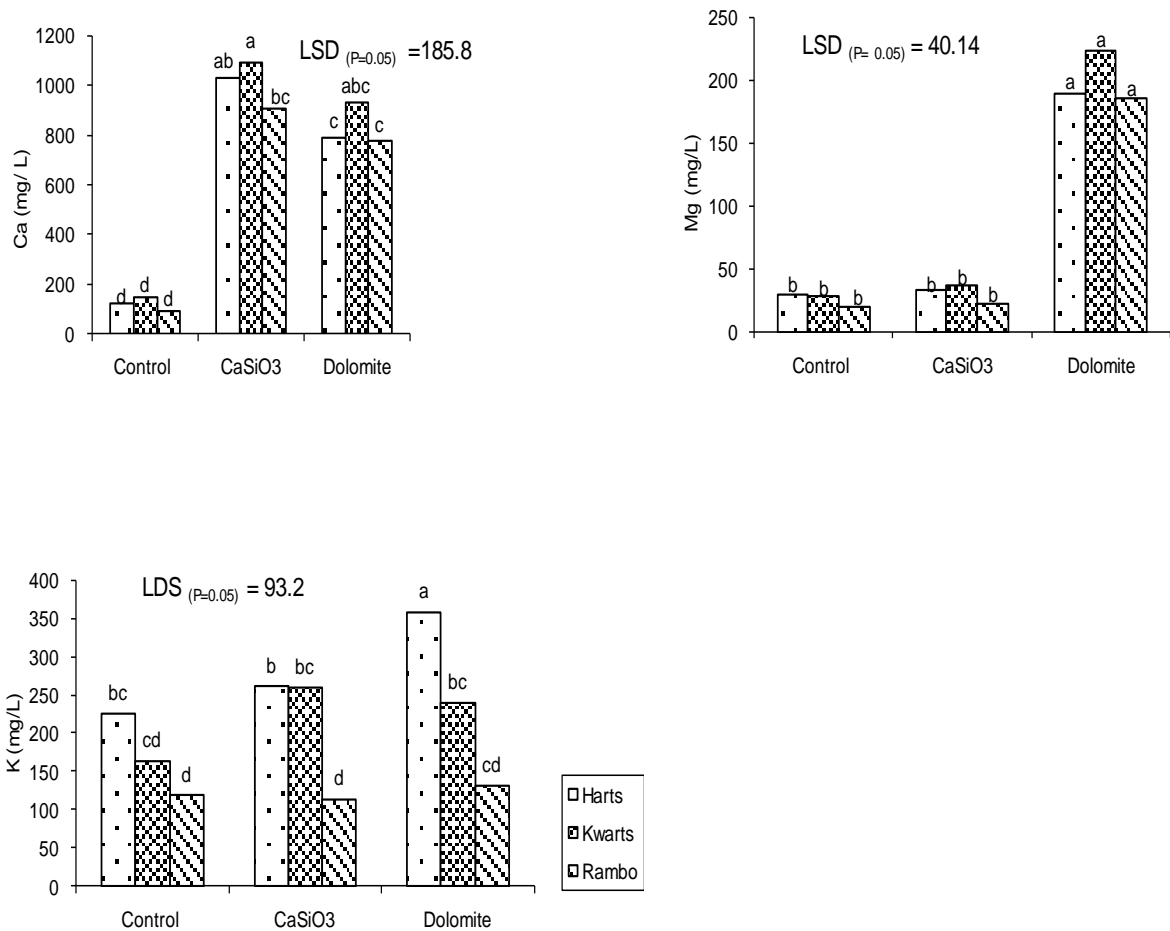


Figure 5. 10: Effect of application of dolomite and calcium silicate on soil Ca, Mg, and K levels at the end of the study

