EVALUATION OF THE EFFECT OF CALCIUM SOURCE APPLICATION ON GROUNDNUT (*ARACHIS HYPOGAEA L.*) YIELD AND QUALITY IN OKHAHLAMBA LOCAL MUNICIPALITY, KWAZULU- NATAL, SOUTH AFRICA

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GERALD SIKHUMBUZO SIKHAKHANA

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DEDICATION

This work is dedicated to my late grandmother, Dumazifunda Magubane, late mother, Siphiwe KaMagubane Sikhakhana, and late father, Maphumulo, all of whom could not live long enough to reap the fruits of their labour. A particular dedication goes to my soul mate, Nokuthula, and my daughter, Nonqubeko Sikhakhana, who have always been a pillar of strength through turbulent times and calm. They gave point and purpose to it all.

DECLARATION

I, **Gerald Sikhumbuzo Sikhakhana**, hereby declare that the dissertation, which I hereby submit for the degree of **MSc in Agriculture** at the University of South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation does not contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source.

I declare that where words from a written source have been used, the words have been paraphrased and referenced, and where exact words from a source have been used, the words have been placed inside quotation marks and referenced.

I declare that I have not copied and pasted any information from the internet, without specifically acknowledging the source and have inserted appropriate references to these sources in the reference section of the dissertation.

I declare that during my study, I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside approval conditions.

I declare that the content of my dissertation has been submitted through an electronic plagiarism detection program before the final submission for examination.

Student signature: ____

Date: _________________________

Supervisor signature: ____________________________________

Date: ________________________

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ABSTRACT

Two field experiments were conducted on sandy loam soils in OKhahlamba Local Municipality (OLM) (Bergville area), KwaZulu-Natal province in South Africa, during the rainy seasons of 2014/15 and 2015/16 to study the effect of calcium source (gypsum) fertilizer application on yield and quality of groundnut (*Arachis hypogaea* L.).

The household economy of OLM is mostly dependent on agriculture and the majority of farmers in this area are small-scale farmers subsisting mainly on maize (constituting the staple diet) and groundnut production. Crop diversification, therefore, becomes an important aspect for farmers, and this is traditionally done using crops that are produced in almost similar agronomic circumstances to that of maize under dryland conditions.

A large proportion of the OLM population depend on groundnut as a vital supplement to their daily food requirements, particularly as a cheap source of protein for resource-poor farmers. Therefore, any scientific approach to increase the yield of groundnut should be considered important in the livelihood of this community. Moreover, groundnut is an excellent rotational crop, since it responds well to fertilizer applied to previous crop and maize, as well as to nitrogen left over by peanut. Thus, farmers save money because they use less fertilizer. The consideration for this study was based upon the above.

The experiment was laid in a randomised complete block design with factorial arrangement, which was replicated three times in 48 plots. The factors studied were four levels of gypsum ($CaSO_4.2H_2O$) i.e. 0 kg/ha, 500 kg/ha, 750 kg/ha, and 1000 kg/ha and four levels of lime ($MgCO_3.CaCO_3$) i.e. 0 kg/ha, 250 kg/ha, 500 kg/ha, 750 kg/ha. Soil pH, cation exchange capacity (CEC), electrical conductivity (EC), pod yield, seed yield, 100 seeds weight, shelling percentage, dry shoot weight, seed moisture content percentage at harvest, and leaf calcium concentration data were collected prior to, and post harvesting.

The application of 500 kg gypsum/ha alone acted as a liming factor for legumes, decreasing acid stress on nodulating bacteria, and improved soil chemical properties (increased soil pH), vegetative growth, yield, and quality of groundnut. The smallholder famers can afford this application rate, since gypsum acts both as a liming factor and as a calcium source to improve crop yield.

The application of 1000 kg gypsum/ha improved seed yield, shelling percentage as well as kernel weight, which is yield, and quality of groundnut under dryland conditions. Since

smallholder farmers practise dryland production, it is advisable to adopt the application of gypsum at the rate of 1000 kg/ha to improve yield and quality of groundnuts. It was also found to be more economical than using both gypsum and lime.

The application of 500 kg gypsum per hectare in combination with 250 kg lime per hectare produced the highest shelling percentage. This combination of two calcium sources (gypsum and lime) is not recommended for small-scale farmers because it is not economical.

The application of 500 kg gypsum per hectare in combination with 750 kg lime per hectare increased pod yield. However, this combination is also not recommended because it is not cost-effective.

The application of 1000 kg gypsum per hectare in combination with 500 kg lime per hectare increased seed yield and produced sound mature kernel (SMK), whereas the application of 1000 kg gypsum alone per hectare also increased seed yield. This combination is also considered unacceptable due to the high increase in input costs.

The application of 750 kg lime per hectare was more effective as an acid ameliorant and led to the improvement of the chemical composition of the soil (increased soil pH), resulting in a higher shoot weight of groundnut. This application also provided the catalyst for stimulating phosphorus production and enhancing the growth of an extensive root system for absorbing water and nutrients. The use of lime in acid soils is highly beneficial because it improves the chemical composition of the soil, ensures the availability of nutrients to plants, serves as an efficient calcium source, and ultimately leads to an improvement in yield.

Results show that the application of gypsum at 1000 kg/ha and lime at 500 kg/ha respectively, significantly improved peanut yield and soil pH. The combination of gypsum and lime (500 kg/ha gypsum and 250 kg/ha lime) significantly improved shelling percentage (yield). Based on data on yield, yield components, and soil chemical properties, it is concluded that gypsum is the best calcium source fertilizer for groundnut production in OLM and lime should only be applied on acid soils to attain optimum groundnut yield in the region.

Key terms: groundnut, calcium, gypsum, seed yield, seed quality, soil pH, electrical conductivity (EC)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 History of cultivated groundnut and trade

Groundnut (*Arachis hypogaea* L) is a popular oilseed crop grown in many countries of the world. It is economically very important and has a number of disparate uses (Kamara, 2010; Cilliers, 2013; Mbonwa, 2013). Pathak (2010) reports the bulk of peanut is mainly produced in India and China, followed by the US. Furthermore, sixty-five percent of the world's peanut production is consumed by China, the US and India. Although this crop has over the centuries spread throughout the world, it is thought to have originated in the Mato Grosso region of Brazil or north-eastern Paraguay, and was taken to Europe, Africa, and Asia by discovery voyagers of the sixteenth and seventeenth centuries (Murata, 2003; Sun, 2005; Kamara, 2010).

Groundnut is the most important legume in OKhahlamba Local Municipality (OLM) and surroundings in terms of an essential supplement to the daily food requirements of a large proportion of population, as well as in crop rotation trials. Small-scale farmers in this area have grown groundnuts for years, mostly on sandy soils, under rainfed conditions, and without supplementary calcium fertilizers. These soils meet the basic physical requirements for peanut production, but they are naturally low in calcium due to the tendency of calcium to leach. This results in low crop yield and overall poor quality (Adams & Hartzog, 1979; Florence, 2011).

Sorenson and Butts (2008) and Florence (2011) determined that growing groundnuts without replenishing calcium has a direct bearing on groundnut production, particularly yield and quality. Murata (2003) observed that lime application is effective as both an acid ameliorant and calcium source, which increases peanut yield on acid soils, and gypsum is more effective than lime because it is readily available.

1.1.2 Effect of calcium on growth and yield of groundnut

It is well established that calcium is a yield-enhancing nutrient in groundnut and it is needed for both good vegetative growth and normal healthy fruit development (Cheema et al., 1991). It has been demonstrated that deficiency of both calcium and phosphorus, particularly calcium, is the possible cause of low yield in groundnut production, and that calcium deficiency leads to a high percentage of aborted seeds (empty pods or pops) and improperly filled pods (Ntare et al., 2008; Kamara, 2010). Sun (2005) and the Association of Official Seed Analysts (AOSA) (2012) reported that a uniform stand of healthy, vigorous seedlings is also essential if growers are to achieve the yield and quality needed for profitable peanut production. Thus, seed quality is also critical to growers. According to Kamara (2010), in order to get good yields, adequate amounts of calcium should be present in the soil from early flowering stage up to pod filling.

Under these circumstances, the use of calcium containing materials such as lime *viz*., dolomitic lime ($MgCO_3.CaCO_3$) and calcitic lime ($CaCO_3$), single superphosphate (SSP), and gypsum ($CaSO_4.2H_2O$), is advocated. It has also been shown that gypsum is the only calcium and sulphur source that can affect the rate of decrease in the percentage of unfilled pods (pops), can yield better shelling percentage, and can affect pod and kernel quality (Omar et al., 1970).

According to Omar et al. (1970) and Chen and Dick (2011), the application of gypsum as a calcium and sulphur source can contribute immensely to an improvement on groundnut yield and quality, compared to both calcitic lime (CL) and dolomitic lime (DL), especially under rainfed conditions. Chen and Dick (2011) further emphasised that gypsum is a multipurpose fertilizer capable of improving both chemical and physical properties of soils. The present study determined the effect of two calcium sources i.e. gypsum and dolomitic lime on yield and quality of groundnuts in OKhahlamba Local municipality.

The significance of both calcium sources (gypsum and lime), as well as the extent to which they enhance groundnut production in OKhahlamba Local Municipality are analysed in this study.

1.1.3 Overview of the research methodology and analytical procedures

The nature of the study (involving the interpretation of a cause and effect relationship between variables) dictates the use of a quantitative research methodology engendering an experimental design. The variables involved include quantities, rates and patterns of application of calcium sources (gypsum and lime), as well as the chemical composition of these sources. A determination was then made of the relative effect on yield and quality of groundnuts brought about by these variables.

The field experiment was conducted in OKhahlamba Local Municipality (Bergville area). Data collection involved observation, documentation, and recording of the fieldwork information regarding yield components and yield/ha *viz*. crop yield, pod weight/ha, shelling percentage, as well as pH, CEC, EC of soil, and calcium analysis of dry matter from groundnut shoots and leaves.

Data analyses were performed by the use of the statistical programme software, SPSS (GenStat Release 14.2). This programme helps expedite data analyses, thereby saving time and enabling the researcher to better understand the relationship between the variables, quantify and ascertain the strength of this relationship, and confirm or contradict what the researcher reads from pertinent literature. The method also provides an indication of the strength of the relationship and the level of confidence that can be placed in the findings (Kumar, 1999).

1.2 PROBLEM STATEMENT

KwaZulu-Natal groundnut production areas are mostly on sandy soils, which generally have low levels of calcium and organic matter. Low calcium is due to the tendency of calcium to leach. As a result, these soils have low cation exchange capacity and poorly retain cationic nutrients such as calcium (Florence, 2011; Astera, 2014). Small-scale farmers in OLM and the rest of UThukela District Municipality are unaware that their soils' potential is limited by soil calcium deficiency. As a result, yields are generally low for small-scale farmers in OLM and surroundings due to calcium deficiency and acid soil infertility. Florence (2011) demonstrates that calcium application to low calcium soils improves yield, increases the percentage of SMK, and improves germination and vigour.

One aim of this study was to evaluate the effects of applying calcium from different sources on the yield and quality of groundnuts.

1.3 THE RATIONALE/JUSTIFICATION AND NEED FOR THE RESEARCH

Several investigators (e.g. Omar et al., 1970; Chen & Dick 2011; Cilliers, 2013) have indicated that as a multipurpose fertilizer, gypsum application will improve physical and chemical properties of soils and enhance the yield and overall quality of groundnuts. According to Murata (2003), calcium is immobile but calcium from gypsum is in available form, ready to be absorbed by the plant roots.

However, scientific data on efficacy, effectiveness, and modalities of gypsum by small-scale farmers in KwaZulu-Natal (KZN) are not well documented. The significance of this study lies in the provision of science-based knowledge from the research on improving groundnut yield and quality in OLM, KZN, by judicious applications of calcium sources such as gypsum. Different application rates of calcium sources (comparing lime and gypsum) were investigated against yield and chemical properties of the soil.

Substantial evidence adduced from this research strengthened the predicted efficacy of calcium sources (such as gypsum) as a calcium fertilizer in groundnut production. This information has contributed greatly to the existing body of knowledge of the groundnut industry in South Africa.

1.4 THE RESEARCH GOAL

The research goal is to determine the application rates of gypsum and lime on groundnut production, as well as their effect on groundnut yield and quality in OLM, KZN province.

1.4.1 Objectives of the study

The objectives of the study are as follow:

1 To determine the application rates of sources of calcium that will produce the highest groundnut yield and quality;

2 To determine rates of application of calcium sources on soil chemical properties, *viz*., soil pH, CEC and EC;

3 To compare the effect of application of calcium from various sources on groundnut yields and quality;

4 To determine the efficacy of calcium sources application at flowering stage of groundnut production; and

5 To determine the impact of application of calcium from different sources at the pod formation stage of groundnut production.

1.4.2 Purpose of the study

The purpose of this study is to evaluate the effects of sources of calcium on soil properties and groundnut yields and overall quality in OKhahlamba Local Municipality, KwaZulu-Natal province.

1.4.3 Hypothesis

Application of calcium from various sources selected using science-based knowledge and the use of appropriate methods and techniques (validated experimentally in this study), would improve groundnut yield and overall quality, as well as enhances soil chemical and physical properties in OKhahlamba Local Municipality, KwaZulu-Natal province.

CHAPTER 2

LITERATURE REVIEW

2.1 ORIGIN AND GEOGRAPHICAL DISTRIBUTION

The cultivated groundnut (*Arachis hypogaea* L.) commonly referred to as peanut or groundnut, is a self-pollinating, annual, herbaceous legume (Sun, 2005). The cultivated groundnut (*Arachis* spp.) is thought to have originated from South America (Krapovickas, 1968; Ramantha Rao, 1988; Hammons, 1994; Weiss, 2000; Kamara, 2010).

Different types of groundnuts were disseminated by the sixteenth and seventeenth century's discovery voyagers throughout the world, including Africa (Krapovickas, 1969, 1973; Gregory et al., 1980; Hammons, 1982; Isleib et al., 1994; Murata, 2003; Mbonwa, 2013). Today, the crop is grown in most tropical, sub-tropical, and temperate regions between latitudes 40 ^{o}N and 40 ^{o}S in Africa, Asia, North, and South America (Cummins, 1986; Kamara, 2010).

Nkambune (1994) and Mbonwa (2013) report that groundnut is an important food crop and principal source of cash income for smallholder farmers in most countries in Sub-Saharan Africa. However, unlike commercial farmers, cultivation practices of smallholder farmers are not informed by technical expertise such as using suitable cultivars and appropriate fertilization programmes to improve crop yield. As a result, yields are relatively low, ranging from 400 kg to 1 ton per ha (Mbonwa, 2013). Apparently, equipped with basic technical crop production skills, these farmers could increase groundnut yields in the region and improve their food security status (Nkambune, 1994; Mbonwa, 2013).

2.2 GROUNDNUT PRODUCTION IN KWAZULU-NATAL

Swanevelder (1994) and Mbonwa (2013) reported that practical problems related to cultivation practices, insect pests and diseases control, the effect of various management variables on yield, and fertilization prompted groundnut research in South Africa in the early 1970s. As a result, research over the years yielded positive results (particularly for commercial famers) such as improved cultivation practices, better cultivars, and successful disease control programmes.

Groundnut is a major oilseed crop in global terms. In South Africa, it is one of the more important cash crops with its average annual gross value of production in the previous ten years up to 2012/2013 season amounting to approximately R 411 256 million (DAFF, 2014). Cilliers (2013) reported that as a crop with high economic value, groundnut could fetch a high price on local markets. Nevertheless, resource limited farmers, especially in the northern and eastern parts of South Africa, grow groundnuts mainly for own consumption.

Despite being an important source of nutrition in the Northern KwaZulu-Natal and Mpumalanga areas, groundnuts are produced on a small scale in these areas including Limpopo province. Groundnuts are commercially produced in Northern Cape, Free State, and North West provinces (DAFF, 2012; Cilliers, 2013). The only district municipalities engaged in the groundnut industry in KwaZulu-Natal is EThekwini, followed by UMgungundlovu and UMzinyathi. ILembe and UThungulu districts are showing a very low flow of exports (DAFF, 2012). UThukela, which is a district municipality of OLM, is currently not featuring as a commercial groundnut-producing district.

Smith (2006) notes, Northern KwaZulu-Natal hosts some of the most suitable soils for growing groundnuts in South Africa. In this region, groundnuts are grown both under dryland (rainfed) and irrigated conditions mainly in areas with heavy summer rainfall (Cilliers, 2013). Resource limited farmers in OKhahlamba Local Municipality and surroundings are practising dryland condition production (extensive production) mainly for own consumption.

The soils of most groundnut producing areas in KwaZulu-Natal province are predominantly sandy with low calcium and organic matter level. Low calcium in these soils is mainly due to the tendency of calcium to leach (Florence, 2011). As a result, these soils have a low cation exchange capacity, which indicates the ability of the soil to retain cationic nutrients, such as calcium (Adams et al., 1993; Levi et al., 2010; Florence, 2011; Astera, 2014).

Calcium is a vital yield-enhancing nutrient in groundnut that is needed for both vegetative and fruit development (Cheema et al., 1991). Cheema et al. (1991) conclude that calcium deficiency in groundnuts negatively affects yield-determining parameters, particularly pod yield, shelling percentage, and sound mature kernels (SMK). As a result, the groundnut yields for smallholder farmers in OLM and surroundings are low due to the lack of inorganic fertilization, particularly calcium sources.

The main crop for most resource-poor farmers in KZN including OLM is maize, which in most cases is a monoculture crop and constitutes staple diet. Adopting the application of calcium sources will not only increase groundnut yield for smallholder farmers, but growing the crop will also help provide an excellent rotation crop for maize, since it enriches the soil with nitrogen (Cilliers, 2013). Therefore, there is a huge potential for increasing smallholder crop yield in the region and thereby improving food security status and nutritional value (Swanevelder, 1994; Mbonwa, 2013).

2.3 ECONOMIC IMPORTANCE AND USES

It is well documented that groundnuts' importance and uses are diversified, ranging from direct consumption, nutritional value, to economic importance (Kamara, 2010; Cilliers, 2013; Mbonwa, 2013). Mbonwa (2013) reports that consumption related benefits of the crop include direct consumption of the kernels as raw, roasted, or boiled kernels, as well as oil extracted from the kernel is used as culinary oil. This crop also plays an important role in nutrition, as it is high in both protein and oil (25−30 % in protein and 40−48 % in oil). Oil from peanuts contains high amounts of energy and fat-soluble vitamins (A, D, E, and K) and essential acids (Nigam, 2014).

The economic aspect is reflected in the research findings of different researchers that groundnut is a high-value crop that is used in the manufacture of a wide range of products e.g. the oil extracted from the groundnut can be used as raw material for manufacturing soap and massage oil (DAFF, 2012; Cilliers, 2013). It was discovered that the oil cake, which is the by-product of the oil extraction process, is used to manufacture glue for wood, animal feed, fertilizers, and antibiotics. It can also be used to sharpen the appetites of polio patients before and after operations (DAFF, 2012).

2.4 EXISTING PRODUCTION PRACTICES

According to Cilliers (2013), groundnut is an excellent crop to grow in rotation with cereal crops, such as maize, because it builds up nitrogen that is needed by cereals. It has been proved that the optimum planting season for groundnuts in South Africa starts from about late October to mid-November, and it is acceptable to extend planting at least to the first week of December (Cilliers, 2013). Smith (2006) and Cilliers (2013) share the view that the minimum soil temperature favourable for germination is 18 °C, and temperatures between 20−30 °C result in 95 % germination (Smith, 2006; Cilliers, 2013).

The ideal land preparation method for peanut production is said to be a conventional tillage, which usually involves primary and secondary tillage operations to obtain a friable seedbed (Cox & Sholar, 1995). Pegging zone depths have been recorded to range between 5 and 10 cm. Soil type also affects pegging zone depths because clay tends to restrict depth (Summer et al., 1988; Jones et al., 1976; Kiesling & Walker, 1978).

Soils favourable for peanut production should be typically deep (900−1200 mm), well-drained, sandy, friable, and high in calcium. Sandy, friable surfaces promote peg entry into the soil and facilitate digging peanuts at harvest with minimal loss of peanuts from vines (Florence, 2011; Cilliers, 2013). Although sand provides ideal physical properties for peanut cultivation, its chemical properties are not ideal and cation exchange capacity is low, which indicates the ability of the soil to retain cationic nutrients, such as calcium (Adams et al., 1993; Levi et al., 2010; Florence, 2011; Astera, 2014).

According to Pidaran (2012), it is important to take into account the effect of planting geometry on growth and yield of crops. Planting geometry is defined as shape, size, and orientation of leaves and stems in relation with spatial distribution. Plant population is observed to be one of the most important attributes, because it determines the quantity of plants to be grown particularly under dryland conditions, suitable cultivar choice, and spacing. Planting geometry therefore affects plant's utilization of water and nutrients, and determines dryland and irrigation plant population, as well as dryland planting time. Mukhtar (2011) and Akpalu et al. (2012) also observe that plant population significantly affects seed and pod yield.

Smith (2006) and Cilliers (2013) emphasize the importance of the correct plants spacing, planting depth, and recommended plant population of 150 000 (dryland) to 300 000 plants per hectare. These authors further recommend that it is also advisable to control weeds, pests, and diseases in order to avoid poor quality and yield reduction. Cilliers (2013) demonstrated that effective weed control should be practised throughout the growing season either chemically or mechanically, or by a combination of the two. This is because groundnut is less competitive with weeds than any other agronomic crops. It is therefore advisable to keep groundnut plants free of weeds for the first 6−7 weeks to prevent yield loss (Melouk & Shokes, 1995).

2.5 NUTRIENT REQUIREMENTS

According to Florence (2011), Gashti et al. (2012), and Arnold (2014), calcium is the most critical element and the major limiting factor to groundnut production. Sufficient calcium in the podding zone, particularly in absorbable form, is essential in both vegetative and reproductive stages of peanut plants. Hence, low calcium levels in soils can reduce peanut yield, grade, and seed quality. However, Hartzog and Adams (1973) recommend that calcium fertilization should be based on the knowledge of soil calcium level prior to planting in order to determine if calcium applications will be effective. Typically, calcium fertilization does not show improvements in yield or seed quality when the soil has adequate calcium.

