UNIVERSITY OF ZULULAND

IMPACT OF SOIL ACIDITY ON GROUNDNUT PRODUCTIVITY IN MPUMALANGA AND KWAZULU - NATAL PROVINCES

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DECLARATION

I, Nkiza, Michael Vilane, declare that the concentrations of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the University of Zululand.

Signed **Date**

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Groundnut [*Arachis hypogaea L.*] is grown on sandy or sandy loam soil by the smallholders in the lowveld region of Mpumalanga and the Northern coast of KwaZulu-Natal. These soils are highly susceptible to leaching, which leads to acid-soil infertility. The goal of the current study was to examine the fertility status of the soils where groundnuts are grown traditionally in Mpumalanga and KwaZulu-Natal in relation to groundnut production with a special emphasis on acid soil infertility factors which include low pH, nutrient deficiencies and toxic levels of manganese [Mn]. First, a soil survey was conducted in the two areas to assess the fertility status of the soils, in which chemical analyses were done for the top 10 cm, 10-40 cm and 40-60 cm soil depth layer. This was followed by two sets of field experiments that examined the performance of groundnut in these soils with and without lime application.

The first experiment [Experiment 1] compared the yield performance of 16 groundnut Varieties in very acid soils at Manguzi in the Northern KwaZulu-Natal and Lowveld College of Agriculture farm near Nelspruit in Mpumalanga lowveld during the 2008-2009 season. In the second experiment [Experiment 2], six varieties selected from Experiment 1 were tested in acid soils during the 2009-2010 season to determine their yield responses to three rates [0, 750 and 1500 kg/ha] of calcitic and dolomitic limes at the Lowveld College of Agriculture farm and calcitic lime at Manguzi. The soils were generally acidic at both sites and low in mineral nutrients. The soils at Nelspruit were particularly deficient in K [22 to 107 mg/kg], and low in Ca [136 to 445 mg/kg] and Mg [28 to 96.6 mg/kg] and differed in this respect from the soils at Manguzi which had higher K [126 to 200 mg/kg], Ca [396 to 1277 mg/kg] and Mg [111 to 166 mg/kg] concentrations whose ranges were substantially above the ranges [40 to 88 mg/kg for K, 100 to 250 mg/kg for Ca and 10 to 30 mg/kg for Mg] considered adequate for groundnut. The soils in Manguzi and Nelspruit were also sufficient in Zn and Mn as the ranges of these nutrients were between 0.4 to 26.1 mg/kg for Zn and 3 to 24 mg/kg for Mn, which were within the ranges [0.5 to 1.0 mg/kg for Zn and 3 to 7 mg/kg for Mn] considered adequate for groundnut. However, at Lowveld College of Agriculture farm these nutrients were higher than at Manguzi.

The sites sampled differed in pH, Ca, Mg, K, P, Fe, Zn, and Mn distribution down the soil profile, but there was no definite trend in the distribution patterns of the nutrients. The soil

pH was highly correlated with Mg at Nelspruit, but at Manguzi, the pH was most correlated with Ca in the 10 to 40 cm soil layer. In Experiment 1, Anel [≥ 1709 kg/ha], ICGV 95714 [1457 kg/ha] and Inkanyezi [1456 kg/ha] yielded well in terms of grain yield under low soil pH conditions in the Mpumalanga lowveld, but at Manguzi the varieties that had outstanding performance under low soil pH were Inkanyezi, Mwenje, ICGV 99529 and RGV-784 which yielded 2358 kg/ha, 1664 kg/ha, 1599 kg/ha and 1444 kg/ha of grain yield, respectively. The application of lime selectively improved the yields of the varieties. Furthermore, the response of the varieties (Anel, ICGV 95714 and Inkanyezi) to lime application at Lowveld College differed from that at Manguzi.

The ability of the test varieties to tolerate soil acidity differed. Varieties JL -24, Inkanyezi, RGV -784 and Rambo were highly sensitive to soil acidity, since their grain yields increased substantially when the lime rates were increased at the Lowveld College of Agriculture farm and at Manguzi. By contrast, varieties Kwarts and ICGV 90071 were insensitive to liming as their grain yields did not respond to liming at the Lowveld College of Agriculture farm. Also, Rambo was insensitive to liming at Manguzi. The variety Kwarts was found to be better suited for acidic soil conditions at Lowveld College of Agriculture farm whereas at Manguzi, Rambo was found suitable for acidic conditions. Groundnut varieties JL-24, RGV-784 and Inkanyezi performed best under half and the recommended lime rates at Lowveld College of Agriculture farm. At Manguzi, Inkanyezi performed outstandingly under half (750 kg/ha) and recommended (1500 kg/ha) lime rate. Of the two limes sources tested at Lowveld College of Agriculture farm, calcitic lime was found suitable as the mean of grain yields were higher in half and recommended lime rates compared to the dolomitic lime. It was noted that in some cases, there was in fact a reduction of yield in some varieties in lime-amended soils. This was most conspicuous for varieties Kwarts at Lowveld College Agriculture farm and Rambo at Manguzi. This could have been caused by interference of Ca and Mg on the uptake of micronutrients such as e.g. Zn or Mn.

CHAPTER 1

1.1. Introduction

Groundnut (*Arachis hypogaea L.)* is believed to have originated in South America and spread to Brazil (Zhao et al., 2012; Sahdev et al., 2015). It was introduced by the Portuguese from Brazil to West Africa and then to South Western India in the 16th Century. Today, groundnut is one of the most important legume crops in the tropical and subtropical regions of the world, where rainfall is moderate, sunshine is abundant and temperatures are high (Nautiyal, 2002). The plant is grown mainly for human consumption, the economic part being the seed, which is either consumed or used for oil extraction. Groundnut oil is the most important product of the crop, which is used for both domestic and industrial purposes. About 75% of the world groundnut production is used in extraction of its edible oil, which is also used for industrial purposes (Craufurd et al., 2006; Reddy and Bentilan, 2012). Groundnut is also used as animal feed viz. cake after oil pressing, seeds, green material as manure and straw (Weiss, 2000; Sahdev et al., 2015). Groundnut seeds typically contain 47-53% oil and 25-36% protein; they also contain about 10-15% carbohydrate and are rich in protein (P); they are also a good source of vitamins B and E (Holbrook et al., 2003). The dry pericarp of the mature pods (known as shells) is used for fuel, as a soil conditioner, filler in fertilizers and feeds, or is processed as substitute for cork or hardboard or composting with the aid of lignin decomposing bacteria (Reddy et al., 2003). These multiple uses of the groundnut plant make it an excellent cash crop for domestic markets, as well as for foreign trade in several developing and developed countries (Weiss, 2000). Groundnut is a self–pollinating, indeterminate, annual, herbaceous legume (Nautiyal, 2002). The fruit is a pod with one to five seeds that develops underground on a needle like structure known as pegs and has elongated ovarian structure (Fabra et al., 2010). Groundnuts together with bambara groundnut are unique among field crops in that their fruits mature underground (Linnemann et al., 1993). Following aerial flowering and fertilization, further development of the fertilized ovules is suspended (Reddy et al., 2003). A meristem at the base of the ovary divides to produce an elongated and geotropic structure, the gynophore, which bends and grows down with the fertilized ovary at its tip to penetrate the soil (Prasad et al., 2009).

When the ovary is well buried in the soil, the ovules develop further into mature fruits (Prasad et al., 2003). Thus, groundnut is best grown on well-drained sandy and sandy loam soils, as these light soils facilitate easy soil penetration of gynophores/pegs as well as the proper development of the pods. In addition, light textured soils facilitate the harvesting of the mature pods (Weiss, 2000). Clay or heavy soils are not suitable for this crop, as they interfere in penetration of pegs and make harvesting quite difficult (Prasad et al., 2003).

The development of groundnut fruits (pods) underground imposes certain nutritional problems and demands that are not found with other field crops. Firstly, the developing pods require to absorb immobile nutrients such as calcium (Ca) directly from the soils since the xylem sap from the roots does not reach the buried fruits (Janila et al., 2013; Fageria and Baligar, 2008). Secondly, the developing pods can get exposed to unfavourable soil conditions, which include low pH and nutrient toxicities. Previous work shows that groundnut pod growth and development are adversely affected by low soil pH per se (Murata et al., 2008). It is also expected that Al and Mn toxicities, often associated with low soil pH infertility, will adversely affect groundnut fruiting in addition to root growth (Fageria and Baligar, 2008). At pH less than 5.0, toxic levels of Al, H, and sometimes manganese (Mn), as well as deficiencies of many macro- and micronutrients, may reduce plant growth in acidic soils (Fageria and Baligar, 2003; Fageria et al., 2009).

Murata et al. (2008) suggested two options for solving the problem of soil acidity. The first option is to apply lime to correct low soil pH and to reduce Mn or Al solubility in soils where toxicities of these elements are being experienced. For most of the resource-poor farmers, liming the soil to correct low pH is not always affordable. In this case, the second feasible option in the short term is to use cultivars that are tolerant to soil acidity. Contingent on the situation, tolerance to soil acidity takes many meanings since it can be associated with many infertility factors.

In one dimension, searching for cultivars that are tolerant to soil acidity may mean identifying genetic tolerance to low pH toxicity per se as well as to Al and Mn toxicities which are usually associated with low soil pH. In another dimension, it may mean identifying genetic material that has an ability to mobilize fixed P, or to absorb adequate Ca and Mg for plant growth from extremely low-levels often associated with acid soils (Murata et al., 2008).

1.2. Problem statement

Sandy soils characterize the land on which smallholder farmers in the Lowveld of Mpumalanga and in Manguzi in the northern part of KwaZulu-Natal grow groundnut in South Africa. Sandy soils are prone to acidity and related soil infertility problems that include micro-nutrient toxicities and macro-nutrient deficiencies (Murata et al., 2002; Kamprath and Smyth, 2004). In spite of the reported negative effects of soil acidity groundnut growth, smallholder farmers do not have their soils analysed to determine fertility (Van der Merwe, 1981). Hence, the fertility status of the soils in relation to groundnut is not known in Mpumalanga and KwaZulu-Natal under the smallholder farmers sector. The present study therefore, examined (1) the fertility status of the soil traditionally used to grow groundnut in Mpumalanga and KwaZulu-Natal, with a special emphasis on acid soil infertility factors like low pH, low availability of Ca and Mg and toxic levels of manganese (Mn) and aluminium (Al) and (2) the genetic diversity of groundnut in tolerating low soil pH and toxicities of Al and Mn and (3) the effect of lime application on groundnut yield in Mpumalanga and KwaZulu-Natal.

1.3. Objectives

1.3.1. To examine the fertility status of the soil traditionally used to grow groundnut in Mpumalanga and KwaZulu-Natal Provinces.

1.3.2. To determine the genetic diversity of groundnut in tolerating low soil pH and toxicities of Al and Mn.

1.3.3. To determine the effect of lime application on groundnut yield in Mpumalanga and KwaZulu-Natal Provinces.

1.4. Hypotheses

1.4.1. Groundnut production by resource poor small-scale farmers in Mpumalanga and KwaZulu-Natal is limited by soil acidity.

1.4.2. Groundnut tolerance to acid soil infertility has genetic basis.

1.4.3. Calcitic and dolomitic lime differ in their effects on the productivity of different groundnut varieties.

CHAPTER 2: LITERATURE REVIEW

2.1. Botanical description of groundnut

Groundnut is an indeterminate, annual, herbaceous legume which may be erect or prostrate depending on the subspecies. It has a well-developed taproot and many lateral roots and nodules (Garcia, 2009; Fabra et al., 2010). The groundnut plant belongs to the class Magnoliopsida, family Fabaceae, and genus *Arachis*. *Arachis hypogaea L*., the only cultivated species in this genus is not known in its wild state (Acquaah, 2005; Fabra, 2010; Doyle and Luckow, 2003; Lavin et al., 2001), but bears resemblance to other wild *Arachis* species in that its fruits mature underground following aerial flowering. There are two commonly cultivated subspecies of groundnut which are distinguished by the location of flowers on the nodes and patterns of branching between vegetative and reproductive branches (Janila et al., 2013; Weiss, 2000) (Table 1.1). The subspecies are (A). *hypogaea hypogaea* (Virginia-type groundnut) and (B). *hypogaea fastigiata* (Spanish and Valencia-type groundnut). Subspecies *hypogaea* has alternate branching between reproductive and vegetative branches, while subspecies *fastigiata* has sequential branching. Each of the subspecies has several botanical types/varieties (Singh and Simpson, 1994). Subspecies *hypoagaea* is divided into botanical varieties *hypogaea* and *hirsute*. Subspecies *fastigiata*, in turn, is subdivided into two botanical varieties, namely *vulgaris* (Spanish) and *fastigiata* (Valencia). The leaves of *Arachis hypogaea L.* are tetrafoliolate, and plants are typically erect and pegs penetrate the soil at an angle of approximately 45°C. The earlier classifications of *Arachis hypogaea L.* were based on growth habit, presence or absence of seed dormancy and relative time to maturity (Singh and Simpson, 1994).

Table 1.1. Subspecies, botanical varieties, market types and growth habits of groundnut (Arachis hypogeaea L.) (Weiss 2000).

Subspecies	Site of flowers and pods	Botanical variety	Market type	Growth habit
‘hypogaea’	Lateral branches	*‘hypogaea’*	Runner	Spreading
		‘hypogaea ‘	Virginia	Bunch
		‘hirsuta’		Erect
’fastigiata’	Main stem	*‘fastigiata’*	Valencia	Erect
		‘vulgaris’	Spanish	Erect

2.2. Morphology and Development

Groundnut seed consists of two cotyledons, a hypocotyl, epicotyl, and radical. There may be 4-5 leaf primordia in the embryo of seed; five are well developed in large seeds and four in small ones. The seedling consists of cotyledons, vegetative axes, and the main axis (Prasad et al., 2009). The hypocotyl is white and is easily distinguished during the early stages of growth, but becomes indistinguishable from the root as the plant matures. The radicle emerges within 24 hours or earlier for vigorous Spanish types and within 36 to 48 h in Virginia types. Groundnut roots do not have typical root hairs, but rather tufts of hairs, which are produced in the root axils (Stalker and Simpson, 1995). During the first few days the developing seedlings are dependent on assimilates stored in cotyledons. The main stem develops from a terminal bud of the epicotyl and two opposite cotyledonary laterals grow at soil level. The main stem can be upright or prostrate and from 12 to 35 cm long or may exceed 1m in runner types. Mainstem leaves account for >50% of the leaf area of plants for the first 35 days, but at 90 days they account only for 10% (Smartt, 1994).

The flowering pattern varies within and between botanical types. The Spanish types flower relatively early and have a broader first flowering peak whereas the Virginia types are later flowering and have multiple flowering peaks (Stalker and Simpson, 1995). The subspecies also vary in their flowering patterns. Generally, one bud per inflorescence reaches anthesis on a given day, but occasionally two or more buds may open on the same day. Flowers open early in the morning as soon as they receive light. The dehiscence of anther occurs just before or when the flower opens or sometimes much earlier (Smartt, 1994). After pollination the pollen tube grows at a rate of 1 cm/h resulting in fertilization within 5-6 hours after pollination. Peg extension is slow at first and takes about 5-6 days to penetrate the bracts. Once pegs are 3-4 mm long they become positively geotropic and start to grow towards the soil (Stalker and Simpson, 1995). The peg bear the ovary with the fertilized ovule at its tips and the peg typically reaches and penetrates the soil surface in about 8-14 days after fertilization. Once the peg enters the soil and penetrates to a depth of 4-5 cm, the tip of the ovary begins to swell and turns horizontally away from the base of the plant and develops into a pod. The fresh weight of the whole pod increases very rapidly during the first 14 days of subterranean growth and pods attain their maximum size after 21 days (Prasad et al., 2009).

2.3. Soil and climatic requirements for groundnut production

2.3.1. Soil requirements

Soils most suitable for groundnut production in South Africa are typically deep (900-1200 mm), structureless, yellow, and yellow-red or red soils with a sandy loam to sandy texture in the topsoil. They include soil forms like Avalon, Bainsvlei and Clovelly (Butterworth and Wu, 2003). The major problem with these soils in relation to groundnut production is that they tend to have low pH and low availability of base nutrients (calcium and magnesium) on account of their high susceptibility to leaching. This potentially exposes the groundnut plants to adverse effects of low soil pH infertility (Fageria and Baligar, 2008). Groundnut is preferably grown on light textured soils ranging from coarse and fine sands to clay loams. The topsoil must have low clay concentration < 20 % with a loose structure so the pegs may penetrate the soil freely (Swanevelder, 1998). These soils, which are the most suitable for groundnut production, are highly susceptible to leaching which removes basic cations from the soil profile leaving a preponderance of H^+ and Al^{3+} ions on the cation exchange sites, and hence, acid soil or low soil pH reactions (Clark and Baligar, 2000). Consequently, in the absence of amelioration, groundnut production is inevitably produced on soils with low cationic nutrients as well as low pH. Under these conditions, both Al and Mn can become a serious problem for groundnut production, depending on the levels of these elements in the soil (Helmy and Ramadan, 2013).

As with all other plants, groundnut requires all sixteen mineral nutrients essential for plant growth. However, responses to direct supplements of most of the nutrients as fertilizers have been very erratic and inconsistent (Gascho and Davis, 1994). Nevertheless, Ca deficiency is considered the most limiting nutrient to groundnut production on most soils. This is because groundnut has a particularly high requirement for Ca in the pod-zone on account of the geocarpic nature of the plant as its fruits mature underground (Murata et al., 2008; Zharare et al., 2010). The developing fruit in its subterranean position does not transpire, and so does not receive xylem sap from the roots. Therefore, it cannot receive phloem immobile nutrients such as Ca that are transported almost exclusively in the xylem sap. Consequently, the developing pods have to absorb Ca for their requirements directly from the soil (Gascho and Davis, 1994; Zharare et al., 2009a). Quite often, Ca levels in the pod zone are not adequate for successful fructification (Kamprath and Smyth, 2004).

2.3.2. Climate requirements

Groundnut is grown in a wide range of temperate and humid regions, but maximum production comes from the semi-arid tropics. For rapid emergence, a soil temperature of above 21^{o}C is required. The temperature of the most rapid germination and seedling development is reported to be about 30^{o}C (Nautiyal, 2002; Sahdev et al., 2015). Temperature is a major environmental factor that determines the rate of crop development. Swanevelder (1998) reported that the lower limit for germination of groundnut is a temperature around 18°C. Temperatures between 20-30°C result in 95% germination. The development and growths is largely influenced by temperature in ground-nut and the optimum air temperature is between 25 and 30˚C (Janila et al., 2013).

Groundnut is adapted to a soil with a pH of 5,3 or if the pH is higher than 8.0, certain elements become unavailable eg. Iron and zinc (Swanevelder, 1998). Although groundnut is considered to be tolerant to acid soils, some cultivars grow well in slightly alkaline soils with a pH of up to 8.0 which helps in nitrogen fixation (Prasad et al., 1999). Groundnut is affected by day length and light intensity and prefers clear days with lots of sunlight for optimum production. The cultivated groundnut (*Arachis hypogaea L*.) exhibits a qualitative response to photoperiod with long days stimulating vegetative growth and reducing pod yields (Nigam et al., 1998).

2.4. Groundnut production and uses in South Africa

Groundnut is a very important food as well as cash crop for the smallholder farmers in South Africa (Mathews et al., 2007). In South Africa groundnut is produced commercially in the North West (29%), Free State (in the Western and North-Western Free State 40%) and Northern Cape (24%) provinces, and by emerging farmers mainly in the Mpumalanga, KwaZulu-Natal (KZN) and Limpopo provinces (Van der Merwe, 1981; DAFF, 2010). The average annual production in South Africa is around 100,000 tons (Swanevelder, 1998). Groundnut is the second most important crop grown by smallholder farmers of South Africa, especially in the Lowveld and Middleveld areas of Mpumalanga province (Mathews and Beck, 1994). Almost all the groundnut produced by the smallholder farmers in South Africa is used locally for home consumption (roasted, boiled, used in cooking, peanut butter and salads etc). Groundnuts are an important source of nutrition in the Mpumalanga areas and northern KwaZulu-Natal and as well as Limpopo province. The crop can also contribute to more viable and sustainable cropping systems in other parts of the country (Swanevelder, 1998). The commercial sector is highly specialized and accounts for around 80% of the total annual area and the smallholder contribute 20% of the total annual production (Mathews and Beck, 1994).

Groundnut is also grown commercially in South Africa as well as in other countries worldwide for its oil. Groundnut oil can be used in various ways at different levels within the industry. It can be utilised as a raw material for manufacturing pharmaceuticals, soaps, hair creams, cosmetics, dyes, paints, lubricants; emulsions for insect control and fuel for diesel engines (DAFF, 2010; Oniya and Bamgboye, 2014). The oilcake that is a by-product of the groundnut oil extraction process serves as a high-protein livestock feed and it can also be used to make glue for wood. Foliage provides silage and forage (Birth et al., 2010).

Groundnut production increased significantly (200 000 tons) during the 2000 to 2001 season because of larger planting areas ± 140 00 ha (DAFF, 2010). South Africa remains a net exporter of groundnut, as production exceeds consumption in most of the years. Although the competition for hectares between various field crops is mounting (ARD. 2008). The constraints faced by the South African smallholder in relation to groundnut production are similar to other Southern African Development Community (SADC) such as Malawi. Kumwenda and Madola (2005) reported that many farmers in communal areas tend to grow only traditional varieties with mostly low yield potential. Although improved varieties and management practices have been recommended to farmers, groundnut yields in Malawi are still very low, similar to the production of smallholder farmers in South Africa.

The decline in productivity of groundnuts is due to several constraints that smallholder farmers encounter (Minde et al., 2008). These constraints include the use of low yielding materials, declining soil fertility through poor management and low nutrient application, inadequate support services such as extension services and credit facilities, diseases and pests as well as a clash in labour demand (Kumwenda and Madola 2005; Mindel et al., 2001). Foliar diseases cause considerable yield reduction and chemical control is beyond the capabilities of the smallholder farmers. None of the groundnut varieties released in South Africa have resistance against the foliar disease complex of early leaf spot (*Cercospora arachidicola*), late leaf spot (*Cercosporidium personatum*) and rust (*Puccinia arachidis*) (Mathews et al., 2007; Van Wyk and Cilliers, 1998). The application of fungicides for disease control is not a viable option for the resource poor, smallholder farmers. With the move towards sustainable agriculture in this country, multi-gene resistance provides the only means to control insect pests and diseases (Van Wyk and Cilliers, 1998; Cilliers and Mathews, 2003). Groundnut yields are poor because of the low, unreliable rainfall, often with midseason or mid-cropping season drought. The dominance of smallholder farmers in groundnut production poses great challenges to buyers in the sense that it is costly to assemble the commodity at one point if the trader is buying large quantities (Minde et al., 2008; Mindel et al., 2001).

2.5. Groundnut production constraints in South Africa

The major production constraints faced by smallholder farmers in South Africa include lack of locally adapted improved varieties, foliar diseases, drought at pod formation, marginal soils with low pH and organic matter, and poor agronomic practices (Mathews and Beck, 1994). Although improved varieties of several indigenous crops have been identified by the Department of Agriculture and Land Administration (DALA) in the past, these are not widely used by farmers due to the absence of institutionalised arrangement to produce and distribute seeds (Mathews and Beck, 1994; Cilliers and Mathews, 2003). Private breeding programmes are a fair alternative, yet the costs are high and the rate of success uncertain. The commercial seed firms are not keen to be involved with the breeding and multiplication of improved seed materials due to the subsistence nature of this crop. The problem is aggravated because most the farmers are dependents on social grants that do not provide them enough money to buy the seeds (Swanevelder, 1994). The commercial farming sector in Mpumalanga produces most of the staple food in large quantities. However, affordability and accessibility for the rural mass of these resources remains a major constraint (Mathews, 2010).

