GROWTH, YIELD AND QUALITY RESPONSE OF BEET (*BETA VULGARIS* L.*)* TO NITROGEN

by

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DECLARATION

I hereby declare that the dissertation submitted by me for the qualification Magister Scientiae Agriculturae degree at the University of the Free State is my own independent work and has not previously been submitted by me at another University/faculty for a degree either in its entirety or in part.

I furthermore cede copyright of the dissertation in favour of the University of the Free State.

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DEDICATION

I dedicate this work to my family: Mr Peter Phakedi Rantao (dad), Mrs Josphine Diketo Rantao (mum), to my brothers and sisters for their moral, emotional and spiritual support, as well as their prayers and encouragement during the course of my studies.

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GROWTH, YIELD AND QUALITY RE-SPONSE OF BEET (*Beta vulgaris* L.*)* TO NITROGEN

ABSTRACT

To study the quality response of beetroot to nitrogen fertilizers, a pot trial was conducted in the glasshouse facility of the Department of Soil, Crop and Climate Sciences, Faculty of Natural and Agricultural Sciences, University of the Free State, during the 2011 season. The effect of five nitrogen sources (limestone ammonium nitrate, ammonium nitrate, urea, ammonium sulphate and urea ammonium nitrate) at five nitrogen levels (0, 50, 100, 150 and 200 kg N ha^{-1}) on beetroot (Detroit Dark Red) on a Bainsvlei soil type was investigated. The data collected was analyzed using Tukey's Least Significant Difference test, at 5% level of significance to determine statistically significant differences between means.

The results showed that all fertilizers used resulted in a reduction in plant height for the first six weeks of growth. Nitrogen application only increased plant height significantly from week 8 where the height of plants that received nitrogen, irrespective of the fertilizer used, were significantly taller than control plants. At week 8 no significant differences in height were noted between various nitrogen application rates, but by week 10 significant differences in plant height were noted between the 50 kg N ha^{-1} and 150 kg N ha^{-1} or 200 kg N ha^{-1} application rates. The findings showed that beet plants reacted better to N-fertilization using ammonium sulphate nitrate and urea ammonium nitrate than other nitrogen sources, although limestone ammonium nitrate and ammonium nitrate also produced improvements in plant growth, whereas plants that received urea showed no improvements.

Nitrogen at 100 kg ha^{-1} resulted in more leaves per plant than its application at other levels. Urea ammonium nitrate as a nitrogen source significantly improved plant leaf area, leaf fresh mass, total fresh mass and root diameter. Application of nitrogen at 200 kg ha^{-1} also increased leaf area, leaf fresh mass, total fresh mass, beet diameter and beet volume. Urea ammonium nitrate increased leaf dry mass by an average of 397% while the lowest leaf dry mass by (139.42% of control) was observed with the use of limestone ammonium nitrate as a nitrogen source. The greatest leaf dry mass was obtained at the highest rate of nitrogen application (200 kg ha^{-1}) and the lowest leaf dry mass was observed at the control level. Beet yields were found to increase as the nitrogen application rate increased, from 2.99 t ha^{-1} in the control treatments to 14.37 t ha^{-1} in the treatments that received 200 kg N ha^{-1}. Fertilizing with urea ammonium nitrate gave the highest yields (12.17 t ha^{-1}), while using limestone ammonium nitrate gave the lowest yields (9.00 t ha^{-1}).

Application of nitrogen at 50 kg ha^{-1} resulted in firmer beets than nitrogen application at other levels. Beets from plants that did not receive any nitrogen were significantly softer than those that received nitrogen at higher levels. The darkening of beet colour (decrease of L^*) was experienced at the control level while the highest changes of colour (increase of L*) was obtained at the highest nitrogen level. Nitrogen at 100 kg ha^{-1} influenced the lowest change of coefficient a from red to green while the control level resulted in more intensive change. The results showed that nitrogen at the control level led to more intensive changes of coefficient b colours from yellow to blue and its application at the highest level resulted in less intensive changes of coefficient b colours from yellow to blue.