Calcium deficiency, particularly on acid, sandy, and low CEC soils, bring about a persistent nutritional problem in peanut (*Arachis hypogaea* L) production, which necessitates calcium supplements (Adams et al., 1993). Murata (2003) and Cilliers (2013) demonstrate that groundnuts are very sensitive to acid soil and adapted to a soil with pH (H_2O) of 5.3 or higher. If the soil pH is higher than 3.5 to 8.0, certain elements become unavailable e.g. iron and zinc.

According to Murata (2003) and Florence (2011), pegging zone calcium is typically increased by adding calcium sources such as lime i.e. dolomitic lime ($MgCO_3.CaCO_3$) and calcitic lime ($CaCO_3$) or gypsum ($CaSO_4.2H_2O$). Dolomitic lime (DL) contains 18 % calcium, calcitic lime (CL) contains 40 % calcium, and gypsum contains 24 % calcium and 16.1 % sulphur(S) in the readily available sulphate form (SO_4).

Sanchez et al. (1997) and Bagarama et al. (2012) determined that like all other crops, peanuts also need such macronutrients as nitrogen (N), phosphorus (P), potassium (K), collectively referred to as NPK, and sulphur for improving crop production. Peanuts' requirements for both potassium (for growth and reproduction) and phosphorus are low (Cox et al., 1982). As a result, groundnuts prefer residual potassium and phosphorus following a well-fertilized crop (Cox et al., 1982; Murata, 2003; Cilliers, 2013). An oversupply of potassium in the soil can induce calcium deficiency, which is reflected in a lower yield and quality (Cox et al., 1982).

2.6 SOIL CHEMICAL PROPERTIES

Several researchers (Farina & Channon, 1988; Shainberg et al., 1989; Wallace, 1989; Summer, 1993; Murata, 2003) identified benefits associated with the application of lime and gypsum regarding crop yield and chemical properties such as soil pH and CEC.

According to Astera (2014), CEC is the ability of the soil to attract, retain, and exchange cation elements at a specific pH and is a measure of how many negatively charged sites are available in the soil. CEC is closely related to EC e.g. in some areas, higher EC indicates higher clay and CEC, resulting in higher yield goals and additional inputs on those sites (Thilakarathna et al., 2014). Researchers such as Thilakarathna et al. (2014) reported that the optimum soil EC level for groundnut should be somewhere above 200 µS cm^{-1} and below 1200 µS cm^{-1}. EC is defined as an indirect measurement that correlates with soil physical and chemical properties that affect crop productivity, including soil texture, cation exchange capacity, drainage conditions, organic matter level, salinity, and subsoil characteristics. It is well documented that both soil texture and clay content can be defined by EC measurements. According to Aza and Mahmoud (2013), the application of different sources of calcium, organic- and inorganic nitrogen on sandy soils directly affect EC, pH, soluble cations and anions, as well as sodium adsorption.

2.6.1 Gypsum as a liming factor

According to Farina and Channon (1988), Shainberg et al. (1989), Wallace (1989), Summer (1993), and Murata (2003), the application of gypsum on acid soils has a broad range of benefits for plant nutrition and yield, as well as soil improvement. These benefits range from the correction of subsoil acidity by increasing exchangeable Ca and decreasing Al^{3+} and H^{+}, resulting in deeper root penetration to improved plant use of water and nutrients in the subsoil. These processes enable crops to better withstand periodic droughts during the season and increased yield.

Furthermore, Murata (2003) noted that gypsum application on acid soils could improve calcium and sulphur nutrition, especially in highly weathered soils. Moreover, these applications can work out as liming factors for legumes, decreasing acid stress on nodulating bacteria, thereby improving crop yield and quality.

2.7 EFFECT OF CALCIUM SOURCES (LIME AND GYPSUM) APPLICATION ON GROUNDNUT YIELD AND QUALITY

2.7.1 Significance of determining soil calcium level prior to planting

Hartzog and Adams (1973) highlighted the importance of knowing the soil calcium level prior to planting in order to determine if calcium sources will have an effect on peanut yield, quality or grade, and germination. Florence (2011) determined that basically, calcium fertilization does not show improvements in yield or seed quality when the soil has adequate calcium.

Different researchers held different views regarding the optimum soil calcium for peanut production. According to Florence (2011) and Arnold (2014), the critical soil calcium value for germination should be 250 mg/kg and critical value for yield should be 150 mg/kg. The literature further distinguishes between critical pegging zone calcium values for irrigated peanuts (>150 mg/kg) and for dryland peanut production, which should be >250 mg/kg.

According to Wiatrak et al. (2006), calcium deficiency is often a problem for peanut production on acidic and sandy soils with low cation exchange capacity (CEC). Arnold (2014) also emphasizes that low calcium levels in soils can reduce peanut yield, grade, and seed quality. Adams et al. (1993), and Sorenson and Butts (2008) observed that the addition of calcium to low calcium soils improves yield, increases the percentage of sound mature kernels (SMK), and improves germination and vigour.

Florence (2011) reports that germination is also limited by inadequate soil calcium and that more calcium is required for maximum germination than for maximum yield and SMK. According to Adams et al. (1993), this suggests that soils used to produce seed, probably need a higher level of available calcium than those used for general production. Tillman et al. (2010) further observed that the amount of soil calcium required might differ among cultivars, as there may be differences in seed size, ability to accumulate seed calcium, seed germination requirements, and tolerance to low calcium soils.

Skelton and Shear (1971), Cox et al. (1982), Gascho and Davis (1994) and Murata (2003) made similar observations that adequate calcium in the pegging zone is essential for proper peanut development and production of high quality seed because this is where developing pods obtain calcium. According to Hartzog and Adams (1973), calcium may be applied as lime or gypsum depending on initial soil calcium, the goal of the grower (i.e. yield or seed production), and size of peanuts to be grown.

2.7.2 Current state of knowledge on advantages of lime application

Hartzog and Adams (1973) observed that lime increases soil pH, alleviates aluminium toxicities, and increases pegging zone calcium. Adams and Hartzog (1979) and Murata (2003) reported that lime has been shown to improve yield and SMK. Adams et al. (1993)

have demonstrated that lime increases soil calcium, which has been shown to benefit germination.

According to Tisdale and Nelson (1975), Ahmed and Tan (1986), Foth and Ellis (1997), and Murata (2003), the other beneficial effects of liming were said to be mainly a reversal of the processes associated with the chemistry of acid soils. This chemistry ranges from an increase in soil pH that affects the solubility of various compounds, encouragement of a more rapid breakdown of organic materials in the soil, release of nutrients for growing plants, and improvement of nitrogen mineralization to symbiotic N-fixation by legumes, which can improve palatability of forages.

2.7.3 Current state of knowledge on disadvantages of lime application

Florence (2011) states that lime is incorporated into the top 15 cm of soil using disc harrow, where it can supply calcium to the pegging zone for up to 20 months and that the long residence time of lime is due to its low solubility. Florence (2011) further argued that the disadvantage of longer residence time and lower solubility of lime is lower calcium concentration in the soil solution, which reduces the calcium gradient to the developing pod.

Harris et al. (2013) determined that if lime is to be used at planting to provide calcium to the pegging zone, this is only supposed to be used when it is recommended according to soil sample results, otherwise, it can raise the pH above recommended levels, thus causing manganese deficiency. Summer et al. (1988) reported that the increased dissolution creates a higher calcium gradient that enhances the rate of diffusion into the developing seed.

2.7.4 Current state of knowledge on benefits of gypsum application

Chen and Dick (2011) and Harris et al. (2013) have indicated that gypsum applications have been shown to improve yield, grade, and germination particularly under rainfed conditions. Observations made by Adams et al. (1993) indicated that while gypsum does not increase pH as lime does, it might be more beneficial to developing pods than lime. Gypsum was observed to produce fewer pods per plant than lime, but the quantity of fully developed pods was greater (Adams et al., 1993).

2.7.5 Current state of knowledge on disadvantages of gypsum application

Alva and Gascho (1991) observed that while gypsum has many benefits, there are some disadvantages *viz*., application of gypsum may reduce the availability of potassium and magnesium in the pegging zone, which may lead to potassium and magnesium deficiencies in the seed, thereby reducing the seed quality. Omar et al. (1970), Singh and Oswalt (1995), and Florence (2011) further observed that a deficiency of these elements also affects vegetative plant growth and health because they are essential in the development of healthy leaves. According to Florence (2011), gypsum is also subject to leaching from the pegging zone and deficiency is created in the developing peanuts.

2.7.6 Effect of rainfall on leaching of surface-applied calcium/gypsum in sandy soils

According to Hartzog and Adams (1973), when lime is applied correctly, adequate amounts of calcium will stay in the pegging zone during a growing season. Conversely, Alva et al. (1989) reported that the leaching of gypsum from the pegging zone might occur before the end of the growing season. Because the majority of applied gypsum may leach within a month of application, it has now been established that gypsum should conventionally be applied 40 days after planting or at early bloom. This ensures that gypsum is present during pegging, as well as when pods are developing. Applying gypsum at early bloom does not ensure that gypsum will supply sufficient calcium for the rest of the growing season. Peanuts will continue to flower 70 to 90 days after initial blooming and create pods that require calcium (Alva et al., 1989).

Florence (2011) indicated that if applied, calcium leaches from the pegging zone prior to harvest, the pods that develop later in the season may be limited by calcium. Rate of leaching is dependent on the amount of gypsum applied, soil texture, and rainfall pattern. High rainfall events and years with above normal precipitation may remove gypsum from the pegging zone and create deficiencies in peanuts developing late in the season (Florence, 2011). Once gypsum dissolves, the rate of leaching was observed to be controlled by soil texture (Walker, 1975; Kiesling & Walker, 1978; Alva & Gascho, 1991).

2.7.7 Effect of calcium sources (gypsum and lime) on shoot and seed calcium concentration

Loganathan and Krishnamoorthy (1977) found that shoot calcium in peanut plants was higher in plants treated with gypsum rather than lime, presumably because of the presence of the readily soluble calcium in the root zone. If this is also true for the pod, gypsum should provide more available calcium than lime and result in higher seed calcium concentrations when equal amounts of calcium are applied in the root zone and in the pod zone respectively.

2.7.8 Calcium movement and location in plant

Skelton and Shear (1971) suggested that replenishing pegging zone calcium is important because peanut plants do not readily translocate calcium from the roots to the developing peanuts. Summer et al. (1988) reported that calcium enters the seed by diffusing directly from the soil through the hull to the seed. Hence, Skelton and Shear (1971) further observed that pods must therefore acquire calcium from the surrounding soil due to a lack of xylem flow into the peg and immobility of calcium in the phloem. The researchers further attributed the lack of xylem flow into the peg to the lack of transpiration once it is underground.

2.7.9 Impact of calcium to potassium ratio on calcium uptake

Alva et al. (1989) argued that soil calcium levels are not the only factor to consider when determining whether a soil is limited by calcium. The calcium to potassium ratio is also important. If it is less than 3:1, then the plant may be limited in its ability to absorb calcium. This is due to competition between calcium and potassium during the diffusion process into the hull. High concentrations of potassium will limit calcium diffusion. Sullivan et al. (1974) found that potassium applications reduced yield, percentage SMK, and extra-large kernels, and slightly increased the incidence of dark plumules. Conversely, Florence (2011) determined that an over-application of calcium might limit general potassium and magnesium uptake by the plant and subsequently reduce yields.

CHAPTER 3

MATERIALS AND METHODS

3.1 SITE SELECTION

The field experiments were conducted in OKhahlamba Local Municipality (Bergville), which is 84 km from the town of Ladysmith (28°45'29.50"S and 29° 15' 09.46"E), KZN province, during the rainy seasons (October to April) of 2014/15 and 2015/16 respectively. Bergville is in the moist transitional tall Grassveld, Bio Resource Group (BRG) 11 with altitude of 900−1400 m above sea level. Frosts are generally moderate but sometimes severe. Bergville has an annual rainfall ranging from 750 mm to 1100 mm.

3.1.1 Soil sampling

Soil samples were taken from the top 15 cm in order to determine the nutrient status, pH, CEC, and EC of the soil. The sampling area was 1265 m^2. The sampling equipment used was the soil probe, which was considered appropriate because each core would be of the same size and depth. The sampling depth of 15 cm is considered standard regardless of tillage practices. The number of cores taken was 35 following a zigzag pattern. These samples were then thoroughly mixed and one composite sample was placed in a 500 g box and sent to the laboratory (Cedara: Soil Fertility and Analytical Services, Pietermaritzburg, KZN).

3.2 ANALYTICAL METHODS USED (SOIL AND MINERAL ANALYSIS)

3.2.1 Soil analysis

The Soil Fertility Laboratory routinely performs the following analyses using the rapid procedures described by Hunter (1975) and Farina (1981): Ambic-2-extractable P, K, Cu, Mn and Zn, KCl-extractable Ca, Mg and acidity, and pH (KCl). NIRS-estimates of organic carbon and clay content are also done routinely. Other soil analyses done are EC, Ca, Mg, K, and Na in the saturation extract, ammonium-acetate extractable Na, pH (water), total carbon, nitrogen, and sulphur, Walkley-Black organic carbon, and particle size distribution. These methods are briefly described below.

Sample preparation: Soil Fertility Laboratory

Soil samples were air-dried at room temperature; they were spread out in drying trays and air forced over them. When dry, the samples were crushed between rubber belts on a soil crusher and passed through a 1-mm sieve. Materials coarser than 1 mm that could not be crushed, such as stones, gravel and concretions were discarded.

Batch handling: Soil Fertility Laboratory

Samples were scooped into trays, each of which contained 11 PVC cups (capacity 70 mL); a tray was used for nine unknown samples, one standard soil sample (for quality control), and one blank. For operations such as dispensing and stirring, and for quality control, batches of three trays (27 samples, three unknowns, and three blanks) were used. Multiple dispensers and diluter/dispensers were used to dispense aliquots of reagent to three samples at a time.

Sample density

Soil samples were analysed on a volume rather than on a mass basis. To enable the conversion of the results to a mass basis, the mass of a 10-mL scoop of a dried and milled sample was measured and the calculated sample density was reported.

pH (KCl)

Ten mL of soil was scooped into sample cups. Twenty-five mL of 1 M KCl solution was added and the suspension is stirred at 400 r.p.m for 5 minutes using a multiple stirrer (the multiple stirrer is equivalent to centrifuge). The suspension was allowed to stand for about 30 minutes, and the pH measured using a gel-filled combination glass electrode while stirring. Deionised water was substituted for the 1 M KCl solution for pH determinations.

Extractable (1 M KCl) calcium, magnesium, and acidity

Two point five mL of soil was scooped into sample cups. Twenty-five mL of 1 M KCl solution was added and the suspension stirred at 400 r.p.m for 10 minutes using a multiple stirrer. The extracts were filtered using Whatman Grade1 Qualitative Filter Paper. Five mL of the filtrate was diluted with 20 mL of 0.0356 M $SrCl_2$, and Ca and Mg determined by atomic absorption spectrometry (AAS). To determine the extractable acidity, 10 mL of the filtrate was diluted with 10 mL of deionised water containing 2−4 drops of phenolphthalein, and titrated with 0.005 M NaOH

Extractible (Ambic-2) phosphorus, potassium, zinc, copper, and manganese

The Ambic-2 extracting solution comprised of 0.25 M NH_4CO_3 + 0.01 M Na_2EDTA + 0.01 M NH_4F + 0.05 gL-1 Superfloc (N100), adjusted to pH 8 with a concentrated ammonia solution. Twenty-five mL of this solution was added to 2.5 mL soil scoop, and the suspension stirred at 400 r.p.m for ten minutes using a multiple stirrer. The extracts were filtered using Whatman Grade1 Qualitative Filter Paper. Phosphorus was determined on a 2 mL aliquot of filtrate using a modification of Murphy and Riley (1962) molybdenum blue procedure as described by Hunter (1974). Potassium was determined by AAS on a 5 mL aliquot of the filtrate after dilution with 20 mL deionised water. Zinc, Cu and Mn were also determined by AAS on the remaining undiluted filtrate.

Effective CEC (ECEC) and acid saturation

Effective CEC was calculated as the sum of KCl-extractable Ca, Mg, and acidity and Ambic-2 extractable K. Percentage acid saturation of the ECEC was calculated as “extractable acidity” x 100/ (Ca + Mg + “extractable acidity”).

Estimate of organic carbon by near-infrared spectroscopy

Organic carbon was estimated for all soil samples, routinely analysed in the Soil Fertility Laboratory, by near-infrared reflectance, using the air-dried, milled soil samples.

Estimate of clay content by near-infrared spectroscopy

Clay content was estimated for all soil samples at the Soil Fertility Laboratory, using a combination of the near-infrared reflectance value of the air-dried, milled soil samples and the measured sample density.

Total carbon and nitrogen in soil

Total C, N, and S were analysed by the automated Dumas dry combustion method using a LECO CNS 2000 (Matejovic, 1996).

Briefly, this method involves weighing samples into a ceramic crucible to which 0.5 g of vanadium pentoxide is added as a combustion catalyst. The vanadium pentoxide also improves the recovery of sulphur. The crucible is introduced into a horizontal furnace, where the sample is burned in a stream of oxygen at 1350 ^{o}C. The gases produced are passed through two infrared cells where the sulphur (as SO_2) and carbon (as CO_2) are determined. Nitrogen is determined (as N_2) in a thermal conductivity cell.

Organic carbon by the Walkley-Black method

This method is based on the Walkley-Black procedure (Allison, 1965) and measures the readily oxidisable organic carbon. The organic matter was oxidised by potassium dichromate in a sulphuric acid medium. The excess dichromate was determined by titration with standard ferrous sulphate solution.

Particle size distribution of soils and soil texture

Suspended clay and fine silt were determined after dispersion and sedimentation, and sand fractions, by sieving, using the procedure described by Day (1965). A 20 g soil sample (<2 mm) was treated with hydrogen peroxide to oxidise the organic matter.

The sample was then made up to 400 ml with deionised water and left overnight. The clear supernatant was siphoned off and the sample puddled. A further addition of deionised water was added, the sample stirred and left overnight. The clear supernatant was again siphoned off. Dispensing agents (NaOH and sodium hexametaphosphate) were added and the sample stirred using Hamilton Beach stirrers.

The suspension was made up to 1 litre in a measuring cylinder and the clay (< 0.002 mm) and the fine silt (0.002−0.02 mm) fractions measured with a pipette after sedimentation. Fine silt plus clay content was measured after 4−5 minutes (the exact time depending on temperature) at 100 mm, and clay after 5−6 h at a depth of 75 millimetres. Sand fractions include very fine sand (0.05−0.10 mm), fine sand (0.10−0.25 mm), medium sand (0.25−0.50 mm) and coarse sand (0.50−2.0 mm), which were determined by sieving. Coarse silt (0.02−0.05 mm) was estimated by difference.

Determination of textural class by means of a textural triangle

Once the particle size distributions of the two soils are known, their textural class was determined from diagram (textural triangle) defining particle size limits of the various textural classes (Soil Classification Working Group, 1991).

Salinity and sodicity

Saturation extracts of soils were analysed for electrical conductivity (EC) using an EC meter; and Ca, Mg, Na and K determined by AAS. Sodium adsorption ratio (SAR) was determined by calculation. SAR = [Na]/ $\{([Ca] + [Mg])/2\}^{0.5}$, where [Na], [Ca] and [Mg] are concentrations of the elements expressed in $mmol_c/L$.

Exchangeable Na

Exchangeable Na was determined by AAS after extraction of a 2.5 mL of soil sample with 25 mL of 1 M ammonium acetate (Soil Classification Working Group, 1991).

Ammonium – N (NH_4^+) and nitrate – N (NO_3^-)

Ammonium – N (NH_4^+) and nitrate – N (NO_3^-) in filtered extracts are measured by segmented flow analysis with a Perstorp Flow Solution lll analyser using the sodium salicylate-sodium nitroprusside-hypochlorite method for NH4 + −N (Perstorp Analytical, 1993) and the sulphanilamide-naphthyl-ethylenediamine method for NO_3^- − N plus NO_2 – N after reduction of nitrate to nitrite with copperised cadmium wire (Willis & Gentry, 1987).

3.2.2 Mineral analysis

Analysis of “minerals” (P, Ca, Mg, K, Na, Zn, Cu, Fe and Mn) in plant material was carried out using Hunter apparatus, similar to that used for soil analysis.

Sample cups:

Three rows of 11 sample cups were placed on trays, which were stored on trolleys for batch handling. As a routine procedure for all determinations, a check sample and a reagent blank were placed at each row of eleven sample cups. That is, there were three check samples and three blanks for every batch of 27 “unknowns”.

Dispenser/Diluters:

Three-aliquot (25 ml) dispenser;

Two-times diluters

Five-times diluters;

Combination dispenser/diluter (2 ml: 8 ml: 10 ml)

Ashing

Procedure

Zero point five grams of plant sample was measured into a 100 ml pre-weighed beaker, and dried in an oven at 105 ^{o}C for two hours. The beaker was then reweighed, and the sample material dry-ashed overnight in a furnace at 450 ^{o}C.

Digestion and filtration procedure

The beaker and ashed contents were removed, cooled and the material wetted with few drops of distilled water. Two ml of conc. HC1 were then added to each sample. The contents were then evaporated slowly to dryness on a water bath in the fume cupboard with the extractor fan on. Using a Fortuner Optifix dispenser, 25 ml of a freshly prepared 1:9 HCI solution (approx. IM HC1) was added. Each sample was stirred using a rubber policeman, rinsing the rod in a beaker of distilled water in between each sample. The contents were then filtered through Advantec 5B: 90 mm diameter filter papers into a clean rack of sample cups.

Determination of Ca Mg, K, Na, Cu, Zn, Mn, Fe and Al

ICP Procedure

The filtrate was diluted with deionized water in the ratio of 5:20. The diluted solution was then analysed for the elements of interest by the inductively coupled plasma-optical emission spectrometric (ICP-OES) technique. The standards were also prepared using the same dilution procedure as the samples.