2.6. Soil acidity and its effect on plant growth

2.6.1. What is soil acidity?

An acid is a substance that gives off hydrogen ions (H^+). A base is a substance that gives off hydroxyl ions (OH^-). The pH is an expression of the concentration of hydrogen ions in solution (pH = - log (H^+ activity). The pH scale ranges from 1 - 14, where pH = 7 is neutral, pH> 7 is basic and pH < 7 is acidic (Petrucci et al., 2007). Soils are acid when a considerable portion of the cation exchange capacity is filled with H^+ and $A1^{3+}$, instead of the basic cations which include Ca^{2+}, Mg^{2+}, K^+ and Na^+. In acidic soils, H^+ and Al^{3+} replace the basic cations from the exchange complex and the basic cations can subsequently be leached deep into the soil profile or groundwater (Edwards et al., 2000; Clark and Baligar, 2000).

Generally, the soil is considered acidic for field crop production if the pH is below 5.0. There are many interacting factors that affect plant growth adversely in acid soils, and these are often referred to as acid soil infertility complex (Dolling and Porter, 1994). The factors include deficiencies of basic cations, toxicities of micronutrients like zinc (Zn), boron (B), copper (Cu), iron (Fe), Mn and Al) and the toxic effects of the H^+ ion itself. Deficiencies arise due to reduced solubility (e.g. molybdenum) or increased leaching due to increased solubility (e.g. basic cations) (Dolling and Porter, 1994). Toxicities of nutrients also arise due to increased solubility (e.g. Al, Mn and Fe) and hence availability to plants. The major toxicities on acid soils are those of Al and Mn and to a minor extent Fe (Dinel et al., 2000).

2.6.2. Measurement of soil pH

There are 3 pools, or sources, of acidity: active, exchangeable or residual.

The active acidity is the quantity of hydrogen ions that are present in the soil water solution. The active pool of hydrogen ions is in equilibrium with the exchangeable H^+ held on the soil's cation exchange complex. This pool most readily affects plant growth (Amundson et al., 2003). Active acidity may be directly determined using a pH meter, such as an electron probe. The exchangeable acidity refers to the amount of acid cations, aluminum and hydrogen, occupied on the cation exchange complex (CEC). When the cation exchange complex (CEC) of a soil is high but has a low base saturation, the soil becomes more resistant to pH changes. As a result, it will require larger additions of lime to neutralize the acidity (Hillel, 2004). The soil is then buffered against pH change**.** The residual acidity comprises of all bound aluminum and H^+ in soil minerals. Out of all pools, residual acidity is the least available (Silva and Uchida, 2000).

2.7. Aluminum toxicity to plants

Aluminum is not an essential plant nutrient, but its toxicity stands out as the most common and foremost yield limiting factor for crops grown in acid soil. Aluminum solubility, and hence toxicity to plants, increases with decreasing pH (Aniol, 1990). Aluminum exists in solution as a number of cationic species (monomers) depending on the soil pH. The Al cationic species include Al^{3+}, Al^{2+} and Al^{+}. At pH>5.2, little Al^{3+} or $Al\{OH\}^{2+}$ species exist in the solution or exchangeable pools, and therefore Al toxicity is rarely a problem above this pH level (Hodges, 2010). The toxicity of this nutrient in plants is greatest near pH 4.5 because the $Al\{OH\}^{2+}$ species, which is even more toxic than the Al^{3+} species, is most soluble at this pH. Also, as soil pH decreases below 5.5 and 5.0, the proportion of the cation exchange sites on clay minerals occupied by Al^{n+} increases (Hayne and Mokolobate, 2001). Thus, an increased Al saturation percentage has been closely associated with a decrease in soil pH. Once cationic nutrients have been replaced from exchange sites, they are vulnerable to leaching, so that plant roots are often unable to obtain sufficient nutrients for optimal growth. In addition, Al competes with these nutrients which exacerbates their deficiency (Smyth and Cravo, 1992).

Aluminium does not appear to be taken up by an active transport mechanism. It rather appears to enter root cells passively by osmosis or with the flow of transpiration water, possibly through damaged membranes (Ryan et al., 1993; Frantzios et al., 2005). Aluminium causes several types of damage in plants. It negatively affects plasma-membrane functions and decreases the influx of Ca^{2+} and Mg^{2+} (Keltjens. 1990; Baligar et al., 2001; Panda and Matsumoto, 2007). For example, it has been shown to block Ca uptake sites in membranes of young root tips (Clark. 1984; Zheng et al., 2005). It also restricts cell wall expansion as it binds to pectins making the wall more rigid (Smyth and Cravo, 1992). It restricts cell division and inhibits many plant metabolism and functions. Aluminium imposes direct detrimental effects on roots with one of the toxicity symptoms being restricted root elongation (Zheng et al., 2005). Long-term exposure of plants to Al inhibits shoot growth by inducing nutrient (Mg, Ca and phosphorus (P)) deficiencies, drought stress, and phytohormone imbalances (Yang et al., 2005). Not only plants are affected; many bacteria, such as those that carry out certain transformations in the nitrogen cycle are adversely impacted by the high levels of soluble Al associated with low soil pH (Wenzl et al., 2001). Some crop varieties are tolerant to large Al concentrations in the root zone by excluding Al from the root apex or through plant tissue tolerance to Al in the symplasm (Wenzl et al., 2001; Yang et al., 2005).

2.8. Manganese toxicity to plants

Unlike Al, Mn is an essential nutrient to all crops at very low levels. However, it is a toxicant when in excess in the soil solution. In fact, Mn toxicity is considered the second most important growth limiting factor after Al toxicity in acid soils (Foy, 1984). The range of optimal soil Mn concentrations for plant growth between toxic and deficient concentrations is very narrow. Plant species and genotypes within species vary widely with regard to their susceptibility to manganese toxicity. Manganese like Al, becomes more soluble as the soil pH decreases below 5.5 (Foy, 1984; Marschner, 1991). Soil acidity, or low soil pH as indicated by an abundance of hydrogen ions (H^+), causes mineral Mn oxides to dissolve and release enough manganese ions (Mn^{2+}) into the soil solution to make the soil toxic to many plants. This is illustrated by the following chemical reaction:

$$MnO_2 + 4H^+ + 2e^- \longrightarrow Mn^{2+} + 2H_2O$$

Manganese in its oxidized form (Mn^{4+}) is not available to plants, while Mn in its reduced form (Mn^{2+}) is readily available for plant uptake. In the above reaction, Mn^{2+} is controlled by more factors (e.g. organic matter, microbial activity and anaerobiosis) than just soil pH, but soil pH is nevertheless the major indicator of Mn availability and toxicity. In reality, each unit decrease in pH results in a 10-fold to 100- fold increase in Mn^{2+} (Havlin et al., 1999).

Manganese toxicity is generally exacerbated by organic amendments. Electrons for the above reaction are often provided directly by organic amendments such as animal manures, crop residues, and composts (Tamimi et al., 1997). Instances of Mn toxicity to lettuce and beans grown in high-Mn soils amended with animal manures have been observed even at pH 7.0 (Hue, 1992). Electrons can also be indirectly made available to react with Mn oxides by depriving the soil of oxygen (O_2), which is the most common and effective electron acceptor. Oxygen deprivation occurs when the soil is flooded or becomes poorly drained. Thus, high-Mn soils should be kept well aerated to provide adequate O_2, otherwise Mn toxicity may occur. If Mn levels in the soil solution exceed the range of 0.1– 0.5 mg/L, then Mn is usually harmful to most crops, except the most tolerant ones (Horst and Marschner, 1978).

Plant symptoms associated with highly toxic concentrations or deficiency of Mn in soils include swelling of cell walls, withering of leaves, brown spots on leaves, crinkling or cupping of leaves and splotches of chlorotic tissues. A high Mn concentration may induce Fe deficiency in plants (Smyth and Cravo, 1992).

Tolerance of plants to Mn toxicity varies across different plant species and even varies among varieties. For example, beans, lettuce, potato, and roses are considered sensitive (less tolerant of Mn); carnation, cucumber, and watermelon are moderate; and field corn, rice, sugarcane, and tomato are tolerant (Zheng et al., 2005). Also, sugarcane has been found to have no toxicity problem when grown in high-Mn soils. The adaptation of many other crops has yet to be tested. Shoots are generally more susceptible to changes in growth compared to roots when Mn toxicity occurs (Foy, 1984).

2.9. Nutrient deficiencies

Generally, soil acidity is attributed to the loss of Ca, K and Mg from the soil as a result of leaching and removal in crops. Consequently, deficiencies of particularly Ca and Mg often accompany soil acidity. Similar with the deficient of P and K, and toxicities of Al, Mn, and Fe (Havlin et al., 1999) restrain the yield potential of groundnut production. In addition, soil acidity can be associated with boron (B) deficiency (Swanevelder, 1998). Whilst B is most available in acidic soils, it is also rather easily leached from such soils (Welch, 1995).

2.10. Effects of soil acidity on biological nitrogen fixation

Low soil pH adversely affects biological nitrogen fixation by legumes in three ways: Firstly, low pH causes deficiency of Mo which is required in rhizobial N fixation. Secondly, low soil pH adversely affects the survival and persistence of the rhizobium bacteria in the soil, and thirdly it adversely affects the infection process. Thus, N deficiency is a common occurrence in legume crops growing in acidic soils (Aarons and Graham, 1991).

2.11. The options of solving the problem for low soil pH for groundnut production

2.11.1. Effects of liming on acidic soils and plant growth

The detrimental effect of low soil pH on plant growth can be mitigated with liming. The liming materials commonly used in South Africa are dolomitic and calcitic limes which contain Ca carbonate ($CaCO_3$). Whilst calcitic lime contains $CaCO_3$ only, the dolomitic lime contains Ca and Mg carbonates $CaMg(CO_3)_2$ (Webb et al., 2003).

The main goal of liming is to neutralize the toxic elements that occur under high acidity (especially Al and Mn), while improving the availability of the desired elements such as P, Ca and Mg (Mengel and Kirkby, 1987).

Liming adds hydroxide (OH^-) ions to the soil solution which then decreases the solubility of Al^{3+}, Mn^{2+}, Fe^{3+}, Zn^{2+} and Cu^{2+} ions. In addition, liming increases the availability of P and Mo and promotes microbial growth, development and processes such as biological nitrogen (N) fixation and nitrification (Fanning and Burch, 1997).

The oxides and hydroxides of Ca are more soluble in water, hence adding lime as $Ca(OH)_2$ (hydrated lime) or $CaCO_3$ (finely ground limestone) to an acidic soil produces the following reactions over time in the presence of water (Lumbanraja and Evangelou, 1991):

$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$

or

$CaCO_3 + H_2O \rightarrow Ca^{2+} + 2OH^- + CO_2$

The OH^- produced by lime will neutralize H^+ in the soil, to form water:

$OH^- + H^+ \rightarrow H_2O$

Ca will also exchange with Al on the exchange complex of clay. The Al then reacts with water to form insoluble $Al(OH)_3$:

$2Al^{3+} + 6H_2O \rightarrow 2Al(OH)_3 + 6H^+$

It is recommend that acidic soil be limed to a pH level between 5.8 and 6.2 so that soluble Mn is reduced to below 0.1 mg/L in the extract of a saturated soil paste (Brad, 2000).

Since acidic soils are frequently associated with Ca and Mg deficiency, liming materials also provide Ca^{2+}, (calcitic and dolomitic lime) as well as Mg^{2+} (dolomitic lime). These are essential for plant growth and can reduce Al and Mn toxicity by competing with Al^{n+} and Mn^{2+} for plant uptake. Where sufficient Mg is present, calcitic limestone may be preferred to avoid the possible build-up of excessive Mg that could have negative effects on the physical condition of the soil (Robinson and Loneragan, 1970).

2.11.2. The application of gypsum

The superiority of Ca from gypsum improving groundnut quality because of the high soluble of gypsum (Baligar, 2001). Hence advantage of lime not only increasing the Ca and Mg status, but also create favorable condition by reducing toxicities of H, Al and Mn (Murata et al., 2003; Toma et al., 2005). There is extensive nutrient mining and soil fertility decline in the smallholder farming sector of southern Africa (Ntare et al., 2008). Furthermore, emphasis is needed to be placed on the application of micronutrients and secondary nutrients such as Ca and Mg (Bationo et al., 2004). Excessive K concentration in the rooting environment of groundnut affects pod development and filling. Hence the availability of soluble Ca during the development of pods is entail for groundnut production (Zharare et al., 2012). However, to get good yields and quality groundnut pods, an adequate amount of Ca should be present in the soil from onset of flowering of crop production (Bationo et al., 2004). Calcium deficiency leads to high percentage of aborted and improperly filled pods (Ntare et al., 2008).

CHAPTER 3. SOIL FERTILITY SURVEY OF SANDY SOILS IN RELATION TO GROUNDNUT PRODUCTION IN MPUMALANGA LOWVELD AND MANGUZI.

3.1. Introduction

The successful production of a crop in a soil depends on the capability of the soil to meet the environmental and mineral nutrient requirements of the crop. Because soils differ in their ability to support the growth of various crops (Mengel et al., 2001), it is always prudent to assess the property of the soils in relation to their capability to support the production of our major crops. This can be done at micro-level, e.g. at farm level or on a larger scale, e.g. at national level. Generally, the assessment of soil at the national level transcends into a soil survey. The nature of a soil survey, however, depends on the objective of the survey. In crop production, a soil fertility survey involving soil testing provides an inventory of those properties that relate to plant growth. These properties include texture, internal drainage, mineral nutrient concentration, pH, and salinity and their spatial distribution over a landscape. Each soil type has a unique set of physical, chemical and mineralogical characteristics, and has particular reactions to use and management. Therefore, in addition to providing information on the capability of the soils to support various crops, the information assembled in a soil fertility survey can be used to predict or estimate the potentials and limitations of the soils' behaviour under different uses (Vara Prasad et al, 2009). Soil fertility surveys also provide information for formulating general or blanket fertilizer recommendations and provide insight into the kind and intensity of land management that will be needed (Vara Prasad et al, 2009).

A soil test is a central component of a soil fertility survey. It is the process by which elements essential for plant growth in the soil are measured in a representative sample, and assessed for their availability to plants (Barker and Pilbeam, 2007). The tests also include the measurement of soil pH, organic matter and exchangeable acidity. In crop production, a soil test is useful for predicting the soil concentration of available nutrients and the required amount of fertilizer and other soil amendments to apply to the soil to adequately support a particular crop. In the present study, soil tests were used in a survey of sandy soils in Mpumalanga lowveld and Manguzi in relation to groundnut production to the determine the genetic diversity of the groundnut in tolerating low soil pH and toxicities of Al and Mn (Mengel et al., 2001).

3.2. Methods and Materials

3.2.1. Survey sites

The soil survey was conducted in two locations that included the lowveld of Mpumalanga province and the northern part of KwaZulu-Natal. In Mpumalanga, five sites [Agricultural College farm 25º 26' 25''S, 30º 58' 57'', Malekutu 25º 22' 59'' S, 31º 16' 18'' E, Numbi 25º 8' 56'' S, 31 º 11' 1'' E, Luphisa 25 º 26' 13'' S, 30 º 58' 23'' E and Masoyi 25º 9' 35'' S, 31º 9' 32'' E] were sampled in the Lowveld near Nelspruit. In northen Kwazulu-Natal, the survey was conducted in Manguzi rural area in the northern coastal region of the province in six different fields [Field D_1 to Field D_6; 26º 59' 27''S, 32º 45' 03'' E] which were 20 meters apart.

3.2.2. Soil sampling procedure

At each of the pit sites, four holes were randomly sampled at 10 meters apart. The mineral nutrition of groundnut is complicated by the fact that groundnut takes up nutrients in the pod-zone (Zharare et al., 2011; Chahal and Virmani, 1973; Chahal, Singh and Shukla, 1979) which extends from the top of the soil to a depth of 10 cm in addition to the root zone, which generally extends to a depth of between 20 to 30 cm (Murata et al, 2008) Therefore three soil samples were obtained per sampling hole at depths 0-10 cm (pod-zone), 10-40 cm (root-zone) and 40-60 cm (subsoil) using an auger. The soils from the three depths were mixed separately in buckets at each of the pit sites, and a composite soil sample of each of the sampling depth was taken for chemical analysis.

3.2.3. Soil preparation for chemical analyses

Soil samples were air dried at room temperature, crushed between rubber belts on a soil crusher, and passed through a 1-mm sieve. Those materials that could not be crushed were discarded.

3.2.4. Soil pH measurement

For each composite soil sample, 10 mL of soil was placed in a beaker to which was added 25 ml of 1 M KCl solution. The resultant suspension was stirred on a shaker at 400 r.p.m. for 5 min. The suspension was allowed to stand for about 30 minutes, and the pH measured using a gel-filled combination glass electrode while stirring.

3.2.5. Mineral nutrient analyses

3.2.5.1. Mineral nutrient extraction

A quantity of 2.5 grams of soil was placed in a beaker and 25 mL of 1 M KCl solution was added to it. The resultant suspension was stirred at 400 r.p.m. for 10 min on a stirrer and filtered using Whatman No.1 paper. This filtrate was used for determining both macro- and micro-nutrients.

3.2.5.2. Determination of calcium and magnesium

Five millilitres of the filtrate was diluted with 20 mL of 0.0356 M $SrCl_{2}$., and the concentrations of Ca and Mg in the filtrate were determined by atomic absorption spectrometry.

3.2.5.3. Determination of phosphorus

Phosphorus concentration was determined from a 2 mL aliquot of the filtrate using a modification of the molybdenum blue procedure of Murphy and Riley (1962) as described by (Hunter, 1974).

3.2.5.4. Determination of potassium

Potassium was determined by atomic absorption spectrometry from a 5 mL aliquot of the filtrate after dilution with 20 mL de-ionised water.

3.2.5.6. Determination of zinc, copper and manganese

The micro-nutrients Zn, Cu and Mn were determined by atomic absorption spectrometry from an undiluted sample of the filtrate.

3.2.6. Data analysis

Since there was no replication within each pit site, there were no suitable statistical analyses of the data other than correlation and regression analyses, of which regression analyses provided a legitimate means of explaining mathematically the relationship between soil nutrients concentration in the soil profile. TableCurve 2D v 5.01 (2004) was used to determine correlations and to produce mathematical functions of the relationships between soil mineral nutrients and soil depth. A SigmaPlot (2001) computer program was used for graphical presentation of the relationships.

3. 3. Results

3.3.1. Chemical properties of the sandy soils in Mpumalanga Lowveld

3.3.1.1. Soil pH

With the exception of one location (Luphisa), the soil pH at the other 4 locations surveyed in Mpumalanga Lowveld was markedly acidic (Table 3.1). At the sites with acidic soils, the pH ranged from 4.3 to 5.0 in the pod-zone (0-10 cm depth) 4.3 to 5.4 in the root-zone (10-40 cm depth) and from 4.5 to 5.2 in the sub-soil (40-60 cm depth). At Luphisa the soil pH was above 6.0 in all soil layers measured. Although there were not differences in soil pH between the three depths, the differences were small enough to be not significant different.

3.3.1.2. Soil P concentration

The sites surveyed in Mpumalanga lowveld varied markedly in the soil P concentration. The site mean ranged from 4.3 mg kg^{-1} at Masoyi to 60.5 mg kg^{-1} at Luphisa (Table 3.1). The distribution of P down the soil profile also varied among the sites. At Numbi and Lowveld College of Agriculture Farm, the soil P concentrations decreased down the soil profile. At Masoyi and Luphisa, it increases down the soil profile, whereas at Malekutu, the soil P concentration was higher in the 10 to 40 cm soil depth than it was in shallower (0-10 cm) or deeper (>40 cm) soil depths.

3.3.1.3. Soil K concentration

There were marked variations in the soil K concentration of the sites of which the mean ranged from 52.3 mg kg^{-1} at Masoyi to 131.3 mg kg^{-1} at Luphisa (Table 3.1). The distribution of K down the soil profile varied among the sites. The soil K concentration increased down the soil profile at Lowveld College farm, Malekutu and Masoyi, but at Luphisa, the K concentration decreased down the profile. At Numbi, the soil K concentration was markedly reduced in the root zone (10- 30 cm depth) than it was in the pod zone (0-10 cm depth) and in the subsoil (>40 cm depth).

3.3.1.4. Soil Ca concentration

The mean site Ca concentration ranged from 204.3 mg kg^{-1} at Masoyi to 420.7 mg kg^{-1} at Agricultural College (Table 3.1). There was no consistent pattern in the distribution of Ca down the soil profile among the sites surveyed. At Masoyi, the soil Ca concentration increased markedly with soil depth. A similar trend in soil Ca concentration was obtained at Numbi and Luphisa, but the differences in soil Ca between the soil depths sampled were not as pronounced as at Masoyi. At the other two sites, the soil Ca either decreased at greater depth than 10 cm (Lowveld Agricultural College) or it was higher at the 10-40 cm soil depth zone compared to the 0-10 and 20-40 soil depth zones (Malekutu).

3.3.1.5. Soil Mg concentration

The soil Mg concentration of the sites sampled was generally low (Table 3.1). The mean sites' Mg concentration ranged from 60.3 mg kg^{-1} at Malekutu to 102.3 mg kg^{-1} at Lowveld Agricultural College (Table 3.1). Generally, the top soil (<10 cm) contained less Mg than the deeper soil layers. Also, the Mg concentration did not seem to vary at soil depth >10 cm (Table 3.1).

3.3.1.6. Soil Mn concentration

Although the soil Mn concentration was generally low, there were marked differences in the soil Mn concentration among sites sampled in Mpumalanga Lowveld region (Table 3.1). The site mean Mn concentration ranged from 2.7 mg kg^{-}soil at Agricultural College farm to 11.2 mg kg^{-1} soil at Masoyi. The Mn concentration tended to be highest in the top 0-10 cm of soil. At Lowveld College of Agriculture Farm and Luphisa there was a tendency for the soil Mn concentration to decrease with increasing soil depth. At Malekutu, Masoyi and Numbi, the Mn concentrations tended to be higher in the 40-60 cm depth (subsoil) zone than in the 10 to 40 cm depth (root) zone (Table 3.1).

3.3.1.7. Soil Zn concentration

There were wide differences in the soil Zn concentration among the sites (Table 3.1). The mean site Zn concentration ranged from 0.5 mg kg^{-1} soil at Masoyi to 16.7 mg kg^{-1} soil at Agricultural college farm (Table 3.1). Furthermore, there was no consistent pattern in the distribution of Zn down the soil profile among the sites surveyed. At Malekutu, the soil Zn concentration markedly decreased with increasing soil depth. At the other three sites (Numbi, Luphisa and Masoyi), the soil Zn concentration tended to be higher in the 10-40 cm soil depth. Generally, the subsoil contained relatively little Zn (0.5 to 3.6 mg kg^{-1} of soil) compared with the pod-zone (0.4 to 26.1 mg kg^{-1} soil) or the root-zone (0.8 to 20.7 mg kg^{-1} soil).