Neither nitrogen source nor nitrogen level had any effect on the pH, sucrose or fructose contents of the roots. Application of nitrogen at 150 kg ha^{-1} resulted in greater total soluble solids content in the roots, while the starch content of plants that received no nitrogen was significantly greater than that of plants receiving nitrogen. Nitrogen application at 100 kg ha^{-1} and at the control level influenced the glucose content, which was significantly higher in these plants than in those that received 50, 150 and 200 kg N ha^{-1}, however, the highest glucose content of the roots was observed at the control level.

Nitrogen application at 200 kg ha^{-1} resulted in higher nitrogen content in the leaves as compared to application of other nitrogen sources at different levels. Limestone ammonium nitrate influenced potassium content of the leaves more than other nitrogen sources. Nitrogen application at 200 kg ha^{-1} resulted in a greater calcium content in the leaves than other nitrogen sources. The highest sodium content of the leaves was observed at 150 kg N ha^{-1} while the lowest sodium content was observed at 50 kg N ha^{-1}. Urea ammonium nitrate had a greater positive influence on the manganese content of the leaves than other nitrogen sources. Plants that received no nitrogen had significantly greater levels of iron in the leaves than at all nitrogen levels. Ammonium nitrate as a nitrogen source influenced the calcium content of the beets more than other nitrogen sources. Other root minerals such as phosphorus, potassium, sodium, magnesium, manganese, copper, iron and zinc were not significantly influenced by nitrogen source or nitrogen level, or the interaction between these factors.

Keywords: Beetroot, *Beta vulgaris* L., limestone ammonium nitrate, ammonium nitrate, urea, ammonium sulphate, urea ammonium nitrate, growth, yield, quality, nitrogen source, nitrogen level.

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CHAPTER 1

INTRODUCTION

Beetroot (*Beta vulgaris L.*) is a member of the Chenopodiaceae family that originated from Germany (Thompson, 2001) and includes silver beet, sugar beet and fodder beet (Deuter & Grundy, 2004). Beetroots are biennials although they are usually grown as annuals producing green tops and swollen roots during the first growing season. The different ways that beetroot are used is in salads, as a hot vegetable to accompany meat and fish, and in pies, in addition to methods for their preservation such as pickling and canning. Beetroot is a good source of minerals, carbohydrates, protein and it has high levels of vitamin B_1 and micro nutrients (Cerne & Vrhovnik, 1999). Considered as a vegetable, beetroot may have many positive influences on human health (Cerne & Vrhovnik, 1999). Beetroot juice is today advocated as a stimulant for the immune system, as well as a cancer preventative and it has long been considered beneficial to the blood, heart and the digestive system (Nottingham, 2004).

It grows best under cool conditions and can be grown successfully almost all year round. The best quality beetroot are obtained if it is cultivated under cool, moist conditions. In South Africa the main beetroot producing regions are North West, Gauteng, Mpumalanga, Kwazulu Natal and Western Cape. The sowing times differ with production areas. In winter rainfall areas seed can be sown from August to end of March and from end of August to middle of March in areas with cool summers. However, seed is sown from March to August in the Lowveld regions of Mpumalanga and Kwazulu Natal. Sowing in the Free State, Northern Cape and Central Karoo is from February to March and from June to December. In the formerTransvaal and Free State Highveld sowing is from January to March and from July to October (Wagner, 1992).

The gross value of beetroot production has shown a steady growth, except for the year 2004 where there was a slight decline (National Department of Agriculture, 2009). This decline can be attributed to the slight decline in prices received by farmers during this period. The greatest contribution of this industry to the gross value of agricultural production was recorded in the 2008 production season when the highest production occurred while the prices were still in the favourable position for the producers. Beetroot is grown all over the world in temperate areas and the world production in the year 2005 was 241 985 317 Mt. The average beetroot production in South Africa is approximately 37 000 tons per annum. This indicates that South Africa is self sufficient in terms of beetroot production and the surplus beetroot is exported (National Department of Agriculture, 2009).