Determination of boron in plants using the Azomethine-H (method)

Reagents:

Azomethine-H Reagent

Zero point nine grams of azomethine-H and 2 g ascorbic acid were dissolved in distilled water (H_2O) and diluted to 100 ml. This solution was freshly prepared daily.

Buffer-Masking Solution

Two hundred and eighty grams of $NH_4C_2H_3O_2$ (Ammonium acetate), 20 g potassium acetate, 20 g tetrasodium salt of EDTA, and 8 g nitrilotriacetic acid were dissolved in 400 ml H_2O.

One hundred and twenty five (125) acetic of acid was added slowly while stirring. The contents were heated if necessary to aid the dissolving process. The contents were then filtered through Whatman # Qualitative Filter Paper Grade 4 to remove any undissolved residue.

1n H_2SO_4:

Twenty-eight ml of conc. H_2SO_4 was diluted to 1L with deionised H_2O. This solution was prepared fresh every 2 days.

Boron Stock Solution:

Zero point two nine grams of boric acid was dissolved in deionised H_2O and the solution diluted to 500 ml. This solution had a concentration of 100 ppm of boron.

Standard Solutions:

From Boron Stock Solution 0.5, 1, 2 and 3 ml were pipette respectively, into 100 ml volumetric flasks and made up to volume using 1N H_2SO_4. These standard solutions represent 5, 10, 20 and 30 mg/litre boron.

The use of 0.5 g sample/10 ml extract corresponds to a range of 0−60 ppm B in the plant, if plant B > 50 ppm the filtrate could be diluted to give B a value between 0 and 60 ppm.

Sample preparation

Zero point five grams plant material was weighed into a porcelain crucible. Calcium oxide (0.1 g/g sample) was added, and the sample ashed at 450 °C overnight. Four drops of deionised H_2O was then added to the ash. The crucible was allowed to cool, after which 10 ml 1N H_2SO_4 was added. The crucible was allowed to stand for 1 hour at room temperature, stirring occasionally with a glass rod to break up the ash. The stirrer was rinsed with deionised water in between samples. The contents were then filtered through Whatman # Grade 1 Qualitative Filter Paper (Schleider Schuell No. 595).The setting standards were then removed from the fridge and allowed to attain room temperature, before use.

Colour development and measurement

Four ml of filtrate was pipetted into a test tube. Four ml buffer masking reagent and 1 ml Azomethine-H reagent were added. The contents were mixed thoroughly by means of a test tube shaker. Colour was allowed to develop for 1 hour; further mixing on the shaker was carried out after half an hour. Absorbency was measured at 420 nm. The concentration of boron in the sample was determined from a standard constructed by plotting absorbency vs concentration of standards in ppm.

The boron result was multiplied by 2 (if 0.5 g of a sample used initially) for ppm (Mg/L). A programme on the computer automatically multiplies the entered result by 2, so if a weight other than 0.5 g was used the result should be converted to an equivalent of 0.5 g before entry on the spreadsheet.

Determination of total carbon (C), nitrogen (N) and sulphur (S) using the Leco CNS 2000 analyser (standard)

The determination of total carbon, nitrogen, and sulphur was carried out using the Dumas (dry combustion) method. The sample was burnt at 1350 ^{o}C in a horizontal furnace. This process converts any elemental carbon, sulphur, and nitrogen in the sample into CO_2, SO_2, N_2 and NO_x. These gases were homogenised in a ballast tank after which they were passed through infrared detection cells to determine the carbon and sulphur content, and through a thermal conductivity cell, to determine the nitrogen content.

The instrument requires the following gases for operation:

- Oxygen (99.999 % pure) – used for combustion of the sample
- Helium (99.9999 % pure) – used as a carrier gas the nitrogen measurement part of the system
- Nitrogen (oil and water free) – used to operate the pneumatics

Other materials that are essential for the operation of the instrument are:

- Anhydrone (magnesium perchlorate) – to remove moisture from the gas stream
- Copper – to remove oxygen from the gas stream
- Catalyst – to speed up the conversion of NO_x to N_2
- Lecosorb – to remove CO_2 from the gas stream

Materials with known certified values for carbon, nitrogen, and sulphur were used to calibrate the instrument.

Determination of the total carbon, nitrogen, and sulphur in plant material

Standard:

LECO Tobacco standard, dried at 105 ^{o}C for 2 hours, cooled in a desiccator for 30 minutes and then weighed.

Procedure:

A batch of samples was weighed out as follows

2 Wastes (tobacco)

8 LECO tobaccos prepared as above

A rack of 49 samples, starting with a waste sample, then a sample of Caversham Rye 2000 Standard, which was repeated in positions 15, 26, 37 and 49.

Approximately 0.125 g of each sample was weighed out into a boat and the actual weight of the sample recorded on the chart. 0.5 g Com-cat was added to each sample and the contents well mixed.

Determination of total carbon, nitrogen, and sulphur in the samples was then carried out using the LECO CNS 2000 analyser, closely following the operational instructions provided by the manufacturer.

Calculation (done by instrument):

% CNS = Mass of C, N or S divided by weight x 100 %

3.3 EXPERIMENTAL DESIGN AND TREATMENT DETAILS

The research project consists of two field trials conducted in 2014/15 and 2015/16 seasons. The experiments were laid in a randomised complete block design (RCBD) with factorial arrangement so that different experimental units (plots) within the blocks would accommodate both gypsum and lime levels of applications (Badu-Apraku et al., 2012).

Conventional tillage was used to plough the experimental areas to a depth of 20 cm. Two calcium sources *viz*. gypsum and DL were applied. The first trial (2014/15 season) received both gypsum and lime treatment. Lime was applied one month before planting, at a rate of 0.45 kg/plot, 0.90 kg/plot and 1.35 kg/plot, and incorporated into the soil. Gypsum was applied at three intervals (split application) i.e. at planting (0.30 kg/plot, 0.45 kg/plot, 0.60 kg/plot), flowering (0.30 kg/plot, 0.45 kg/plot, 0.60 kg/plot), and pod formation stage (0.30 kg/plot, 0.45 kg/plot, 0.60 kg/plot). In 2015/16 season, gypsum was used in the absence of lime. Four levels of calcium in the form of gypsum (0 kg/ha, 500 kg/ha, 750 kg/ha, and 1000 kg/ha) and four levels in the form of DL (0 kg/ha, 250 kg/ha, 500 kg/ha, 750 kg/ha) were investigated.

Treatments were replicated in 48 plots (three replicates). Plot size was 18 m^2 (3 m x 6 m), with 5 rows and plant population of 222 000 plants/ha. Planting was done on 18 December 2014 and on 23 December 2015 during the main rainy seasons. The cultivars planted in 2014/15 and 2015/16 seasons were Kwarts and Tufa respectively. Both cultivars were certified seeds (small seeded Spanish type) that are suitable for dryland production. According to Smith (2006) and Cilliers (2013), the recommended planting time in South Africa is mid- or late October to mid-November and can be extended to the first week of December.

Mono ammonium phosphate with zinc (MAP + zinc) and ammonium phosphate fertilizers were applied at planting, according to RCBD treatments and soil test results respectively. The application rates in 2014/15 and 2015/16 seasons were 275 kg/ha (0.495 kg/plot) (MAP + zinc) and 90 kg/ha (0.162 kg/plot) (MAP) respectively.

Both chemical and mechanical weed control methods were used, *viz*. pre and post-emergence herbicides and hand hoes respectively. S-metolachlor pre-emergence herbicide was applied immediately after planting to control weed growth. Post-emergence weed control started from six to seven weeks after planting and thereafter as and when necessary. Post-emergence herbicides used were Bendioxide (thiadiazine) and propaquizafop. Mechanical weed control methods were used to control weed species that survived chemical weed control. After seven weeks, weeding was done mechanically as and when necessary.

Seven days (one week) after planting, germination started. When flowering started five weeks (35 days) after germination, 20 kg/ha (0.036 kg/plot) (the same rate for 2014/15 and 2015/16 season) nitrogen fertilizer i.e. limestone ammonium nitrate (LAN) was applied (as per soil test results) to enhance vegetative crop growth and stimulate nitrogen fixation. Germination percentage in 2014/15 and 2015/16 seasons attained 75 % and 97 % respectively. After six weeks, gypsum was applied at flowering stage.

Insecticide (deltamethrin) and fungicide (azoxystrobin) were applied to control insects and fungal infections respectively. An aphicide i.e. Malathion was also applied to control aphids infestation. After twelve weeks, another level of gypsum was applied at pod formation stage, during which time calcium is in high demand for promoting fruit development. Treatment factors are listed in the order: GYPSUM, LIME (Appendix 5).

3.4 ACQUISITION OF ETHICAL CLEARANCE

Before commencement of data collection, ethical approval was required and was duly requested from the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, UNISA, specifically for the research project: **Evaluation of the effect of calcium source (gypsum) application on groundnuts yield and quality in OKhahlamba Local Municipality, KwaZulu-Natal, South Africa**. Ethics clearance for the abovementioned project (Ref. No. 2014/CAES/060) was granted for the duration of the study.

3.5 DATA COLLECTION

After planting, growth stages of the crop (germination, flowering, pod formation) were monitored on a weekly basis and data collected using quantitative methods**.** Data collected included weather information (rainfall in mm, temperature in ^{o}C, percentage relative humidity), crop yield, pod weight/ha, shelling percentage, 100 seeds weight, pH, CEC and EC of soil, and calcium analysis of dry matter from groundnut shoots and leaves.

Groundnut harvesting was done manually and sundried. Picking commenced when the moisture content of the seeds was on average 6.7 %, which is close to the 7 % suggested by Cilliers (2013). Data collected are presented in Appendix 2 and 3. Variables measured were shoot weight (kg/ha), unshelled pods (kg/ha), shelling percentage, 100 seeds weight, and moisture percentage. Crop yield was assessed by measuring yield components and yield/ha parameters i.e. unshelled pods, shelled pods, pod weight/ha, 100 seeds weight, shelling percentage, and seed/kernel yield. Shelling percentage was calculated as follows:

$$\text{Shelling percentage} = \frac{\text{Shelled pods}}{\text{Unshelled pods}} \times 100$$

3.6 DATA ANALYSIS

Data were subjected to analysis of variance (ANOVA) using GenStat Release version 14.2 (statistical programme software, SPSS). Means were separated using Fisher's unprotected testing least significant differences (LSD) at 5 % level.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Soil analysis of experimental sites

Soil physical and chemical properties during 2014/15 season

The soil at the experimental site was classified as Oakleaf with a good structure. This soil is loamy sand to sandy loam (Macvicar et al., 1977) with an effective rooting depth of 1000 mm on the slope range of 0 to 12 %.

The results of the soil analysis for 2014/15 growing season are presented in Table 4.1 and Figures 4.1 and 4.2. From the soil analysis of the present study, it was observed that the soil in the first site was acidic (pH 3.88). Nutrient requirements for groundnut production (2014/15 season) were 20 kg/ha nitrogen (N), 60 kg/ha phosphorus, zinc (Zn), and zero potassium (K). The acid saturation was 27 %, which was above the 20 % permissible acid saturation (PAS) value for groundnuts.

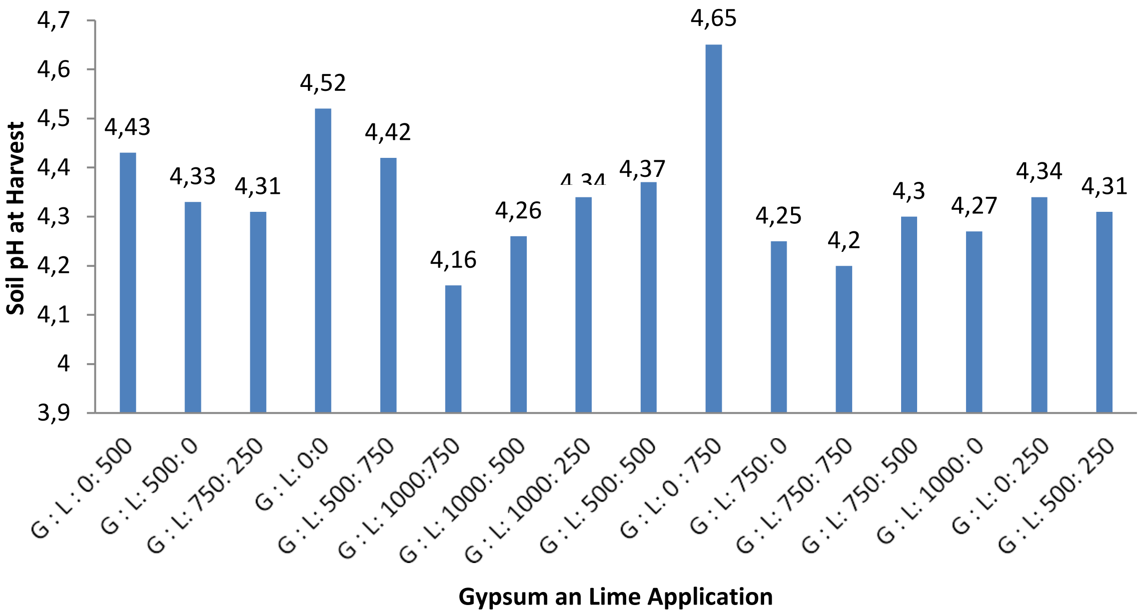

Figure 4.1**:** Effect of calcium sources on soil pH (2014/15)

The statistical results of EC are presented on Figure 4.2. The grand mean for EC was 89.52. The highest mean was143.50 at lime alone application rate of 750 kg/ha, whereas the control recorded the lowest mean, which was 52.39.

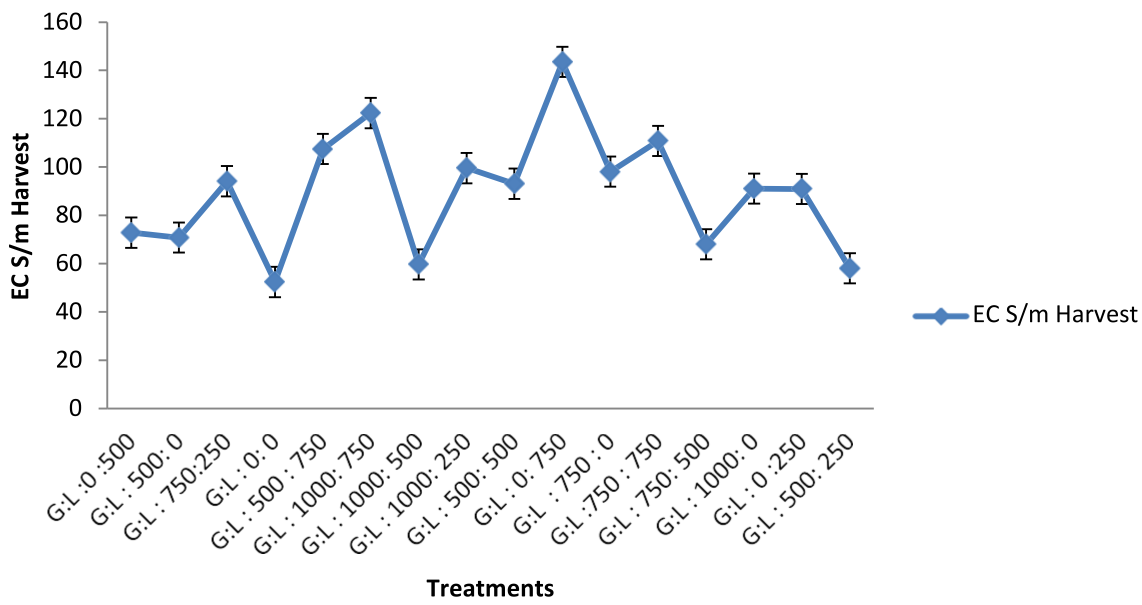

Figure 4.2**:** Relative effect of calcium sources on electrical conductivity (harvest) (2014/15)

Table 4.1

The chemical characteristics of Oakleaf soil form used (2014/15)

Chemical variable measured	**Concentration/value**
Phosphorus	5 mg/L
Potassium	211 mg/L
Calcium	313 mg/L
Magnesium	145 mg/L
Zinc	1.0 mg/L
Manganese	10 mg/L
Copper	2.4 mg/L
pH	3.88 (KCI)
Exchangeable acidity	1.20 cmoI/L
Acid saturation	27 %
Total	**4.49 cmoI/L**

Soil physical and chemical properties during 2015/16 season

The soil was classified as Oakleaf with a good structure, which is loamy sand to sandy loam (Macvicar et al., 1977) with an effective rooting depth of 1000 mm on the slope range of 0 to 12 %.

The results of the soil analysis for 2015/16 growing season are presented in Table 4.2 and Figures 4.3 and 4.4. From the soil analysis of the present study, it was observed that the soil in the second site was non-acidic (pH 5.48). Nutrient recommendations for groundnut production (2015/16 season) were 20 kg/ha N, 20 kg/ha P, and zero K. The acid saturation was 1 %, which was below the 20 % permissible acid saturation (PAS) value for groundnuts. The statistical results of EC are presented in Figure 4.4. The grand mean for EC was 78.4. The highest mean was 84.1 at gypsum alone application rate of 750 kg/ha and the lowest mean 66.1 (control).

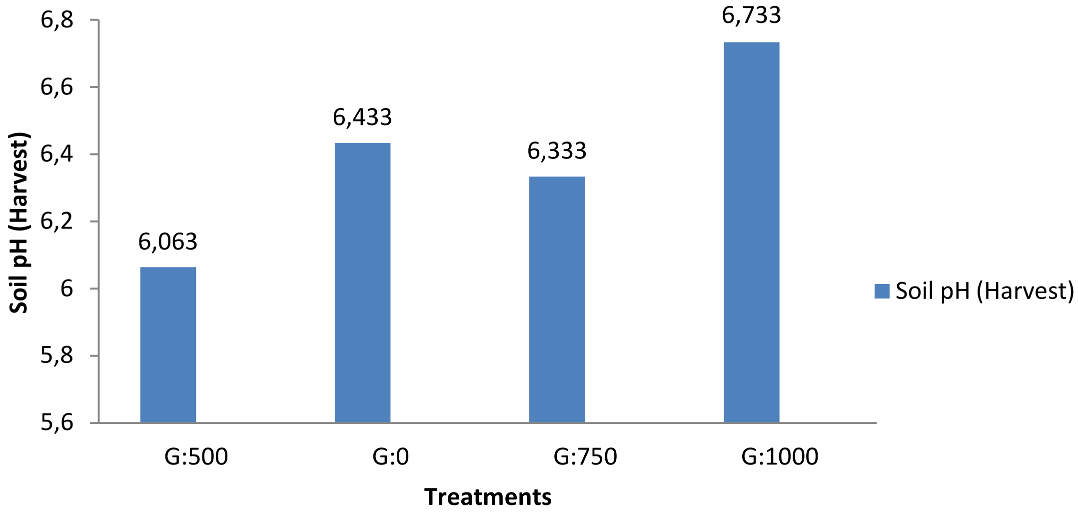

Figure 4.3**:** Effect of gypsum application on soil pH (2015/16)

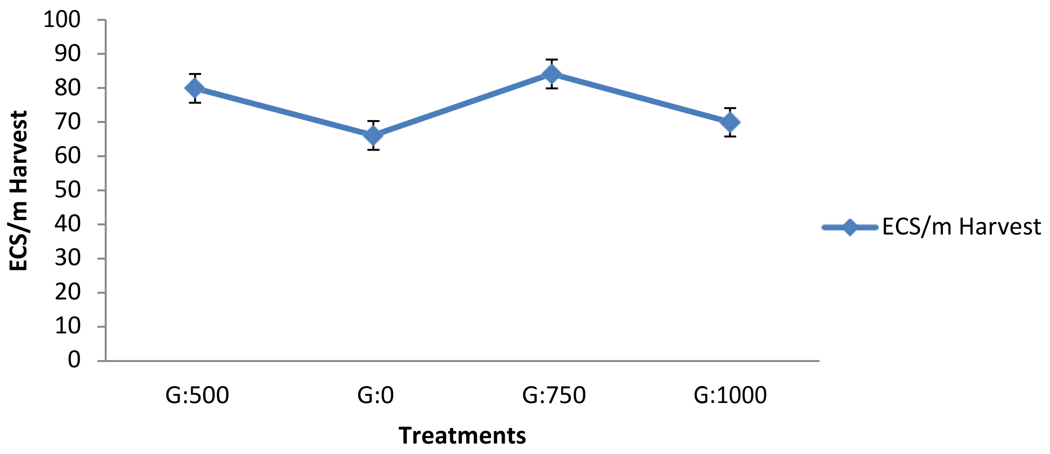

Figure 4.4**:** Effect of gypsum application on electrical conductivity (harvest) (2015/16)

Table 4.2

The chemical characteristics of Oakleaf soil form used (2015/16)

Chemical variable measured	**Concentration/value**
Phosphorus	24 mg/L
Potassium	576 mg/L
Calcium	1031 mg/L
Magnesium	290 mg/L
Zinc	4.5 mg/L
Manganese	7 mg/L
Copper	1.9 mg/L
pH	5.48 (KCI)
Exchangeable acidity	0.06 cmoI/L
Acid saturation	1 %
Total	**9.06 cmoI/L**

4.1.2 Weather data during the growing periods

Weather data during 2014/15 season

Rainfall (mm)

The total rainfall distribution and rainy days during the growing period of 2014/15 is shown in Table 4.3 and Figures 4.5 and 4.6.

Total rainfall recorded in that season was 490 mm (Table 4.3). January recorded the highest rainfall amount (261 mm) and highest number of rainy days (6). The least amount of rainfall (25 mm) and the least number of rainy days were recorded in April (Figures 4.5 and 4.6).