Table 3.1. Variations in soil pH, P, K, Ca, Mg, Mn and Zn levels down the soil profile at five sites in Nelspruit

Sampling Sites	Soil depth (cm)	Soil pH (KCl)	P	K	Ca	Mg	Mn	Zn
					(mg kg^{-1})			
Agricultural College	0-10	4.3	41.2	106.2	445	96.7	4.2	26.1
	10-40	5.4	30	78.6	408	106.2	2.4	20.7
	40-60	5.2	13.2	73.6	409	104	1.4	3.4
Site mean		5.0	28.1	86.1	28.1	102.2	2.7	16.7
Malekutu	0-10	5.0	23	72	238	43	6.3	4.4
	10-40	5.2	27.2	76	308	69	4.3	3.8
	40-60	4.5	5.7	78	232	69	5.3	0.5
Site mean		4.9	18.6	75.3	259.3	60.3	5.3	2.9
Numbi	0-10	4.7	29.5	107	287	54	8.5	7.2
	10-40	4.8	27.3	81.7	342	67.7	5.7	10.6
	40-60	4.5	19.7	108.3	356	68.3	7	1.5
Site mean		4.7	25.5	99.0	328.3	63.2	7	6.4
Luphisa	0-10	6.3	44.5	62	325	69.5	4	9.7
	10-40	6.4	60	76	326	79.5	3	10.2
	40-60	6.2	77	256	330	136	2	1.9
Site mean		6.3	60.1	131.3	327.0	95.0	3	7.3
Masoyi	0-10	4.5	2	22	136	28	24	0.4
	10-40	4.3	4	52	168	46	4.5	0.8
	40-60	4.8	7	83	309	116	5	0.4
Site mean		4.5	4.3	52.3	204.3	63.3	11.2	0.5

3.4. The relations between basic cations (Ca, Mg and K) in Mpumalanga lowveld

The relationships between soil Ca, Mg and K in the pooled data differed (Table 3.2). Calcium was strongly correlated with Mg, but was not with K. Magnesium was also weakly correlated with K. The correlation between these macro-nutrients decreased in the order Ca and Mg> Ca and (Mg+K) = Mg and (Ca+K) >K and (Ca+Mg) >Mg and K> Ca and K, with the strongest correlation (r^2 value) of 0.6419 (Ca and Mg) and the weakest having an r^2 value of 0.0358 (Ca and K) (Table 3.2).

Among the separate soil depth zones sampled, Mg and Ca were strongly and positively in the pod zone (top 10 cm depth) and root zone (10-40 cm), but in the sub soil 40-60 cm depth), the correlation between these two nutrients was weak (Table 3.2). Over the entire soil profile, the soil Mg concentration was strongly and positively correlated with soil Ca concentration (Figure. 3.1A) and so was the case in the 0-10 cm soil depth (Figure. 3.1B) and in the 10-40 cm soil depth (Figure. 3.1C).

Table 3.2. The correlations between soil Ca, Mg and K concentrations over the entire soil profile in the different soil depths layers for the sites in Mpumalanga lowveld

Soil-chemical parameters	r^2 correlations values			
	Pooled data for the soil profile	0-10 cm soil depth layer	10-40 cm soil depth layer	40-60 cm soil depth layer
Ca and Mg	0.6419	0.9036	0.8648	0.2555
Ca and K	0.0358	0.6493	0.4854	0.0774
Mg and K	0.3124	0.5162	0.0963	0.0982
Ca and (Mg+K)	0.3597	0.2761	0.3989	0.0468
Mg and (Ca+K)	0.2445	0.2304	0.2279	0.0583
K and (Ca+Mg)	0.3677	0.2617	0.1519	0.4656

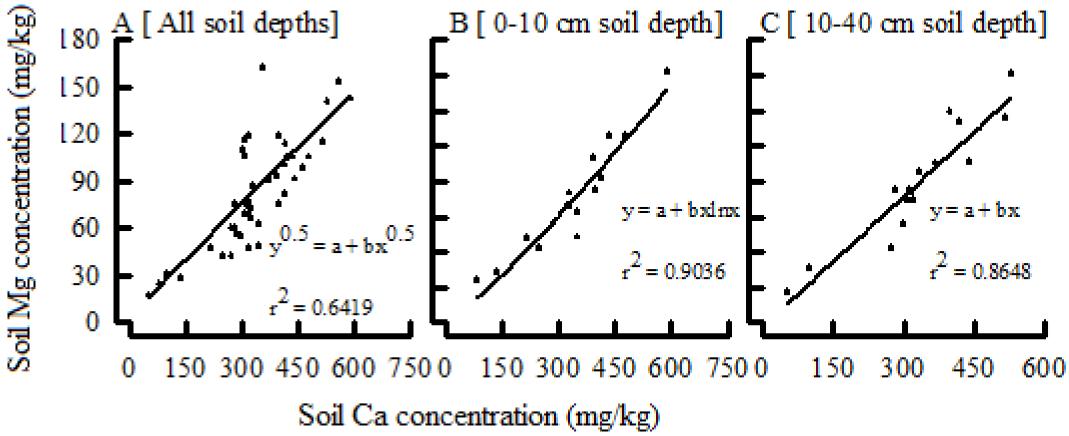

Figure 3.1. The relationships between soil Ca and Mg concentrations for pooled data of the whole soil profile (A), in the top 10 cm soil layer (B) and in the 10-40 cm soil depth (C) for the sites sampled in Mpumalanga Lowveld.

Although there was no correlation between the soil Ca and K concentration in the pooled data of the soil profiles, in the separate soil zones samples, there was a positive correlation between Ca and K, which was strongest in the top 10 cm of the soil (r^2= 0.6493) and decreased with increasing soil depth to insignificant (r^2= 0.0774) in the 40-60 cm soil depth (Table 3.2). Soil Mg and K concentrations were only positively correlated in the top 10 cm soil depth (Table 3.2). The relationship of soil K concentration with soil Ca and Mg concentrations in the 0-10 cm soil layer were linear (Figure.3. 2).

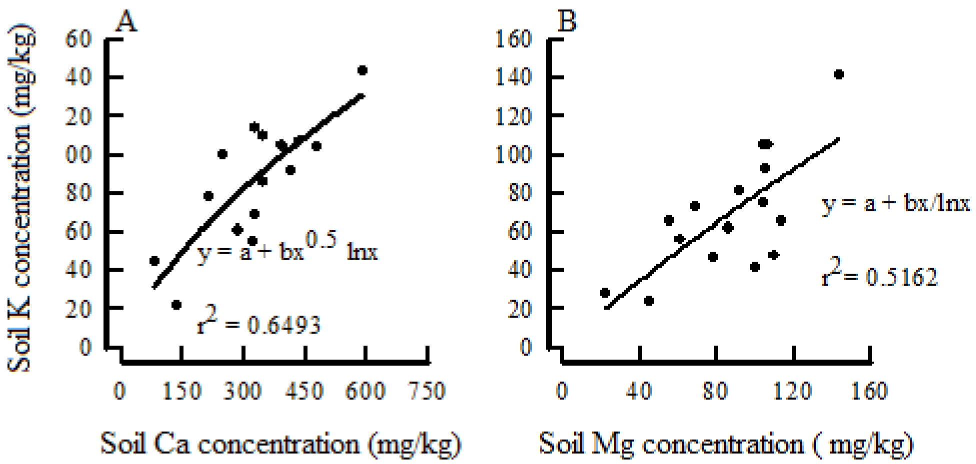

Figure 3. 2. The relationships between the concentration of K in soil and that of Ca (A) and Mg (B) in the top 10 cm soil layer for the sites sampled in Mpumalanga Lowveld.

There was a weak, but positive correlation between soil Ca concentration and the sum of soil Mg and K concentrations the strength of which decreased down the soil profile (Table 3.2 and Figure 3. 3). The soil Mg concentration not correlated with the sum of soil Ca and K concentrations in the pool data and in the different soil layers (Table 3.2).

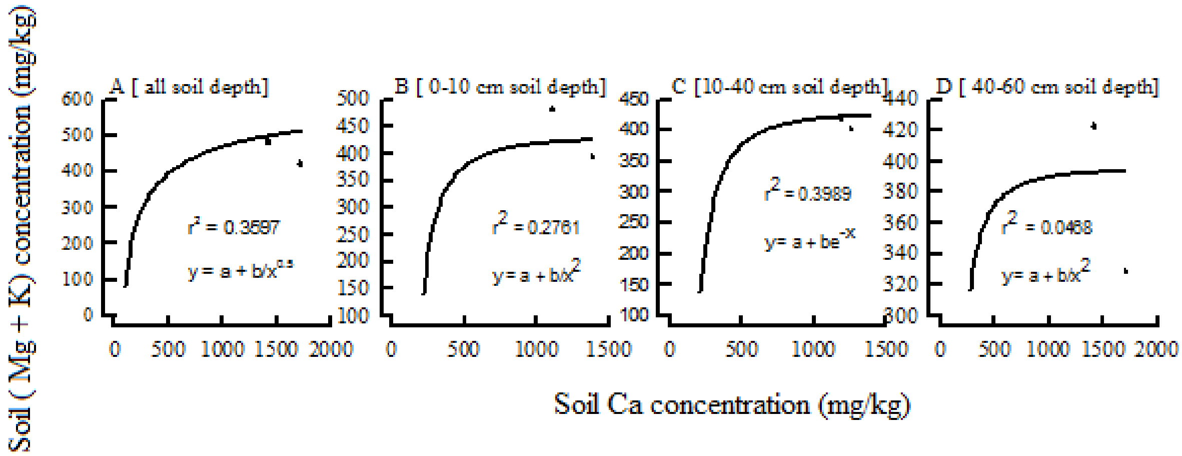

Figure 3.3. The relationships between the Ca concentration and the total sum of Mg and K concentrations in the different soil profile for the sites sampled in Mpumalanga Lowveld.

3.5. The relationships between soil pH and the soil concentrations of basic cations in Mpumalanga Lowveld

The soil pH was more correlated with soil Mg concentration than it was with Ca or K (Table 3.3), but the relationship between Mg and soil pH, although positive in all cases, differed with soil depth (Figure 3. 4). Between the three basic cations, the soil pH had the least correlation with the soil K concentration (Table 3.3). The correlation coefficient between soil Ca concentration and soil pH was highest (r^2 = 0.3963) in the root-zone (i.e.10-40 cm soil depth) and least (r^2 = 0.1605) in the subsoil (40-60 cm soil depth). There was no correlation between the soil pH and the combined concentrations of the basic cations in the soil (Table 3.3).

Table 3.3. The correlations between soil Ca, Mg, K and pH concentrations over the entire soil profile different soil depth layers for the sites in Mpumalanga Lowveld

Soil -chemical parameters	r^2 correlations values			
	Pooled data for the entire soil profile	0-10 cm soil depth layer	10-40 cm soil depth layer	40-60 cm soil depth layer
Ca and pH	0.2793	0.2798	0.3963	0.1605
K and pH	0.0481	0.0845	0.1461	0.2249
Mg and pH	0.3279	0.4189	0.4330	0.4523
(Ca+Mg) and pH	0. 1831	0.1339	0.093	0.0589
(Ca+K) and pH	0.0194	0.0225	0.057	0.0677
(Mg+K) and pH	0.0279	0.059	0.0516	0.1050
(Ca+Mg+K) and pH	0.1295	0.0700	0.0163	0.1786

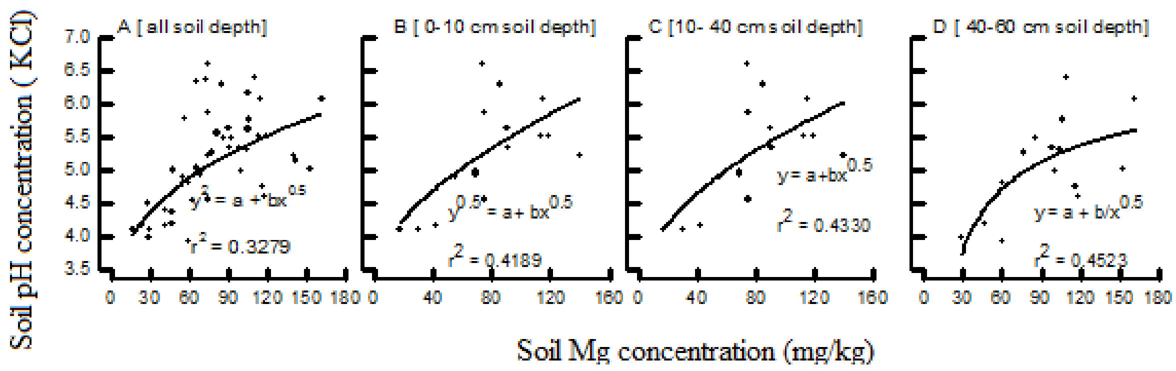

Figure 3.4. The relationships between soil concentration of pH and the soil concentrations of Mg in the pooled data of the soil depths (A), the top 10 cm soil layer (B), the root zone (10-40 cm soil layer) (C) and sub soil (40-60 cm soil layer) (D) for the sites sampled in Mpumalanga Lowveld.

3.6. Chemical analyses of sandy soils in Manguzi in the northern coastal KwaZulu–Natal

The soil contained markedly more Ca than Mg or K (Table 3.4). The values for K and Mg fell within similar ranges among the sites sampled. Generally, the soil concentration of the nutrients analysed were markedly higher in the top 10 cm of the soil profile than in the lower horizons (Table 3.4).

3.6.1. Soil pH

The mean site pH of the soils at the five locations surveyed at Manguzi was variable, but the values were acidic, ranging from 4.6 to 4.8. (Table 3.4). The pH of the top 10 cm soil layer ranged between 4.82 and 5.39, and there was a tendency for the pH to decrease with increasing soil depth at most of the sites.

3.6.2. Soil P concentration

The site mean values of soil P concentration ranged from 3.4 to 13.0 mg kg^{-1}(Table 3.4). In its distribution down the soil profile, the P concentration varied within a narrow range at each of the sites sampled. The P concentration was generally higher in the top 10 cm layer of the soil than in the lower horizons. However, at most of the sites, the P concentrations in 10-40 (root zone) and the 40-60 (subsoil) soil depths did not differ markedly (Table 3.4).

3.6.3. Soil K concentration

The mean site values for K ranged from 98 to 176 mg kg^{-1}. At each of the sites, the soil K concentration was highest in the top 10 cm layer of the soil. At three of the sites (D_1, D_3 and D_5), the soil K concentration was lowest in the 10-40 soil depth layer. At the other three sites (D_2, D_4 and D_6), it decreased with increasing soil depth (Table 3.4).

3.6.4. Soil Ca concentration

The soil Ca concentration ranged from 396 to 1277 mg kg^{-1} in the top 10 cm soil layer, 173 to 481 mg kg^{-1} in the 10-40 cm soil depth and from 247 to 497 mg kg^{-1} in the 40-60 cm soil depth (Table 3.4). In the majority of the cases (sites D_1, D_3, D_5 and D_6), the soil Ca was lowest in 10 to 40 cm soil depth layer. In few of the cases (sites D_2 and D_4), the soil Ca decreased with increasing soil depth.

3.6.5. Soil Mg concentration

The sites' mean soil Mg concentration ranged from 83 to 166 mg kg^{-1}. In its distribution down the soil profile, the Mg concentration either decreased with increasing soil depth (sites D_2, D_4 and D_6) or was lowest in the 10-40 cm soil depth (D_1, D_3 and D_5) (Table 3.4).

3.6.6. Soil concentration of micro-nutrients Zn and Mn

Of the two micronutrients measured, the soil concentration of Mn was generally higher than that of Zn. The mean site Zn concentration ranged from 0.7 to 2.7 mg kg^{-1}, whereas that of Mn concentration ranged from 2.3 to 7.1 mg kg^{-1}(Table 3.4). As with macronutrients Ca, Mg, K and P, the soil concentrations of the micronutrients Zn and Mn was markedly higher in the top 10 cm of the soil than in the lower soil horizons. In this soil layer, the soil Zn and Mn concentrations varied from 0.7 to 4.3 mg kg^{-1} and from 3.3 to 14.3 mg kg^{-1}, respectively, compared with the ranges 0.6 to 2.8 mg kg^{-1} of Zn and 1.3 to 3.7 mg kg^{-1} of Mn in the 10 to 40 cm soil depth or 0.7 to 2.8 mg kg^{-1} of Zn and 2.3 to 5 mg kg^{-1} of Mn in the 40-60 cm soil depth layers. In their distribution down the soil profile, the Zn and Mn concentrations were either lowest in the 10 to 40 cm soil depth (root) zone or in the 40-60 cm soil depth (subsoil) zone. Nonetheless, differences in the Zn and Mn concentrations between the 10-40 cm soil depth and the 40-60 soil depth were very marginal.

Table 3.4. Variations in soil P, K, Ca, Mg, Mn and Zn levels down the soil profile at six sites in Manguzi.

Sampling sites	Soil depth (cm)	Soil pH (KCl)	P	K	Ca	Mg	Mn	Zn
					(mg kg^{-1})			
Field D_1	0-10	5.07	15.7	167	1218	156	8	3.4
	10-40	4.79	9	86	443	104	3.3	1.0
	40-60	4.45	9.7	119	485	124	5	2.7
Site mean		4.8	11.5	124	715	128	5.4	2.4
Field D_2	0-10	5.32	13.7	200	560	166	6.3	2.4
	10-40	4.66	12.7	188	348	110	3.3	2.8
	40-60	4.56	12.7	140	247	90	5	2.8
Site mean		4.8	13.0	176	385	122	4.9	2.7
Field D_3	0-10	5.09	12	154	1277	155	12	4.3
	10-40	4.75	7	72	481	108	3	1.1
	40-60	4.47	6	100	497	128	4.7	1.0
Site mean		4.8	8.3	108.7	751.7	130	6.6	2.1
Field D_4	0-10	5.22	5.7	168	396	120	4.3	3.0
	10-40	4.47	4	131	309	118	2.7	1.7
	40-60	4.27	9.3	123	282	70	3.7	2
Site mean		4.7	6.3	140.7	329	102.7	3.6	2.2
Field D_5	0-10	4.82	8	126	1007	144	14.3	2.7
	10-40	4.63	5.7	74	347	83	3.7	1.1
	40-60	4.4	7	94	465	110	3.3	0.8
Site mean		4.6	6.9	98	606	112	7.1	1.5
Field D_6	0-10	5.39	4	187	406	111	3.3	0.7
	10-40	4.25	2.3	100	173	91	1.3	0.6
	40-60	4.29	4	84	252	73	2.3	0.7
Site mean		4.6	3.4	123.7	277	91.7	2.3	0.7

There were no relationships between Ca and K or between Mg and K, whereas the soil Ca and Mg concentrations of the six sites sampled were strongly and positively correlated in the polled data of the soil profiles and in all soil layers (Table 3.5; Figure 3.5). However, the nature and strength of the relationship varied down the soil profile (Figure 3.5). The relationship was markedly stronger (r^2=0.8787) in the 40-60 cm soil layers than it was in the 10-40 cm soil layer (r^2=0.5989) or in the top 10 cm soil layer (r^2=0.6082). There was a weaker positive correlation (r^2 = 0.4209) between Ca and the sum of the Mg and K concentrations in the root zone 10 to 40 cm soil depth layer.

Table 3.5. The correlations between soil Ca, Mg and K concentrations over the entire soil profile in the different soil depths layers for the sites in Manguzi

Soil chemical parameters	r^2 correlations values			
	Pooled data for the entire soil profile	0-10 cm soil depth layer	10-40 cm soil depth layer	40-60 cm soil depth layer
Ca and Mg	0.7832	0.6082	0.5989	0.8787
Ca and K	0.0015	0.0077	0.0819	0.0075
Mg and K	0. 0033	0.0216	0.0135	0.0132
Ca and (Mg+K)	0.2357	0.2528	0.4209	0.2850
Mg and (Ca+K)	0.1724	0.1918	0.2053	0.2092
K and (Ca+Mg)	0.1658	0.2525	0.1763	0.1678

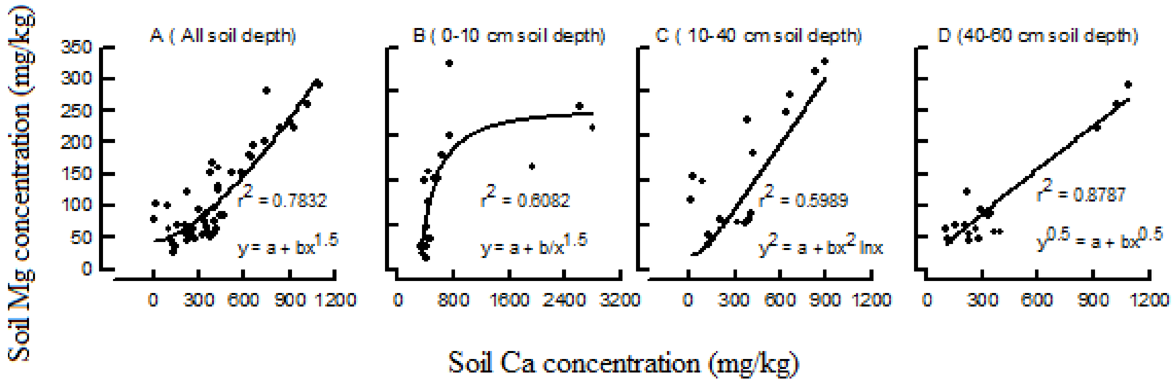

Figure 3. 5. The relationships between soil Ca and Mg concentrations in the pooled data of the whole soil profile (A), in the top 10 cm soil layer (B), in the 10-40 cm soil layer (C) and in the 40 – 60 cm soil layer (D) for the sites sampled in Manguzi.

3.7. The relations between soil pH and basic cations at Manguzi

Soil pH in the top 10 cm soil layer was not correlated with Ca, but was positively correlated with Mg or K, albeit the relationships were weak (Table 3.6). However, the soil pH was strongly and positively correlated with soil Ca in the 10-40 cm soil layer (r^2=0.7275) and to a lesser extent (r^2=0.4685) in the 40-60 cm soil layer (Table 3.6; Figure 3. 6). The soil pH was only weakly and positively correlated (r^2 = 0.3610) with soil K in the in the top 10 soil layer.

The correlations between the soil Mg concentration and pH in all soil layers were weak, but positive (r^2 varied from 0.32 to 0,387) (Table 3.6 and Figure 3. 7). There was poor correlation between the soil pH and the sum of basic cations (Ca + Mg), (Mg + K) or (Ca+Mg+K).

Table 3.6. The correlations between soil Ca, Mg, K and pH concentrations over the entire soil profile different soil depth layers for the sites in Manguzi

Soil-chemical parameters	r^2 correlations values			
	Pooled data for the entire soil profile	0-10 cm soil depth layer	10-40 cm soil depth layer	40-60 cm soil depth layer
Ca and pH	0.4653	0.0310	0.7275	0.4685
Mg and pH	0.3837	0.3799	0.3251	0.3867
K and pH	0. 1238	0.3610	0.0115	0.0027
(Ca+Mg) and pH	0.0272	0.2680	0.0609	0.0223
(Ca+K) and pH	0.0303	0.2700	0.1145	0.0222
(Mg+K) and pH	0.0057	0.0354	0.046	0.0290
Zn and pH	0.1865	0.902	0.5288	0.3219
Mn and pH	0.0517	0.2412	0.1878	0.0889
Total basic cations (Ca+Mg+K) and pH	0.0092	0.0366	0.0517	0.0435

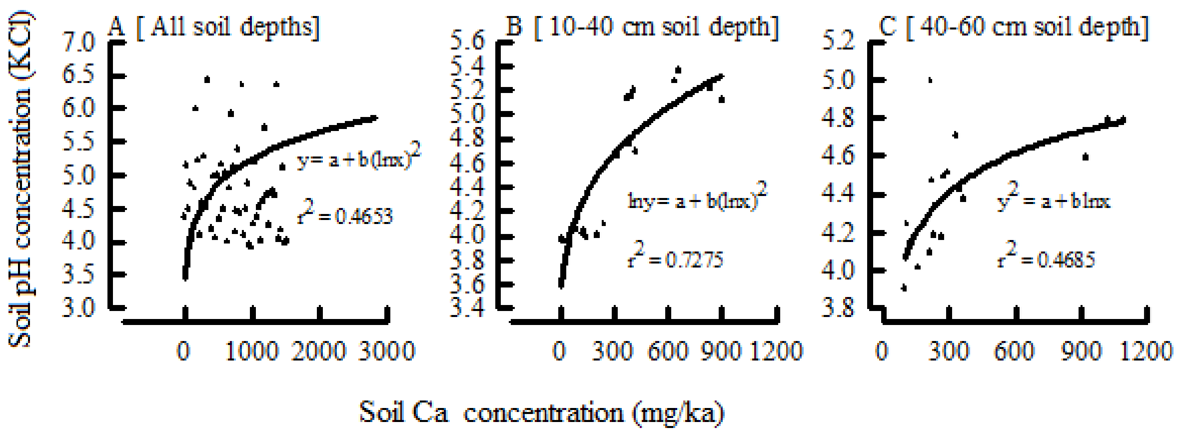

Figure 3. 6. The relationship between the soil pH and soil Ca concentration for pooled data of the whole soil profile (A), in the 10- 40 cm soil depth layer (B) h and in the 40-60 cm soil depth layer (C) for the sites sampled in Manguzi.