DISCUSSION

An agricultural liming material is defined as a material that contains Ca and Mg compounds which are capable of neutralizing soil acidity (Barber, 1967). These include calcite, dolomite, hydrated lime and industrial by-products such as calcium silicate and fly ash. Ameliorating soil acidity using common agricultural lime is limited by increasing cost especially to farmers with limited resources. There are inexpensive by-products with liming abilities and can also add other important soil nutrients. Application of calcium silicate led to the production of a high shoot dry mass compared to dolomite. Higher vegetative growth may have been due to rapid nutrient uptake of plants grown in calcium silicate. High nutrient uptake after application of calcium silicate was reported in maize by Mbakwe (2008). Both limes resulted in improved growth because they break Al and Fe phosphate in the soil making it available for plant uptake. Phosphorus uptake was reportedly increased by enhanced mineralization of organic P as affected by both limes (Haynes, 1992); however, CaSiO_3 had higher P uptake compared with dolomite. Application of lime was also reported by Ranjit *et al.* (2007) to increase P uptake by groundnut plants. Potassium was applied in all treatments including control but decreasing of K under high soil acidity emphasizes that K is one of the nutrients that may be deficient in acid soils. Potassium is a cation and, therefore, it is not held permanently on cation exchange sites; the application of basal fertilizer only, may still result in K deficiency in acid soils where lime is not applied.

Under high acid saturation Al, Mn and Fe concentrations in plant tissue were high and concentrations of Ca, Mg and K were lower. The increase in shoots Al, Mn and Fe was expected since Al toxicity is associated with high levels of Al, Mn and Fe in acid soils; Levels

of Ca, Mg and K were lower due to leaching. Soil acidity was corrected by application of lime (Caires *et al.*, 2003) which significantly increased soil Ca and Mg concentration and decreased Al, Mn, and Fe concentration. Use of both lime sources resulted in increased nutrient uptake. However, calcium silicate treatments had higher Ca, K, and P uptake compared with dolomite treatments. The increase in dry matter following calcium silicate treatment may be due to increased nutrient uptake.

The effect of soil acidity on vegetative growth is more expressed when there is drought, since soil acidity and Al toxicity affect root development making them unable to reach deeper to drawn moisture. In this study plants were watered on a daily basis and also basic fertilizer was applied in all treatments, therefore, application of either lime source had no significant effect on vegetative growth. Caires *et al.* (2008) reported that soil acidity had no effect on growth when there was no rainfall limitation. The significant decrease in pod mass when no lime was applied showed that an increase in vegetative growth may not always result in increased groundnut yield. Decreased pod mass under high acid saturation was caused by the high number of empty pods or pops found in the control (no lime treatment). Pops result from seed abortion caused by poor Ca supply to developing pods (Brandy, 1947; Heming *et al.*, 1982; Smartt, 1994). Application of both dolomite and CaSiO₃ resulted in increased yield and yield components.

Groundnuts are produced for their proteins and oil. Although groundnuts have high protein content, the observed increase in protein under low soil pH may be attributed to soil acidity stress. Commercial oil extractors will prefer cultivars with a higher oil content. The reduction in oil content at high acid saturation suggests that the tolerant cultivars may not be popular

with oil manufactures but will certainly have benefits for others including food and animal feed industries. However, application of either lime source increases the oil content of the crop.

CONCLUSION

Both lime sources decreased soil acid saturation, slightly increased soil pH and increased soil nutrients which ultimately increased plant growth and yield. There was no significant difference between calcium silicate and dolomite on most components measured. It can therefore be used to ameliorate soil acidity and increase Ca concentration which is important for groundnut yield improvement. Rambo showed evidence of tolerance to soil acidity because of its ability to reduce Al uptake and increase Ca uptake.

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CHAPTER 6

GENERAL DISCUSSION

Among the abiotic factors drought (Camberlin and Diop, 1999) and inherent soil infertility (Swanevelder, 1998) are major limiting factors to groundnut production. Soil acidity results in toxicity of Al and Mn, which affects root development resulting in poor roots that are unable to reach deeper for moisture absorption and therefore plants become susceptible to drought. The first study assessed the effect of soil acidity on 10 groundnut genotypes used in South Africa, since soil acidity is a main concern for smallholder farmers who cannot afford lime or, sometimes, even basal fertilizers. Groundnuts have been reported to be moderately tolerant to soil acidity (Adams and Pearson, 1976; Munns and Fox, 1977; Foster, 1981); the tolerance differs among genotypes and developmental stage. The results of this study suggest that the Virginia and Runner genotypes are more tolerant to soil acidity measured in terms of Al, Mn and Ca uptake. The genotype JL 24 is moderately tolerant while Harts, Anel, Robbie, Sellie, RG784 and Jasper were susceptible (Table 3.7). Exclusion of Al is one mechanism which has been reported in plants (Taylor, 1995; Kochain, 2004; Rellen-Alvarez *et al.*, 2006) for tolerating high acidity. Low tissue Al concentration in Rambo, Billy, Selimani and JL 24 may suggest the exclusion of Al by these genotypes, which makes them tolerant to various degrees.