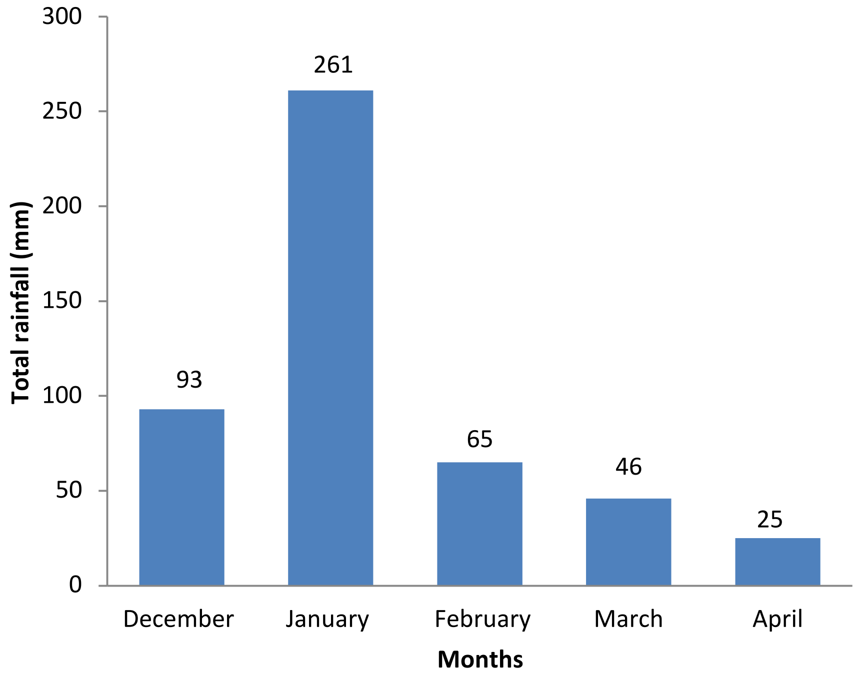

Figure 4.5: Monthly rainfall received during 2014/15 growing season.

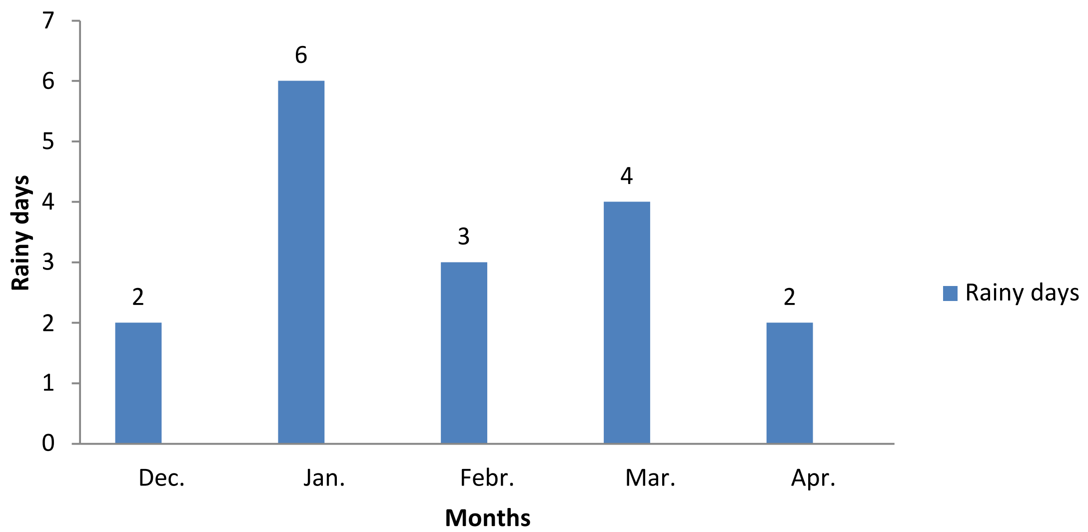

Figure 4.6: Rainy days during 2014/15 growing season

The 490 mm, which was the total rainfall received in 2014/15 season, was a little lower than 500–700 mm recommended by Smith (2006) for good dryland yields. The total rainfall received during the growing season was also poorly distributed and erratic.

Temperatures (^{o}C)

Average monthly temperatures during the growing season ranged from 9.0 ^{o}C to 27.9 ^{o}C and the highest average temperature was recorded in January (27.9 ^{o}C) while the lowest (9.0 ^{o}C) was recorded in April (Figure 4.7).

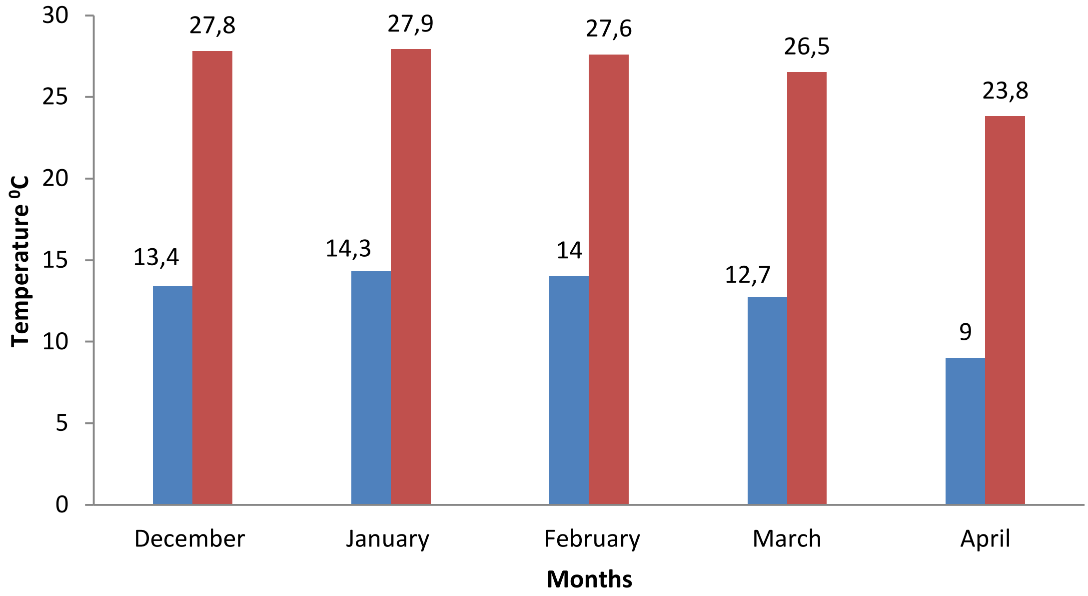

Figure 4.7**:** Monthly temperatures during 2014/15 growing season

These temperatures were below the optimum germination range of 20–30 ^{o}C. Average temperature for December ranged from 13.4 ^{o}C and 27 ^{o}C, which was below an optimum germination range of 20–30 ^{o}C.

Relative humidity (%)

Relative humidity recorded was between 61 % and 65 % in 2014/15 season (Figure 4.8).

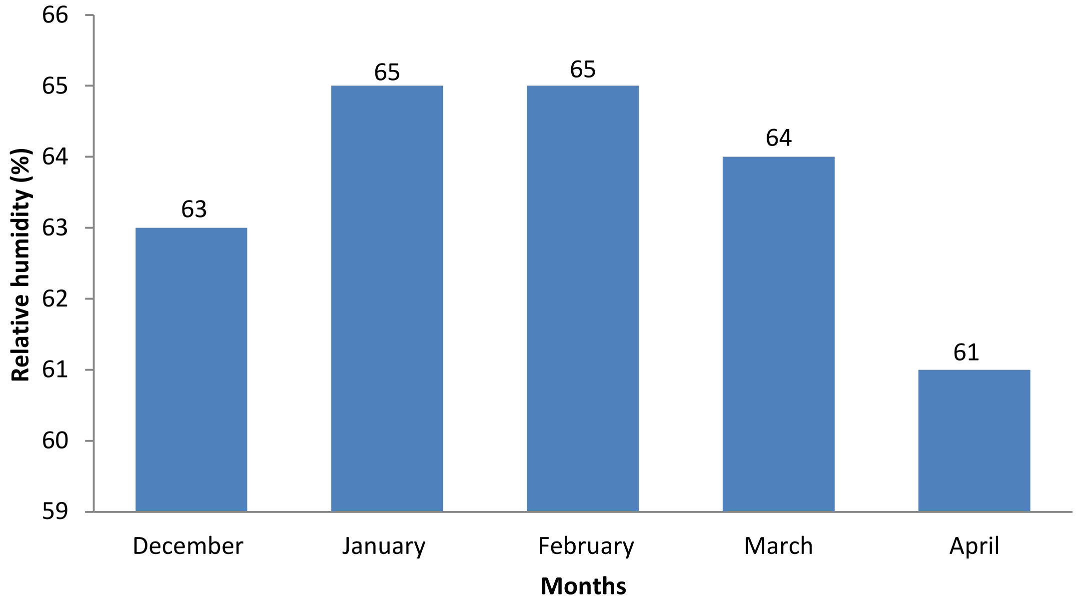

Figure 4.8**:** Monthly relative humidity during 2014/15 growing season

Table 4.3

Temperature (°C), relative humidity (%), total rainfall (mm), and number of rainy days (2014/15)

Month	**Temperature (°C)**		**Relative humidity (%)**	**Total rainfall (mm)**	**Rainy days**
	Min	**Max**			
Rainy season					
December	13.4	27.8	63	93	2
January	14.3	27.9	65	261	6
February	14.0	27.6	65	65	3
March	12.7	26.5	64	46	4
April	9.0	23.8	61	25	2
Total				**490**	**17**

Weather data during 2015/16 season

Rainfall (mm)

The total rainfall distribution during the growing period of 2015/16 is shown in Table 4.4 and Figure 4.9. Total rainfall recorded in that season was 811.6 mm (Table 4.4). January recorded the highest rainfall amount (336.6 mm) and the highest number of rainy days (10). The least amount of rainfall (15 mm) was recorded in April (Figures 4.9 and 4.10).

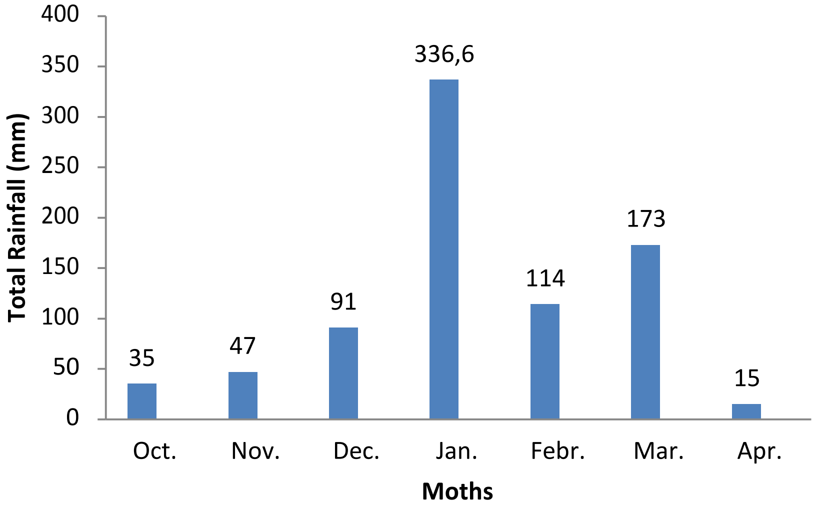

Figure 4.9**:** Monthly rainfall during 2015/16 season

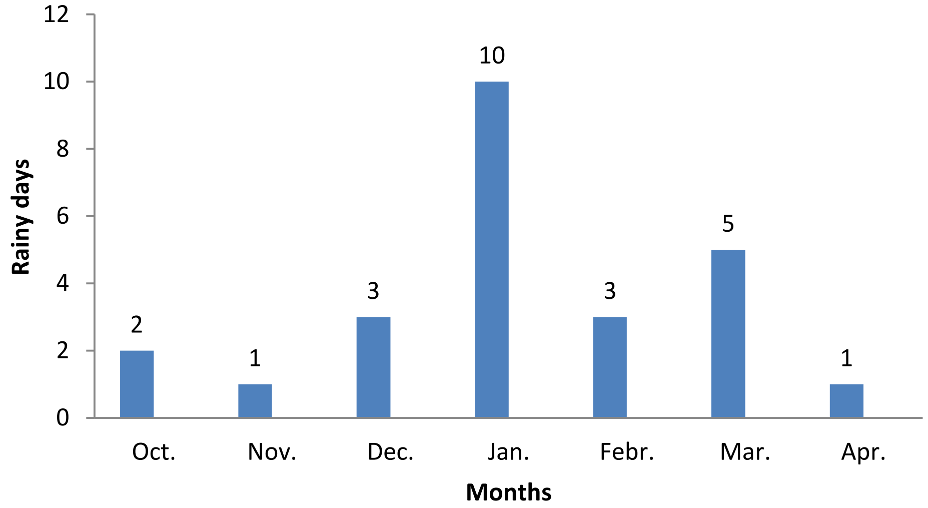

Figure 4.10**:** Rainy days during 2015/16 season

Temperatures (^oC)

The maximum mean temperatures for both months were high, ranging between 30.9 ^oC and 29.4 ^oC respectively (Table 4.4; Figure 4.11).

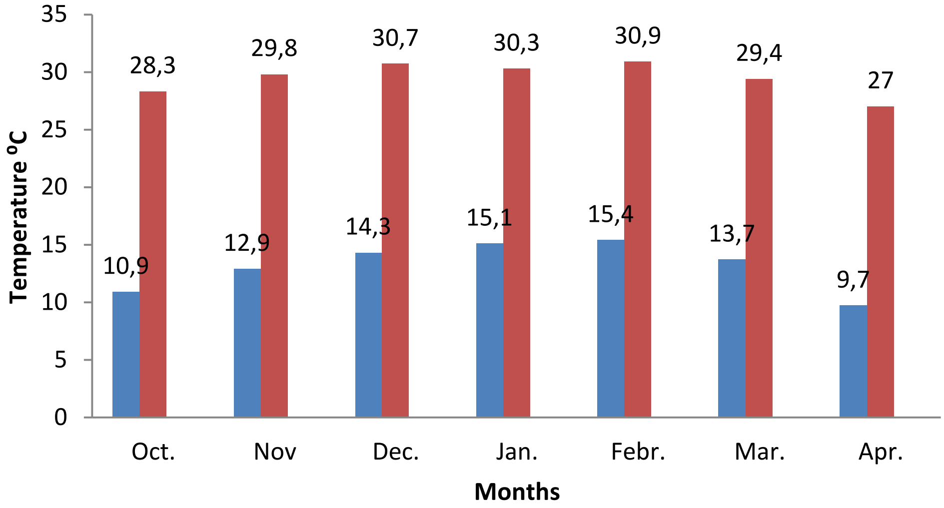

Figure 4.11**:** Monthly temperatures during 2015/16 season

Average monthly temperatures during the growing season ranged from 9.7 ^oC to 30.9 ^oC and the highest average temperature was recorded in February (30.9 ^oC), while the lowest (9.7 ^oC) was recorded in April (Figure 4.11). These temperatures were close to the optimum germination range of 20–30 ^oC. However, the average monthly minimum temperatures were below 18 ^oC recommended by Cilliers (2013) as a minimum temperature for germination. Average temperatures for December ranged between 14.3 ^oC and 30 ^oC.

Relative humidity (%)

Relative humidity recorded was between 57 % and 66 % in 2015/16 season (Figure 4.12).

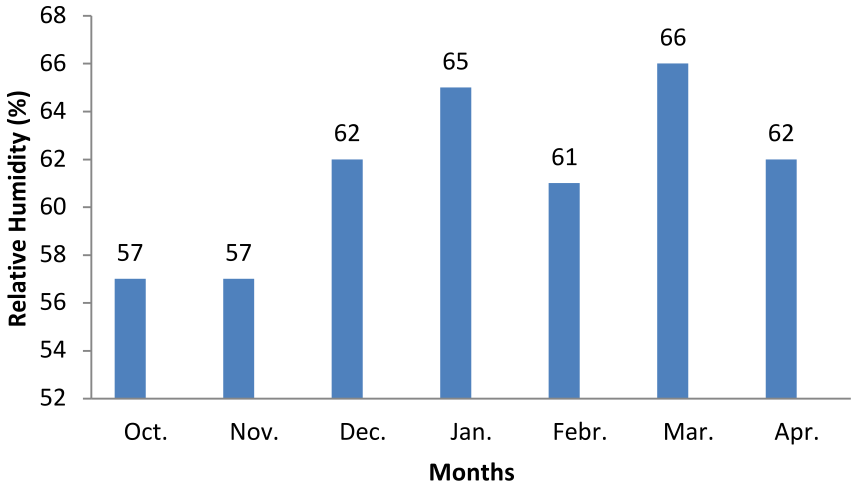

Figure 4.12**:** Monthly relative humidity during 2015/16 season

Table 4.4

Temperature (^{o}C), relative humidity (%), total rainfall (mm) and number of rainy days (2015/16)

Month	**Temperature (^{o}C)**		**Relative humidity (%)**	**Total rainfall (mm)**	**Rainy days**
	Min	**Max**			
Rainy season					
October	10.9	28.3	57	35	2
November	12.9	29.8	57	47	1
December	14.3	30.7	62	91	3
January	15.1	30.3	65	336.6	10
February	15.4	30.9	61	114	3
March	13.7	29.4	66	173	5
April	9.7	27.0	62	15	1
Total				**811.6**	**25**

4.1.3 Yield determination during growing seasons

Yield determination (yield components) for 2014/15

Shelling percentage analysis

The results of shelling percentage analysis are presented in Figure 4.13. The grand mean of shelling percentage was 51.5. The highest mean was 65.0 at the application rate of 500 kg/ha gypsum and 250 kg/ha lime. The lowest mean was 42.7 at the application rate of 250 kg/ha lime.

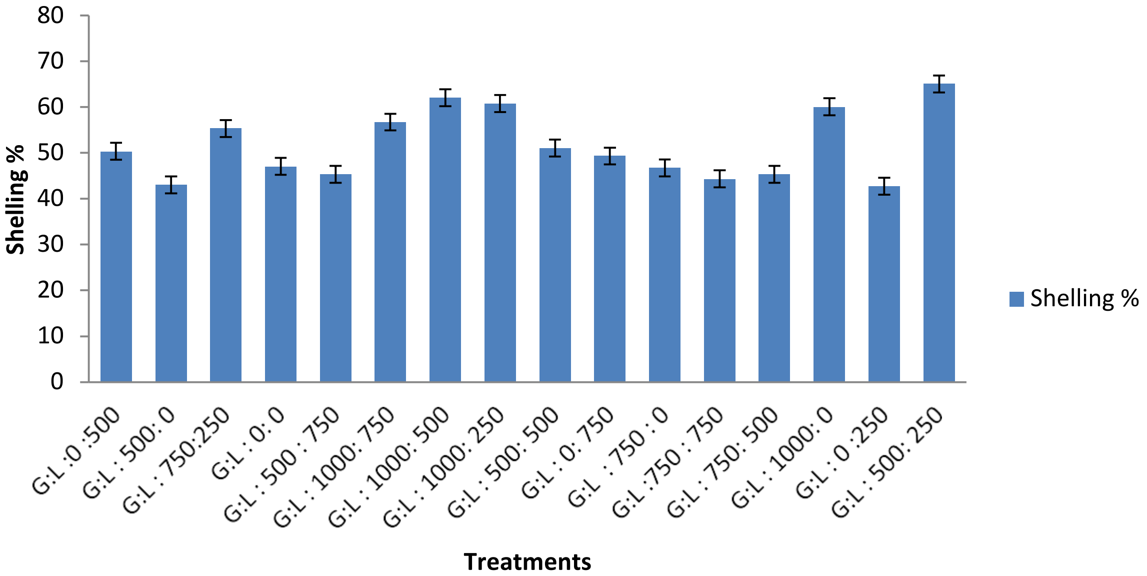

Figure 4.13**:** Relative effect of calcium sources on shelling percentage (2014/15)

Table 4.5

Mean comparison of yield components as affected by different treatments

Treatments (G:L)	**Unshelled (kg)**	**Shelled (kg)**	**Shelling %**	**Moisture %**	**Soil pH**
0:500	1.59	0.907	50.3	6.5	4.43
500:0	1.59	0.737	43.0	7.3	4.33
750:250	1.78	1.005	55.3	6.5	4.31
0:0	1.55	0.577	47.0	7.1	4.52
500:750	2.44	1.135	45.3	7.1	4.42
1000:750	2.07	1.167	56.7	6.1	4.16
1000:500	2.41	1.487	62.0	6.3	4.28
1000:250	1.98	1.217	60.7	6.6	4.34
500:500	1.92	1.026	51.0	7.1	4.37
0:750	2.14	0.875	49.3	6.3	4.65
750:0	2.05	0.970	46.7	6.7	4.25
750:750	1.67	0.763	44.3	6.6	4.20
750:500	2.26	1.137	45.3	6.8	4.30
1000:0	1.67	1.013	60.0	6.9	4.27
0:250	1.94	0.798	42.7	6.7	4.34
500:250	2.23	1.477	65.0	6.8	4.31
Mean	1.955	1.018	51.5	6.7	4.34
LSD $_{(0.05)}$	1.1354	0.8623	29.99	1.21	0.187
CV $_{(\%)}$	34.8	50.8	34.9	10.9	2.6

Pod yield analysis

The results of pod yield analysis are presented in Figure 4.14. The grand mean of pod yield (unshelled pods) was 1.955. The highest mean was 2.442 at the combination of gypsum and lime at application rate of 500 kg/ha and 750 kg/ha respectively. The lowest mean was 1.545 (control).