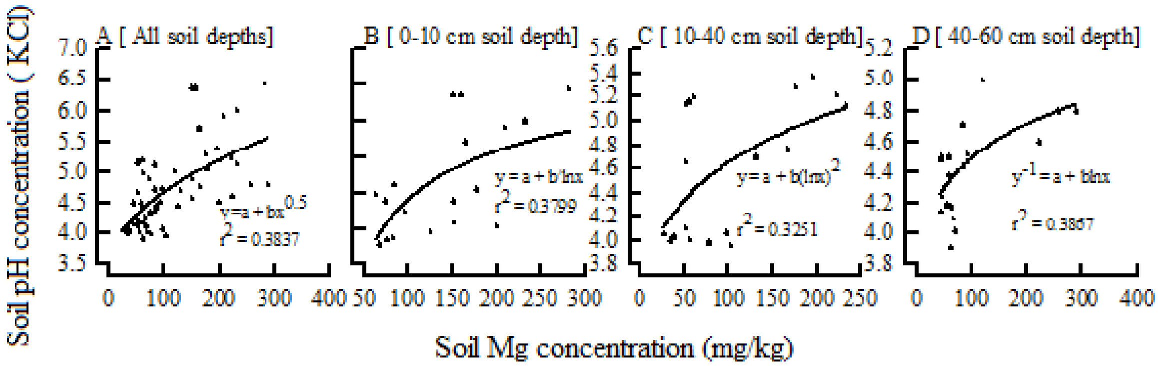

Figure 3.7. The relationship between the soil Mg and pH concentration for pooled data of the whole soil profile (A), the top layer 10 cm (B), in the 10 - 40 cm layer (C) and in 40 - 60 cm soil depth (D) for the sites sampled in Manguzi.

3.8. Discussions

3.8.1. Adequacy of mineral nutrients for groundnut production

Generally, the soils surveyed were markedly acidic. With the exception of one site in Mpumalanga, the soil pH values were less than 5.5, the lower limit in the pH range 5.5-6.5 considered optimal for crop production. The basic cations concentrations of soil were also generally low and so were Zn and Mn, which the only micronutrients analysed in the survey soils. The concentration of the basic cations was lower but the concentrations of the micronutrients Zn and Mn were higher in Mpumalanga lowveld soils compared to the Manguzi soils.

Any consideration of soil fertility for groundnut production has to take into account the stratified distribution of Ca, Mg, K and Zn down the soil profile. This is because the availability of these nutrients in the different soil layers of the soil profile affects the productivity of groundnut differently (Zharare et al., 1993; 2011; Scott et al., 1999). Due to its geocarpy (the development of fruit underground), groundnut has, on one hand, a relatively high demand for Ca in the pod-zone (topmost 10 cm soil layer) for successful pod development compared with that required for vegetative growth in the root zone (10-40 cm soil depth) (Cox et al., 1982; Desai et al., 1999). On the other hand, the soil concentrations of

Mg and K in the peg-zone should be relatively low to minimize the inhibition of these nutrients on Ca uptake by the groundnut pods from the peg-zone (Baruah and Barthakur, 1997; Alva et al., 1991). When they are in excess of Ca in the pod-zone, pop production increases (Zharare ,1996; Foster, 1981). The current study determined that the pod-zone Ca level ranged from136 to 445 mg/kg of soil in the peg-zone in Mpumalanga lowveld and from 173 to 1218 mg kg^{-1} in KwaZulu –Natal Northern Coastal area. These values were above 100 mg/kg, the soil Ca level considered adequate for proper pod development of groundnut in South Africa (Swenevelder, 1998). Also, Cox et al. (1982) reported that Ca of 125 mg kg^{-1} was adequate for runners and 250 mg kg^{-1} was required for Virginia type. Hartzog and Adams (1973) reported that a soil Ca concentration of 100 mg kg^{-1} was regarded as sufficient for groundnut production and there was no need for gypsum application, but soils with Ca concentration below 87.5 mg kg^{-1} needed gypsum application. With the current study, there are no sites falling below 87. 5 mg kg^{-1}. Thus, gypsum application is not necessary in these soils. However, there is need to balance soil Ca with that of Mg and K at some of the sites.

Wolt and Adams (1979) determined in a solution culture experiment that Ca/(Ca+Mg+K) ratio of 0.25 was highly correlated with the maximum fruit weight per cavity while only a ratio of 0.1 was needed for vegetative growth. In the present study, at Mpumalanga, the ratio in the pod zone was above this value at three of the sites (0.3-0.4), but fell below this value at two of the sites (0.11-0.17). In Manguzi, the ratio at all the sites sampled was above 0.7, which suggested a higher availability of Ca to the groundnut pods in the Manguzi soil compared to the Mpumalanga lowveld soil.

As for the other macro-nutrients nutrients analysed, generally, 40 to 88 mg/kg of K (Hanlon et al. (1990), 10 to 30 mg/kg of Mg (Davis-Carter et al.,1993) and 5 to 10 mg/kg of P (Cope et al., 1984) in the soil are considered adequate for healthy vegetative growth of groundnut. In the present study, the Ca ranged from 168 to 408 mg/kg, the Mg ranged from 46 to 106.2 mg/kg, K ranged from 52 to 81.7 mg/kg and P ranged from 4 to 30 mg/kg in Mpumalanga lowveld. In Manguzi, the current study showed that Ca ranged from 173 to 481 mg/kg, the Mg ranged from 83 to 118 mg/kg, K from 72 to 188 mg/kg and P ranged from 2.3 to 12.7

mg/kg. These ranges are for the root zone 10 to 40 cm soil layer at both sites. Thus, only P had levels that were lower than the optimal range for healthy vegetative growth at some sites.

Magnesium tended to be more in the pod-zone soil layer than in the root-zone and sub soil layers at Manguzi, but in Mpumalanga, the Mg concentration was higher in the root-zone. The higher Mg concentration in the pod-zone in Manguzi might have negative implications on the uptake of Ca by developing pods since Mg in the peg-zone suppresses Ca and Zn uptake by groundnut from the peg zone (Zharare et al., 2011), and both of these nutrients are required in the pod-zone for proper pod development (Gani et al., 1992; Zharare et al., 1993). Furthermore, omission of Mg in the pod culture solution was shown by Zharare et al. (1993) to improve groundnut pod and seed development (Rosolem and Caires, 1998; Maccio 2002).

Although groundnut require Zn in the pod-zone, the soil Zn levels required in the pod-zone to satisfy the requirements for groundnut pod development have not yet been determined. Nonetheless groundnut is said to require about 0.5 mg/kg to 1.0 mg/kg Zn in the soil (Cope et al., 1981, Hanlon et al., 1990, Plank. 1989, Parker et al., 1991). Singh et al. (2009) reported that Zn concentration of less than 0.5 mg/kg is deficient and 1.0 mg/kg is sufficient. In the present study, the Zn level in the pod-zone varied from 0.4 to 26.1 mg/kg in Mpumalanga lowveld and 0.7 to 4.3 mg/kg in Manguzi. In the root zone, the levels of Zn ranged from 0.6 to 2.8 mg/kg in Manguzi. With the exception of one site (Agricultural College) in Mpumalanga lowveld, these levels are substantially higher than the critical soil Zn level (0.5 to 1.0 mg/kg soil) required for optimal groundnut production under soil pH 5.5 to 7.0 (Cope et al.,1981; Hanlon et al.,1990; Plank, 1989; Parker, 1990). Therefore, substantial groundnut yield suppression from Zn deficiency is not expected in both sites (Lowveld College of Agriculture farm and Manguzi).

Manganese deficiency is usually not a problem in groundnut production. Rather there is potential for toxicity, because groundnut is grown on sandy soils, which under natural circumstances are usually acidic. However, even though the soils are acidic, the soil Mn levels in Mpumalanga lowveld (4 to 24 mg/kg) and Manguzi (3 to 14 mg/kg) are too low to cause toxicity in groundnut. Rather, Mn deficiency might be expected in both locations. The critical soil Mn level for groundnut is 3 mg/kg to 7 mg/kg in soil with a pH between 5.5 and 7.0 (Cope et al.,1981; Hanlon et al.,1990; Plank, 1989; Parker, 1990) which is considerably lower than the soil Mn levels obtained in Mpumalanga lowveld and Manguzi.

3.8.2. Relationship between pH and mineral nutrients in the soil profile

Generally, the soil pH is influenced by the presence of Ca and Mg in the soil (Smith. 1995; Zharare 1996). In the present study, there were significant correlations between the soil pH and the Ca, Mg or K concentrations. However, the level of the correlations varied between Mpumalanga and Manguzi, and also down the soil profile. Although soil pH is generally controlled by the soil Ca concentration (Mupangwa, 2007), in Mpumalanga lowveld, Mg was the most correlated with soil pH at all soil depth sampled. Calcium was only correlated with soil pH in the root zone, but to a lesser extend compared with Mg. The soil pH was not correlated with the combined soil concentrations of Ca, Mg and K. At Manguzi, Ca was not correlated with soil pH in the topmost 10 cm soil layer. However, it was the most correlated with the soil pH in the root-zone (r^2=0.7275) and in the subsoil (r^2=0.4685). The soil pH was also correlated with the Mg concentration, at all soil depths sampled, but to a weaker extend in the root-zone and subsoil zones than Ca. Surprisingly, the pH in the topmost 10 cm of the soil was significantly correlated with the sum of soil K and Mg concentrations. As with Mpumalanga, the soil pH was not correlated to the sum of Ca and Mg concentrations. The weak correlations between soil pH and the sum of soil Ca and Mg concentrations at both sites is at variance with most reports in the literature that indicate that the soil pH is controlled by the combined soil concentrations of these nutrients (Parischa and Tandon, 1993).

3.8.3. Relationships between Ca, Mg and K in the soil profile

Mclean (1971) reported that there was an inverse relationship between exchangeable Ca, Mg and total bases. In the present study, no negative correlations were observed between Ca and Mg. In both Mpumalanga lowveld and Manguzi, soil Mg was significantly and positively correlated with soil Ca in the top 40 cm soil layers. However, the two sites differed in that Mg was not correlated with Ca in the subsoil at Mpumalanga whilst in Manguzi, it was very strongly and positively correlated (r^2=0.88) with Ca in the subsoil. Also, K was strongly positively correlated with Ca in the top 40 cm soil layer, whereas it was not correlated with Ca at Manguzi. The reasons for these differences are not at present clear, but they do show that soil nutrient dynamics differ from place to place.

CHAPTER 4. EVALUATION OF SIXTEEN GROUNDNUT VARIETIES FOR TOLERANCE TO SOIL ACIDITY

4.1. Introduction

Soil analysis results presented in Chapter three indicated that most soils in Mpumalanga and the northern coastal area of KwaZulu–Natal, where groundnut is traditionally grown by small-holder farmers, are acidic and poor in mineral plant nutrients. Both the problem of low soil pH and low mineral nutrient concentrations are exacerbated by the inability of the small-holder farmer to provide appropriate remedial measures. Whilst low pH can be easily rectified by application of lime and mineral nutrient deficiencies by fertilizer application, these amendments (calcitic and dolomitic limes) are beyond the affordability of the resource-poor farmers in the rural areas. One way to deal with crop production in acid soils is to use varieties that are tolerant to soil acidity. The objective of the study described in this chapter was to explore the genetic diversity of groundnut germplasm currently available in South Africa for its tolerance to acid-soil infertility.

4.2. Materials and Methods

Field trials were carried out during the 2008-2009 season to evaluate 16 groundnut varieties for their tolerance to low pH in small scale farmers' fields in the Lowveld region of Mpumalanga and in the northern coastal area of KwaZulu-Natal. In the Mpumalanga lowveld, the field trial was conducted at the Lowveld College of Agriculture Farm. In the northern coastal region of KwaZulu-Natal, the field trial was conducted at Manguzi.

4.2.1. Description of experimental sites

(a) Description of the Lowveld College of Agriculture farm site

The site of the experiment at the Lowveld College of Agriculture Farm, Nelspruit (25° 26' 25''S, 30° 58' 57'' E; altitude of 640 m) is characterized by a wet, warm summer season and a cool, dry winter. The rainfall received during the growth of the crop at the experimental site was 610 mm. It was well distributed and adequate for groundnut production. The average temperature varied from 18 to 35°C during the cropping season. The soil is a sandy loam, which is ideal for groundnut production. The basic cation (Ca, Mg and K) concentration in the plough-layer ranged from 347 to 550 mg $kg^{-1}$of Ca, 72.3 to 125.1 mg kg^{-1} of Mg and 91.6 to 150 mg kg^{-1} of K which is assumed to be suitable for groundnut production.

(b) Description of Manguzi experimental site

The second experimental site for the trial was at Manguzi (26° 59' 27''S, 32° 45' 03'' E; altitude of 61 m). The experiment was carried under rain-fed conditions and there was no rain gauge place in this experiment during the cropping season. The soil is a sandy loam, which is ideal for groundnut production.

4.2.2. Plant materials

The groundnut varieties tested included two Virginia Bunch types (Bill and Inkanyezi), two Valencia types (Ka-Ngwane Red and Kano) and the rest were Spanish types (Table 4.1). The groundnut varieties differed in seed size and growth duration. Of the sixteen groundnut varieties evaluated, two were developed in Zimbabwe, nine were developed by the Agricultural Research Council, Grain Crops Institute (ARC-GCI) at Potchefstroom in South Africa and five were developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in India. Furthermore, variety Rambo was used as the control in both experiments (Table 4.1).

Table 4.1. Details of groundnut varieties evaluated

Subspecies *hypogaea L.* :	Characteristics	Where developed
Virginia bunch		
Bill	Dark green foliage, 2 seed per pod and variegated testa,	South Africa
Inkanyezi	Dark green foliage, 3 or 4 seed per pod and bright red testa,	South Africa
Valencia		
Ka-Ngwane Red	Dark green foliage, 45% (3 or 4 seed per pod), bright red testa,	South Africa
Kano	Green foliage,72 % (3 or 4 seed per pod) and tan testa,	Nigeria
Spanish		
JL-24	Light green foliage, 2 seed per pod and tan testa,	South Africa
Harts	Green foliage, 58% (2 seeds per pod) and red testa,	South Africa
Mwenje	Green foliage, 2 seed per pod and tan testa,	Zimbabwe
Nyanda	Green foliage, 2 seed per pod and tan testa,	Zimbabwe
Akwa	Green foliage, 2 seed per pod and tan testa,	South Africa
Kwarts	Green foliage, 2 seed per pod and tan testa,	South Africa
RG – 784	Dark green foliage, 2 seed per pod and red testa,	South Africa
Anel	Green foliage, 2 seed per pod and tan testa,	South Africa
Rambo	Green foliage, 2 seed per pod and tan testa,	South Africa
ICGV 90071	Green foliage, 2 seed per pod and tan testa,	India
ICGV 99529	Green foliage, 2 seed per pod and tan testa,	India
ICGV 95714	Green foliage, 2 seed per pod and tan testa,	India

4.2.3. Experimental design

At Lowveld College of Agriculture farm, the varieties were evaluated in two adjacent fields that differed in soil pH. In one of the fields (Field 1) the soil pH was slightly acidic (pH 5.53), but was within the optimum pH range (5.5-6.2) for groundnut (Gibbons, 1980). In the second field (Field 2), the soil was much more acidic (pH 4.54). At Manguzi, the groundnut varieties were planted in soil with an even stronger acidity (pH 4.21). The groundnut varieties were planted in a randomized complete block design (RCBD) with four replications. The plot size was four rows that were 5 m long with inter-row and intra-row spacing of 70 cm and 10 cm, respectively. Groundnut seeds were planted 5-7cm deep. The net plot was the four rows with 1m discarded on either ends of the rows.

4.2.4. Land preparation and cultural practices

The land was prepared using mould-board plough after which a compound fertilizer NPK 2:3:2 (22) +Zn (5%) was applied at a rate of 250 kg/ha. This was followed by discing to incorporate the fertilizer into the top 25 cm of the soil and also to smoothen the seedbed.

A pre-emergent herbicide Dual gold (S-Metalochlor) was applied at 1.0 litre per hectare at planting. A follow-up one round of manual weeding was carried out six weeks after planting.

Gypsum was applied at a rate of 500 kg/ha at the onset of first flowers to an enhance the pod filling process and make soluble Ca available for the pods. A supplementary irrigation of 87 mm was applied during the cropping season at the Lowveld College of Agriculture farm. The plants were harvested from the net plot when 75-80% of the nuts matured. The plants were harvested manually and the pods picked by hand. The pods were placed in bags that allowed free air circulation and were left to dry in a protected and shaded area.

4.2.5. Data collection

4.2.5.1. Soil Analyses

Soil samples taken before the experiment was planted were analysed by the Soil Laboratory at KwaZulu-Natal for its macro-nutrients (K, Ca, Mg and P), micro-nutrients (Fe, Zn, Cu, B, Mn and Mo) and Al concentration. Stand establishment was recorded at seven days after planting by counting the number of plants that emerged in the net plot. A final stand at harvest was also recorded.

During the growth of the plants, the incidence of foliar diseases was visually scored on a scale of 1-9 where '1' is no disease and '9' is heavy with more than 50% defoliation (Subrahnamyam et al., 1995).

4.2.5.2. Plant tissue analyses

Samples of youngest fully expanded leaves (YFEL) were taken at the onset of flowering and analysed at Plant Laboratory (KwaZulu –Natal) for the nutrient (K, Ca, Mg, P, Al, Fe, Zn, Cu, and Mn) status.

4.2.5.3. Yield data

The number of days to maturity for each variety was recorded when 70-80% of the pods had matured. After the pods were air dried, to constant weight, the dry weights of the pods per plot were recorded. The pods were grouped into single, double and multi-compartmented pods based on the number of nuts per pod. The number and mass of the pods in each of these categories were recorded. The pods were later shelled and the mass of the seeds per pod category were recorded along with the 100 seed mass. These numbers of ovarian cavities that contained seeds were recorded and expressed as a percent of total ovarian cavities. The shelling percent was calculated by the formula = (seed weight/ pod weight) x 100. The seed yield in kilogram per hectare was calculated by the formula = (Dry pods yield x shelling x 10000) /net plot.

4.2.6. Data analysis

Analyses of variance of the data collected were performed using the Genstat 12th edition software package and regression relationships were fitted using Table curve 2D version 1.5*. The means of the treatments were separated by the least significant difference (LSD) at 5% level.

4.3. Results

4.3.1. Groundnut growth and yield performance at Nelspruit

4.3.1.1. General observation on plant growth

In general, the stand establishment was satisfactory. The growth of the plants was vigorous, and there was no pest problem. There were no visible nutrient deficiency symptoms observed during the growth of the varieties. Nonetheless, growth of plants in the field with low soil pH 4.54 was slightly slower than in the field with pH 5.53.

4.3.1.2. Days taken to maturity

The soil pH did not significantly affect the maturity duration of the plants (Table 4.2). The average mean days taken to maturity were 137 under the soil pH 5.5 and 136 under soil pH 4.54. The differences in the number of days taken to maturity among the varieties were not large enough to be significant among varieties. However, the interaction between variety and pH level was highly significant ($p = 0.01$). It was observed that under pH 4.54, several varieties matured earlier than under pH 5.53.

Table 4.2. The days taken to Maturity by the 16 groundnut varieties at soil pH 5.53 and 4.54 at Nelspruit Lowveld College of Agriculture farm in Mpumalanga (data are means of four replications and varieties are ranked in the order of decreasing seed yield performance.

Groundnut variety	Days to Maturity (DTM)		Difference in DTM (negative signifies less days at pH (5.53)
	Soil pH 5.53	Soil pH 4.54	
Inkanyezi	138	136	2
RG – 784	139	136	3
Anel	138	136	2
Mwenje	135	135	0
JL- 24	135	135	0
Kwarts	135	136	-1
ICGV 99529	137	136	1
Nyanda	135	135	0
ICGV 95714	135	136	-1
Kano	135	135	0
Bill	139	136	3
Rambo(control)	138	136	2
ICGV 90071	139	135	4
Akwa	135	135	0
Harts	136	136	0
Ka-Ngwane Red	136	136	0
Mean	137	136	1
$LSD_{(0.05)}$ Variety	1.7*		
$LSD_{(0.05)}$Field	0.6**		
CV%	1.3		

* = $P \leq 0.05$, ** = $P \leq 0.01$ and NS = not significant different

4.3.1.3. Dry pod yield

The pod yield performance of the groundnut varieties at pH 4.54 was lower than that at pH 5.53. The pod yield of the varieties at pH 4.54 ranged from 925 kg/ha in Kwarts to 2307 kg/ha in Anel compared with the range of 1342 (Ka-Ngwane Red) to 3346 kg/ha(Inkanyezi) at pH 5.53 (Table 4.3). The average pod yield at soil pH 5.53 and 4.54 was 2341 kg/ha and 1630 kg/ha respectively (Table 4.3). Nine varieties (Inkanyezi, RG - 784, Anel, ICGV 90071, ICGV 95714, Mwenje, JL-24, Kano and ICGV 99529) had significantly greater pod yield than the control (Rambo) at soil pH 5.53. The yield differences with the control variety Rambo (2283 kg/ha) were significantly greater ($p \geq 0.05$) in Inkanyezi (3346 kg/ha), RG784 (3273 kg/ha) and Anel (2680 kg/ha). Pod yields were comparatively lower in six varieties (Kwarts, Nyanda, Bill, Harts, Akwa and Ka-Ngwane Red) compared to Rambo under optimum soil pH (5.53). At pH 4.54, significantly greater ($p \geq 0.05$) pod yields were obtained in Anel (2307 kg/ha), ICGV 95714(2172 kg/ha) and Inkanyezi (2166 kg/ha) than Rambo (1276 kg/ha). All the varieties except Ka-Ngwane Red recorded lower pod yields at the low pH (4.54) than at the higher soil pH (5.5.3). In the case of Ka-Ngwane Red, it performed significantly better at the lower soil pH (1607 kg/ha) than at the higher soil pH (1342 kg/ha). The pod yields increases in the varieties that performed better at the higher pH ranged from 286 kg/ha in Harts to 1297 kg/ha in RG - 784. However, the greatest percentage increase was 134% recorded for Kwarts compared with the lowest percentage increase of 16% for Anel.

Table 4.3. The pod yield performance of 16 groundnut at soil pH 5.53 and 4.54 at Nelspruit Lowveld College of Agriculture farm, Mpumalanga

Groundnut variety	Pod yield (kg/ha)		Variety mean pod yield (kg/ha)	Yield increase (kg/ ha) at pH 5.53 compared with pH 4.54	%Percentage yield increase at pH 5.53 compared with pH 4.54
	Soil pH 5.53	Soil pH 4.54			
Inkanyezi	3346	2166	2756	1181	54.52
RG – 784	3272	1976	2624	1297	65.64
Anel	2680	2307	2493.5	373	16.17
Mwenje	2444	1670	2057	774	46.35
JL- 24	2433	1875	2154	558	29.76
Kwarts	2170	925	1547.5	1245	134.59
ICGV 99529	2314	1348	1831	965	71.59
Nyanda	2114	1624	1869	490	30.17
ICGV 95714	2567	2172	2369.5	396	18.23
Kano	2393	1480	1936.5	913	61.69
Bill	2074	1343	1708.5	731	54.43
Rambo (Control)	2283	1276	1779.5	1007	78.92
ICGV 90071	2639	1618	2128.5	1021	63.10
Akwa	1610	1210	1410	400	33.06
Harts	1772	1486	1629	286	19.25
KaNgwane Red	1342	1607	1474.5	-265	-16.49
Mean	2341	1630	1986	711	
$LSD_{(0.05)}$ Variety	467.9**				
$LSD_{(0.05)}$ Interaction field x field=165.4**					
CV%	23.7				

** = P ≤ 0.01

4.3.1.4. Seed yield

The varieties differed significantly in their seed yield performances. However, their performances were dependent on soil pH (Table 4.4). As with pod yield, the seed yield was poorer at the lower soil pH compared to the higher soil pH. The seed yield (Table 4.4) at pH 5.53 ranged from 801 kg/ha in Ka-Ngwane Red (Valencia) to 2611 kg/ha in Inkanyezi (Virginia bunch). At soil pH 4.54, it ranged from 744 kg/ha in Kwarts (Spanish) to 1709 kg/hain Anel (Spanish). The overall average seed yield at soil pH 5.53 was 1647 kg/ha compared with 1128 kg/ha at soil pH 4.54.