Adequate supply of N fertilizers to beetroot promotes growth, and increases both yield and quality when applied at optimum rates (Goodlass *et al*., 1997). Nitrogen is crucial in nutrition of beetroot. This element is required for plant growth and is an important component of proteins, enzymes and vitamins in plants. Intensive application of fertilizer mixtures can cause excessive nitrogen in crops. Since vegetables are the most important source of nitrate in human nutrition, the concern for its accumulation in fresh foods is higher than others (Hemmat *et al.,* 2010). Nevertheless, nitrate accumulation in beetroot can have a detrimental impact on human health. After entering the human body, nitrate can be reduced to nitrite which can enter the blood stream and induce methomoglobinemia (Hemmat *et al.,* 2010).

The effect of nitrogen fertilizers on beetroot yield and quality has been studied by many investigators. Webster (1969) reported that the maximum yield of beetroot was obtained when 264 kg N ha^{-1} of ammonium sulphate was applied to a soil. Wallace (1975) recommended that no N fertilizer be applied for beetroot. Wilson (1975) recommended cited field trials results which showed that the highest yields of spinach and beetroot were obtained at 400-500 and 300 kg N ha^{-1} respectively when a combination of ammonium sulphate and calcium ammonium nitrate was used. Badawi *et al.* (1995) reported that the maximum yield of beetroot was obtained when 260 kg N ha^{-1} of ammonium sulphate was applied to a sandy loam soil.

Excess nitrogen application also increases proline levels, partially by increasing leaf area index (Monreala *et al.,* 2007). On the other hand, root quality as TSS and sucrose were significantly decreased by increasing nitrogen rates (Moustafa *et al.,* 2000; Seadh, 2004). Nitrogen fertilizing is important and 300 to 400 kg N ha^{-1} of limestone ammonium nitrate or ammonium sulphate depending on soil analysis is applied in two or three dressings during the growing season, with 150 kg N ha^{-1} usually being applied at planting and the rest when plants are about 10 to 15 cm high.

The beetroot seed contains adequate N reserves to sustain the plant through germination. Once the seedling reaches the cotyledon stage, N in the soil is accessed by plant roots for leaf development. Adequate N is needed at this stage for optimum seedling growth and subsequent canopy development (Amber *et al.,* 2009). However, once the beetroot and the canopy have developed, continued uptake of nitrates from the soil can stimulate excessive canopy growth at the expense of sugars stored in the root. Excessive amounts of late season available N also increase concentrations of nitrates, salts, and other impurities in beetroot (Amber *et al.,* 2009).

Inorganic fertilizers are fertilizers mined from mineral deposits with little processing (e.g. lime, potash or phosphate rock), or industrially manufactured through chemical processes (e.g. urea) and they do not supply humus to the soil, so the nutrient and water holding capacity of the soil may be less than that found with organic fertilizers. This lower capacity as well as high solubility of inorganic fertilizer leads to faster leaching of nitrogen from the soil (Taiz & Ziger, 1991). Inorganic fertilizers vary in appearance depending on the process of manufacture. The particles can be of many different sizes and shapes (crystals, pellets, granules or dust) and the fertilizer can include straight fertilizers (containing one nutrient element only), compound fertilizers (containing two or more nutrients usually combined in homogeneous mixture by chemical interaction) and fertilizer blends (formed by physical blending mineral fertilizers to obtain desired nutrient ratios).

Beetroot production requires a fertile soil that will provide all the nutrients necessary to promote growth, yield and quality. Soils vary widely in their ability to supply nitrogen for plant growth (Thompson, 2001). This nitrogen supplying potential varies with soil type, past fertilization and cropping history, as well as rainfall received and the irrigation water applied that affects the extent of nitrogen loss from leaching soils. Most nitrogen fertilizer recommendations are based on past fertilization and cropping histories. Although some of these recommendations are reliable, there is a need for using both soil and tissue testing procedures for accurate fertilizer recommendations for maximum beetroot production (Thompson, 2001).

Shifting cultivation as practiced by small scale farmers in South Africa to restore soil fertility in sustaining cropping can no longer meet up with the increased need for food supply due to increasing population. The length of fallow period required to replenish the nutritional status of the soil in order to maintain soil productivity has to be shortened. These farmers also use whatever fertilizer sources they have to provide crops with essential elements for growth and development and the problem they are faced with is to know how much fertilizer to apply for a specific crop (Gontcharenko, 1994). Farmers have also increased application of nitrogen, phosphorus and potassium fertilizers year by year without considering the response of different species to the levels and sources (Wang *et al*., 2006).