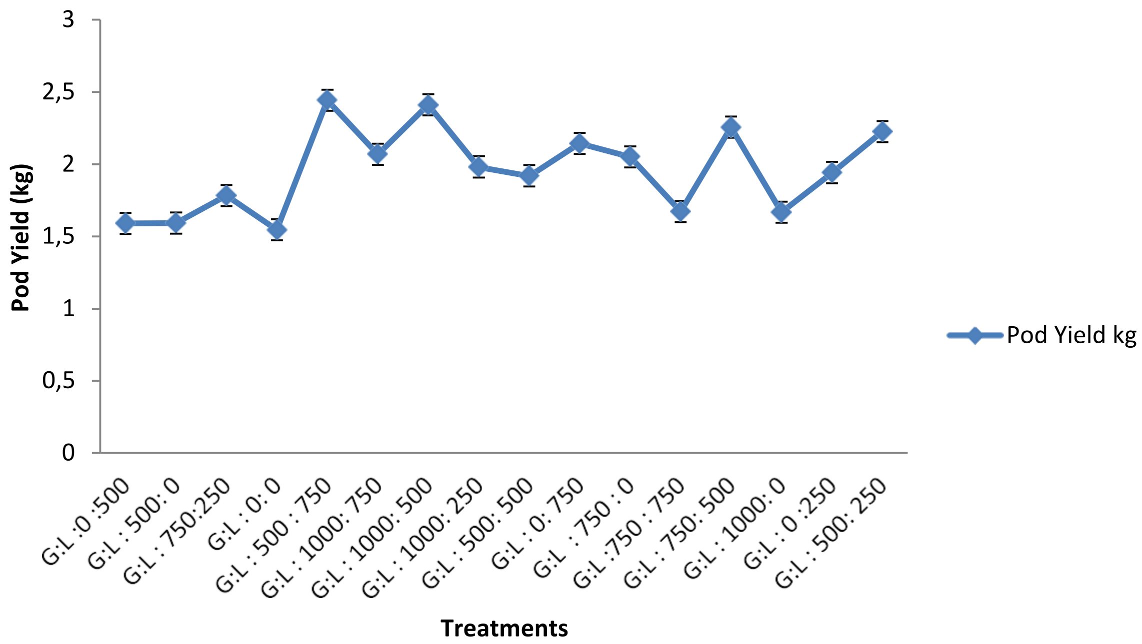

Figure 4.14**:** Relative effect of calcium sources on pod yield (2014/15)

Seed yield analysis

The results of seed yield (shelled pods) analysis are presented in Figure 4.15. The grand mean of seed yield was 1.018. The highest and the lowest means were 1.487 and 0.577 at the combination of gypsum and lime (1000 kg/ha gypsum and 500 kg/ha lime) and control, respectively.

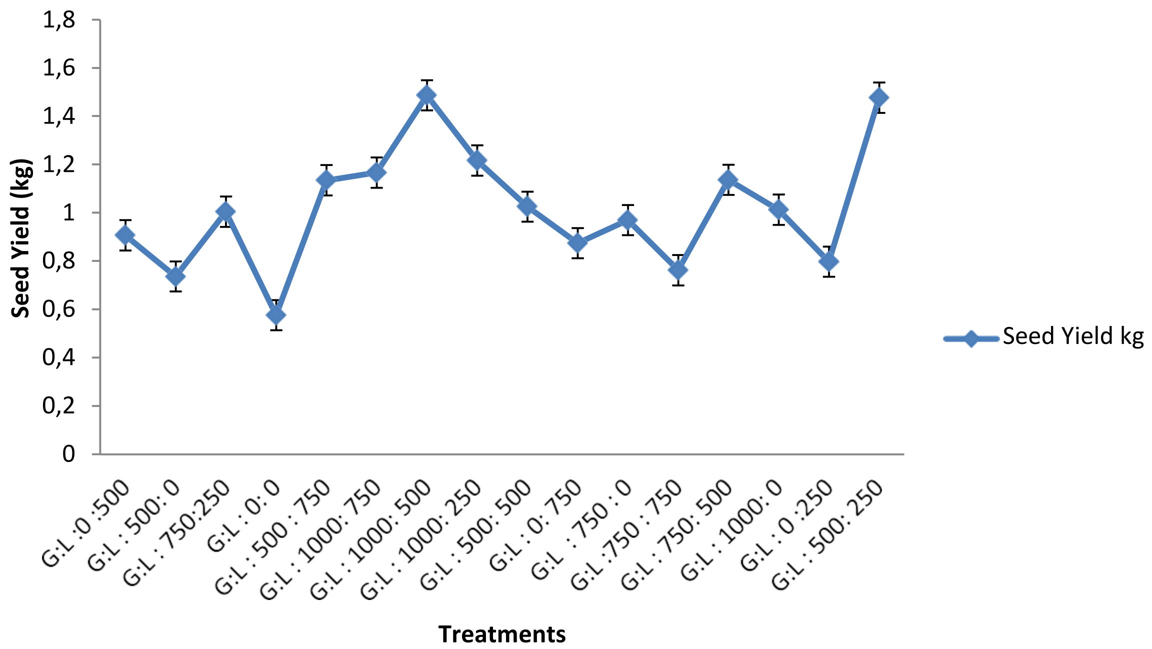

Figure 4.15**:** Relative effect of calcium sources on seed yield (2014/15).

Dry shoot weight analysis

Figure 4.16 shows the results of dry shoot weight analysis. The grand mean of dry shoot weight was 8.65. The highest mean was 9.50 at the application rate of 750 kg/ha lime while the lowest mean was 7.33 at the combination of gypsum and lime (1000 kg/ha gypsum and 750 kg/ha lime).

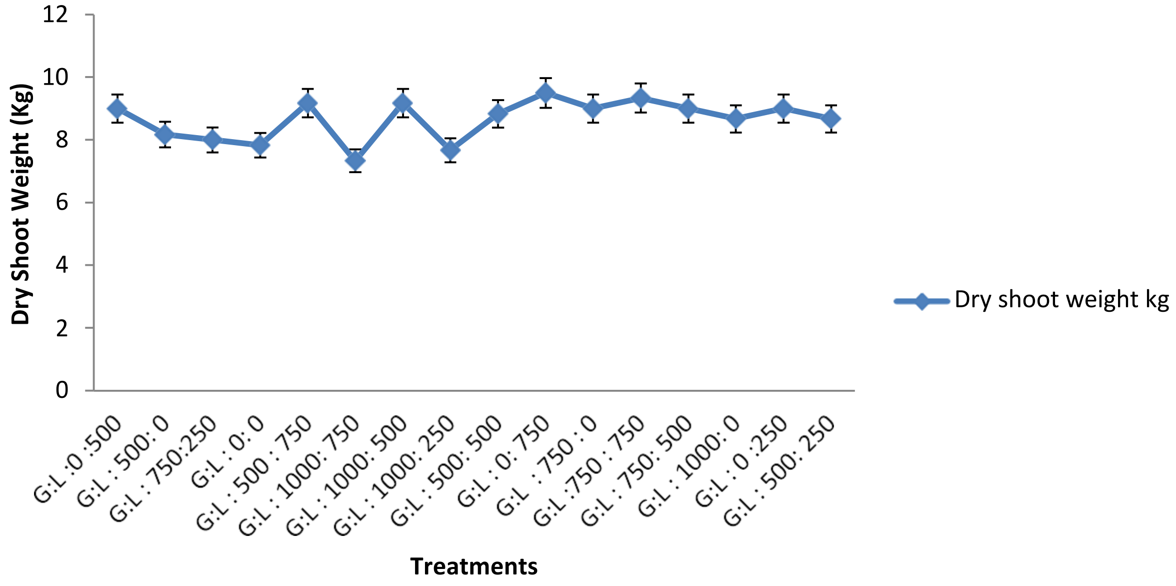

Figure 4.16**:** Relative effect of calcium sources on dry shoot weight (2014/15)

Moisture percentage analysis at harvest

The results of moisture percentage analysis at harvest are presented in Figure 4.17. The grand mean of moisture percentage at harvest was 6.7. The highest mean was 7.3 at the application rate 500 kg/ha gypsum and the lowest mean was 6.1 at the combination of gypsum and lime (1000 kg/ha gypsum and 750 kg/ha lime).

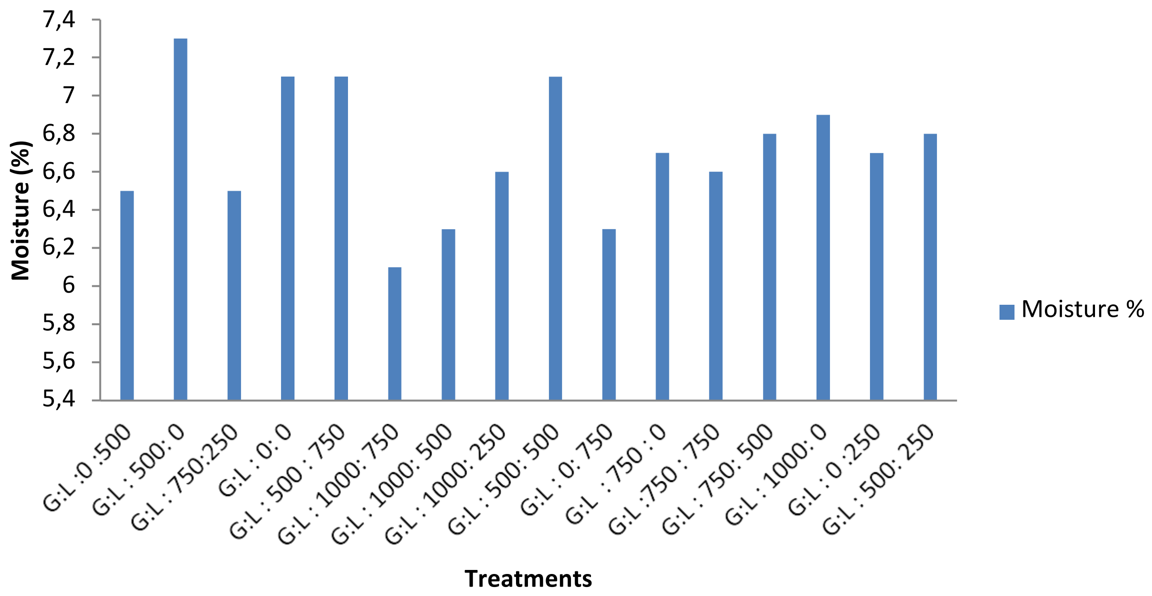

Figure 4.17**:** Relative effect of calcium sources on seed moisture content at harvest (2014/15).

Yield determination (yield components) for 2015/16

Shelling percentage analysis

The results of shelling percentage analysis are shown in Figure 4.18. The grand mean of shelling percentage was 59.032. The highest mean was 65.314 at the application rate of 750 kg/ha gypsum, while the lowest mean was 53.777 at the application rate of 500 kg/ha gypsum.

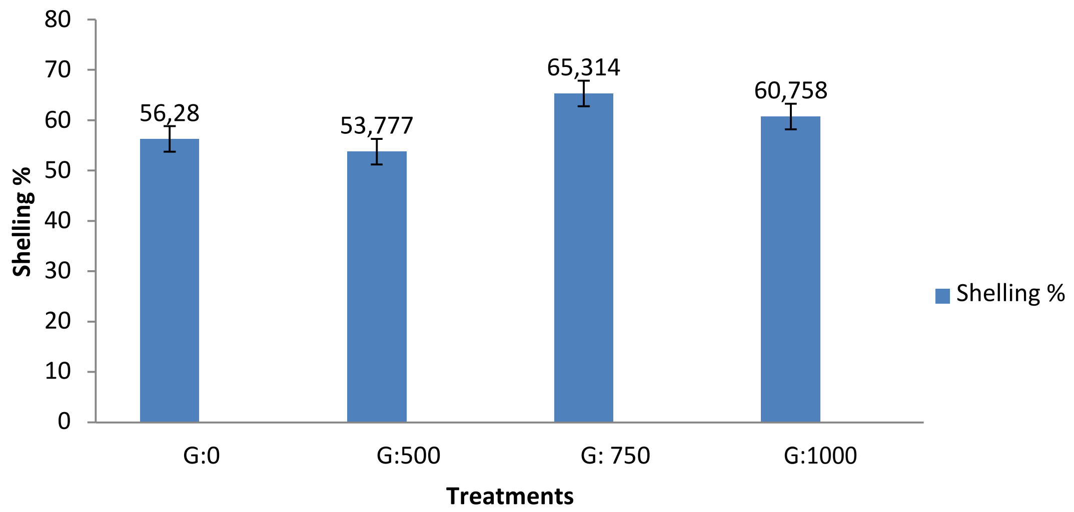

Figure 4.18: Effect of gypsum application on shelling percentage (2015/16)

Table 4.6

Mean comparison of yield components as affected by gypsum treatments

Treatments (Gypsum)	**Dry shoots (kg)**	**Unshelled (kg)**	**Shelled (kg)**	**Shelling %**	**Moisture %**	**% 100 seeds**
0	7.556	4.282	2.376	56.280	6.2	44.7
500	7.694	4.392	2.330	53.777	6.1	44.8
750	7.236	4.589	2.975	65.314	6.3	44.6
1000	6.868	3.925	2.462	60.758	6.1	45.3
Mean	7.338	4.297	2.536	59.032	6.2	44.9
LSD $_{(0.05)}$	1.0876	1.0006	0.6391	8.3267	0.36	2.51
CV $_{(\%)}$	18.0	28.3	30.6	17.1	7.1	6.8

100 seed weight analysis

The results of 100 seed weight analysis are shown in Figure 4.19. The grand mean of 100 seed weight was 44.9. The highest mean was 45.3 at the application rate of 1000 kg/ha gypsum and the lowest mean was 44.6 at the application rate of 750 kg/ha gypsum.

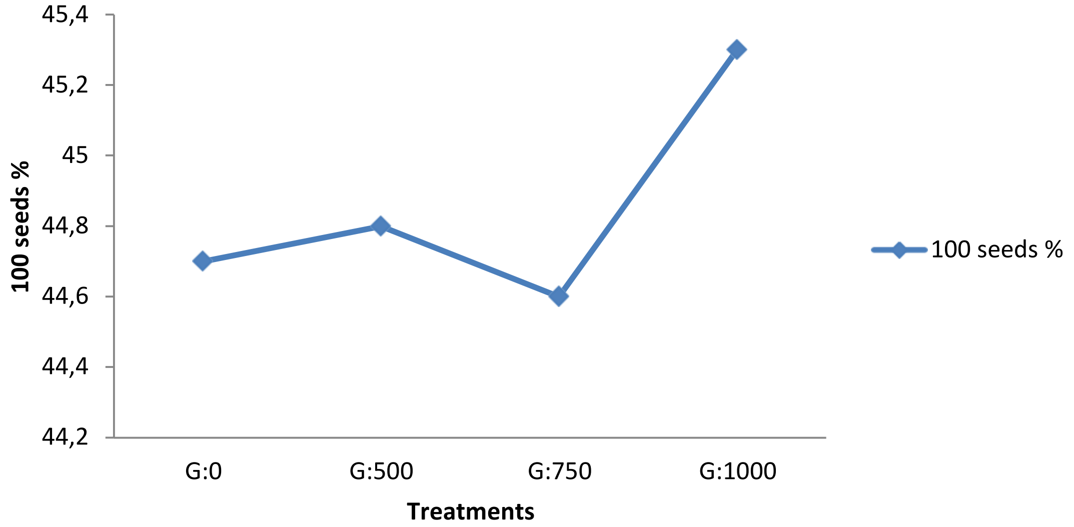

Figure 4.19**:** Effect of gypsum application on 100 seeds weight (2015/16)

Pod yield analysis

The results of pod yield analysis (2015/16 season) are presented in Figure 4.20. The grand mean of pod yield was 4.297. The highest mean was 4.589 at the application rate of 750 kg/ha gypsum while the lowest was 3.925 at the application rate of 1000 kg/ha gypsum.

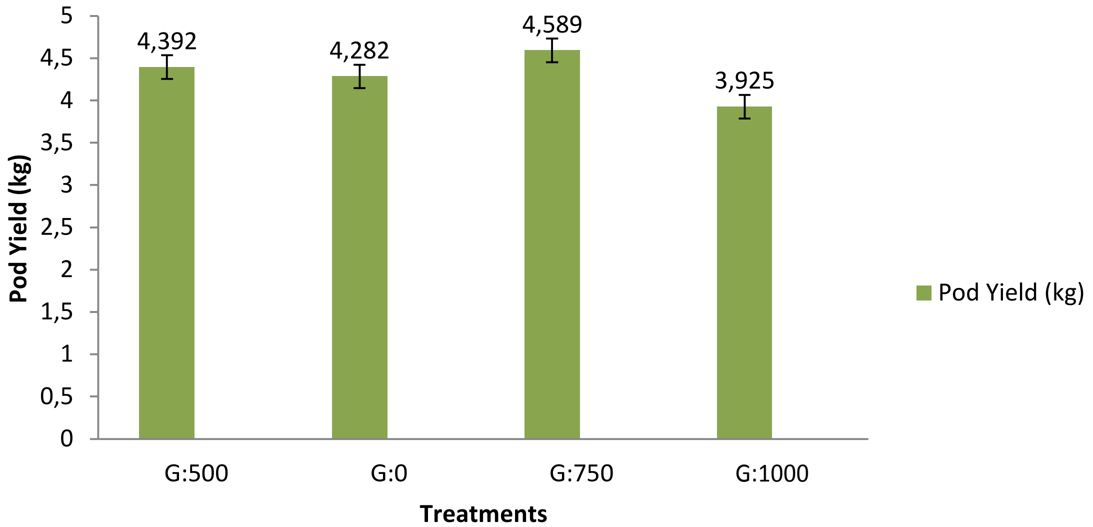

Figure 4.20: Effect of gypsum application on pod yield (2015/16)

Seed yield analysis

The results of seed yield analysis (2015/16) are presented in Figure 4.21. The grand mean of seed yield was 2.536. The highest mean was 2.975 at the application rate of 750 kg/ha gypsum and the lowest mean was 2.330 at the application rate of 500 kg/ha gypsum.

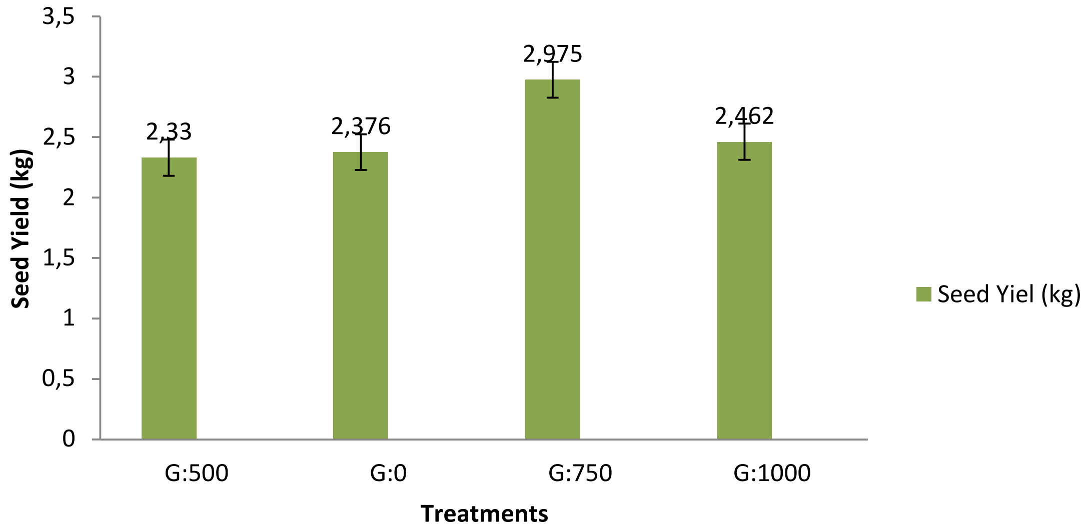

Figure 4.21**:** Effect of gypsum application on seed yield (2015/16)

Dry shoot weight analysis

The results of dry shoot weight analysis (2015/16 season) are presented in Figure 4.22. The grand mean of dry shoot weight was 7.338. The highest mean was 7.694 at the application rate of 500 kg/ha gypsum while the lowest mean stood at 6.868 at the application rate of 1000 kg/ha gypsum.

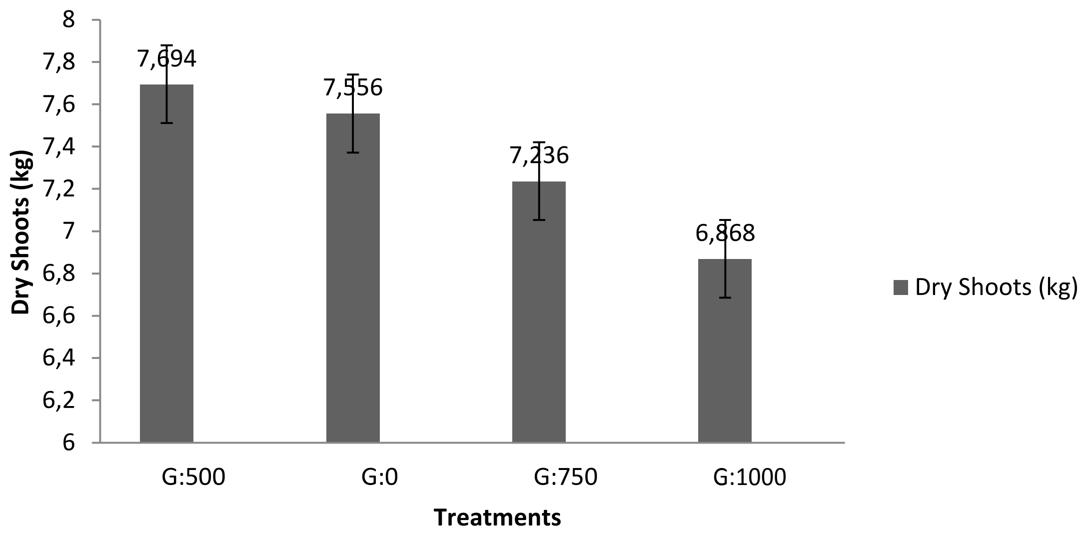

Figure 4.22**:** Effect of gypsum application on dry shoot weight (2015/16)

Moisture percentage analysis at harvest

The results of moisture percentage analysis at harvest (2015/16 season) are presented in Figure 4.23. The grand mean of moisture percentage at harvest was 6.2. The highest mean of moisture percentage was 6.3 at the application rate of 750 kg/ha gypsum. The lowest mean was 6.1 at the application rates of 500 kg/ha and 1000 kg/ha gypsum.