Eleven of the varieties tested produced greater seed yield than the control variety Rambo at soil pH 5.53. However, the differences in seed yield with Rambo (80.68 kg/ha) at pH 5.53 were only significant ($p \pm 0.05$) for Inkanyezi (2611 kg/ha), RG784 (2347 kg/ha) and Anel (1983 kg/ha).

At pH 4.54, fourteen varieties yielded higher than Rambo, significantly in only three varieties, namely; Anel (1709 kg/ha), ICGV 95714 (1457 kg/ha) and Inkanyezi (1456 kg/ha). Varieties Kwarts and Rambo recorded the lowest yields under soil pH 4.54. As with pod yield, in contrast to the rest of the varieties, Ka-Ngwane Red yielded better at the lower soil pH than at the higher soil pH (Table 4. 4). Kwarts was the most sensitive variety to pH. The yield of this variety increased by 143% at high pH 5.53 compared with the yield at pH 4.54. Varieties ICGV 99529, RG - 784, Inkanyezi, Rambo and Bill were also highly sensitive to pH with increase in seed yield ranging from 70 to 87% at the higher compared with the lower soil pH (Table 4.4). Harts was the least sensitive, showing a very small seed yield increase of approx. 2% when the variety was grown at soil pH 5.53 compared with soil pH 4.54. Varieties Anel and ICGV 95714 were also not sensitive to soil pH, showing increases in seed yield of 11 and 16 % at the higher soil pH, respectively. However, Anel was the third top yielder among the 14 varieties, whereas ICGV 95714 ranked ninth in terms of seed yield (Table 4.4).

Table 4.4. The seed yield performance of 16 groundnut varieties at soil pH 5.53 and 4.54 at Nelspruit, Mpumalanga

Groundnut variety	Seed yield (kg/ha)		Seed yield increase	% seed
	Soil pH 5.53	Soil pH 4.54	(kg/ ha) at pH 5.53 compared with pH 4.54	yield increase at pH 5.53 compared with pH 4.54
Inkanyezi	2611	1456	1155	79.33
RG – 784	2347	1256	1091	86.86
Anel	1984	1709	274	16.03
Mwenje	1879	1267	612	48.30
JL- 24	1812	1370	442	32.26
Kwarts	1804	774	1061	142.61
ICGV 99529	1672	981	691	70.44
Nyanda	1636	1150	487	42.35
ICGV 95714	1618	1457	162	11.12
Kano	1530	1001	529	52.85
Bill	1502	855	648	75.79
Rambo(Control)	1440	797	643	80.68
ICGV 90071	1311	1029	282	27.41
Akwa	1221	824	397	48.18
Harts	1176	1158	18	1.55
Ka-Ngwane Red	801	996	-195	-19.58
Mean	1647	1128	519	
$LSD_{(0.05)}$ Variety	370.9**			
$LSD_{(0.05)}$ Field	131.2**			
CV%	27			

**= $P \leq 0.01$

The average shelling percentage at soil pH 5.53 (70 %) did not differ significantly from that at soil pH 4.54 (69 %). However, there were significant differences between the varieties in shelling percentage (Table 4.5). Also, the shelling percentages of the varieties were affected differently by the field soil pH. Eleven varieties recorded a greater shelling percentage than the control variety (Rambo) at soil pH 5.53, whereas at the lower soil pH (4.54), fifteen varieties recorded a higher shelling percentage than Rambo. Kwarts recorded the highest shelling percentage (81-82%) at both soil pH 5.53 and 4.53. In general, the Spanish varieties recorded greater shelling percentages than the other types (Table 4.5). The ICRISAT variety ICGV 90071 recorded significantly lower shelling percentage (49%) than Rambo at soil pH 5.53.

Except for Inkanyezi, RG784, Bill, ICGV 90071, Akwa and Harts, the shelling percentage in most of the varieties was not sensitive to field soil pH (Table 4.4). Varieties ICGV 90071 and Harts had higher shelling percentages at the lower soil pH than at the higher soil pH, whereas this was the reverse for Inkanyezi, RG -784, Bill and Akwa (Table 4.5).

Table 4.5. The Shelling percentage of 16 groundnut varieties at soil pH 5.53 and 4.54 at Nelspruit, Mpumalanga

Groundnut variety	Shelling percentage (%)		Differences in SH (%) between soil pH 5.53 and pH 4.54
	Soil pH 5.53	Soil pH 4.54	
Inkanyezi	78	68	10
RG – 784	72	64	8
Anel	74	74	0
Mwenje	77	76	1
JL- 24	75	73	2
Kwarts	82	81	1
ICGV 99529	72	73	-1
Nyanda	77	71	6
ICGV 95714	63	67	-4
Kano	63	67	-4
Bill	72	63	9
Rambo(control)	63	59	4
ICGV 90071	49	64	-15
Akwa	75	63	12
Harts	67	78	-11
Ka-Ngwane Red	60	61	-1.
Mean	70	69	1
$LSD_{(0.05)}$ Variety	6.31**		
$LSD_{(0.05)}$ Field X Variety	8.92*		
CV%	9.2		

* = $P \leq 0.05$, ** = $P \leq 0.01$

4.3.1.5. Hundred Seed Mass

The average hundred seed mass (HSM) for the varieties tested was 38.22 grams at soil pH 5.53 and 33.58 grams at soil pH 4.54. The large-seeded variety Rambo recorded the highest hundred seed mass (HSM) as expected and Ka-Ngwane Red recorded 29.75 grams at soil pH 5.53. At soil pH 4.54 Rambo and Harts were the varieties that recorded the highest hundred seed mass (47 grams and 42.5 grams respectively). The variety with the lowest hundred seed mass at this soil pH was ICGV 99529 with a hundred seed mass value of 25.75 grams (Table 4.6). There was no correlation between the hundred seed mass (HSM) and the shelling percentage amongst all the varieties (r^2 = 0.344) (data not shown). Except for Anel, JL-24, Kano and Rambo, in the rest of the varieties, the hundred seed mass did not appear to be sensitive to soil pH (Table 4.6).

Table 4.6. The Hundred seed mass of 16 groundnut varieties at soil pH 5.53 and 4.54 at Nelspruit, Mpumalanga

Groundnut variety	Hundred seed mass(g)		Differences in hundred seed mass (g)
	Soil pH 5.53	Soil pH 4.54	
Inkanyezi	37.75	36	1.75
RG – 784	37	32.25	4.75
Anel	38.25	32.25	6
Mwenje	35.5	31.5	4
JL- 24	40.5	33.25	7.25
Kwarts	36.25	33	3.25
ICGV 99529	30.5	25.75	4.75
Nyanda	34.75	32.5	2.25
ICGV 95714	30.5	29.5	1
Kano	42.75	32.5	10.25
Bill	38.75	34.25	4.5
Rambo(control)	67.25	47	20.25
ICGV 90071	36.25	32	4.25
Akwa	36	32.25	3.75
Harts	39.75	42.5	-2.75
Ka-Ngwane Red	29.75	30.75	-1
Mean	38.22	33.58	4.64
$LSD_{(0.05)}$ Variety	4.62**		
$LSD_{(0.05)}$ Field	0.6**		
$LSD_{(0.05)}$ Field x variety	6.5*		
CV (%)	13		

* = $P \leq 0.05$, ** = $P \leq 0.01$

4.3.1.6. Pod filling

The proportion of ovarian cavities that had seed was generally higher at the lower soil pH than at the higher field soil pH (Table 4.7). At pH 5.53, the range of the proportion of ovarian cavities that contained seeds among the varieties was 39-63 % compared with the higher range of 64-76 % at pH 4.54. However, at both soil pH values, the differences among most of the varieties were not significantly.

Table 4.7. The proportion of ovarian cavities (%) that contained seed for each groundnut variety at field soil pH5.53 and pH4.54 at Nelspruit, Mpumalanga

Groundnut variety	Ovarian cavity (%)		Difference in proportion of ovarian cavities occupied by seed between field soil pH 5.53 and 4.54.
	Soil pH5.53	Soil pH4.54	
Inkanyezi	55	69	-14
RG – 784	58	70	-12
Anel	51	73	-22
Mwenje	56	69	-13
JL-24	53	70	-17
Kwarts	63	64	-1
ICGV 99529	58	66	-8
Nyanda	55	68	-13
ICGV 95714	49	70	-21
Kano	39	75	-36
Bill	54	74	-20
Rambo	51	71	-20
ICGV 90071	58	65	-7
Akwa	59	66	-7
Harts	61	65	-4
Ka-Ngwane Red	48	76	-28
Mean	54.37	69.34	
$LSD_{(0.05)}$variety	10.89*	3.96**	
CV%	14		

* = P ≤0.05, ** = P ≤0.01

4.3.1.7. The Ca, Mg, K, and P concentrations at first flower in YFEL of 16 groundnut varieties grown in soil of pH 5.53.

With the exception of P, whose concentration in the leaf ranged between 0.3 and 0.4%, in the majority of the varieties (14 of the 16 varieties) all the other macronutrients analysed (K, Mg and Ca) differed significantly among the varieties. The differences in tissue Mg, which ranged from 0.36 to 0.5%, were not as pronounced as those for K and Ca, which ranged from 1.31 to 2.16 % and from 0.71 to 1.08%, respectively (Table 4.8). Thus, tissue K concentration had the greatest variation and difference among the varieties followed by tissue Ca concentration.

Table 4.8. The Macronutrients concentration (%) in YFEL of 16 groundnut varieties grown in soil of pH 5.53 of young fully expanded leaves (YFEL) of the groundnut

S. No	Groundnut variety	Nutrient concentration			
		Ca (%)	Mg (%)	K (%)	P (%)
1	Inkanyezi	0.91	0.40	1.64	0.31
2	RG - 784	1.06	0.38	1.55	0.24
3	Anel	0.88	0.44	1.68	0.39
4	ICGV 90071	0.90	0.42	1.74	0.32
5	ICGV 95714	1.02	0.41	1.51	0.26
6	Mwenje	0.92	0.41	1.64	0.34
7	JL-24	0.94	0.44	1.15	0.33
8	Kano	0.82	0.39	1.77	0.34
9	ICGV 99529	0.71	0.37	1.74	0.30
10	Rambo(control)	1.03	0.39	2.02	0.32
11	Kwarts	1.01	0.39	1.84	0.30
12	Nyanda	1.01	0.49	1.92	0.33
13	Bill	0.96	0.50	2.14	0.41
14	Harts	0.94	0.36	2.16	0.38
15	Akwa	1.02	0.42	1.84	0.36
16	Ka-Ngwane Red	1.08	0.42	1.31	0.33
Mean		0.95	0.42	1.73	0.33
$LSD_{(0.05)}$		0.17*	0.07*	NS	NS
CV%		11	10	21	18

* = $P \leq 0.05$ and NS = not significant different

4.3.1.8. Tissue micronutrient concentrations at first flower in leaves of 16 groundnut varieties grown in soil with pH 5.53

Among the micro-nutrients whose tissue concentrations were analysed, Cu whose values ranged from 3.90 to 6.07 mg kg^{-1} had very little variations among the varieties. Tissue Fe concentration which ranged from 131.7 to 210.3 mg kg^{-1} had the most variation among the varieties followed by Zn, which ranged from 111.7 to 170 mg kg^{-1} (Table 4.9). With respect to Mn, Ka-Ngwane Red had exceptionally high leaf Mn concentration (151 mg kg^{-1}) compared with the rest of the varieties (101-139.3 mg kg^{-1}). In addition, this variety together with Rambo and Nyanda had very high Zn values.

Table 4.9. The Fe, Zn, Mn, and Cu concentration (mg kg^{-1}) in YFEL of 16 groundnut varieties grown in soil of pH 5.53

Groundnut variety	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
Inkanyezi	131.7	144.7	124.7	5.30
RG – 784	193.7	129.3	119.7	4.63
Anel	164.7	145.0	124.7	5.07
ICGV 90071	210.3	111.7	120.7	4.80
ICGV 95714	153.3	145.0	112.7	4.67
Mwenje	135.0	145.0	110.7	5.37
JL-24	168.7	131.3	101.0	5.13
Kano	169.0	153.3	115.0	5.77
ICGV 99529	166.7	128.0	110.7	5.33
Rambo(control)	180.7	170.0	122.7	4.73
Kwarts	164.3	137.7	126.0	4.73
Nyanda	134.0	156.3	139.3	5.73
Bill	187.7	144.3	118.0	6.07
Harts	149.0	143.7	125.0	5.27
Akwa	139.7	133.7	110.0	5.83
Ka-Ngwane Red	161.3	161.3	151.0	3.90
Mean	163.1	142.5	120.7	5.15
$LSD_{(0.05)}$ variety	78.1*	45.33*	32.66*	NS
CV%	29	19	16	17

* = $P \leq 0.05$ and NS = not significant different

4.3.1.9. Leaf concentrations of Na and Al

Among the non-essential nutrients whose tissue concentrations were analysed, Na varied widely among the groundnut varieties from 116 to 1476 mg kg^{-1}. Tissue Al concentration varied within a narrow range of 113 to 211 mg kg^{-1} among the varieties. With respect to Na, Ka-Ngwane Red had exceptionally high Na (1476 mg kg^{-1}) compared with the rest of the varieties (116-1126 mg kg^{-1}). In addition, this variety together with Harts, Kwarts and RG - 784, had very high Al values. No significant difference was recorded in the Na and Al concentrations (data not shown).

4.3.1.10. Ca, Mg, K and P concentrations in seeds of groundnut grown in soils with pH 5.53 and 4.54 at Lowveld College of Agriculture farm

There were low variations in the concentrations of Ca, K, Mg and P in the seed tissues between plants grown in the field with pH 5.53 and pH 4.54. However, significant differences in the tissue concentrations of these mineral nutrients were recorded between the varieties. The most mineral concentration variation of the seed among the varieties was with (K with 12.4% and Ca with 14.4%) which ranged from 0.59 % in ICGV 99529 to 1.02 % in ICGV 90071 at pH 5.53 and from 0.54 % in Bill to 0.88% in Inkanyezi at pH 4.54 (Table 4.10).

In the case of Ca, its concentration variations in seed among the varieties were little. Its range extended from 0.03 in ICGV 90071 to 0.08 % in ICGV 99529 at both pH levels. However, Mwenje, Kwarts, Nyanda and ICGV 99529 with similar seed tissue Ca concentration (0.07-0.08 %) had significantly higher Ca concentrations than the other varieties. Anel, JL-24, Harts had similar seed tissue Ca concentration which ranged from 0.05 to 0.06 % whereas as Inkanyezi, RG - 784 shared same seed Ca concentration of 0.04 % in both pH levels. Furthermore, Ka-Ngwane Red seeds had 0.05 % Ca, and in the case of Bill it ranged from 0.04 at pH 5.53 to 0.03 % at pH 4.54 (Table 4.10). There was poor correlation between seed Ca concentration and the yield of the varieties.

As with seed Ca concentration, the seed P concentrations of varieties varied within a narrow range. The range extended from 0.45 in Rambo to 0.58 % in RG - 784 at pH 5.53 and from 0.48 in Rambo to 0.56 % in Bill at pH 4.54. These varieties ICGV 90071, RG - 784 had similar seed tissue P concentration (0.55-0.58 %) at pH 5.53. whereas RG - 784 and Bill shared similar P concentration (0.55-56%) at pH 4.54, which had significantly higher P concentrations than for the other varieties (Table 4.10). Similar to Ca, there was poor correlation between seed P concentration and the yield of the varieties.

As with seed Ca concentration, the seed Mg concentrations of varieties varied within a narrow range. The range extended from 0.10 % in ICGV 90071 to 0.23 % in variety JL- 24 at pH 5.53 and 0.10 % in Inkanyezi to 0.24 % in variety Akwa at pH 4.54. Varieties Kano, Bill and Ka-Ngwane Red had similar seed tissue Mg concentration (0.19 %) in both pH levels (Table 4.10).

There was a strong negative correlation (r^2 = 0.717) between the pooled seed Ca and K concentrations of the varieties grown in field with pH 5.53 (Figure 4.1A). This was in contrast to the weak correlation (r^2 = 0.291) between the concentrations of the two nutrients in the seed of varieties grown at pH 4.54 (data not shown). Similarly, there was a strong negative correlation between seed Mg and K concentrations (r^2 = 0.618) of varieties grown in the field with pH 5.53 (Figure 4.1B), but a weak negative correlation (r^2 = 0.364) between Mg and K concentration of varieties grown in the field with pH 4.54 (data not shown).

Seed Mg concentration had a highly significant positive relationship (r^2=0.800) with seed Ca concentration of varieties grown in field with pH 5.53 (Figure.4.1C). By contrast, of groundnut varieties grown in the field with the lower pH, the correlation was very weak (r^2 = 0.274).

Table 4.10. The macronutrient concentration (%) in seeds of groundnut grown in soils with pH 5.53 and 4.54 at Lowveld College of Agriculture farm

Groundnut variety	Ca%		Mg %		K%		P%	
	pH5.53	pH4.54	pH5.53	pH4.54	pH5.53	pH4.54	pH5.53	pH4.54
Inkanyezi	0.04	0.04	0.19	0.10	0.86	0.88	0.53	0.53
RG – 784	0.04	0.04	0.19	0.20	0.98	0.87	0.58	0.55
Anel	0.05	0.06	0.21	0.22	0.68	0.67	0.49	0.51
Mwenje	0.07	0.07	0.20	0.22	0.71	0.66	0.49	0.52
JL- 24	0.05	0.06	0.23	0.23	0.65	0.63	0.53	0.52
Kwarts	0.07	0.06	0.20	0.21	0.68	0.58	0.51	0.48
ICGV 99529	0.08	0.08	0.22	0.22	0.59	0.61	0.52	0.53
Nyanda	0.07	0.07	0.22	0.23	0.69	0.63	0.51	0.53
ICGV 95714	0.05	0.04	0.22	0.23	0.73	0.76	0.58	0.52
Kano	0.05	0.04	0.19	0.19	0.71	0.68	0.53	0.51
Bill	0.04	0.03	0.19	0.19	0.81	0.54	0.53	0.56
Rambo	0.04	0.05	0.18	0.20	1.01	0.78	0.45	0.48
ICGV 90071	0.03	0.03	0.10	0.19	1.02	0.92	0.55	0.54
Akwa	0.06	0.06	0.22	0.24	0.68	0.63	0.50	0.50
Harts	0.05	0.06	0.21	0.22	0.69	0.67	0.53	0.53
Ka-Ngwane Red	0.05	0.05	0.19	0.19	0.71	0.72	0.53	0.52
Mean	0.05	0.05	0.204	0.212	0.762	0.703	0.52	0.51
$LSD_{(0.05)}$ Variety	0.09**		0.013**		0.104**		0.041 **	
$LSD_{(0.05)}$ Field	NS		0.004 **		0.04*		NS	
CV%	14.4		5.2		12.4		6.8	

*= P ≤0.05, **= P ≤0.01 and NS = not significant different

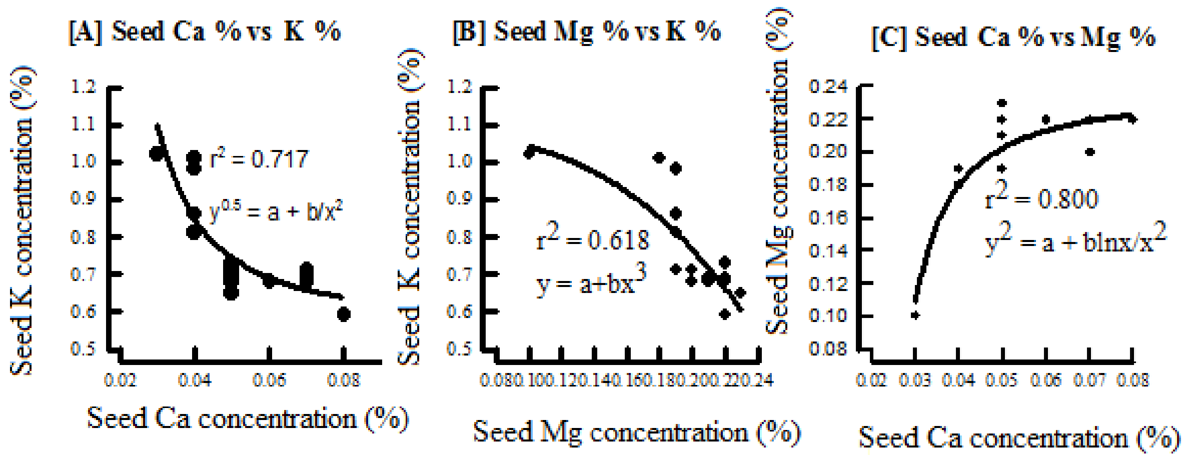

Figure 4.1. The relationship between the concentration of K and Calcium (A), between the concentration of K and Magnesium (B), and between the concentration of Mg and Calcium (C) in groundnut seeds grown in soil with pH 5.53 at the Lowveld College of Agriculture farm.

4.3.1.11. Concentrations of the micro-nutrients (Zn, Cu, Mn and Fe) in seeds of groundnut grown in soils with pH 5.53 and 4.54 at the Lowveld College of Agriculture farm

Among the micronutrients that were measured (Zn, Cu, M and Fe), with the exception of Cu, the concentrations of the micronutrients in seeds' tissues (Table 4.11) were more varied among the varieties. There was a tendency for the concentration of the micro-nutrients in the seed to be more at higher soil pH than at the lower soil pH (Table 4.11). The concentration of Cu in the seed, which had the least variation ranged from 6.03 to 8.43 mg kg^{-1} at pH 5.53 and from 5.37 to 9.2 mg kg^{-1}at pH 4.54. The seed Fe concentration ranged from 22.7 to 44 mg kg^{-1} at pH 5.53 and from 19.7 to 39.3 mg kg^{-1}at pH 4.54. The seed Zn concentration ranged from 49.33 to 76.67 mg kg^{-1}at pH 5.53 and from 46.67 to 66.33 mg kg^{-1} at pH 4.54 (Table 4.11). With respect to Mn, it ranged 14 to 34 mg kg^{-1} at pH 5.53 and from 13.33 to 37 at pH 4.54 mg kg^{-1} among the varieties. Harts had exceptionally high Mn concentration in its youngest fully expanded leaves (YFEL) (34 to 37 mg kg^{-1}) compared with other varieties. In addition, it was among the 3 varieties that had high Zn concentration (66.33 to 76.67 mg kg^{-1}) in the youngest fully expanded leaves (YFEL); the other varieties being Kano (63.67 to 75.67 mg kg^{-1}) and Ka-Ngwane Red (66.33 to 74.33 mg kg^{-1}).