Nitrogen (N) is by far the most abundant nutrient element taken up from soils and subsequently removed by a vegetable crop (Brandenburg, 1980). An adequate supply of nitrogen can promote plant growth and increase crop production (Collins & McCoy, 1997), but excessive and inappropriate use of nitrogen fertilizers causes accumulation of compounds such as nitrates, pigments and ascorbic acids in the edible products. The nitrogen forms taken up by plants are ammonium (NH_4^+) and nitrate (NO_3^-), with some plants showing preference for one or the other. Ammonium and nitrate nutrition directly influences the yield and chemical composition of vegetables (Collins & McCoy, 1997).

Nitrogen is necessary to produce a reliable and optimal yield of quality vegetables. It is however, the most difficult element to manage in a fertilization system in order to ensure an adequate, yet not excessive amount of available nitrogen within the rhizosphere from planting to harvest (Peck, 1981). A crop that is over fertilized with nitrogen may be more susceptible to diseases than those that are not, or may have elevated nitrate levels in vegetable tissues (Everaats, 1994). Vegetable crops such as brussel sprouts have been found to have a bitter taste when over fertilized with nitrogen and produce undesirable elongated sprouts.

Many studies have been conducted to compare the influence of nitrogen fertilizers on the growth, yield and quality of beet (Goh & Vityakon, 1983; Cerne & Vrhovnik, 1999; Bok *et al*., 2003; Deuter & Grundy; 2004). However, most of these studies concentrated more on fertilizers such as chicken manure, kraal manure, potassium nitrate, 2:3:2 (22), urea and LAN as nitrogen fertilizers and they did not consider the effects of other nutrient elements such as phosphorus and potassium contained in some of these fertilizers, or the effects of pathogens in organic fertilizers (Goh & Vityakon, 1983).

Lee *et al*. (1971) and Peck *et al.* (1974) paid more attention to the yield and aspects such as nitrates, pigments, ascorbic acids, betanines and accumulation of dry matter while concentrating less on growth parameters, or external and internal quality parameters such as root diameter and volume, defects, grading, firmness, pH, total soluble solids, sucrose, glucose and starch content and plant analyses. Their research focused more on the influence of fertilization with different nitrogen sources and levels only on the chemical composition of undesirable and desirable substances in beet. It is therefore, apparent that much more research is needed to better define nitrogen source and optimum level for the growth, yield and quality of beet.

The main objective of this study was to evaluate the growth, yield and quality response of beet to nitrogen fertilizers. Within this main objective the following two sub-objectives were identified:

- To determine the optimum rate of N to maximize growth, yield and quality of beetroot on a specific soil under controlled conditions.
- To evaluate the effect of different N sources and application rates on the growth, yield and quality of beetroot under controlled conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 Importance of nitrogen in beetroot production

Essential mineral elements may be classified as major elements or macro nutrients that are required in relatively large amounts (Bidwell, 1979). Nitrogen, phosphorus and potassium are three major nutrients of concern to producers. Nitrogen is usually more responsible for increasing the growth of plants than any other element. It is a component of proteins and is therefore involved in regulating most processes that occur in plants (Goncharenko, 1994). It is the most important element for beetroot in fertilizers, as few soils contain sufficient quantities in readily available form (nitrate or ammonium), to provide for maximum growth. Where there is shortage of nitrogen, yield is drastically reduced, and may even be halved on some soils. The fertilizer has a remarkable effect on the appearance of the crop, most noticeably by improving the colour and vigour of the leaf canopy. This has led to a widespread over-use of nitrogen, which decreases quality (Cooke & Scott, 1993).

Nitrogen is crucial in the nutrition of beet. It is an element that influences beet growth, yield and quality. Beet absorbs nitrogen in considerable quantities, but the optimum quantity is set within a limited range. It is referred to as a balance wheel of beet nutrition because of the fact that the efficiency of other nutrients is based on it (Sayed, 1988). Sayed (1988) showed that increasing nitrogen application to beet increased root and top dry mass, leaf area index and crop growth rate. EL-Shafei (1991) reported that increasing nitrogen fertilizer level led to a significant and gradual increase in root and top fresh mass plant^{-1}, and root dry mass accumulation compared to the control.