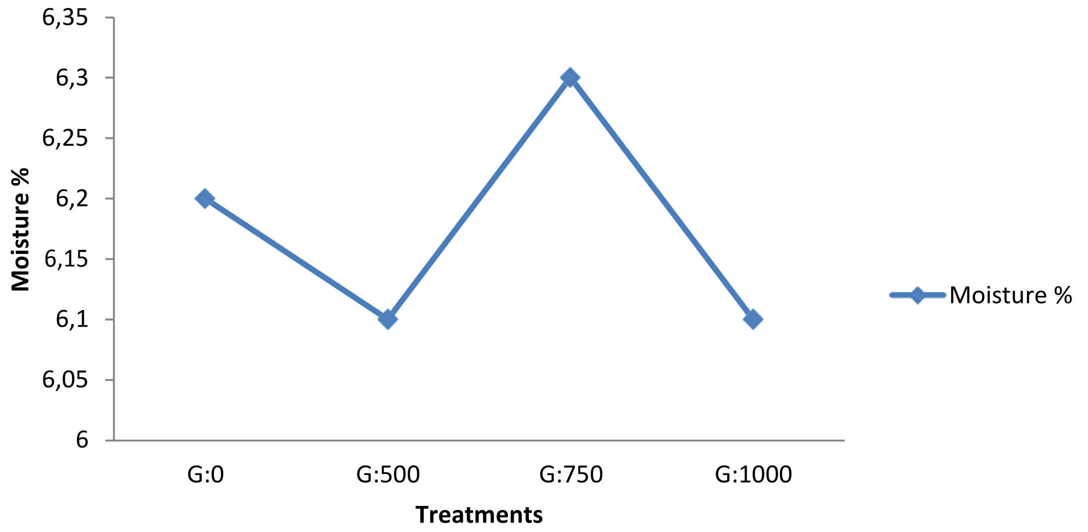

Figure 4.23**:** Effect of gypsum application on moisture percentage (2015/16)

4.1.4 Leaf element percentage analysis (2014/15 season)

Leaf calcium percentage analysis

The results of leaf calcium percentage analysis are presented in Figure 4.24. The grand mean of leaf calcium percentage analysis was 0.92. The highest mean of leaf calcium concentration was 1.12 at the combination of gypsum and lime (1000 kg/ha gypsum and 500 kg/ha lime). The lowest mean was 0.71 at the application rate of 1000 kg/ha gypsum.

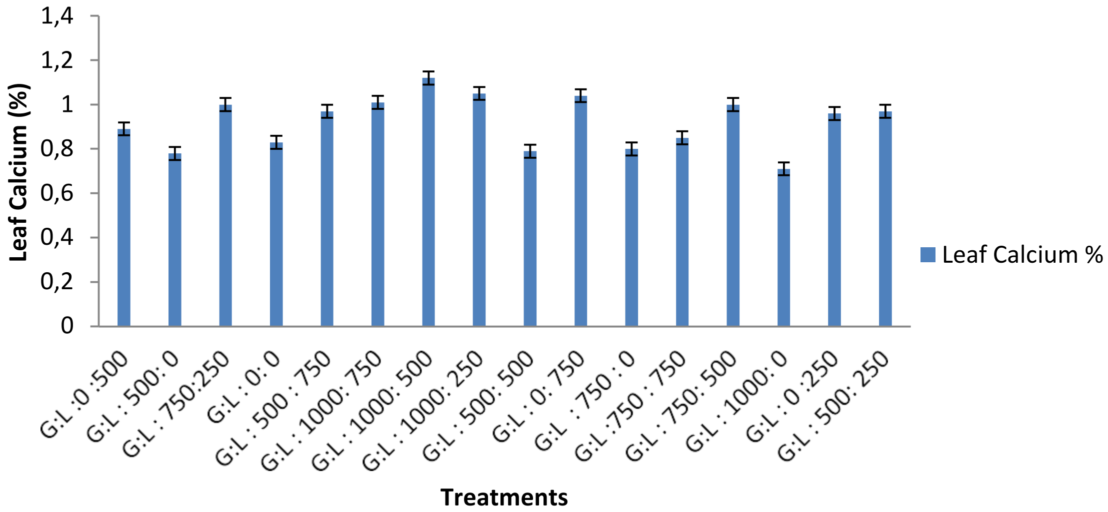

Figure 4.24**:** Relative effect of calcium sources on leaf calcium concentration (2014/15)

Table 4.7

Comparison of mean leaf Ca, Mg, Na and Zn concentration as affected by various treatments (2014/15 season)

Treatments (G:L)	**Ca**	**Mg**	**Na**	**Zn**
0:500	0.89	0.44	144.12	30
500:0	0.78	0.38	148.09	33
750:250	1.00	0.39	180.42	38
0:0	0.83	0.41	164.99	34
500:750	0.97	0.42	165.03	36
1000:750	1.01	0.41	2.2.35	40
1000:500	1.12	0.45	195.52	40
1000:250	1.05	0.44	113.10	35
500:500	0.79	0.35	164.33	27
0:750	1.04	0.37	200.61	43
750:0	0.80	0.39	139.68	33
750:750	0.85	0.42	133.37	32
750:500	1.00	0.42	185.42	38
1000:0	0.71	0.39	177.67	30
0:250	0.96	0.44	200.32	33
500:250	0.97	0.38	223.79	34
Mean	0.92	0.41	171.18	35
LSD $_{(0.05)}$	0.329	0.089	82.420	12.7
CV $_{(\%)}$	21.4	13.1	28.9	21.8

Analysis of other leaf elements concentration (magnesium, sodium and zinc) (2014/15 season)

Leaf magnesium concentration analysis

The results of leaf magnesium concentration analysis are presented in Figure 4.25. The grand mean of leaf magnesium concentration was 0.41. The highest mean of leaf magnesium concentration was 0.45 at the combination of gypsum and lime (1000 kg/ha gypsum and 500 kg/ha lime). The lowest mean was 0.35 at the application rate of 500 kg/ha lime.

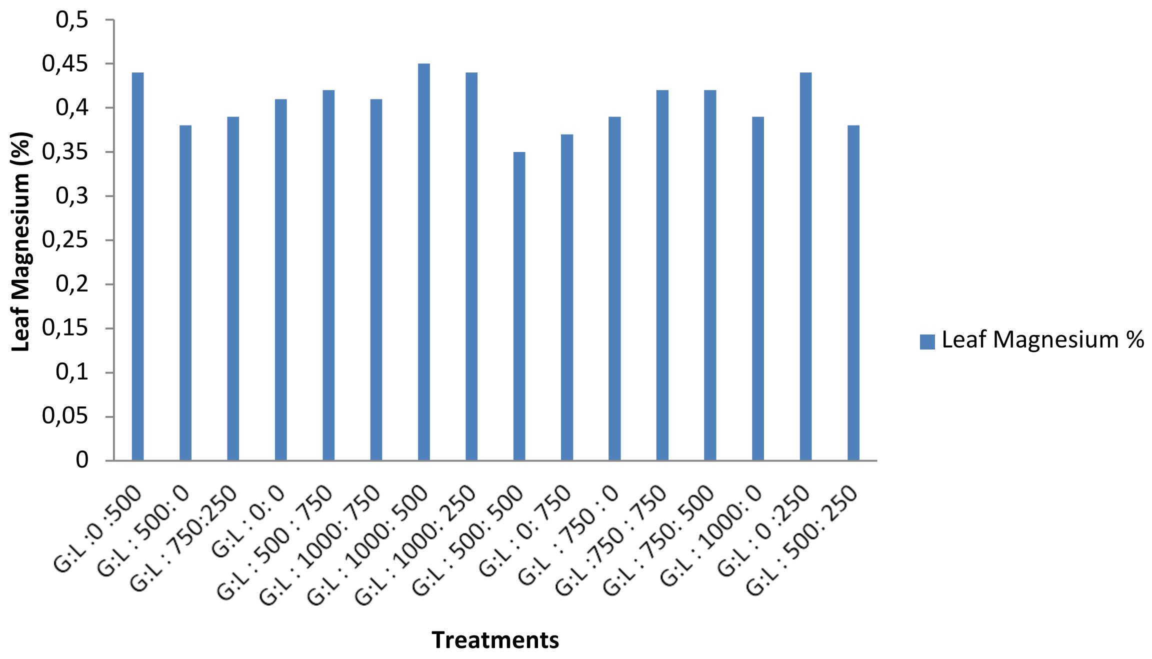

Figure 4.25**:** Relative effect of calcium sources on leaf magnesium concentration (2014/15)

Leaf sodium percentage analysis

The results of leaf sodium percentage analysis are shown in Figure 4.26. The grand mean of leaf sodium percentage was 171.18. The highest mean of leaf sodium percentage was 223.79 at the combination of gypsum and lime (500 kg/ha gypsum and 250 kg/ha lime). The lowest mean was 113.10 at the combination of gypsum and lime (1000 kg/ha gypsum and 250 kg/ha lime).

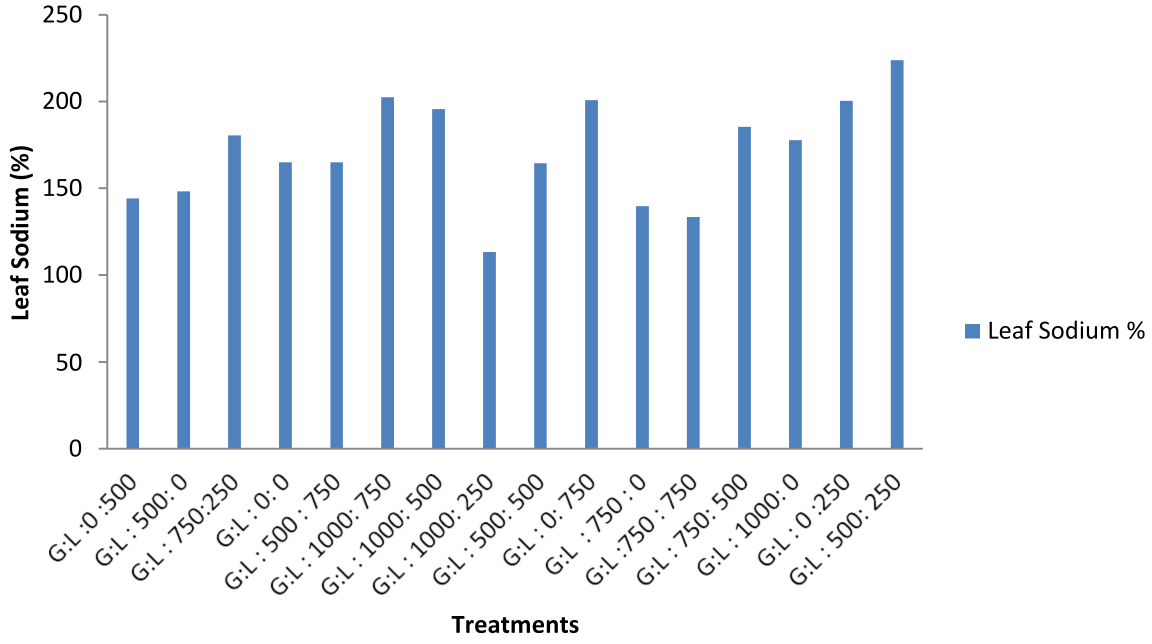

Figure 4.26**:** Relative effect of calcium sources on leaf sodium concentration (2014/15)

Leaf zinc concentration analysis

The results of leaf zinc concentration analysis are shown in Figure 4. 27. The grand mean of leaf zinc concentration was 35. The highest mean of leaf zinc concentration was 43 at the application rate of 750 kg/ha lime. The lowest mean was 27 at the combination of gypsum and lime (500 kg/ha gypsum and 500 kg/ha lime).

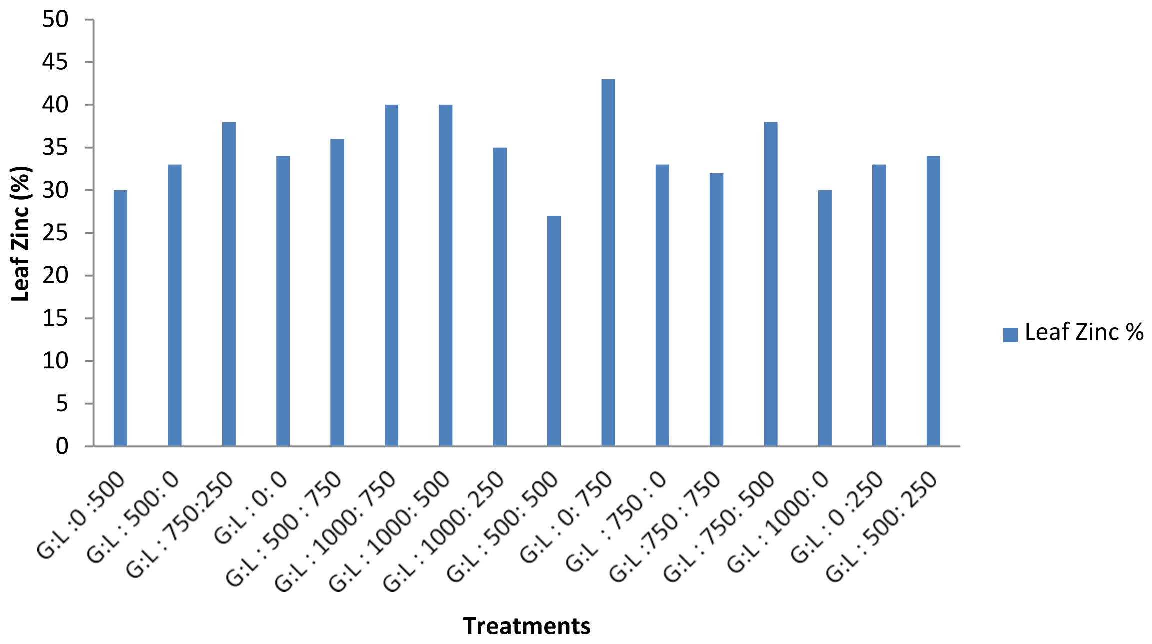

Figure 4.27**:** Relative effect of calcium sources on leaf zinc concentration (2014/15)

4.1.5 Leaf calcium percentage analysis for 2015/16 season

Leaf calcium concentration analysis

The results of leaf calcium concentration analysis are presented in Figure 4.28 and Table 4.8. Grand mean of leaf calcium percentage analysis was 1.55. The highest mean of leaf calcium percentage was 1.61 at gypsum application rate of 1000 kg/ha and the lowest mean was 1.42 (control).

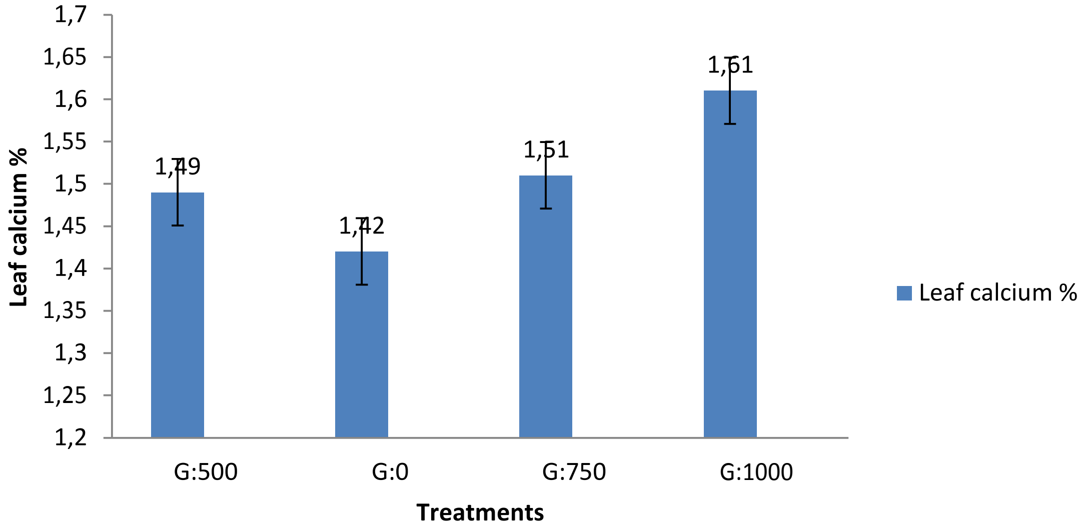

Figure 4.28**:** Effect of gypsum application on leaf calcium concentration (2015/16)

Table 4.8

Comparison of mean leaf Ca, B, Na, N and Al concentration as affected by gypsum treatments (2015/16 season)

Treatments (G:L)	**Ca**	**B**	**Na**	**N**	**C**
500	1.49	20.	257.7	3.24	45.05
0	1.42	18.	325.4	3.30	45.15
750	1.51	20.	377.0	3.48	45.36
1000	1.61	19	294.5	3.23	45.00
Mean	1.55	19.	313.2	3.28	45.10
LSD $_{(0.05)}$	0.182	2.4	159.15	0.449	0.992
CV $_{(\%)}$	7.1	7.4	30.5	8.2	1.3

Analysis of other leaf elements concentration (boron, sodium, nitrogen and aluminium) (2015/16 season).

Leaf boron concentration analysis

The results of leaf boron concentration analysis are presented in Figure 4.29. The grand mean of leaf boron concentration was 19. The highest mean of leaf boron concentration was 20 at gypsum application rates of 500 kg/ha and 750 kg/ha. The lowest mean was 18 (control).

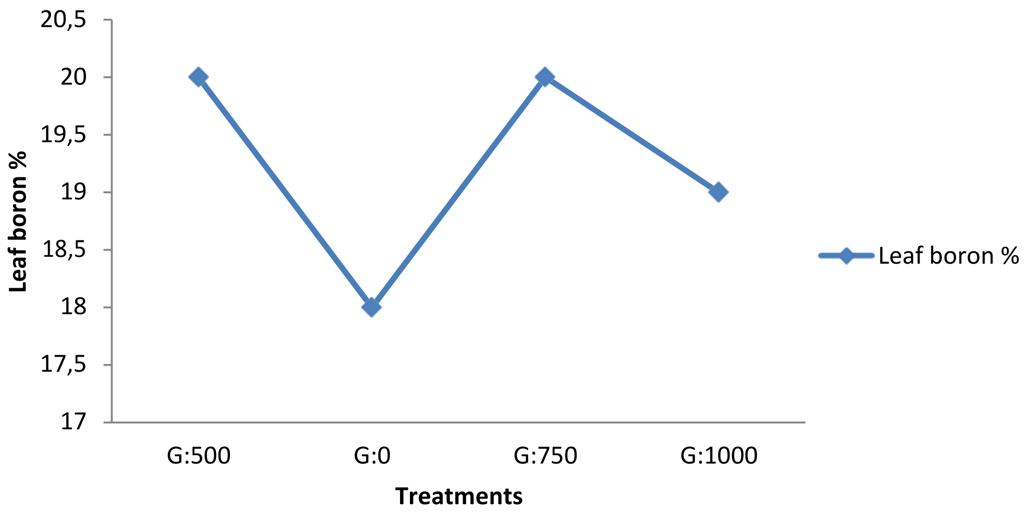

Figure 4.29**:** Effect of gypsum application on leaf boron concentration (2015/16)

Analysis of leaf sodium percentage

The results of leaf sodium percentage analysis are presented in Figure 4.30. The grand mean of leaf sodium percentage was 313.2. The highest mean of leaf sodium percentage was 377.0 at gypsum application rate of 750 kg/ha. The lowest mean was 257.7 at gypsum application rate of 500 kg/ha.

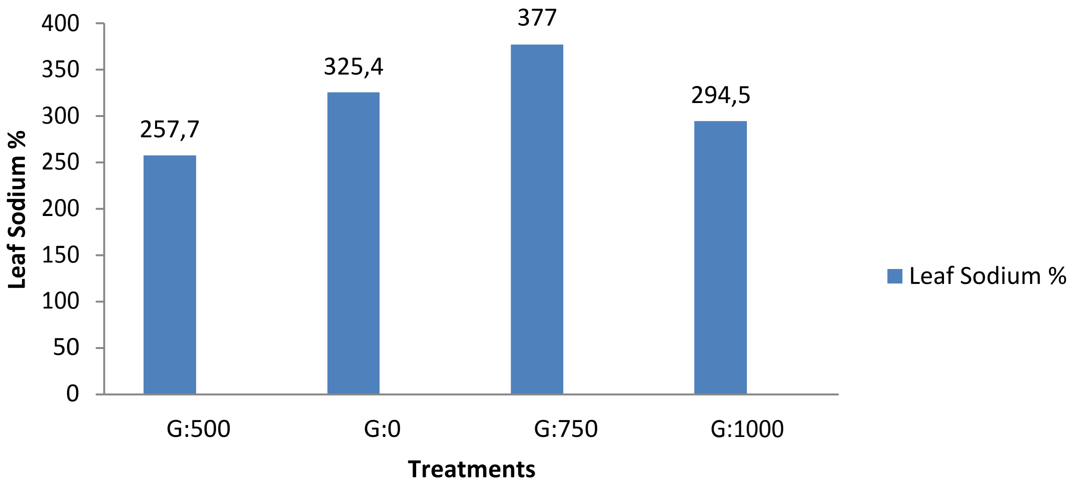

Figure 4.30**:** Effect of gypsum application on leaf sodium concentration (2015/16)

Leaf nitrogen concentration analysis

The results of leaf nitrogen concentration are presented in Figure 4.31. The grand mean of leaf nitrogen concentration was 3.28. The highest mean was 3.48 at the gypsum application rate of 750 kg/ha. The lowest mean was 3.23 at gypsum application rate of 1000 kg/ha.