With Zn, significant differences were observed amongst all the varieties and highly significant differences were observed between the soil pH levels. Fourteen varieties had higher seed Zn concentrations compared to Rambo at pH 5.53 and twelve had higher seed Zn concentrations compared to the control variety Rambo at pH 4.54 (Table 4.11). The highest seed Zn concentration was observed in variety Harts (76.67 mg kg^{-1}) while the lowest was in variety Inkanyezi (49.33 mg kg^{-1}) at pH 5.53 and at pH 4.54 the highest seed Zn concentration was observed in two varieties Ka-Ngwane Red and Harts (66.33 mg kg^{-1}) while the lowest was observed in two varieties Bill and Inkanyezi (46.67 mg kg^{-1}).

With copper, no significant difference observed amongst all the varieties tested and also among the fields (pH 5.53 and t pH 4.54). At pH 5.53, two varieties ICGV 90071 and Bill had higher seed Cu concentrations, compared to the control variety Rambo. Also, at pH 4.54 one variety (ICGV 90071) had higher seed Cu than Rambo (Table 4.11). The highest seed Cu concentration was observed in variety Bill (28.17 mg kg^{-1}) and the lowest in variety ICGV 95714 (6.03 mg kg^{-1}) at pH 5.53 while at pH 4.54, the highest seed Cu concentrations were observed in variety ICGV 90071 (11.03 mg kg^{-1}) and the lowest in variety ICGV 95714 (5.37 mg kg^{-1}).

With manganese there was a highly significant differences observed amongst all the varieties and there was no significant difference between the fields regarding the Mn concentrations. Fourteen varieties had the higher seed Mn concentrations compared to the control variety Rambo at pH 5.53 (Table 4.11) and twelve varieties had higher seed Mn concentrations compared to Rambo at pH 4.54. The highest Mn concentrations in all use seeds were observed in variety Harts (34 mg kg^{-1}) and the lowest in two varieties Rambo and Inkanyezi (14 mg kg^{-1}) respectively at pH 5.53 At pH 4.54, the highest seed Mn concentrations was observed in variety Harts (37 mg kg^{-1}) and the lowest in variety Inkanyezi (13.33 mg kg^{-1}).

With iron, there was no significant difference amongst all the varieties and also there was no significant difference between the soil pH 5.53 field and the soil pH 4.54 filed. Eleven varieties had higher seed Fe concentrations compared to control variety Rambo at pH 5.53 whereas at pH 4.54 five varieties had higher seed Fe concentrations compared to Rambo. The highest Fe concentrations in all use seeds were observed in varieties ICGV 90071 (45 mg kg^{-1}) and the lowest in variety Mwenje (22.7 mg kg^{-1}) at pH 5.53 (Table 4.11). At pH 4.54 the highest seed Fe concentrations were observed in variety Kwarts (39.3 mg kg^{-1}) and the lowest in variety ICGV 95714 (19.7 mg kg^{-1}).

Table 4.11. The micronutrients concentration (mg kg^{-1}) in seeds of 16 groundnut varieties grown in soil with pH 5.53 and 4.54 at Lowveld College of Agriculture farm

Groundnut variety	Zn (mg kg^{-1})		Cu (mg kg^{-1})		Mn (mg kg^{-1})		Fe (mg kg^{-1})	
	pH5.53	pH4.54	pH5.53	pH4.54	pH5.53	pH4.54	pH5.53	pH4.54
Inkanyezi	49.33	46.67	7.57	8.17	14	13.33	28	36.3
RG – 784	55	49	8.43	8.17	18	18.67	39	28
Anel	62.67	57.67	6.53	7.27	23.33	24	31.3	22.7
Mwenje	62	63	6.37	7.2	25	26.67	22.7	20.7
JL- 24	69.33	63.33	7	5.83	24.67	27.33	40.3	34.7
Kwarts	67.33	55.33	7.27	7.73	28	26	37	39.3
ICGV 99529	62.33	53.67	7.07	6.93	28.67	24	44	30.7
Nyanda	67.33	62	7.6	8.1	26.67	28.67	32.7	29.3
ICGV 95714	58.33	51.33	6.03	5.37	24	18	34.3	19.7
Kano	75.67	63.67	7.17	7.67	22.67	20.67	29.7	34.7
Bill	58	46.67	28.17	8.8	17.33	16	39.7	28
Rambo(control)	49.67	51.33	8.17	8.83	14	18	32	32.7
ICGV 90071	66.33	61.33	11.23	11.03	19.33	18.67	45	28
Akwa	56.33	55.33	7.43	9.2	22	24.67	40.3	36
Harts	76.67	66.33	7.23	5.7	34	37	35.7	30.3
Ka-Ngwane Red	74.33	66.33	7.57	6.37	22.67	21.33	40.7	29.3
Mean	63.17	57.06	8.8	7.7	22.77	22.69	35.8	30
$LSD_{(0.05)}$ Variety	8.27**		NS		4.11**		NS	
$LSD_{(0.05)}$ Field	2.92**		NS		NS		NS	
CV%	11.7		17.1		15.7		16.3	

** = $P \leq 0.01$ and NS = not significant

4.4. Groundnut growth and yield performance at Manguzi

At Manguzi, the varieties varied significantly P>0.01 in all measured yield parameters (Table 4.12). There were large variations in pod yield among the varieties (Table 4.12). The pod yield varied from 548 kg/ha in Bill to 2817 kg/ha in Inkanyezi (Table 4.12). The Inkanyezi variety out-yielded all the varieties tested except RG-784. Although Bill had the least pod yield among the varieties, it did not differ significantly from Akwa, Harts, JL24, Ka-Ngwane-Red and Kwarts. With a pod yield of 1126 kg/ha, the control variety Rambo ranked tenth, and surpassed Akwa, Harts, JL24, Ka-Ngwane-Red, Kwarts and Bill. However, it did not differ significantly from all varieties except Inkanyezi, RG-784, Mwenje and ICGV-99529, which surpassed it.

With a seed yield of 2358 kg/ha, Inkanyezi significantly out-yielded all the other varieties (Table 4.12). The seed yield was under 2000 kg/ha among the rest of the varieties, ranging from as little as 383 kg/ha in Bill to 1664 kg/ha in Mwenje. The control variety Rambo ranked eleventh out of the 16 varieties that were tested. Although Bill was at the bottom of the list with 383 kg/ha seed yield, it did not differ significantly in seed yield from ICGV-90071, Kano Rambo, Harts, JL24, Ka-Ngwane Red and Kwarts.

The mean number of pods per plants varied from 4.66 to 28.07 per plant. Inkanyezi had the most number of pods per plant (approx. 28 pod per plant), but did not differ significantly from RG-784 (26.44 pods per plant), Mwenje (22.24 pods per plants) and ICGV-99529 (25.26 pods per plant). Bill had the least mean pod number per plant (4.66), but did not differ significantly from Kano, Rambo, Akwa, Harts, JL24, Ka-Ngwane Red and Kwarts whose mean pod number per plant ranged from 6.16 to 10.02. An analysis of the relationship between pod yield and the mean number of pods per plant at Manguzi indicated that the pod yield was highly correlated with the pod number (Figure. 4.2).

There were marked variations in the shelling percentage among the test varieties (Table 4.12). The shelling percentage varied from 39.4% in Kano to 84% in Kwarts. Six of the varieties (Inkanyezi, Mwenje, ICGV-99529, Anel, Akwa and Kwarts) had high shelling percentage ranging amongst them from 80 to 84%. By comparison to this range, the shelling percentage was particularly low in Kano (39.4%), ICGV-90071 (55.7%) and Rambo (59.6%). There was no relationship between seed yield and shelling percentage among the varieties.

The differences in seed-set between the varieties were not as large as those for the shelling percentage. Seed-set was lowest in Kano pods in which 64% of the ovarian cavities were occupied by seeds. In the rest of the varieties, seed-set ranged from 71.4 (Rambo) to 93 % (ICGV-99529). There was no relationship between seed-set and seed yield.

The hundred seed mass (HSM) varied within a narrow range from 20.07 in ICGV-90071 to 38.23 in Rambo (Table 4.12). Thus hundred seed mass (HSM) was not significantly different among most of the varieties and there was no relationship between hundred seed mass (HSM) and seed yield among the varieties.

Table 4.12. Pod yield, seed yield, shelling %, pod number per plant, seed-set and 100 seed mass of 16 groundnut varieties grown at Manguzi (data are means of three replications and the varieties are ranked in order of decreasing pod yield).

Groundnut Variety	Pod yield (kg/ha)	Seed yield (kg/ha)	Pods Plant^{-1}	Shelling %	Ovarian cavities with seed (%)	100 seed mass (g)
Inkanyezi	2817	2358	28.07	83.7	75.5	32.74
RG-784	2234	1444	26.44	64.8	75.4	21.87
Mwenje	2067	1664	23.24	80.2	78.1	29.93
ICGV-99529	1916	1599	25.26	83.6	93	24.23
Kano	1540	621	9.17	39.4	64.3	23.32
Anel	1497	1233	12.7	81.5	83.2	30.44
Nyanda	1382	1051	15.33	76.3	78	28.42
ICGV-90071	1342	743	16.87	55.7	91.4	20.07
ICGV-95714	1233	806	15.05	64.8	86.6	20.42
Rambo	1126	673	7.48	59.6	71.4	38.23
Akwa	979	827	9.37	83.8	87.3	29.23
Harts	926	721	9.34	78.1	72.4	35.92
JL24	855	653	8.22	77.1	79.1	27.34
KaNgwane-Red	840	578	6.16	67.2	76.5	26.89
Kwarts	752	639	10.02	84.1	87.4	25.57
Bill	548	383	4.66	69.9	80.5	29.61
Mean	1378	1000	14	72	80	28
LSD$_{(0.05)}$variety	608.3**	405**	5.6**	5.73**	12.39**	5.625**
CV%	19.4	21	26	6.2	9.3	12.2

** = $P \leq 0.01$

There was a positive correlation (r^2=0.7979) between the pod yield per plant and pod number per plant. As the pod yield increased, the number of pods increased in a sigmoid pattern with a linear increase in yield between 1500 to 3000 pod numbers per plant (Figure. 4.2)

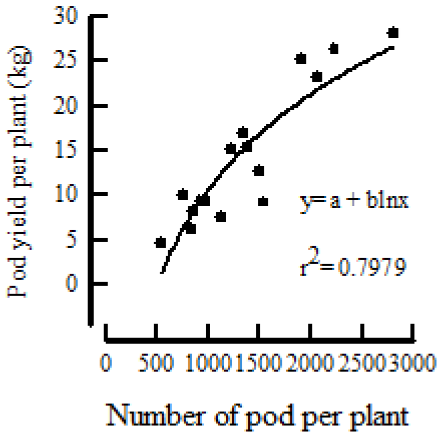

Figure. 4.2. The relationship between mean pod per groundnut pod yield and the mean number of pod per plants at Manguzi.

4.5. Nutrient concentration in pod tissues of 16 groundnut varieties grown at Manguzi

4.5.1. Macronutrients

There was little variation among the varieties in the concentrations of Ca, Mg and P compared with K in seed tissue (Table 4.13). The seed Ca concentration in majority (75%) of the varieties fell in the range 0.03 to 0.04 (Table 4.13). Exceptions were Kano and Anel, which each had 0.02% and ICGV-99529 with 0.05%. The seed tissue Mg ranged from 0.16 to 0.22% in approximately. 63% of the varieties (Table 4.13). The seed tissue P concentration ranged between 0.34 and 0.47%, with Ca with 44% of the varieties having seed tissue P concentration greater than 0.4% (Table 4.13). There was a marked difference among the varieties in seed tissue K, which ranged from 0.63 in ICGV-99529 to 1.17% in RG-784. Only three of the varieties (Inkanyezi, RG-784 and ICGV-90071) had seed tissue K concentration greater than 1.00%. Generally, the seed macronutrient concentrations were less at Manguzi than they were in both the pH 4.54 and pH 5.53 soils at the Lowveld College of Agriculture farm.

Table 4.13. Macronutrient (Ca, Mg, K and P) concentrations in the seed tissue of 16 groundnut varieties grown in acid soil at Manguzi

Groundnut variety	Macronutrient concentration in tissue			
	Ca (%)	Mg (%)	K (%)	P (%)
Inkanyezi	0.03	0.16	1.14	0.4
RG-784	0.03	0.16	1.17	0.43
Mwenje	0.04	0.21	0.72	0.41
ICGV-99529	0.05	0.22	0.63	0.44
Kano	0.02	0.17	0.8	0.41
Anel	0.02	0.18	0.74	0.34
Nyanda	0.04	0.21	0.8	0.41
ICGV-90071	0.03	0.17	1.16	0.42
ICGV-95714	0.03	0.2	0.89	0.47
Rambo	0.04	0.17	0.98	0.37
Akwa	0.04	0.2	0.74	0.38
Harts	0.04	0.2	0.7	0.39
JL24	0.03	0.19	0.68	0.39
Ka-Ngwane-Red	0.03	0.18	0.81	0.41
Kwarts	0.03	0.19	0.75	0.37
Bill	0.02	0.16	0.91	0.39
Mean	0.03	0.19	0.85	0.40
$LSD_{(0.05)}$ variety	0.01*	0.01*	0.05*	0.06*

* = $P \leq 0.05$

As was the case with seed tissue Ca, Mg, K and P concentrations, the shell concentrations of these mineral nutrients varied among the varieties within narrow ranges. Thus, the values of these mineral nutrients in the shell tissue did not differ significantly amongst most of the varieties (Table 4.13A). The range of the shell Mg concentrations (0.12 to 0.18%) of the varieties overlapped with that (0.16-0.22%) for the varieties' seed Mg concentrations. By contrast, the shell Ca concentrations (0.15 -0.31) increased 3-folds (ICGV-99529) to 11-folds (Bill) that in the respective seeds. In juxtaposition to tissue Ca concentration which was much lower in the seeds than in the shells, the seeds contained markedly higher concentrations of P than the shells. In the shells the range of P concentration was 0.04 to 0.11% compared with the range 0.34 to 0.44% in the seed tissue (Table 4.13). Thus, the seed P concentrations were from 3.8-fold (Inkanyezi) to 8.8-fold (ICGV-99529) of that in the respective shells. For each of the varieties, the K concentration was markedly higher in the shells than in the seeds, but the range of the shell K concentration (0.83 – 1.64%) overlapped with that (0.63-1.17%) for seed K concentration (Table 4.13A).

Table 4.13A. Macronutrient (Ca, Mg, K and P) concentrations in the pod shell tissue of 16 groundnut varieties grown in acid soil at Manguzi

Groundnut variety	Macronutrient concentration in tissue			
	Ca (%)	Mg (%)	K (%)	P (%)
Inkanyezi	0.2	0.18	1.32	0.11
RG-784	0.25	0.15	1.6	0.11
Mwenje	0.26	0.15	0.96	0.05
ICGV-99529	0.15	0.15	1.17	0.05
Kano	0.15	0.13	1.34	0.09
Anel	0.16	0.11	1.12	0.05
Nyanda	0.15	0.14	0.96	0.05
ICGV-90071	0.25	0.14	1.4	0.1
ICGV-95714	0.17	0.16	1.33	0.07
Rambo	0.22	0.14	1.29	0.06
Akwa	0.21	0.12	0.84	0.04
Harts	0.31	0.18	1.05	0.04
JL24	0.2	0.15	0.9	0.06
Ka-Ngwane Red	0.18	0.12	1.17	0.07
Kwarts	0.22	0.17	1.64	0.06
Bill	0.22	0.16	1.63	0.05
Mean	0.21	0.15	1.23	0.07
$LSD_{(0.05)}$	0.08*	NS	0.31*	0.03*

* = P ≤ 0.05 and NS= not significant different

4.5.2. Micronutrients

Similarly, to the seed tissue macronutrient concentrations, those of the micronutrients that were measured (Fe, Zn, Mn and Cu) varied within a narrow range, hence their concentrations did not vary significantly between most of the varieties (Table 4.14). The concentration ranges of seed Zn (30 – 43 mg kg^{-1}), Mn (18 – 43 mg kg^{-1}) and Fe (20 – 43 mg kg^{-1}) were similar, but that for Cu (5.4 –11.6 mg kg^{-1}) was markedly lower. The Zn concentration ranged from 30 to 43 mg kg^{-1}. Groundnut variety ICGV 99529 had the highest seed Fe, Zn, Mn and Cu concentration, whereas the concentration of these nutrients tended to be lowest in Bill.

Table 4.14. Micronutrient (Fe, Zn, Mn and Cu) concentrations in the seed tissue of 16 groundnut varieties grown in acid soil at Manguzi

Groundnut variety	Micronutrients concentration in tissue			
	Fe(mg kg^{-1})	Zn (mg kg^{-1})	Mn(mg kg^{-1})	Cu(mg kg^{-1})
Inkanyezi	52	32	19	6.5
RG-784	28	32	20	7.9
Mwenje	24	46	38	9.4
ICGV-99529	54	43	44	11.6
Kano	34	40	19	5.8
Anel	22	32	20	7.5
Nyanda	24	40	34	7.7
ICGV-90071	30	32	20	7.1
ICGV-95714	35	38	24	5.9
Rambo	28	34	28	8.1
Akwa	26	32	28	7.7
Harts	26	34	43	6.9
JL24	28	38	36	7.8
Ka-Ngwane Red	30	42	22	6.8
Kwarts	26	32	34	5.4
Bill	20	30	18	5.8
Mean	30.44	36.06	27.94	7.37
$LSD_{(0.05)}$	4.6*	7.2*	6.8*	2.1*

*=P ≤0.05

The shell Mn (50 – 121 mg kg^{-1}) and Fe (55 – 127 mg kg^{-1}) concentrations were more variable among the varieties compared to the concentrations in the seeds (Table 4.14). Those of shell Zn (12 – 16 mg kg^{-1}) and Cu (5.4 – 10.5 mg kg^{-1}) varied within narrow ranges among the varieties (Table 4.14A). The concentration ranges of shell Mn and Fe were comparable whereas that for the shell Zn was much lower (Table 4.14A). The Zn concentrations in the shells were 1.9-fold to 3.2 fold lower than those in the respective seeds. By contrast those of shell Mn were from 1.8-fold to 4.2-fold higher than in the respective seeds. Copper was the only mineral nutrient whose concentration ranges in the shells (5.4 – 11.6 mg kg^{-1}) and in the seeds (5.4-10.5 mg kg^{-1}) were similar.

Table 4.14A. Micronutrient (Fe, Zn, Mn and Cu) concentrations in the seed shell tissue of 16 groundnut varieties grown in acid soil at Manguzi

Groundnut variety	Micronutrients concentration in tissue			
	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
Inkanyezi	91	12	50	5.9
RG-784	67	14	53	5.5
Mwenje	115	16	101	7.1
ICGV-99529	113	14	72	7.9
Kano	73	16	56	6.9
Anel	64	10	60	7.6
Nyanda	127	16	77	7.5
ICGV-90071	73	16	55	5.5
ICGV-95714	87	14	77	5.3
Rambo	87	14	74	7.2
Akwa	87	12	77	10.5
Harts	127	16	121	6.2
JL24	62	16	94	7.2
Ka-Ngwane Red	55	14	63	6.9
Kwarts	105	14	88	6.2
Bill	76	12	76	5.4
Mean	88.06	14.13	74.63	6.80
$LSD_{(0.05)}$variety	8.2*	NS	12.8*	NS

***=**P $\leq$ 0.05 and NS = not significant different

4.6. Discussions

4.6.1. Yield performance of the varieties in relation to production under farmer conditions.

In both the lowveld region of Mpumalanga province and Manguzi on the north coast of KwaZulu-Natal province, groundnut is produced under dry land conditions. In the present study, the groundnut varieties tested received only 87 mm of supplementary irrigation at Lowveld College of Agriculture farm and none at Manguzi. They were therefore grown under moist conditions that were similar to those of dry land production by the farmer. Under the farmers' management conditions, in which lime application is seldom done to correct low soil pH, dry land groundnut pod yields normally range from 693 to 1825 kg/ha in the Lowveld region of Mpumalanga province (Swanevelder, 1998; Mathews, 2003; Mengel et al., 2001). In the present study, the pod yield ranged between 925 - 2307 kg/ha of the varieties in acid soil (pH 4.53) at the Mpumalanga Lowveld College of Agriculture farm and the range 546 – 2817 kg/ha at Manguzi had considerable overlap with the average pod yield ranged compared to that of the farmers in the Lowveld region of Mpumalanga province. Only three of the 16 varieties tested, wiz; ICGV 95714 (2172 kg/ha), Anel (2307 kg/ha) and Inkanyezi (2166 kg/ha) had pod yields that were markedly above pod yield range for the farmers. Similarly, in the acid soil (pH 4, 21) at Manguzi, only four of the varieties tested, wiz; Inkanyezi (2817 kg/ha), RG-784 (2234 kg/ha), Mwenje (2067 kg/ha) and ICGV-99529 (1916 kg/ha) had pod yields that were above the pod yield range of the farmers in the Lowveld region of Mpumalanga province. By contrast, the pod yields of all the varieties grown at the Lowveld College of Agriculture farm at pH 5.53, which is considered to be within the optimal pH range (5.5-6.2) for groundnut, were markedly above the average pod yield range reported for the farmers in the lowveld of Mpumalanga, except for Ka-Ngwane Red (1342 kg/ha), Akwa (1610 kg/ha) and Harts (1772 kg/ha). The marked improvement of the groundnut varieties under the favourable pH indicates that the acid nature of most of the soils in Mpumalanga and Manguzi (Chapter 3) could limit groundnut productivity considerably.

Because of the acid nature of most of the sandy soils on which groundnut is grown in the Mpumalanga lowveld and in Manguzi (Chapter 3), it is desirable to use a variety that is tolerant of soil acidity, if groundnut is planted in the absence of liming. Among the varieties that were tested, there was a marked difference in the ranking of the varieties in terms of pod and seed yield between Manguzi and the Lowveld College of Agriculture farm. At Manguzi (soil pH 4.21) the four topmost yielders whose pod yield was above the pod yield range (693 - 1825 kg/ha) for the farmers in Mpumalanga were (in the decreasing yield order); Inkanyezi (2817 kg/ha), RG-784 (2234 kg/ha), Mwenje (2067 kg/ha) and ICGV-99529 (1916 kg/ha).

At the Lowveld College of Agriculture farm, in the acid soil (pH 4.53, the list in decreasing pod yield order consisted of Inkanyezi (2166 kg/ha), Anel (2307 kg/ha), ICGV 95714 (2172 kg/ha) and RG - 784 1976 kg/ha). The reasons for this difference in the ranking of the topmost yielder between the two sites cannot be deduced from this study. The varieties that appeared in the list of topmost yielders at both the Lowveld College of Agriculture farm (Table 4.3) and Manguzi (Table 4.12) were Inkanyezi, RG-784 and Mwenje. The pod yields of these three varieties at Manguzi (2817, 2234 and 2067 kg/hafor Inkanyezi, RG-784 and Mwenje, respectively) did not differ markedly from those obtained with supplementary irrigation in acid soil (2166, 1976 and 1670 kg/ha respectively) at the Lowveld College of Agriculture farm. Thus, Inkanyezi, RG-784 and Mwenje appeared to be the most stable variety for universal use in acid soil. On the basis of both pod and seed yield, ICGV-99529 can be added as a fourth variety suitable for cultivation at Manguzi. Varieties Anel and JL-24, which also gave satisfactory yields at the Lowveld College of Agriculture farm (Table 4.3 and Table 4.4), are additional varieties suitable for use on acid soils in the lowveld region of Mpumalanga. Among the topmost yielders, Inkanyezi, RG-784, Mwenje and JL-24 showed an added advantage that their pod and seed yields were highly and positively improved at pH in the range considered suitable for groundnut production. Thus, these varieties are expected to respond strongly to lime application on sandy soils. By contrast, of the high performance varieties at the Lowveld College of Agriculture farm, Anel maintained high yields of both pods and seeds in acid and favourable pH conditions. It was the topmost seed yielder in acid soil indicating that this variety should be seriously considered for production in acid soils in the absence of liming. Among the rest of the varieties, RG - 784, together with Inkanyezi presented impressively high seed yield performance under high pH at Lowveld College of Agriculture farm. Thus, Inkanyezi and RG-784 could be considered more suitable for production under the more favourable soil pH of 5.53. Nonetheless, Inkanyezi could be a serious contender for production in acid soil, also.