Sorour *et al.* (1992) and Nemeat-Alla (1997) reported that increasing nitrogen rates increased plant dry mass, crop growth rate, net assimilation rate and leaf area index. Sharief *et al*. (1997) reported that increasing nitrogen fertilizer rate up to 180 kg N ha^{-1} significantly increased leaf area index, fresh and dry weights of roots, as well as the foliage per plant compared with applying 90 kg N ha^{-1}. Mahasen (1999) showed that raising nitrogen fertilizer levels improved all growth characters. Nemeat (2001) reported that ammonium nitrate as a nitrogen fertilizer source surpassed other nitrogen fertilizer sources, i.e. urea or ammonium sulphate, in beet and produced the greatest beet diameter, root and top fresh mass, top yields as well as total soluble solids percentage.

Haunold (1983) showed that with a normal application of fertilizer, 50% of the nitrogen was taken up by the crop, 20% was left in the soil and 30% disappeared, presumably by denitrification or leaching. Few mineral soils under continuous cropping can provide more than 60 kg ha^{-1} of nitrogen each year without regular additions of fertilizer (Cooke & Scott, 1993). The crop thus obtains part of its nitrogen requirement from applied fertilizer and part from soil reserves, mainly from decaying organic matter plus a small amount from unused fertilizer applied to previous crops. The amount of fertilizer applied as basal application greatly affects the amount of nitrogen present in the crop at harvest. Without any fertilizer, crops may contain as little as 25 kg N ton^{-1} when grown in soil with small reserves of nitrogen and 100 kg N ton^{-1} when grown on relatively fertile soil. With an excessive supply of fertilizer and/or residues in the soil, there are reports of the crop taking up more than 400 kg ha^{-1} nitrogen (Cooke & Scott, 1993). Recent work with ^{15}N in several countries has helped the understanding of nitrogen uptake by beetroot.

2.2 Nitrogen fertilizer requirement

Many investigations have been made into the nitrogen requirement of beetroot on different soils, usually classified either by texture, or by soil group or series (Webster *et al*., 1977). With few exceptions, the overwhelming evidence is that, for a given climatic zone, neither of these classifications is useful in predicting nitrogen requirement. Organic soils form a separate group which can easily be defined, e.g. by loss of ignition, and there is good evidence that less nitrogen fertilizer is needed on some of these soils (Bidwell, 1979).

In the case of organic mineral soils, crude relationships have been established between total nitrogen concentration and fertilizer requirement. However, these relationships are unreliable for mineral soils which contain little organic matter. In these soils, fertilizer requirement is determined by the amount of available nitrogen present before sowing beetroot, and that which is present in ammonium or nitrate forms; together called ‘mineral’ nitrogen. In addition to mineral nitrogen present, beetroot takes up nitrogen during the growing season. This is a product of the breakdown of soil organic matter, mainly due to bacterial activity, which releases ammonium and nitrate (Cooke & Scott, 1993).

The increase in mineral nitrogen present in the soil has been used as a guide to the potentially available nitrogen. Increasingly accurate estimates can be made of the amount of nitrogen which the crop can obtain from the soil throughout the growing season (Tinkler, 1983). These estimates can then be used in a crop growth model to predict the amount of fertilizer necessary under widely varying conditions (Greenwood *et al.,* 1984).

Having determined the total quantity of nitrogen fertilizer required by the crop, it is important that applications are made correctly and in the best form to achieve the desired uptake. Early work with urea led to the belief that it was slightly less effective than ammonium nitrate (Tomlinson, 1989) but more recent experiments have detected little difference between the two forms. (Thompson, 2001) All of these forms will quickly provide the necessary uptake if rainfall (or irrigation) follows application to ensure that the nitrate is present in the zone round the roots (Mengel & Kirby, 1987).