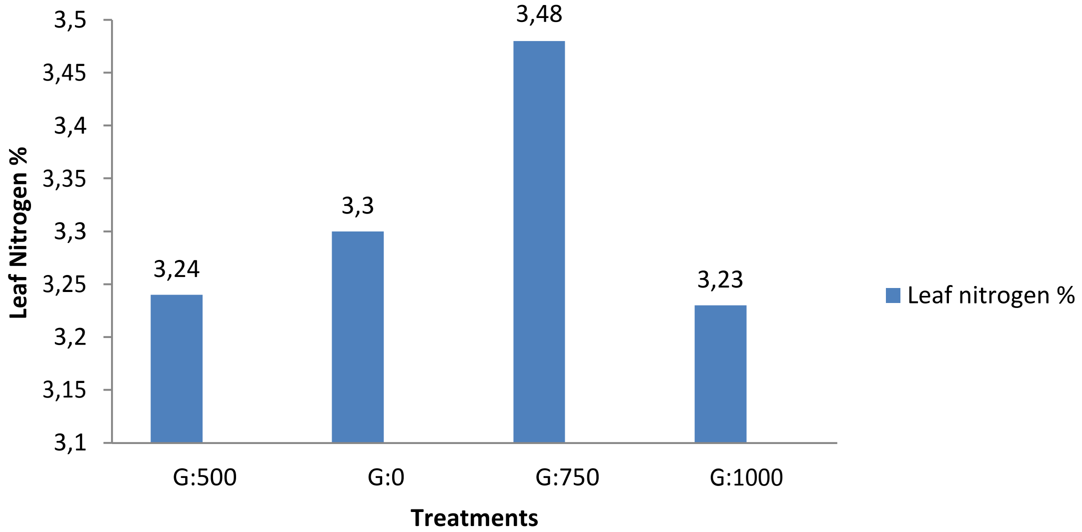

Figure 4.31**:** Effect of gypsum application on leaf nitrogen concentration (2015/16)

Analysis of leaf aluminium concentration

The results of leaf aluminium concentration are presented on Figure 4.32. The grand mean of leaf aluminium concentration was 142. The highest mean was 164 at gypsum application rate of 500 kg/ha. The lowest mean was 135 at gypsum application rate of 750 kg/ha.

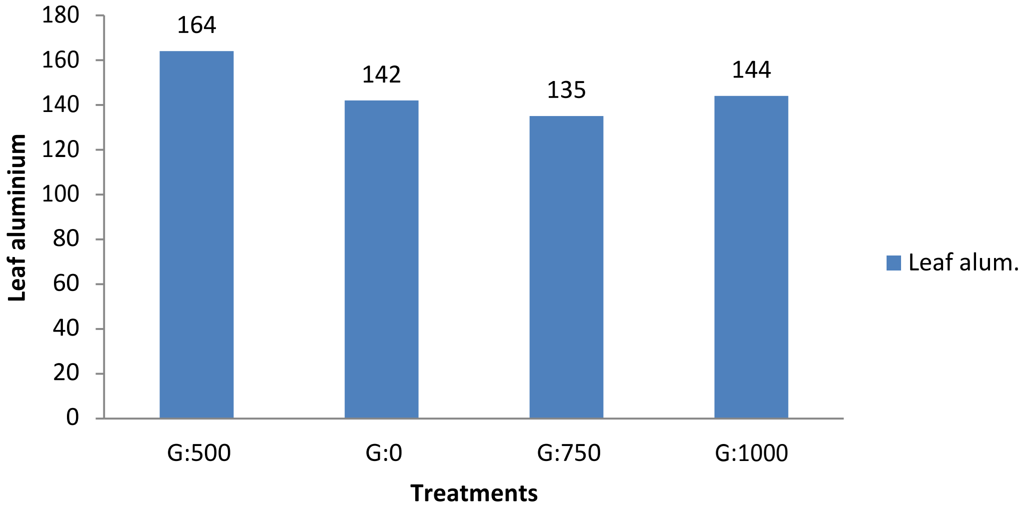

Figure 4.32**:** Effect of gypsum application on leaf aluminium concentration (2015/16)

4.2 DISCUSSION

4.2.1 Soil physical and chemical properties

Soil analysis of the study areas (first and second site) showed that both soil forms were Oakleaf and sandy, to sandy loam. The initial soil pH during the first season ranged from 3.88 to 4.1 (acid soil), which indicated the lower levels of soil pH for groundnut optimum yield. This indicated that soil pH levels were increased by different application rates of gypsum, reaching the highest mean of 6.92.

Gypsum application rate of 750 kg/ha had the highest pH value mean ($\rho \leq 0.05$). Lime alone application rates of 500 kg/ha and 750 kg/ha increased soil pH means ($\rho \leq 0.05$). In addition, gypsum application rates did influence the electrical conductivity (EC) of the soil. The data showed that gypsum application rate at 750 kg/ha had the highest EC of 84.1 mS/m. This suggested that electrical conductivity increased with the increase of gypsum application rate (Thilakarathna et al., 2014).

According to Murata (2003), soils with pH values below 5.0 require liming. At this low pH level, bacteria grow poorly while fungi thrive and organic matter does not readily accumulate. The low pH of the soil may be attributed to low levels of bases in the soil, since pH is largely determined by the amount of these bases (Kamara, 2010). Murata (2003) also reported that low levels of bases may also be attributed to the uptake by plants of more base cations such as potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) than of mineral anions, resulting in increased acidity in the soil due to the release of hydrogen ions (H^+) by plant roots in exchange for base cations.

The first site received both gypsum and lime treatments at different application rates. Soil pH at harvest was significantly different ($\rho \leq 0.05$). Lime alone application rates at 500 kg/ha and 750 kg/ha increased soil pH means at ≤ 0.05 probability, whereas lime and gypsum combined (1000 kg/ha and 750 kg/ha) and (750 kg/ha and 750 kg/ha) significantly reduced soil pH values. The highest application rates of gypsum and lime at 1000 kg/ha and 750 kg/ha did not increase soil pH. However, the soil pH of the control increased to 4.52. This was attributed to heavy rain (261 mm) received in January 2015, eliciting the drift of lime treatment to the control.

However, gypsum alone application significantly increased soil pH at the rate of 500 kg/ha. This observation is in concordance with the observation of Murata (2003) that gypsum application can work as a liming factor for legumes, decreasing acid stress on nodulating bacteria, thereby improving crop yield and quality, and can increase the pH of some soils. Thilakarathna et al. (2014) also observed that the application of 250 kg/ha of gypsum increased the soil pH from 4.1 to 5.0.

The fertility status of the soil at the site (2014/15) implies that the low pH was the major limiting factor to crop growth because soil pH is the foundation of essentially all soil chemistry and nutrient reaction, and should be the first consideration when evaluating a soil test. Consequently, both macro- and micro-nutrients become unavailable to crops, eliciting poor vegetative and reproductive growth, low yield, and poor quality (Murata, 2003). Hence, yields were not significantly different with the average yield of 1.5 ton/ha.

Based on statistical results of the present study (2014/15 season), EC and CEC were not significantly different at $\rho \leq 0.05$ level. The grand mean for EC was 89.52. The highest EC mean was 143.50 at lime alone application rate of 750 kg/ha, whereas the lowest mean was 52.39 (control).

The application of gypsum and lime at different rates did not affect the EC and CEC in the soil. According to Thilakarathna et al. (2014), CEC is closely related to soil electrical conductivity (EC) e.g. in some areas, higher EC indicates higher clay and CEC, resulting in higher yield goals and additional inputs on those sites.

Conversely, Thilakarathna et al. (2014) observed that gypsum application increased soil pH, CEC, as well as EC, and that gypsum will improve the pod filling without changing the soil pH. The researchers further explained that an optimum soil EC level for groundnut should be somewhere above 200 µS cm^{-1} and below 1200 µS cm^{-1}, and any soil < 200 µS cm^{-1} does not have enough available nutrients to the plant and may be a sterile soil with minimum microbial activity. On the other hand, an EC above 1200 µS cm^{-1} may indicate that the salt content of the fertilizer is high or perhaps there could be a salinity problem, due to lack of drainage.

From the soil analysis of the present study (2015/16), it was observed that the soil in the second site was non-acidic (pH 5.48). Consequently, according to Murata (2003), this pH range was above pH 5.3 and no lime application was required. MAP fertilizer mixture was applied as per soil test results. Hence, the experiment received only one treatment (gypsum). Soil pH at harvest was not significantly different.

Regarding the availability of major nutrients, the fertility status of the soil at the second site was relatively optimal, because the acid saturation was 1 %, which was below 20 % and thus conformed to PAS value for groundnut production.

Generally, when compared with the average yield of 1 ton/ha, the average yield for the second season (2015/16) was significantly different reaching a remarkable 2.9 ton/ha. This could be attributed to relatively slightly favourable weather conditions during the 2015/16 growing season, as well as differences in soil chemical properties.

4.2.2 Weather conditions during growing periods

The annual rainfall received during 2014/15 growing season was 490 mm and 811.6 mm in 2015/16 season. Rainfall received in 2015/16 season was relatively above the 500−700 mm range, which is recommended by Smith (2006) for good dryland yields. The distribution of the total rainfall for both growing seasons was yet poor and erratic, which was demonstrated by the disproportionately high precipitation recorded in January 2015 (261 mm) and 336.6 mm in January 2016.

The total rainfall (93 mm) received in December 2014 and 91 mm in December 2015 was considered sufficient to meet the moisture requirements of the crop at planting time, because according to Cilliers (2013), sufficient moisture in the soil at planting time is essential. However, maximum mean temperatures were high ranging between 27.8 °C and 30.7 °C in December 2014 and December 2015 respectively, which to a certain extent, elicited moisture depletion through evaporation.

Nevertheless, 261 mm and 336.6 mm rainfall received in January 2015 and January 2016 respectively, helped replenish moisture in the soil. On the other hand, such high rainfall received in January 2015 and January 2016 respectively, might have had an effect on the leaching of calcium (in gypsum) below the pegging zone (Harris et al., 2013). However, the application of other levels of gypsum in March 2015 and 2016 might have mitigated that impact.

Rainfall received in February (65 mm) and March (46 mm) 2015 was relatively lower than rainfall received in February (114 mm) and March (173 mm) 2016. Consequently, crop yield was affected. Optimum rainfall received in February and March 2016 ensured sufficient moisture during the critical stages of flowering and pegging of the crop, and the yield was bound to increase significantly. Yields for 2015/16 season were significantly different and relatively higher than those yields of the 2014/15 season.

These rains coincided with the flowering and pegging stages of the crop when the crop is in high demand of moisture. This is in concordance with Kambiranda et al. (2016), Okello et al. (2010) and Singh and Kumar (2015) who report that insufficient water at the time of flowering, pegging and fruiting significantly reduce yield. On the contrary, Singh and Kumar (2015) and Kambiranda et al. (2016) report that water stress does not affect the flower initiation process during 30−45 days after planting, however the first flowers produced up to 45 days do not form pegs. No rainfall was recorded in May (2015 and 2016), which was good, because, according to Cilliers (2013), too much rain at harvest reduces the quality of groundnut, particularly if the crop is left to dry in the field.

The average monthly minimum temperatures in 2014/5 and 2015/6 seasons ranged between 13.4 °C (December 2014) and 14.3 °C (December 2015). These temperatures were below 18 °C, which is recommended by Cilliers (2013) as a minimum temperature for germination. According to Cilliers (2013), groundnut seed germination is slow when temperatures are below the minimum of 18 ºC. Hence, germination percentage in 2014/15 season was affected and bound to be poor (below 75 %).

Although the minimum mean temperature (14.3 °C) in 2015/16 season was below an acceptable minimum of 18 °C, the range of 14.3 °C and 30.7 °C was close to an optimum germination range. Hence, that temperature range was bound to stimulate a positive effect on germination (Cilliers, 2013). Germination percentage attained in the 2015/16 season was 97 %. Temperatures during the growing seasons were moderately high but decreased towards winter season, which occurred as the crop was reaching maturity. However, maximum temperatures remained above 20 °C (2014/15) and 26 °C (2015/16) respectively until April.

The ambient percentage relative humidity during harvesting (2014/15 and 2015/16 seasons) was considered favourable, because according to Kamara (2010) percentage seed moisture content is determined by the relative humidity at harvest. Thus, the groundnut seed was able to attain 6.7 % moisture content and 6.2 % at harvest in 2014/15 and 2015/16 respectively, which is close to the 7 % recommended by Cilliers (2013) as optimum seed moisture content to start shelling. The balance between rainfall, relative humidity and temperature is considered an important determining factor for yield and quality in this area.

4.2.3 Yield (yield components) determination during growing seasons

Shelling percentage is regarded as the most important yield component because it determines the quality of kernels, i.e. the production of sound mature kernels (SMK), since the final yield depends on kernels (Gashti et al., 2012). Murata (2003) also reported that SMK is a good reflection of seed quality.

Yields in the 2014/15 season were not significantly different ($\rho > 0.05$) from various combinations of treatment with the average yield of 1 ton/ha. Moreover, it was observed that treatments with a combination of gypsum and lime recorded higher average yield. Murata (2003) also observed that plants treated with gypsum had the highest proportions of mature pods per plant, sound mature kernels, and shelling percentage, and the least percentage of pops.

However, when compared with the average yield of 1 ton/ha, yields in 2015/16 season were significantly different ($\rho \leq 0.05$), reaching a remarkable 2.9 ton/ha. Factors such as prevailing weather conditions during growing seasons and differences in soil chemical properties might have contributed to the differences in yields. As a result, 97 % germination was attained during the 2015/16 season, which was higher than 75 % germination as recorded during the 2014/15 season. Yield in 2015/16 was relatively higher than in 2014/15.

The statistical results of yield components such as pod yield, seed yield, dry shoot weight, and moisture percentage during both seasons were not significantly different at $\rho \leq 0.05$ level. The results of the present study show that the combination of gypsum and lime at the application rate of 500 kg/ha gypsum and 250 kg/ha lime produced the highest shelling percentage of 65 %. The highest application rate of gypsum alone at 1000 kg/ha produced the highest shelling percentage of 60 %, as well as increased the SMK weight.

Similar observations were made by Gashti et al. (2012) and Murata (2003) who report that the application of 1000 kg/ha of gypsum increased kernel yield, resulting in a positive correlation between shelling percentage and kernel weight, i.e. bigger kernels. The researchers further observed that gypsum application increased sound mature kernels to 87 %. According to Gashti et al. (2012), this is because gypsum is relatively more soluble than lime and is easily absorbed. This suggests that gypsum application increases yield and improves the quality of peanuts. Conversely, Taruvinga (2014) observed that gypsum application at the rate of 150 kg/ha increased shelling percentage. According to Kamara (2010), treatments with 100 kg/ha calcium or 200 kg/ha calcium gave higher shelling percentages and 100 seed weight.

The highest application rate of lime alone at 750 kg/ha produced 49.3 % shelling percentage, which was lower than 50.3 % recorded for lime alone, at the application rate of 500 kg/ha. Hence, it is more economical to apply lime at the rate of 500 kg/ha than at the rate of 750 kg/ha in terms of increasing shelling percentage. The combination of gypsum and lime application at the rate of 500 kg/ha and 750 kg/ha recorded the highest pod yield yet, with the control being the lowest. Murata (2003) observed that 4000 kg/ha of lime increased the proportion of mature pods to 74 %.

Results of the present study indicate that the combination of gypsum and lime (1000 kg/ha gypsum and 500 kg/ha lime) increased the seed yield with the control being the lowest. However, gypsum application (1000 kg/ha) also increased seed yield more than the lime application (750 kg/ha) does. These results support the assertion by Cheema et al. (1991) that the application of 1000 kg/ha of gypsum at the time of flowering increased seed yield under rainfed conditions.

Results from the experiments with the dry shoot weight indicated that the application of lime alone, at the rate of 750 kg/ha increased shoot weight, while the combination of gypsum and lime (1000 kg/ha and 750 kg/ha) application did not significantly affect shoot weight. According to Kamara (2010), the shoot weight attribute is associated with vegetative growth of the crop, and the increase in shoot weight is due to phosphorus application. Phosphorus is known to promote the development of more extensive root systems and to enable the plants absorb more water and nutrients from the soil. These attributes are reflected in the high biomass. Hence, the application of lime at the rate of 750 kg/ha in the present study served as a catalyst and made the application of phosphorus (MAP + zinc) effective in enabling the plants to absorb more water and nutrients from the soil, as well as increasing the shoot weight (vegetative growth).

The average moisture content of seeds at harvest was 6.7 %, which is close to the seed moisture content recommended by Cilliers (2013) to start shelling. Gypsum application at the rate of 500 kg/ha significantly affected the percentage seed moisture content, while the combination of gypsum and lime (1000 kg/ha and 750 kg/ha) gave the lowest seed moisture content. The highest application rate of gypsum (1000 kg/ha) also produced higher percentage seed moisture content than lime application rate of 750 kg/ha in terms of percentage seed moisture content at harvest. Kamara (2010) reported that groundnut seed moisture content was not affected by biological, chemical, or organic fertilizers but rather by relative humidity of the surrounding atmosphere at the time of harvest.

In the present study, there was no statistically significant difference from various combinations of treatment ($\rho > 0.05$), with the average yield being 1.5 ton/ha. Moreover, it was observed that treatments with combination of gypsum and lime recorded higher average yield. Murata (2003) observed that plants treated with gypsum had the highest proportions of mature pods per plant, sound mature kernels, and shelling percentage, and the least percentage of pops.

The soil in the experimental site conducted during 2015/16 growing season was non-acidic. Hence, a single calcium source (gypsum) was applied. Based on the results of the present study, the application of gypsum at the rate of 750 kg/ha produced the highest shelling percentage of 65.3 %, thereby increasing SMK, which suggested the improvement of yield and quality of groundnuts. This shelling percentage was higher than the 65 % shelling percentage produced by the combination of gypsum and lime application (500 kg/ha gypsum and 250 kg/ha lime) in the first experiment. No significant difference was observed between gypsum treatments in 100 seed weight. The average seed weight was 44.9. Gypsum fertilization (1000 kg/ha) exhibited a significant effect on 100 seed weight at $\rho \leq 0.05$ level. However, Kamara (2010), observed that 100 kg/ha calcium or 200 kg/ha calcium gave higher percentage of 100 seed weight.

The application of gypsum at the rate of 750 kg/ha produced a significantly highest pod yield with the control being the lowest, while the highest pod yield in the first experiment was produced by the combination of gypsum and lime application (500 kg/ha gypsum and 750 kg/ha lime). The highest gypsum application rate at 1000 kg/ha decreased pod yield far below the pod yield produced by gypsum application rate of 500 kg/ha. Results of the present study (2015/16 season) indicate that the application of gypsum at the rate of 750 kg/ha significantly increased the seed yield while the application of 1000 kg/ha gypsum, reduced seed yield. In the first experimental site (acidic soil), 1000 kg/ha gypsum application increased seed yield. On the other hand, Kamara (2010) observed that the application of calcium at the rate of 100 kg/ha had a significant effect on pod and seed yields at $\rho \leq 0.05$ level.

Results from the experiments with the dry shoot weight indicated that the application of gypsum (500 kg/ha) increased shoot weight, while the highest application rate of gypsum (1000 kg/ha) did not significantly affect shoot weight. The application of lime at the rate of 750 kg/ha significantly increased shoot weight (first experiment). A similar observation was made by Kamara (2010) that the application of calcium at the rate of 100 kg/ha and 200 kg/ha had significantly higher dry shoot weight than the control.

The average moisture content of seeds at harvest was 6.2 %, which is close to the seed moisture content (7 %) as recommended by Cilliers (2013) to start shelling. Gypsum application (750 kg/ha) significantly affected the percentage seed moisture content, while the gypsum application rates at 500 kg/ha and 1000 kg/ha gave the lowest seed moisture content. The study conducted by Kamara (2010) revealed that the application of calcium did not significantly influence the moisture content of the seed.

To sum up, grain yield was not significantly different at $\rho \leq 0.05$ level in both experimental sites. However, when compared with dryland production average of 1 ton/ha it was significantly above the dryland production benchmark, reaching the average of 2.5 ton/ha. The highest yield obtained was 2.97 ton/ha at the application rate of 750 kg/ha gypsum, followed by 1000 kg/ha of gypsum application rate, which produced 2.46 ton/ha. This suggests that gypsum application rate of 750 kg/ha increases the shelling percentage as well as grain yield of groundnuts. Visual observation attests that 0 kg/ha, 750 kg/ha and 500 kg/ha of gypsum produced better quality grade compared to 1000 kg/ha application rate of gypsum.

4.2.4 Leaf calcium concentration analysis and other elements

According to Murata (2003), leaf analysis is important for determining the nutritional health of plants. The results for leaf samples were not significantly different at $\rho \leq 0.05$ level, implying that gypsum and lime applications did not affect the levels of calcium concentration in the leaves of groundnuts.

Murata (2003) reported that the established nutrient sufficiency level for calcium in the groundnut leaves is 1.2 to 2.0 %. The grand mean for leaf calcium percentage analysis was 0.92. The highest mean for leaf calcium percentage was 1.1243 at gypsum and lime combined application rates of 1000 kg/ha and 500 kg/ha, and the lowest mean was 0.7078 at gypsum alone application rate of 1000 kg/ha. These values were below the established sufficiency level, which means that neither gypsum nor lime alone treatment affected leaf calcium concentration.

All the calcium sources investigated in the present study generally produced an increase in leaf calcium concentration, an observation that apparently contradicts that of Murata (2003). However, the increases in leaf calcium concentration in the present study were the highest with gypsum application at the immediate application rates. Similarly, the other elements determined did not affect the levels of calcium concentration in the leaves of groundnuts.

The established nutrient sufficiency level for magnesium in groundnut is 0.3 to 0.8 % (Murata, 2003). The highest mean of leaf magnesium concentration was 0.45 at the combination of gypsum and lime (1000 kg/ha gypsum and 500 kg/ha lime). The lowest mean was 0.35 at the application rate of 500 kg/ha lime. The application of lime (DL) alone at the rate of 500 kg/ha produced high leaf magnesium concentration, which is attributed to the fact that DL contains magnesium (Murata, 2003).

Results of leaf samples for the second season (2015/16) were significantly different at $\rho \leq 0.05$, meaning that gypsum application did affect the levels of calcium and aluminium concentration in the leaves of groundnuts, but other elements (sodium, zinc, boron, nitrogen and carbon) were not significantly different. However, aluminium and calcium elements were significantly different at $\rho \leq 0\ 05$ level. This suggests that different gypsum application rates contributed in the movement and concentration of aluminium and calcium in groundnut leaves. Increased soil pH levels also contributed in the balanced absorption of all essential elements by groundnut roots (Murata, 2003).