4.6.2. Sensitivity of pod and seed yield to soil pH at Lowveld College of Agriculture farm.

The growing of the test varieties in two adjacent fields that differed in soil pH with one field being acidic and the other having an optimal pH for groundnut production presented an opportunity to assess the sensitivity of pod and seed yield of the varieties to soil pH. Generally, pod yield (Table 4.3) was less sensitive to soil pH compared to seed yield (Table 4.4). Among the 16 varieties tested, Kwarts was outstanding in that it was highly sensitive to soil pH compared to the rest of the varieties as indicated by 134.59 and 142.61% increases in pod (Table 4.3) and seed (Table 4.4) yield, respectively when grown in soil with pH 5.53 compared to pH 4.54. Other varieties whose seed yield was markedly sensitive to soil pH were Inkanyezi, RG784, ICGV 99529, Bill and Rambo whose increases in seed yield at soil pH 5.53 compared to pH 4.54 ranged between 70.44-86.86 %. The corresponding increases in pod yields for the varieties were, however, markedly lower, particularly for Bill and Inkanyezi, which together with Mwenje had a modest increase of between 46.35 and 54.52 % (Table 4.3) compared with the range of 61.69 -78.92 % for RG - 784, ICGV 99529, Rambo and ICGV90071. Although pod yield for ICGV 90071 showed marked improvement at the more favourable pH compared with the lower soil pH, its seed yield was not as sensitive as the pod yield to soil pH as indicated by the 27.41 % increase in seed yield compared with 63.10 % for pod yield at soil pH 5.53 in contrast to pH 4.54. For unknown reasons, the shelling percent of ICGV 90071 as well as that for Harts decreased markedly (by 15 % for ICGV 90071 and 11 % for Harts) when the varieties were grown at the higher pH rather than at the lower soil pH. The varieties Akwa, Bill, Inkanyezi and RG784 showed a marked increase in shelling percentage (by 8-12%) at pH 5.53 compared with pH 4.54, and this partly accounted for the substantial increase in seed yield of these varieties at pH 5.53. The most startling result was the decrease of pod yield of Ka-Ngwane Red at the higher soil pH compared to the lower soil pH. This is contrary to reports in the literature, which indicates that groundnut yield performance is adversely affected at low soil pH (Zharare et al, 2010; 2012; Murata et al., 2008; 2013; Gascho and Davis 1994). Although groundnut yield decrease at high pH may be expected (Murata et al., 2002; 2013; Lu and Sucoff, 2001), the soil pH of 5.53 is considered favourable for groundnut and not high enough to adversely affect groundnut yields, unless this variety is particularly sensitive to high soil pH. This is however highly unlikely, since the yield of this variety was low at both soil pH values in which groundnut was grown in the present study.

Another source of increase to improved seed yield at pH 5.53 was the increase in seed size at this favourable soil pH compared to the seed size at pH 4.54. However, the contribution made by seed size to the increase in seed yield noted at the higher pH was marginal in most of the varieties. Only in Kano and Rambo was the contribution from increased seed size somewhat substantial.

Based on the results of solution culture studies by Murata et al. (2008; 2013), more ovarian cavities of groundnut pods were expected to contain seed at the higher pH than at lower soil pH. In the present study, there was a tendency for the varieties to increase the proportion of ovarian cavities filled with seeds at pH 5.53, i.e. seed abortion was less at the higher pH than at the lower soil pH. Thus, improved seed-set at the higher pH also contributed to increased yield at soil pH 5.53 compared to that at soil pH 4.54.

It should be noted that the varieties differed markedly in the extent to which, shelling %, seed size and seed set contributed to the yield increases at pH 5.53 compared with the yield at soil pH 4.54. However, it is not possible to explain the high seed yield increase for Kwarts at soil pH 5.53, because none of the above parameters changed significantly between the two soil pH values. The only way Kwarts may have increased its seed yield at pH 5.53 compared with that at pH 4.54 was by increasing the number of pods per plant. Unfortunately, this parameter was not determined in this study at Mpumalanga Lowveld Agricultural farm, and is therefore not possible to determine how this parameter contributed to the yield increases noted at pH 5.53.

4.6.3. Macronutrients nutrient concentrations in the YFEL at the Lowveld College of Agriculture farm

In terms of vegetative growth, the P concentrations in the youngest fully expanded leaves (YFEL) which ranged from 0.24 % to 0.41 % were sufficient in quantities for unrestricted groundnut plant growth. Values of K concentrations which varied from 1.31 % in Ka-Ngwane Red to 2.16 % in Harts were within the range known to be adequate for groundnut vegetative growth (Lu and Sucoff, 2001). The Ca concentrations in the youngest fully expanded leaves (YFEL) ranging from 0.82 in Kano to 1.06% in Ka-Ngwane Red were within the range (1.25 % to 2.0 % Ca) considered sufficient for optimal vegetative growth of groundnut (Gascho and Davis, 1994). Similar results were observed on the critical nutrient level in relation to plant growth by Alsaeedi and Elprince (2000) and Bolland and Bennan (2008).

4.6.4. The micronutrient concentrations in groundnut leaves at pH 5.53

The Cu values which ranged between 3.90 to 6.07 mg kg^{-1} in groundnut youngest fully expanded leaves (YFEL) were at a marginal level compared with the optimum range of 5 to 20 mg kg^{-1} (Plank, 1989). Although the Valencia type variety Ka-Ngwane Red had the lowest Cu concentration in the youngest fully expanded leaves (YEFL) (3.90 mg kg^{-1}), which was far below the minimum level (5 mg kg^{-1}) considered adequate, this did not seem to impair its productivity in terms of pod and seed yield (Lu and Sucoff, 2001; Murata et al., 2008).

The Mn concentrations in the youngest fully expanded leaves (YFEL) of the test varieties (101 – 151 mg kg^{-1}) were within concentration levels (20 to 350 mg kg^{-1}) considered suitable for the groundnut (Plank, 1989). Similarly, the values for Fe which ranged from 131.7 to 210.3 (mg kg^{-1}) were within the range considered adequate for unrestricted groundnut growth. The Zn concentrations which ranged from 111.7 mg kg^{-1} to 170 mg kg^{-1} were excessive compared with the range 20 to 60 mg kg^{-1}considered optimal for the healthy vegetative growth of groundnut (Plank, 1989). Nonetheless, the levels did not seem to be detrimental to the groundnut.

4.7. Seed tissue mineral nutrient concentrations

4.7.1. Macronutrients

Seed Ca, Mg and P concentrations of the varieties were generally higher at Nelspruit than they were at Manguzi, whereas it was the opposite for seed K concentration. The reasons for the differences seem to differ with location in related to groundnut production which expected as the weather conditions of the two locations are not the same.

In the present study, for the plants grown at both soil pH 5.54 and 4.53 at the Lowveld College of Agriculture farm, these nutrients (Ca, Mg and P) were in adequate concentration in the seeds of all the varieties tested (Table 4.10). At Manguzi, Mg, K and P were also in adequate concentrations in the seed, but the seed Ca concentration range extended from deficient to marginal among the varieties. This probably accounts for the lower seed yields at Manguzi compared with that at Nelspruit Lowveld College of Agriculture farm. The dismal seed yield performance of Kano against a high pod yield appears to emanate from poor pod filling due to Ca deficiency (Murata et al., 2008; Desai et al.,1999). An interesting case is presented by Anel. This groundnut variety, like Kano and Bill, had deficient levels of seed Ca (0.02%). However, despite the deficient seed Ca level, Anel had reasonable pod yield (2680 kg/ha) and ranked 5th among the 16 varieties tested. This suggests that although Anel is a poor Ca absorber, but an efficient utilizer of tissue Ca (Lu and Sucoff, 2001; Nigam et al., 2004). The efficient utilization of tissue Ca (internal Ca) probably explains the stable seed yield of Anel at Nelspruit Lowveld College of Agriculture farm, which was similar in the favourable pH (1984 kg/ha) and low pH (1709 kg/ha). There is therefore a need to examine further in detail the utilization of internal Ca in this variety.

In addition to efficient utilization of scarce mineral nutrients, one other important attribute for groundnut to have is efficient absorption of Ca by the pods from the soil and its transport from pod shell to the seed (Kamprath and Smyth, 2004; Ndjeunga et al., 2006; Fageria and Baligar, 2008). This is because pod filling and seed quality are positively correlated with seed Ca concentration (Murata et al., 2008). Thus, efficient absorption of Ca by the pods from the soil and its transport from pod shell to the seed are most desirable in acid soils, which are usually deficient in Ca (Fernandez et al., 2000; Lu and Sucoff, 2001; Nigam et al., 2004). Of the 16 groundnut varieties tested, ICGV 99529 was outstanding in that at both Nelspruit and Manguzi, it had the highest Ca concentration. At Manguzi (where data for shell nutrients is available), this was astonishing despite being amongst the varieties with lowest shell Ca concentration. Therefore, the conclusion that comes out of this observation is that ICGV 99529 is efficient in the translocation of Ca from the pod shell to the seed. Incidental to having the highest seed Ca concentration, ICGV 99529 also had the lowest seed K concentration. Although this seems to reflect antagonism of Ca on K uptake by the pods (Nigam et al., 2004), it may not be the case, since its shell K was amongst those in the high concentration range. Thus, it does appear to reflect an altered transport system in ICGV 99529 that favours the transport of Ca than K from the pod shell to the seeds. It is noteworthy that ICGV 99529 also had the lowest Na concentration in the seeds and shells compared to the other varieties, which reflects an ability to discriminate against the uptake and translocation of Na in addition to that of K (Nigam et al., 2004). The ability to efficiently transport Ca to the seed from the pod shell in ICGV 99529 may offer advantages under Ca deficient soil conditions, not only in terms of seed yield, but also in terms of germinability of the resultant seeds. This is because germination of groundnut seeds is positively correlated with seed Ca concentration (Nigam et al., 2004; Gascho and Davis, 1994). The ability to discriminate against Na may also help in tolerating saline and sodic soil related problems.

4.7.2. Micronutrients

Currently, the internal seed Fe, Zn. Mn and Cu requirements are not known, hence it is not possible to determine the adequacy of the ranges of the concentrations obtained in this study. Noteworthy in this study, was again the high concentrations of seed Cu, Mn and Fe in ICGV 99529 compared to other varieties under dry land conditions at Manguzi. Furthermore, ICGV 99529 was among the varieties with high seed Zn, which together suggests that this variety has superior nutrient transport capacity from pod shell to the seed under constrained moisture conditions compared to the rest of the varieties.

4.8. Comparison of pod filling at Manguzi and Nelspruit Lowveld College of Agriculture farm.

The proportions of ovarian cavity with seeds for plants grown at higher soil pH in Nelspruit Lowveld College of Agriculture farm were lower than those for the respective varieties grown at lower pH at Nelspruit and Manguzi. The involvement of the deficiency of Ca and other nutrients in these differences is discounted since at Nelspruit, the seed mineral nutrients' status of plants grown at the higher and at the lower soil pH were similar.

CHAPTER 5. EFFECT OF LIMING ON GROUNDNUT PRODUCTIVITY IN MPUMALANGA AND KWAZULU-NATAL

5.1. Introduction

One way to deal with production of crops in acid soils is to use acid tolerant varieties, especially in situations involving severely under-resourced farmers. However, acid tolerant plants may slow the acidification of the soil but will not prevent it. Liming will eventually become necessary, otherwise the soil will eventually become so acidic that crop production will be drastically reduced (NLWRA, 2002). Calcite and dolomite are the most commonly used liming materials, but other materials are available (Agfact, 2005).

Soil acidity is accompanied by leaching of calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations and other basic cations. This is especially more pronounced in sandy soils (Crozier and Hardy, 2003), which are the most suitable for groundnut production. Application of finely crushed limestone is the most practical and common way to ameliorate acid soils to pH favourable for plant growth (Agfact, 2005), and is an economical source of Ca. If dolomitic limestone is used, it also supplies Mg. Furthermore, the liming materials release Ca (calcitic and dolomitic limes) and Mg (dolomitic) more slowly over a period of three to four years, and hence may be better protected from leaching than when other soluble fertilizers are used (Crozier and Hardy, 2003). In addition to taking into account the soil pH values, lime recommendations must take into account differences in pH buffering capacities among soils as well as differences in tolerance to acidity among crop species and varieties (Crozier and Hardy, 2003). Crops and varieties also vary in optimum pH (Osmond et al., 2002), and hence the recommended lime rates vary with crop and even with the variety. To be most effective, lime must be applied uniformly and thoroughly incorporated into the soil well before the crops are planted to allow sufficient reaction time with the soil. If not correctly applied, strips of under limed and over limed soil could occur, which could possibly reduce crop yields.

In this study six groundnut varieties, selected on the basis of their performance in Experiment 1, were tested in acid soils during the 2009-2010 season to determine their yield responses to calcitic and dolomitic limes.

5.2. Materials and Methods

Field experiments were conducted during the 2009-2010 season which examined the response of groundnut to dolomitic or calcitic lime at Lowveld College of Agricultural Farm in Mpumalanga and to calcitic lime at Manguzi in northern KwaZulu-Natal.

5.2.1. Soil chemical analyses

Soil samples were taken before planting of the experiment and analysed by the Soil Lab at Cedara (Department of Agriculture) in KwaZulu-Natal for their nutrient status in terms of macro-nutrients (K, Ca, Mg, P), and micro-nutrients (Fe, Zn, Cu, B, Mn and Mo) as well as their Al concentration.

5.2.2. Treatments and experimental design at Lowveld College Farm in Mpumalanga

Six groundnut varieties were evaluated for their response to calcitic and dolomitic lime applications under supplementary irrigation. The varieties included JL-24, Inkanyezi, Kwarts, ICGV 90071, RG-784 and the control Rambo. In addition to the control treatment in which there was no lime applied, there two (2) liming treatments each for both the calcitic and dolomitic limes in which lime was applied. They included three liming rates wiz; no lime application, $^1/_2$ of the recommended rate (750 kg/ha) and the recommended liming rate (1500 kg/ha). The groundnut varieties and the lime levels were arranged as a factorial experiment laid out in a completely randomized block design with three replicates.

5.2.3. Treatments and experimental design in Manguzi

The same six groundnut varieties used at the Lowveld College farm were grown at Manguzi under rain-fed conditions (Table 5.1). However, only the calcitic lime was tested at Manguzi, also involving the recommended rate (1500 kg/ha) and ½ recommended rate (750 kg/ha) in addition to the control (no lime application). The groundnut varieties and the liming treatments were arranged as a factorial experiment laid out in a completely randomized block design with three replicates.

Table 5.1. Groundnut varieties that were evaluated for response to lime at Lowveld Agricultural College Farm and Manguzi

Groundnut Variety	Yield performance in 2008-2009 season (Chapter 4)
JL-24	1875 to 2433
Inkanyezi	2166 to 3346
Kwarts	925 to 2170
RG -784	1976 to 3272
ICGV 90071	1618 to 2639
Rambo	1276 to 2283

5.2.4. Plot size

The gross plot size was four rows that were 4 m long with intra-row and inter-row spacing of 10 cm and 70 cm, respectively. The net plot consisted of four inner rows, with 0.5 m discarded at either end of the rows.

5.2.5. Cultural practices

The land was prepared using a mould-board plough after which a compound fertilizer NPK 2:3:2 (22) +Zn (5%) was applied at a rate of 250 kg/ha. This was followed by discing to incorporate the fertilizer into the top 25 cm of the soil and also to smoothen the seedbed. The lime sources were applied at 8-9 cm deep and covered with thin layers of soil at planting. Groundnut seeds were then planted 5-7cm deep.

Dual gold (S-Metalochlor) was applied at planting at a rate of 1.25 litres per hectare within 2 days of planting as a pre-emergence herbicide to control broad and slender leaves. A follow-up of one round of manual weeding was carried out at six weeks after planting to keep the plots free of weeds.

Gypsum was applied at a rate of 500 kg/ha by broadcasting in bands over the crop rows at the onset of flowering to an enhance the pod filling process and make soluble Ca available for the pods. At Lowveld College farm, where supplementary irrigation was available, the application of gypsum was followed by a light application of water. In total, the crop received a supplementary irrigation of 60 mm at Lowveld College farm.

5.2.6. Harvesting and processing

The varieties were harvested when 75-80% of the nuts matured from a net plot of four rows. The plants were harvested manually and the pods picked by hand. The pods were air dried in bags that allowed free air circulation.

5.2.7. Data collection

Stand establishment was assessed at seven days after planting by counting the number of plants that emerged in the net plot. A final stand was taken at harvest by again counting the number of plants in the net plot.

Samples of youngest fully expanded leaves (YFEL) were taken at the onset of flowering and analysed at Plant Laboratory (KwaZulu –Natal) for tissue K, Ca, Mg, P, Al, Fe, Zn, Cu, and Mn concentrations.

The duration to maturity for each variety was recorded when 70-80% of the pods had matured. At harvest, the numbers of plants in the net plot were counted, and the plants uprooted by hand. The pods were separated from the hauls and their weights per net plot recorded after which they were air-dried. After twenty-five days of air drying, the dry weights of the pods per plot were recorded. The pods were separated into three categories of single, double and multi-compartmented pods and the number of the pods in each of these categories counted and then weighed. The pods were shelled and the number of seeds per pod category determined. The weights of the seeds per pod category were recorded and so was the 100 seed mass. The shelling per cent was calculated by the formula = (seed weight/ seed number) x 100. The seed yield in kilogram per hectare was calculated by the formula = (Dry pods yield x shelling %) /100, The Hundred seed mass was calculated by the formula = (Shelling %/ seed number) x 100 and the Number of nut per pods was calculated by the formula = Seed number/ pod number.

5.2.8. Data analysis.

An ANOVA analysis was performed on the data using the Genstat 12th edition software package. The differences amongst the treatment means were separated by the least significant difference (LSD at 5% level). The grain yield was further subjected to regression analysis.

5.3. Results

5.3.1. General observations on crop growth

In general, the stand establishment at both sites was satisfactory and the plants grew vigorously. The plants were healthy and free from symptoms of foliar diseases (Early and late leaf spots, and rust) which were closely monitored during the cropping season. The pests and insecticides were not severe on the plants. Only bird damages were monitored on daily bases since it occurs during the days which were also not large enough to interfere with yields at harvesting.

The pH values of the soils at the two sites used for the experiment at the Lowveld College of Agriculture farm was markedly acidic. In the top soil (0-10 cm), the pH was 4.5 and 4.9 in the field in Block A and Block B, respectively. The pH of the roots zone soil (10-40 cm) and the sub-fell between 4.5 to 4.9 which were on the ranged of acidity (Table 5.2). Similar soil conditions were observed at Manguzi where the experiment was planted (Table 5.2).

Table 5.2. The average means of soil pH concentration at Nelspruit and Manguzi

Fields	Soil profile depths (cm)	Nelspruit	Manguzi
		Soil pH (KCl)	
Block A			
	0-10	4.5	4.9
	10-40	4.9	4.8
	40-60	4.9	4.6
Block B			
	0-10	4.9	4.6
	10-40	4.5	4.7
	40-60	4.7	4.6
Mean		4.73	4.70

5.4. Crop performance at Lowveld College of Agriculture farm

5.4.1. Duration to maturity

There were differences in the days taken by the groundnut to maturity between the two lime sources (Table 5.3). When calcitic lime was used, the average mean days taken to maturity were 139, but when dolomitic lime was used, the days increased to 145. All varieties tested took longer to mature with dolomitic lime compared with calcitic lime. The differences in time taken to maturity between the calcitic and dolomitic treatments were most pronounced in ICGV 90071. Groundnut varieties JL-24 and Kwarts were the least sensitive to lime type. Within the lime type, there were no significant differences between the recommended and the $^{1}/_{2}$ recommended lime rates in days taken to maturity.

Table 5.3. The average means of days taken to maturity of the groundnut varieties in calcitic and dolomitic lime treatments

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for means of lime rates
			Days to maturity		
			Calcitic lime		
JL-24	123	122	122	122	NS
Inkanyezi	152	155	154	154	4*
Kwarts	123	123	122	122	NS
RG -784	158	155	154	154	5*
ICGV 90071	154	146	149	147	4*
Rambo	136	132	132	133	7*
Mean	141	139	139	140	NS
			Dolomitic lime		
JL-24	123	124	123	123	2*
Inkanyezi	152	162	162	158	3*
Kwarts	123	125	123	124	3*
RG -784	158	162	162	162	NS
ICGV 90071	154	162	162	162	4*
Rambo	136	145	142	141	7*
Mean	141	147	146	145	NS
Lsd($_{0.05}$)for variety = 4**					
Lsd($_{0.05}$) for lime type = 2**					
CV%	4.0				

*= P ≤0.05, ** = P ≤0.01and NS = not significant different

5.4.2. Plant establishment

The source of lime did not significantly affect the establishment of the varieties (Table 5.4). The average of plant count per plot at harvesting for the varieties under the calcitic and dolomitic lime were 140 and 137, respectively. However, there were significant differences amongst the varieties in plant count. ICGV 90071 had the least plant count in both dolomitic and calcitic lime.

Table 5.4. The average means of plant count per plot at harvesting of the groundnut varieties in calcitic and dolomitic lime treatments

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for means of lime rates
		Plant count at harvesting			
		Calcitic			
JL-24	153	182	182	172	10*
Inkanyezi	124	162	159	148	18*
Kwarts	167	172	176	172	12*
RG -784	118	130	128	126	25*
ICGV 90071	77	84	95	85	18*
Rambo	123	158	118	133	31*
Mean	127	148	143	139	NS
		Dolomitic			
JL-24	153	171	178	167	10*
Inkanyezi	124	143	139	136	18*
Kwarts	167	170	166	168	13*
RG -784	118	136	132	129	25*
ICGV 90071	77	88	108	91	18*
Rambo	123	128	131	127	31*
Mean	127	140	142	136	NS
$Lsd_{(0.05)}$ for variety =19.84**					
CV%	20				

*= P ≤0.05, **= P ≤0.01 and NS = not significant different

5.4.2. Pod yield

There was no consistent pattern in the response of the groundnut varieties to liming with dolomite and calcite. Varieties JL-24, Kwarts and Rambo tended to perform better when the soil was limed with calcite than with dolomite, whereas varieties RG-784, ICGV 90071 and Inkanyezi performed better when the soil was limed with dolomite rather than with calcite (Table 5.5).

The varieties differed significantly in mean pod dry yields. Under the dolomitic lime treatments, JL-24 and RG-784 were the most productive varieties. JL-24 significantly out-yielded all other varieties except RG-784 (Table 5.5), but under the calcitic lime treatments, RG-784 significantly out-yielded all other varieties except JL-24 (Table 5.5).

The liming rate affected the pod dry yields differently among the varieties (Table 5.5). There was a trend for the pod yield to increase with increasing calcitic lime application rate in varieties JL-24 and Inkanyezi, and with increasing dolomitic lime application rate in ICGV 90071. In the rest of the varieties, the application of dolomite or calcite at the recommended liming rate reduced pod yield compared to the ½ recommended rate. Kwarts was particularly more sensitive compared to other varieties to high lime application as its pod yield declined by 66 and 53 % at the ½ recommended rate of the calcitic and dolomitic limes, respectively, compared to no lime application.