As the supply or availability of growth factors such as water and mineral nutrients increase, the growth rate and yield of a crop increases. Nitrogen is found to be the most important growth limiting factor in numerous field experiments that have been carried out in the past (Mengel & Kirby, 1987; Wiesler & Horst, 1992). Healthy crop growth is one of the best ways of preventing nitrate leaching because a healthy crop grows and absorbs nitrogen from the soil faster. Improved moisture conditions usually translate into higher yields up to a point where other limiting factors come into play. Excess moisture can reduce yield due to leaching losses of nitrate, as well as loss of nitrates by conversion (denitrification) to gases that escape from the soil.

All vegetables have different requirements regarding nitrogen nutrition and fertilization (Goodlass *et al*., 1997). Leafy greens such as mustard, cabbage and spinach are heavy users of nitrogen, while broccoli and sweet corn also require more nitrogen than some other vegetables. Legumes obtain nitrogen from the atmosphere and do not require heavy nitrogen fertilization. Proper nutrition is essential for satisfactory crop growth and production. Efficient application of the correct types and amounts of fertilizers and time of application is important in achieving profitable yields (Marschner, 1986; Mengel & Kirby, 1987). The quantitative nitrogen requirements of vegetable crops consist of the amount of nitrogen that will actually be taken up by the plant and integrated into its biomass and the quantity of nitrogen that must nevertheless be present in the soil in order for the crop to achieve its full potential yield (Bidwell, 1979).

In South Africa the recommendation for nitrogen fertilisation of beetroot is 100 to 140 kg N ha^{-1} (FSSA, 2007).

2.3 Effect of nitrogen during germination, emergence and growth

When seed is sown to a stand, very high amounts of nitrogen fertilizer can kill some seedlings, slow emergence of others and decrease the number of plants which establish. Initially, various forms of placement were tested but these involved the use of more sophisticated and expensive equipment than that which was already present on most farms. Later work showed that an initial broadcast application permits full establishment and gives optimum early growth. Once the crop is established, the required balance of nitrogen fertilizer can be applied with impunity at the 2-4 true leaf stage (Amstrong *et al.,* 1983).

In addition to improving the colour of the leaves, nitrogen noticeably increases their size and number. Early in the season, therefore, nitrogen increases dry matter production per unit area, mostly from leaves and petioles (Amstrong *et al.*, 1983). Later in the season, nitrogen maintains this increase in leaf and petiole dry matter. In practical terms, nitrogen fertilizer applications need to be planned to boost the early growth of the leaf canopy, to maintain it throughout the period until harvest but to avoid excessive vegetative growth which inevitably depresses root quality (Goodlass *et al*., 1997).

2.4 Nitrogen fertilizers

Nitrogen fertilizers can be broadly classified into the following four groups depending on the chemical form in which the nitrogen is present. Ammonium fertilizers, nitrate fertilizers, combined ammonium and nitrate fertilizers and amide fertilizers.

Ammonium fertilizers contain nitrogen in the form of the ammonium ion, NH_4^+. When applied to soil, the ammonium ions in the fertilizer are adsorbed by soil colloids and are not lost through leaching, but are fairly rapidly converted to the nitrate form by bacterial action. Most crops are able to take up some of their nitrogen as ammonium ions, particularly in the early stages of growth, so that ammonium fertilizers provide a satisfactorily nitrogen supply, either before or after nitrification. Ammonium fertilizers are acid forming and their continuous application may result in increasing soil acidity. Examples of ammonium fertilizers are ammonium sulphate, ammonium nitrate, and ammonium chloride (Fertilizer & plant nutrition guide, 1984).

Nitrate fertilizers contain their nitrogen in the form of the nitrate ion, NO_3^-. Most plants absorb a high proportion of their nitrogen in this form. Nitrate fertilizers are not retained by soil colloids. Thus, if application of nitrate fertilizers is followed by heavy rains or irrigation there is a very good possibility of nitrogen being lost by leaching. Nitrates also tend to undergo denitrification particularly when applied to waterlogged soils. Nitrate fertilizers are alkaline in their effect when applied to soil. Sodium nitrate and calcium nitrate are examples (Goh & Vityakon, 1983).