CHAPTER 5

CONCLUSIONS

5.1 CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to determine the relative effect of calcium source (gypsum) on yield and quality of groundnut (*Arachis hypogaea* L.) in OKhahlamba Local Municipality, KwaZulu-Natal province, South Africa. Findings from the experiments suggest that the use of gypsum as a source of calcium represents a better source of calcium fertilizer for obtaining higher yields and improving the quality of groundnut produced in OLM.

The studies have provided a detailed understanding on the efficacy of gypsum and lime application under different combinations of agricultural parameters and weather conditions. Analysis of these findings and the contents of this thesis are being transformed into an "easy-to-understand" format for transmission to the OLM Authorities, farmers, and the local community. To enhance the participation of smallholder farmers in the project, an information day was organised. Local farmers from OLM were invited. Agricultural scientists from Dundee Research Station conducted lessons on groundnut production. The focal point of lessons was the effect of calcium fertilizer application (particularly gypsum) on yield and quality of groundnuts. The potential benefits to these stakeholders would be immense, as it would affect, *inter alia*, the commercial standing of the Municipality.

5.1.1 Conclusions

From the study, the following conclusions can be drawn.

The application of 500 kg gypsum/ha alone acted as a liming factor for legumes, decreasing acid stress on nodulating bacteria, and improved soil chemical properties (increased soil pH), vegetative growth, yield, and quality of groundnut.

The application of 1000 kg gypsum/ha improved seed yield, shelling percentage, as well as sound mature kernel (SMK), yield and quality of groundnut under dryland conditions.

The application of 500 kg gypsum per hectare in combination with 250 kg lime per hectare produced the highest shelling percentage.

The application of 500 kg gypsum per hectare in combination with 750 kg lime per hectare increased pod yield.

The application of 1000 kg gypsum per hectare in combination with 500 kg lime per hectare increased seed yield as well as SMK, whereas the application of 1000 kg gypsum alone per hectare also increased seed yield.

The application of 750 kg lime per hectare was more effective as an acid ameliorant; thus leading to improvement of the chemical composition of the soil (increased soil pH) and shoot weight of groundnut. This application acted as a catalyst that stimulated the production of phosphorus, which enhanced the growth of extensive root systems for absorbing water and nutrients.

Yields were not significantly different at $\rho \leq 0.05$. However, when compared with the average yield of 1 ton/ha, yields were significantly different reaching a remarkable 2.9 ton/ha. Based on data on yield, yield components, and soil chemical properties, it is concluded that gypsum is the best calcium source fertilizer for groundnut production in OLM and lime should only be applied on acid soils to attain optimum groundnut yield in the region.

The seed maturity and quality of groundnut in this study were determined largely by the shelling percentage, pod and seed yield (SMK), as well as were influenced by gypsum and lime application and the amount of rainfall in the growing season.

5.1.2 Recommendations

From the findings of this study, it is recommended that:

Trials should be repeated in multiple locations to increase the statistical power to confirm the results of this study whereby the effect of lime, gypsum, and single superphosphate (SSP) on yield and quality of groundnut in UThukela District Municipality will be investigated further.

Gypsum should be used particularly by smallholder farmers as a calcium source fertilizer to improve yield and quality of groundnut, and as a liming factor. This is so, because it is shown to be uneconomical to use the combination of gypsum and lime.

Lime should only be used if the soil is acidic, in order to raise the pH and supply calcium to the pegging zone.

Smallholder farmers should grow groundnut after maize, because groundnut responds well to fertilizer applied to the previous crop (residual) rather than to direct application. Maize, on the other hand, responds well to nitrogen left over by groundnut, since groundnut is a legume crop, and is good in nitrogen fixation. Thus, the farmers would be able to save money using less fertilizer while maintaining the soil fertility and soil health.

Smallholder farmers should be made aware of these cost-effective guidelines, which are based on sound scientific findings. They would thereby be able to enhance yield and quality of groundnut, and hence make an immense contribution towards improving the nutritional and food security status of the region. The attainment of high yields would mean that farmers would secure sufficient surplus that could be sold for generating valuable income for improving their standard of living, and eventually joining the mainstream of groundnut industry in South Africa.

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APPENDICES

Appendix 1: Nutrient contents in one ounce (28.35 g) of raw groundnut kernels (adapted from: Nigam, 2014).

No	Nutrient	Amount	% Daily requirement	Functions/Remarks
1.	Calories	161.0	n/a	Energy rich food due to its fat content; a very high proportion of unsaturated fats and high satiety value makes groundnut part of healthy food
2.	Protein	7.3 g	14.2 %	A powerhouse of less expensive vegetable protein
3.	Total carbohydrates	4.6 g	1.5 %	Good for diabetic diets due to its low Glycaemic Index (a measure of the at which carbohydrates from a particular food breakdown and release glucose in blood stream)
4.	Dietary fibre	2.4 g	9.4 %	Reduces risk of some types of cancer, helps control blood sugar levels, and may help reduce the levels of cholesterol in blood
5.	Total fat	14.0 g	21.8 %	Concentrated source of energy, provides essential fatty acids, carries fat soluble vitamins such as A, D and E and helps maintain healthy skin; suitable for Indian style of cooking due to its high smoking point (240^{o}C)
	Saturated fat	1.9 g	9.5 %	A low proportion of saturated fat (bad fat); saturated fat intake should be less than 10 % of the total daily intake of calories

	Monounsaturated fat	6.9 g	n/a	Monounsaturated fats help to remove cholesterol from the blood, thus giving protection from heart attack
	Polyunsaturated fat	4.4 g	n/a	Along with monounsaturated fats, polyunsaturated fats are healthy and necessary for the healthy body
6.	Vitamin E	2.4 mg AT	17.5 %	Vital antioxidant, which protects Vitamin A and the body's cells and tissues from damage; important for the immune system and might aid in the prevention of tumour growth; plays a role in preventing coronary heart disease
7.	Folate	68 mcg	16.5 %	Important for the development of new cells in the body, particularly during growth and pregnancy; helps to prevent birth defects
8.	Niacin	3.26 mg	16.3 %	Functioning in more than 50 of the body processes, niacin is primarily important in the release of energy from the food that we eat as well as in maintenance of healthy skin, the nervous system, and the digestive tract
9.	Thiamine (B_1)	0.18 mg	12 %	Needed to ensure normal functioning of the nervous system, appetite, and digestion
10.	Riboflavin (B_2)	0.04 mg	21.3 %	Releases energy from the food we eat, helps skin stay healthy, and assists in the normal functioning of the eye

11.	Vitamin B_6	0.10 mg	5.7 %	Makes and breaks down proteins in the body and makes red blood cells used to transport oxygen in the body
12.	Zinc	0.93 mg	5.9 %	Aids in the formation of protein, wound healing, blood formation, taste perception, appetite, night vision, general growth and maintenance of all tissues
13.	Copper	0.32 mg	15.2 %	Important in the formation of haemoglobin, health of bones, blood vessels, and nerves
14.	Selenium	2.0 mcg	2.8 %	A trace element required in small quantities for normal functioning of the immune system
15.	Magnesium	48 mg	12.5 %	Important in the building of bones and teeth, creation of protein, transmission of nerve impulses, and maintenance of body temperature
16.	Phosphorus	107 mg	10.6 %	Component of all soft tissues that are fundamental to growth, maintenance, and repairs of bones and teeth
17.	Potassium	200 mg	5.3 %	Needed to ensure water balance in the body and in the creation of protein; helps in the release of energy from nutrients and aids in nerve impulse transmission
18.	Calcium	26 mg	3.5 %	Needed for development and maintenance of healthy bones and teeth
19.	Sodium	5 mg	0.22 %	Naturally low sodium food

20.	Iron	1.3 mg	8.1 %	Aids in transport and distribution of oxygen the body’s cells
21.	Boron	1.0 mg	100 %	Major factor in the metabolising of calcium in the body and plays significant role in development and maintenance of strong and healthy bones
22.	Cholesterol	0.0 mg	–	Free from cholesterol
23.	Arginine	0.88 g	n/a	Improves wound healing and immunity
24.	Total Phytosterols	62.4 mg	n/a	These phytochemicals help to prevent diseases and enhance health
25.	Resveratol	73 mcg/g without skin	n/a	Ounce for ounce groundnuts have about half of the amount of resveratol in wine (160mcg/g); resveratol, a photochemical, has a possible role in reducing cancer and can inhibit build-up of platelets blood vessels; a potent antioxidant which can reduce the oxidation of LDL cholesterol
26.	Beta-sitosterol	18.4 mg	n/a	Has anticancer properties and prevents cholesterol uptake
1 = USDA Database for Standard Reference.				

Appendix 2: Yield components data collected during 2014/15 season

Plot	Shoot weight (kg/ha)	Unshelled (kg/ha)	Shelled (kg/ha)	Shelling %	Moisture %
1.	**7**	1.070	0.335	31	6.6
2.	9	1.645	0.840	51	6.8
3.	7.5	1.585	0.905	57	7.2
4.	7.5	1.120	0.850	75	7.2
5.	10	2.470	0.440	17	6.8
6.	8.5	2.535	1.280	50	5.8
7.	8.5	2.180	1.470	67	7.0
8.	7.5	2.530	1.650	65	6.2
9.	9	0.895	0.390	43	6.9
10.	8.5	1.290	1.140	88	7.0
11.	10	2.235	0.965	43	6.9
12.	5	1.905	0.980	51	6.9
13.	9	2.700	0.965	35	6.3
14.	10	1.430	0.0.735	51	7.1
15.	10	2.555	1.470	57	6.6
16.	10.5	3.220	2.115	65	6.8
17.	8	1.780	0.845	47	6.8
18.	9.5	2.875	1.915	66	7.2
19.	9	2.120	1.225	57	7.3
20.	9.5	2.105	1.090	51	6.8
21.	10.5	2.725	0.495	18	6.6
22.	8	1.095	0.345	31	7.5
23.	10.5	1.230	0.580	47	6.7
24.	10	2.905	1.575	54	7.1
25.	8.5	1.850	1.150	62	6.8
26.	8	1.590	0.697	43	6.7
27.	8	1.580	0.760	48	7.2
28.	8.5	1.850	1.110	60	6.3
29.	10	2.605	1.328	50	6.8

30.	10	1.475	0.545	36	7.0
31.	11	2.465	0.525	21	7.2
32.	10	2.713	0.130	4	6.7
33.	6	1.025	0.280	27	8.3
34.	5.5	0.790	0.385	48	7.6
35.	7.5	2.255	1.360	60	5.8
36.	7.5	1.860	1.620	87	6.8
37.	5	1.820	1.110	60	6.3
38.	10	2.395	1.355	56	5.2
39.	8.5	2.180	1.350	61	5.0
40.	10	2.970	2.100	70	6.6
41.	7.5	1.630	1.155	70	6.4
42.	6	0.800	0.400	50	6.4
43.	8	1.795	0.720	40	5.8
44.	7.5	1.715	1.155	67	6.7
45.	8	1.980	1.050	53	7.4
46.	10	1.635	0.765	46	6.8
47.	9	2.145	1.415	65	4.7
48.	9.5	2.470	1.805	73	6.1

Appendix 3: Yield components data collected during 2015/16 season

Plot	Shoot weight (kg/ha)	Unshelled (kg/ha)	Shelled (kg/ha)	Shelling %	Moisture %	100 seeds weight g
1.	7.165	5.875	3.500	59.574	5.9	41.0
2.	7.550	6.095	3.625	59.475	6.2	40.5
3.	7.555	5.890	3.475	58.998	5.9	39.0
4.	6.350	6.230	3.880	62.279	6.0	38.0
5.	6.615	6.435	3.385	52.603	6.3	48.5
6.	6.615	5.540	3.395	61.282	6.2	45.5
7.	5.875	4.695	2.950	62.833	6.2	40.0
8.	3.490	3.610	2.080	57.618	6.8	44.5
9.	6.060	5.490	2.975	54.189	6.3	48.0
10.	7.110	7.145	3.465	48.495	6.0	39.0
11.	3.330	4.415	3.090	69.989	7.0	47.5
12.	9.987	9.555	5.465	57.195	6.8	41.0
13.	5.671	5.600	3.345	59.732	6.3	40.0
14.	6.115	5.715	3.265	57.130	6.0	37.5
15.	7.036	5.135	1.445	28.140	6.2	44.0
16.	8.678	7.955	3.505	44.060	6.8	39.5
17.	8.405	4.230	2.5556	60.402	6.0	48.5
18.	7.510	5.875	3.560	60.596	5.9	49.5
19.	5.845	5.375	3.255	60.558	5.8	45.0
20.	7.230	6.520	3.690	56.595	6.3	44.5
21.	6.915	5.840	2.580	44.178	7.3	43.5
22.	6.905	5.445	3.215	59.045	6.3	47.0
23.	7.095	5.210	3.835	73.608	6.0	47.0
24.	6.560	6.185	4.660	75.344	5.9	48.5
25.	6.495	4.405	2.585	58.683	5.9	45.5
26.	7.765	7.420	3.850	51.887	5.9	45.5
27.	8.885	7.790	4.940	63.415	6.3	47.0
28.	7.710	7.700	4.450	57.792	6.0	41.5
29.	7.640	6.505	2.100	32.283	5.8	49.5

30.	8.270	7.230	4.730	65.422	5.8	48.5
31.	7.040	4.345	3.180	73.188	5.9	47.0
32.	5.814	5.780	3.665	63.408	7.1	50.0
33.	8.655	1.480	0.915	61.824	5.6	42.0
34.	9.987	8.945	3.820	42.705	6.3	47.0
35.	7.975	7.235	4.025	55.632	5.6	42.0
36.	8.620	7.130	4.305	60.379	6.9	42.0
37.	7.850	7.220	4.690	64.958	5.9	45.0
38.	9.455	4.885	2.885	59.058	5.9	44.5
39.	7.215	7.460	4.750	63.673	5.9	46.5
40.	8.235	7.485	4.100	54.776	7.5	46.5
41.	5.150	0.985	0.420	42.640	6.0	47.5
42.	9.635	7.885	4.620	58.592	6.2	46.5
43.	6.245	5.600	5.125	91.518	5.9	43.5
44.	9.987	9.755	6.620	67.863	6.0	49.0
45.	8.025	7.750	4.325	55.806	5.9	46.0
46.	8.685	7.445	5.915	79.449	6.4	44.0
47.	8.170	7.785	4.870	62.556	6.5	51.0
48.	7.070	6.720	4.175	62.128	6.1	48.5

Appendix 4: Descriptive statistics on key variables

	N	Minimum	Maximum	Mean	Std. deviation
Unshelled kg	48	1	3	1.95	.622
Shelled kg	48	0	2	1.02	.490
Shelling %	48	4	88	51.54	17.240
Dry shoot weight kg	48	5	11	8.65	1.391
Moisture %	48	5	9	6.71	.714
Initial soil pH	48	4	4	3.78	.000
Soil pH harvest	48	4	5	4.34	.199
EC mS/m harvest	48	29	266	89.52	44.189
Leaf analysis Ca %	48	1	1	.92	.198
Leaf analysis Na mg/kg	48	89	336	171.18	51.096

Appendix 5: Analysis of variance (ANOVA)

Source of variation	**Degree of freedom (d.f.)**
Block stratum	2
Block. Plots stratum	
GYPSUM	3
LIME	3
GYPSUM. LIME	9
Residual	30
Total	**47**

Appendix 6: Ethical clearance for groundnut research project

UNISA

2014-07-25

Ref. Nr.: 2014/CAES/060

To:
Student: GS Sikhakhana
Student nr: 07658397
Supervisor: Prof TC Davies
Department of Agriculture and Animal Health
College of Agriculture and Environmental Sciences

Dear Prof Davies and Mr Sikhakhana

Request for Ethical approval for the following research project:

Evaluation of the effect of calcium source (gypsum) application on groundnuts yield and quality in Ladysmith local municipality, Kwazulu-Natal, South Africa

The application for ethical clearance in respect of the above mentioned research has been reviewed by the Research Ethics Review Committee of the College of Agriculture and Environmental Sciences, Unisa. Ethics clearance for the above mentioned project (Ref. Nr.: 2014/CAES/060) is **given** for the duration of the study.

Please be advised that should any part of the research methodology change in any way as outlined in the Ethics application (Ref. Nr.: 2014/CAES/060), it is the responsibility of the researcher to inform the CAES Ethics committee. In this instance a memo should be submitted to the Ethics Committee in which the changes are identified and fully explained.

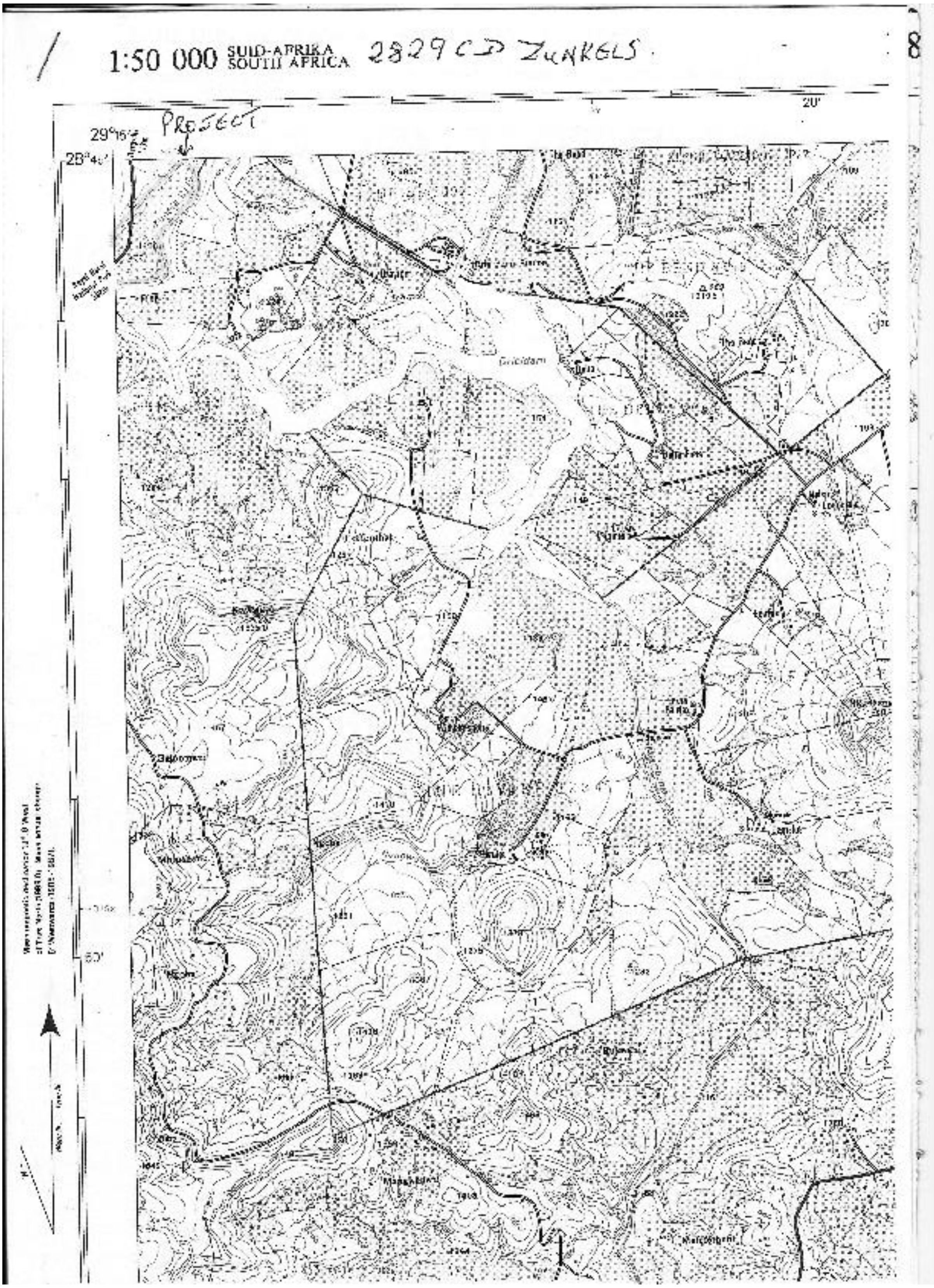
The Ethics Committee wishes you all the best with this research undertaking.

Kind regards,

Prof E Kempen,
CAES Ethics Review Committee Chair

p|p 30|7|2014
Prof MJ Linington
Executive Dean: College of Agriculture and Environmental Sciences

Appendix 7: Groundnut research project locality map



Appendix 8: Soil sampling log sheet (2014/15 season)

SOIL SAMPLING LOG SHEET

Collector: G.S. Sikhakhane

Date: 16 July 2014

Location and GPS coordinates: Bergville

Latitude: 28° 45' 29.71" S

Longitude: 29° 15' 11.92" E

Sampling equipment: Soil sampler

Sampling area (size): 126.5 m^2

Number of samples and sampling pattern: The number of cores taken was 35 following a zig-zag pattern. Samples were thoroughly mixed up and one composite sample was placed in a soap box and sent to laboratory for nutrients, soil pH and cation exchange capacity (CEC) analysis.

Sampling depth: 15cm using soil probe sampling equipment

Soil type and texture: Soil classified as Oakleaf form with good structure

Soil colour: Redish brownish

Previous land use: The land was previously on maize

Current land use: The land is currently on groundnuts

Appendix 9: Soil sampling log sheet (2015/16 season)

SOIL SAMPLING LOG SHEET

Collector: G.S. Sikhakhana

Date: 23 July 2015

Location and GPS coordinates: Bergville

Latitude: 28° 45' 46.88 S

Longitude: 29° 12' 17.31 E

Sampling equipment: Soil Sampler (Soil probe)

Sampling area (size): 1265 M^2

Number of samples and sampling pattern: The number of cores taken was 25 following a zig-zag pattern. Samples were thoroughly mixed and one composite sample was placed in a 500g box and sent to laboratory for nutrients, soil pH, electrical conductivity (EC), soil P and cation exchange capacity (CEC) analysis

Sampling depth: 15 cm

Soil type and texture: Soil classified as Oakleaf soil form with good structure

Soil colour: Reddish/brownish

Previous land use: The land was previously on sweetpotatoes

Current land use: The land is currently on groundnuts