Table 5.5. Dry pod yield response of six groundnut varieties to calcitic and dolomitic lime application

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for means of lime rates
			Dry pod yield in kg/ha		
			Calcitic		
JL-24	2400	2882	3286	2856	204*
Inkanyezi	1764	1772	2383	1973	353*
Kwarts	1578	534	535	882	250*
RG -784	2495	2626	2486	2536	499*
ICGV 90071	1575	949	1056	1193	353*
Rambo	1301	2072	1190	1521	611*
Mean	1852	1806	1823	1827	NS
			Dolomitic		
JL-24	2400	2534	1900	2278	204*
Inkanyezi	1764	2146	2026	1979	353*
Kwarts	1578	739	604	974	250*
RG -784	2495	1971	3321	2596	499*
ICGV 90071	1575	1616	1078	1423	353*
Rambo	1301	1393	954	1216	611*
Mean	1852	1733	1647	1744	NS
$Lsd_{(0.05)}$ for variety =353**					
$Lsd_{(0.05)}$ Varieties x lime type =499*					
CV%	21.7				

*= P ≤0.05, ** = P ≤0.01 and NS = not significant different

5.4.3. Seed yields

The varieties differed markedly in seed yield performances. JL-24 significantly out-yielded all other varieties under both calcitic and dolomitic lime applications (Table 5.6). There were also marked differences in the manner in which the varieties responded to dolomitic or calcitic lime rates. In the case where lime was applied as the calcitic compound, seed yield of JL-24 and Inkanyezi increased with increasing lime rate. In Kwarts, the seed yield was decreased by lime application to the same extent of the ½ recommended rate and at the recommended rate. In the rest of the varieties, the seed yield was optimised at the ½ recommended rate.

When the lime was applied as the dolomitic compound, the seed yield of JL-24 and Inkanyezi were optimised at the ½ recommended rate. In JL-24, the yield decreased significantly when the dolomitic lime was increased to the recommended liming rate, whereas in Inkanyezi, the seed yield was essentially the same of the recommended lime rate as at the ½ recommended rate. The seed yield of Kwarts was decreased with the application of dolomitic lime compared to no lime application as was the case with calcitic lime application. Groundnut variety ICGV 90071 and Rambo were not significantly responsive to dolomitic lime application, but showed a strong tendency for the seed yield to decrease at the recommended lime application rate. RG -784 was the only groundnut variety that seemed to benefit from the recommended liming rate, since it yielded the most in this liming rate.

Table 5.6. Seed yield response of six groundnut varieties to calcitic and dolomitic lime application

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for means of lime rates
		Seed yield in kg/ha			
		Calcite			
JL-24	1748	2182	2392	2107	139*
Inkanyezi	1129	1254	1620	1334	240*
Kwarts	1223	410	405	679	170*
RG -784	1529	1704	1563	1599	340*
ICGV 90071	836	520	675	677	240*
Rambo	854	1317	825	999	416*
Mean	1220	1231	1247	1233	NS
		Dolomite			
JL-24	1748	1934	1341	1674	139*
Inkanyezi	1129	1398	1429	1319	240*
Kwarts	1223	602	470	765	170*
RG -784	1529	1150	2147	1609	340*
ICGV 90071	836	880	558	758	240*
Rambo	854	825	643	774	416*
Mean	1220	1132	1098	1150	NS
$LSD_{(0.05)}$ for variety =240**					
$LSD_{(0.05)}$ for lime type =240*					
CV%	22				

*=P ≤ 0.05, **= P ≤ 0.01, and NS = not significant different

5.4.5. Shelling percentage (%)

The shelling percentage differed significantly among the test varieties, but was not affected by the type of the lime (Table 5.7) nor the liming rate. However, there was a tendency for the shelling percent to be lower under dolomitic lime compared to the calcitic lime. The groundnut variety ICGV 90071 recorded the lowest shelling percentage in both the dolomitic (54%) and the calcitic (58%) lime. Kwarts had significantly higher mean shelling percent than all varieties, except JL-24 in both the dolomitic (78%) and calcitic (76%) limes.

Table 5.7. Shelling percentage of six groundnut varieties grown in soils limed with calcite and dolomite.

Groundnut variety	Shelling percentage %		
	Calcitic lime	Dolomitic lime	Mean per variety
JL-24	74	73	74
Inkanyezi	67	66	67
Kwarts	76	78	77
RG -784	63	61	62
ICGV 90071	58	54	56
Rambo	66	64	65
Mean	67	66	67
$LSD_{(0.05)}$ for varieties	4**		
CV%	8.6		

**=$P \leq 0.01$

5.4.6. Hundred Seed Mass

There was very little variation in seed mass between the varieties. Hence, there were no significant differences in mean seed mass among most of the varieties; for example, among JL-24, Inkanyezi, Kwarts and RG-784 whose hundred seed mass ranged between 30-34 grams. Groundnut ICGV 90071 had the lowest mean seed mass (28g/100 seeds), but did not differ significantly from Inkanyezi and RG-784. Rambo had significantly the highest seeds' mass (50g/100 seeds) as was expected. The type of lime did not significantly affect the seed mass of the test varieties, but there was a tendency for the seed mass to be lower under dolomitic than under the calcitic lime. The liming rates also did not significantly affect the seed mass.

Table 5.8. Hundred seed mass of six groundnut varieties in calcitic and dolomitic lime applications

Groundnut variety	100 seed mass (g)		
	Calcitic lime	Dolomitic lime	Mean per variety
JL-24	34	34	34
Inkanyezi	31	30	31
Kwarts	34	36	35
RG -784	30	29	30
ICGV 90071	29	28	29
Rambo	52	49	51
Mean	35	34	35
$LSD_{(0.05)}$ for variety = 4**			
CV% 17.5			

** = $P \leq 0.01$

There was a significant difference amongst the fields in the response to the two lime sources tested. The field with dolomitic lime had high ovarian percentage compared with the field with calcitic lime. The average mean of the field with dolomitic lime is 61.6 % and with calcitic is 57.79 %. However, in the variety Inkanyezi there was a tendency of the ovarian percentage increasing with the half recommended and recommended rates in both lime sources.

Table 5.9. Effect of calcitic and dolomitic lime application rates on the percentage of ovarian cavities occupied by seeds in six varieties at Lowveld College of Agriculture Farm

Groundnut variety	Control 0 kg/ha	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for lime rate
		Calcitic			
JL-24	58	59	57	58.06	0.89*
Inkanyezi	54	60	60	57.88	1.55*
Kwarts	54	58	57	56.39	1.09*
RG -784	60	57	58	58.00	2.18*
ICGV 90071	57	57	58	57.33	1.55*
Rambo	58	59	60	59.06	2.68*
Mean	56.83	58.29	58.25	57.79	NS
		Dolomite			
JL-24	61	60	60	60.04	0.89*
Inkanyezi	62	63	64	62.89	1.55*
Kwarts	62	61	59	60.87	1.09*
RG -784	62	62	63	62.58	2.18*
ICGV 90071	63	62	58	61.25	1.55*
Rambo	62	62	62	62.17	2.68*
Mean	62.1	61.7	61.0	61.6	NS
CV%	3.9				

*= $P \leq 0.05$ and NS = not significant different

5.5. Crop Performance at Manguzi

5.5.1. Pod yield per hectare

The pod yields of the varieties responded differently to the liming treatments (Table 5.10). Varieties JL-24, ICGV 90071 and Rambo were not significantly affected by the liming treatments. Inkanyezi optimized its pod yield at the $^1/_2$ recommend lime rate (750 kg/ha calcitic lime), its yield being significantly reduced in the cases where lime was not applied or when it was applied at the recommended rate (1500 kg/ha calcitic lime). In Kwarts, the pod yield only increased significantly compared to no lime application when the liming rate was increased to the recommended rate. In variety R-784, applying the lime at the $^1/_2$ recommended rate significantly increased pod yield compared to no lime application, but increasing the lime application to the recommended rate had the same effect as the $^1/_2$ recommend lime rate.

Table 5.10. Effect of calcitic lime rate on dry pod yield of six groundnut varieties at Manguzi

Groundnut Variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for lime rate
JL-24	1159	1277	1216	1217	NS
Inkanyezi	1144	2607	2361	2037	254*
Kwarts	1099	975	1547	1207	320*
RG -784	832	1020	1033	962	132*
ICGV90071	1104	1064	1039	1069	NS
Rambo	1311	773	1189	1091	NS
Mean	1108	1286	1398		
$LSD_{(0.05)}$ for differences between varieties =605 *					
CV%	25.6				

*= P ≤0.05 and NS= not significant different

5.5.2. Grain yield per hectare

As in the case of pod yield, the seed yield responded to the liming treatments differently among the varieties. The seed yields of varieties JL-24, RG-784 and Rambo were not significantly affected by the liming treatments whereas those of Inkanyezi and Kwarts were significantly affected. In Inkanyezi, both the $^{1}/_{2}$ recommended and the recommended liming rates increased the seed yield significantly compared to no lime application, but to the same extent. In Kwarts, the seed yield significantly increased compared to the control (no lime application) when the lime was applied at the recommended rate. Noteworthy is that the pod yield advantage of RG-784 (Table 5.11) due to liming was not translated to significant increases in seed yield (Table 5.11).

Table 5.11. Effect of calcitic lime rate on grain yield of six groundnut varieties at Manguzi

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for lime rate
JL-24	696	786	711	731	NS
Inkanyezi	615	1387	1202	1068	243*
Kwarts	697	579	947	741	146*
RG -784	356	462	476	431	NS
ICGV90071	446	420	357	408	NS
Rambo	723	348	564	545	NS
Mean	589	664	710		
$LSD_{(0.05)}$ for differences between varieties =330*					
CV%	25.7				

*= $P \leq 0.05$ and NS = not significant different

The seed yield at the Lowveld College of Agriculture farm had marked increased yield compared to Manguzi. The average means ranged from 677 to 2017 kg/ha at Lowveld College of Agriculture farm and from 408 to 1068 kg/ha at Manguzi (Table 5.12).

Table 5.12. A comparison of mean seed yield between Manguzi and Lowveld College of Agriculture farm of six varieties in the calcite lime treatments

Groundnut variety	Seed yield (kg/ha)		Seed yield differences (kg/ha)
	Manguzi	Lowveld College farm	
JL-24	731	2107	1376
Inkanyezi	1068	1334	266
Kwarts	741	679	-62
RG -784	431	1599	1168
ICGV90071	408	677	269
Rambo	545	999	454
Mean	654	1233	578.5
$LSD_{(0.05)}$ for differences between varieties =260.8*			

*= $P \leq 0.05$

5.5.3. Shelling percentage

The shelling percentage differed significantly among the varieties, the means of which ranged from 38% in ICGV 90071 to 61% in JL-24 (Table 5.13). The shelling percentage of JL-24 was not sensitive to liming rate, whereas in the rest of the variety it was markedly affected, but differently so. There was a tendency for the shelling to be decreased by liming in Inkanyezi, Kwarts, ICGV 90071 and Rambo. RG784 was the only variety in which liming improved the shelling percent (Table 5.13).

Table 5.13. Effect of calcitic lime rate on shelling % of six groundnut varieties at Manguzi

Groundnut Variety	Control (0 kg/ha)	½ recommended rate (750 kg/ha)	Recommended rate (1500 kg/ha)	Variety Mean	$LSD_{0.05}$ for lime rate
JL-24	61	61	60	61	NS
Inkanyezi	61	55	49	55	4.2*
Kwarts	63	54	59	58	5.1*
RG -784	41	48	46	45	3.2*
ICGV90071	40	40	34	38	4.8*
Rambo	54	43	43	47	4.2*
Mean	53	50	49		
$LSD_{(0.05)}$ for differences between varieties =3.2*					
CV %	20.6				

*= P ≤ 0.05 and NS-not significant different

5.5.4. The percentage of ovarian cavities occupied by seeds

The mean percentage of ovarian cavities occupied by seeds (seed-set) varied among the varieties within a narrow range from 80% in JL-24 to 91% in Kwarts (Table 5.14). Whilst the pooled means of the varieties did not vary between the liming rates, seed set in most of the varieties, except ICGV 90071 and Rambo, was significantly affected by the liming rates. There were however marked differences in the way the varieties were affected by the liming rates. In JL-24 seed-set was significantly increased by liming, but there was no advantage of increasing the liming rate from the $^1/_2$ recommended rate to the recommended rate. In Inkanyezi and RG-784, there was significant seed abortion in both no lime and the recommended rate compared to the $^1/_2$ recommended lime rate. In Kwarts, the percentage of ovarian cavities occupied by seeds decreased with each increase in the lime rate.

Table 5.14. Effect of calcitic lime rate on the percentage of ovarian cavities occupied by seeds in six varieties at Manguzi.

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety mean	$LSD_{0.05}$ for lime rate
JL-24	81	94	92	80	6*
Inkanyezi	87	93	85	89	6*
Kwarts	95	92	86	91	5*
RG 784	78	91	81	83	6*
ICGV 90071	86	83	87	85	NS
Rambo	89	90	91	90	NS
Mean	86	86	87	86	
LSD ($_{0.05}$) for differences between varieties =5*					
CV %	18.1				

*= P ≤ 0.05 and NS = not significant different

5.5.5. Hundred Seed Mass

The liming rate had no significant effects on the pooled means of hundred seed weights of the six varieties, but with the exception of Rambo, the varieties were individually affected significantly by the liming rate, though differently. In JL-24 and ICGV 90071, the seed weight decreased significantly only when the lime was applied at the recommended rate compared to no lime application. In Kwarts and RG-784, the seed weight was significantly higher at the recommended rate compared to the $^1/_2$ recommended lime rate and the control (no lime application). In Inkanyezi, the seed weight was optimised at the $^1/_2$ recommended rate, with the weight in the control and the recommended rate treatments being significantly lower. No correlation was found between seed weight (Table 5.15) and seeds-set (Table 5.14).

Table 5.15. Effect of calcitic lime rate on hundred seed mass in six varieties at Manguzi.

Groundnut variety	Control (0 kg/ha)	½ recommended lime rate (750 kg/ha)	Recommended lime rate (1500 kg/ha)	Variety Mean	$LSD_{0.05}$ for lime rate
JL-24	27	28	24	26	2*
Inkanyezi	23	29	26	26	4*
Kwarts	25	24	28	26	2*
RG - 784	22	23	27	24	3*
ICGV90071	20	20	17	19	3*
Rambo	24	22	26	24	NS
Mean	24	26	25		
$LSD_{(0.05)}$ for differences between varieties=2*					

*=P ≤0.05 and NS = not significant different

5.6. Discussions

5.6.1. Comparison of groundnut yield performance between Lowveld College of Agriculture farm and Manguzi.

Groundnut yield performance is the most sensitive to soil moisture and calcium status with severe adverse consequences if moisture (Mofongoya et al., 2006; Murata et al., 2003) and Ca (Zharare et al., 2009; Buah and Mwinkaera, 2009; Raza et al., 2013) deficits occur during the reproductive growth stages. Of the two test sites, the crop received supplementary irrigation at the Lowveld College farm in Mpumalanga lowveld, but not at Manguzi. This explains why all the yield parameters (pod yield, grain yield, shelling percentage, and hundred seed mass) were higher at Lowveld College farm than they were at Manguzi, where the rainfall received was 586 mm. The differences in mean seed yield of the varieties between the two sites were assumed to reflect differences in the sensitivity of the varieties to the drier environment at Manguzi. Among the varieties tested, varieties JL-24 and RG-784 were the most sensitive to production under dry land conditions with yield decreases in the calcitic lime treatments that were in excess of 1000 kg/ha. Thus, these two varieties appeared suitable for production under supplementary irrigation. Kwarts was the least sensitive to dry land conditions, but its yield potential under supplementary irrigation was very low (Table 5.12). Noteworthy among the varieties was Inkanyezi, which produced satisfactorily under both supplementary irrigation and dry land conditions. This variety produced in excess of 1000 kg/ha seed yield at both test sites, with the yield at the Lowveld College farm being only 266 kg higher (Table 5.12).

5.6.2. Effects of lime on yield parameters other than grain and seed yield

Other than plant population and pod production per plant, groundnut yield is generally a function of seed–set, weight per seed and shelling percent. These parameters are sensitive to Ca status in the pegging zone (Zharare, 2009a; Koyama et al., 2001; Karnataka J, 2007). Often seed abortion, manifested as pops (empty pods) due to Ca deficiency (Zharare et al., 2009; Brix et al., 2002) is the main cause of poor groundnut yields in acid soils (Mapfumo and Giller, 2001; Veeramani and Subrahmaniyan, 2012; Raza et al., 2013). Pop production is invariably accompanied by low weight per seed and low shelling percent (Zharare et al., 2009a). Generally, seed-set, weight per seed and shelling percent are parameters that are considered to benefit from improved Ca supply in the pegging zone (Murata et al., 2008), and hence are expected to respond positively to increasing Ca supply in the pegging zone. This is especially so in acid soils, because of their low Ca status. In the present study, liming was done in a way that deposited Ca in the pegging zone, and so was expected to positively influence seed-set, weight per seed and the shelling percent. Contrary to this expectation, soil Ca supplied by the liming materials was not universally beneficial to these parameters. Rather, in most of the cases, liming impacted negatively on these parameters. Decreases in these parameters seemed to be responsible for the negative responses to lime with most of the groundnut varieties tested. Again, because of the nature of the present study, the sources of the decreases were not determined, but the suppress effect of Ca and Mg on micronutrient uptake, e.g. Zn and Mn (Zharare et al, 2009a; Babu et al., 2004) cannot be ruled out.

CHAPTER 6. THE GENERAL DISCUSSIONS AND CONCLUSIONS OF THE ENTIRE STUDY

6.1. General Discussions

Groundnut is one of the crops grown by smallholder farmers in the Mpumalanga lowveld in the Mpumalanga province and in Manguzi in the north-eastern region of KwaZulu-Natal province of South Africa, where it contributes substantially to household food security. In these areas, the crop is grown in sandy soils with no fertilizer inputs. On account of their low cation exchange capacity, sandy soils have low nutrient reservoirs. Furthermore, they are highly susceptible to nutrient leaching, which further exacerbates soil acidity and nutrient deficiencies. It was thus one of the objectives to characterise the nutrient status of the sandy soils in the Nelspruit lowveld and Manguzi, with reference to their ability to support profitable groundnut production. The other objectives were to assess the performance of a range of improved groundnut varieties on acid, sandy soils and the response of selected varieties to dolomitic and calcitic lime application. The overarching aim was to assess the potential of groundnut production in the two areas (Mpumalanga lowveld and Northern KwaZulu-Natal Provinces) under low-input conditions.

6.2. Groundnut production constraints identified by soil chemical analyses.

With the exception of one site in the Mpumalanga lowveld, the soil pH values at the sites that were sampled were generally low in both locations, the mean site pH being in the range of 4.5 to 6.3 at Mpumalanga lowveld and 4.6 to 4.8 in Manguzi. The soil acidity extended throughout the soil profiles (to a depth of 60 cm) in which groundnut pods and roots are expected to grow. However, in Manguzi, the root-zone and subsoil were markedly more acidic than the pod-zone layer (top 10 cm layers) soil. Low soil pH in the root-zone of legume crops is known to negatively interfere with rhizobial nitrogen fixation in addition to negatively interfering with root growth (Brix et al., 2002) and nutrient uptake (Koyama et al., 2001; Yan et al., 1992). Furthermore, low pH in the pod-zone is now known to be detrimental to pod growth and filling (Murata et al., 2008; Quereix et al., 2001). Thus, soil acidity was identified as a common factor that is expected to constrain groundnut productivity at both sites.

Soil acidity has been a major limiting factor to crop production worldwide largely due to the toxic effects of labile aluminium (Al) and manganese (Mn) and to the paucity of available calcium (Ca) on root growth (Shainberg et al., 1989). Acid subsoil is much more difficult to treat because of the expensive energy required to incorporate lime to ever increasing depths (Shainberg et al., 1989). Gypsum has received considerable attention because of its ability to ameliorate subsoil acidity and improve plant rooting (Sumner and Carter, 1988). A point to note in the amelioration of soil acidity in both locations is the pronounced acidity in the subsoil compared to topsoil, which is particularly higher in Manguzi. Therefore, any acid soil amelioration programme on these soils must take this problem into consideration. There are two approaches that can be used. One approach is deep lime application (Naidu et al., 1990; Cox et al., 1982). Since the soils are sandy, some movement of Ca is expected to reach the subsoil (Sumner, 1990). A second and less expensive approach is surface application of gypsum or phosphogypsum. Due to the appreciable solubility of these compounds, soluble Ca in these compounds will readily move down the soil profile to ameliorate Al toxicity and to supply the needed Ca in the subsoil (Sumner, 1990; Hunter, 1989). These two approaches are expensive however for the smallholder farmers in Manguzi and Mpumalanga lowveld. A short term, cheaper alternative will be to grow varieties that are tolerant of soil acidity. Three varieties (ICGV 95714, Anel and Inkanyezi) at Lowveld College of Agriculture farm and four varieties (Inkanyezi, RG - 784, Mwenje and ICGV 99529) at Manguzi were identified as the most outstanding performers under low soil pH in the current study. These varieties represent a pool of genes that are tolerant to low soil pH. Further genetic improvement of groundnut for tolerance to low soil pH could go a long way in improving groundnut productivity on acidic soil infertility, particularly for smallholder farmers.

Additional soil fertility problems to soil acidity included low concentrations of Ca, Mg and K in both the Mpumalanga lowveld and Manguzi, and deficient levels of Zn, especially in the rooting zone and subsoil layer in Manguzi. Among the macro-nutrients, K was sufficient in

Manguzi soils whereas it together with Mg were moderately sufficient in Mpumalanga lowveld. The low level of Mg in addition to low Ca levels means that liming must be done with dolomite to address Mg deficiency in addition to Ca deficiency (Crozier and Hardy, 2003). At Manguzi, the application of Zn in addition to K is recommended to address both K and Zn deficiency problems.

6.3. Groundnut performance in lime-ameliorated and unameliorated acid soils

Whilst soil amendments can be applied to ameliorate soil acidity, they tend to be beyond the reach of most smallholders farmers in the Mpumalanga lowveld and Manguzi. Use of varieties that can tolerate soil acidity is a cheaper alternative in the short term. Consequently, the present study examined the performance of 16 improved varieties in acid soils as well as the response of selected varieties to liming with the objective of selecting varieties that might be used for production on acid soils without much compromise on yield. Of the six varieties that were tested JL-24, Inkanyezi, RG -784 and Rambo appeared to perform well under both non-ameliorated and lime-ameliorated acid soils at Lowveld College Agriculture farm, whereas at Manguzi varieties JL-24 and Inkanyezi perform well under similar soil conditions (Table 5.6 and Table 5.11). Hence, such varieties can be used for groundnut production in acid soils. Some variety such as RG-784 performed poorly in non-amended soils, but performed extremely well under lime-amended soils at Manguzi (Table 5.11). Thus, where farmers can afford lime, this group of varieties can be used. It should be noted that in some cases, there was in fact a reduction of yield in some varieties in lime-amended soils. This was most conspicuous for varieties Kwarts (at Lowveld College Agriculture farm) and Rambo (at Manguzi). This could have been caused by interference of Ca and Mg in the uptake of other nutrients e.g. Zn or Mn.It must be noted that the type of lime did not matter whether it was applied as dolomitic or calcitic. However, given the insufficient soil Mg and Ca levels, it will be prudent to apply dolomitic over calcitic lime. The negative yield response to lime application means that it needs to be amended with application of those nutrients whose uptake is negatively affected by liming, e.g. Zn and Mn.

6.4. Future work emanating from this research

The present work has established that soil acidity is a major constraint on the sandy soils in the groundnut producing areas of the Mpumalanga lowveld and Manguzi as well as deficiencies of Ca, Mg, K and Zn. Furthermore, the study has established that there is variation among the varieties tested in the tolerance of groundnut to soil acidity and their response to liming, thus reflecting genetic diversity in these attributes. I therefore recommend that future work should focus on gaining knowledge on the genetic basis for the tolerance of some groundnut varieties to soil acidity. The studies should include the ability of roots of acid tolerant varieties to grow in acid soils and to extract Ca, Mg, K and Zn at low soil levels, and then use the information to improve the groundnut genetically for production in acid soils.

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