The genotypes with large seeds which take longer times to maturity i.e. Rambo, Billy and Selmani were less susceptible to soil acidity compared to shorter maturity genotypes (Harts, Anel, Sellie and Robbie). The acid tolerant genotypes above are not grown routinely in South

Africa especially by smallholder farmers because of their long growth period and high water requirements (Swanevelder, 1998). Hence such farmers might need to be introduced to their advantages in acid soils. JL 24 is one of the genotypes that is popular among smallholder farmers (Matthews *et al.*, 2007), and since this study suggests that it is moderately tolerant to soil acidity, it can be used by smallholder farmers maintain reasonable yields in acid soils. Application of lime is major method of ameliorating soil acidity. The increase in cost of lime has necessitated research to find alternate inexpensive liming material that can be used by farmers with limited capital. The study compared dolomite to inexpensive industrial by-product calcium silicate slag, in relation with nutrient availability, uptake and yield of groundnut. The results showed that CaSiO can be successfully used to ameliorate soil acidity and provide deficient nutrients like Ca required for groundnut production (Figure 5.9 and Figure 5.10).

Understanding the effect of environmental condition at all developmental stages is important to crop growth as their effect at any stage can influence yield (Fageria and Baligar, 1997). A further study in this series was carried out to evaluate the effect of soil acidity to establishment phase and assess different cultivars for tolerance or susceptibility to soil acidity, and determine whether that stage could be used as a rapid screening tool stage. Young seedlings are reported to be more susceptible to Al toxicity than older plants (Mosor- Pietrazewska, 2001). The results of that study showed that seedling developmental stage was sensitive to high soil acidity and Al toxicity. The response differed with genotypes; Rambo appeared to be more tolerant than Harts and Jasper. During the vegetative stage plants appeared to be more tolerant to soil acidity as compared to the early establishment stage and also have clear difference. Where water and nutrients are non-limiting, Caires *et al.* (2003) reported that crops like

soybean were tolerant to soil acidity. Groundnut yield depends on canopy development (plant height, leaf number and area, and number of branches) and reproductive nodes (Phakamas *et al.*, 2008). Reduced vegetative growth in infertile acid soils may affect yield negatively. Application of a basic fertilizer ensures good plant growth during the vegetative stage and also increases number of axils which translates to more flowers. Vigorous vegetative growth may only increase the number of pods (Table 5.1 and Table 5.1); however, the pod filling stage is mainly dependent upon availability of calcium, phosphorus, and sulphur in the soil (Ranjit *et al.*, 2007). Yield formation is the most affected stage by soil acidity in groundnut production.

The main aim of the study was to identify genotypes tolerant to acidity and to assist smallholder farmers who do not use any ameliorate in acid soil to maintain stable yield of groundnut and provide some food security. The study identified Rambo, Billy, Selmani as tolerant and JL 24 as moderately tolerant cultivars that can be grown. Also CaSiO_3 can be used as an alternative to well known agricultural limes.

RECOMMENDATIONS

The following recommendations may be made, based on observations made during the study

- Different genotypes examined have different response to high acid saturation, the results of this study suggest that the Virginia and Runner genotypes are more tolerant to soil acidity. The genotype JL 24 is moderately tolerant while Harts, Anel, Robbie, Sellie, RG784 and Jasper were susceptible. Future studies under field conditions may be necessary to confirmation the greenhouse results.
- Spanish cultivars are normally grown in South Africa. However the study showed that only JL 24 can perform better on acid soil. Future studies on improving Spanish cultivars production on acid soil may be necessary.
- The vegetative growth of groundnuts was not affected by high acid saturation but provided that water and base nutrients are available. However yield formation stage was the most affected by soil acidity. On field condition without irrigation, water availability can be a problem. The future studies on effect of soil acidity infertility and water stress on groundnuts production.
- Lastly some cultivars in the study had lower aluminium shoots concentration, indicating the possibility of Al exclusion. Further research on groundnuts Al tolerant mechanism may provide useful information.

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APPENDICES

Appendix 1: Protein Standard Curve