Combined ammonium and nitrate fertilizers contain both the ammonium and nitrate ions. They thus have some of the same properties, both advantages and disadvantages of the ammonium and nitrate fertilizers. The nitrate nitrogen is readily available to plants for immediate use, whereas ammonium nitrogen becomes available to plants at a later stage, when it is transformed to nitrate by microbial processes in the soil. These fertilizers are soluble in water and suitable for use with most crops and soils. The commonly used straight fertilizers of this type are ammonium nitrate, ammonium sulphate nitrate and calcium ammonium nitrate (Everaats, 1994).

Amide fertilizers are simple organic compounds in which the nitrogen is not readily available to plants. When applied to the soil, amide fertilizers are rapidly converted to ammonium form and then later to nitrate form through microbial activity. They are generally soluble in water and some care is therefore necessary in soil application so that nitrogen is not lost by leaching. Urea is by far the most important example of this type of fertilizer (Sayed, 1988).

2.4.1 Advantages of nitrogen fertilizers

- The primary advantage of using packaged commercial fertilizer is that nutrients are immediately available to plants (FSSA, 2007).
- The exact amounts of a given element can be calculated and given to plants (AVRDC, 1990).

2.4.2 Disadvantages of nitrogen fertilizers

- Commercial fertilizers, especially nitrogen, are easily leached below the level of the plants' root system by rain or irrigation.
- Over application that is too close to the roots of the plant may cause "burning" (actually a process of desiccation by the chemical in fertilizers).
- Over application of commercial fertilizers can build up toxic concentrations of salts in soils, leading to a contamination of ground water (FSSA, 2007).

2.5 Crop nitrogen management

Factors to be considered in the placement of fertilizers include crop root characteristics, crop requirements at various growth stages, applied fertilizer characteristics, moisture availability, the climate when fertilizer is to be applied and the time of application (FSSA, 2007). Rooting depth and root distribution play an important role in determining the optimal placement of nitrogen fertilizers. The rooting depths of young plants would be considerably less, making it more critical for nitrogen fertilizers to be properly placed (AVRDC, 1990).

Banding fertilizer refers to the application of fertilizer at planting, thus placing the fertilizer to either one or both sides and below the seed at planting. Care should be taken as placement too close to the seed can cause seed burn and inhibit germination. Broadcasting of fertilizers refers to the uniform application of fertilizers across the entire soil surface. This may be done before the field is ploughed, immediately before planting, or while the crop is growing, although this is not a practice that is recommended for most vegetable crops. Broadcasting is efficient and often the method of choice in areas with perennial plants (Grubinger, 1999).

Comparison of band placement and broadcasting methods as far as application levels and the corresponding yields are concerned, is determined by the fertility level of the soil. Band placement of fertilizer is usually more effective than broadcasting in soils with low soil fertility and low application levels. As application levels increase there is a point where yields will actually begin to decrease in the case of band-placement and the efficiency of broadcast application will exceed that of band-placement while the yield still increases. In high fertile soils there are much smaller differences between these two application methods at low fertilization levels (FSSA, 2007).

Side-dressing is the post-emergence application of fertilizer alongside the crop row or to closely spaced crops. This assists in supplying nitrogen in a readily available form to growing plants (Fertilizer & Plant nutrition guide, 1984). Fertigation is the application of soluble fertilizer through an irrigation system. Application of chemicals through irrigation should be safe for field use, should not reduce yield, and should be soluble and compatible (Archer, 1988).

Foliar application refers to the spraying of leaves of growing plants with very dilute fertilizer solutions. The foliar application of mineral nutrients by means of sprays offers a method of supplying nutrients to plants more rapidly than methods involving root application. This method can be an effective remedy for a crop suffering from a nutrient deficiency. These solutions may be prepared in a low concentration to supply any one plant with a nutrient or a combination of nutrients. Foliar fertilizers are diluted solutions applied directly to leaves and cannot be relied upon to supply the total nitrogen, phosphorus and potassium needs of plants, but can be used to supplement soil applications of these nutrients (Marschner, 1986; Archer, 1988; Grubinger, 1999). The most efficient way to apply nitrogen is by soil application. Foliar application of nitrogen should be viewed as a temporary or emergency solution only (Hauck, 1976).

2.6 Frequency/ timing of application

Crop, soil and nutrient type influence the time of fertilizer application. The development pattern of vegetable crops differs, and therefore nutrient needs vary. Rainfall and temperature influence the availability of nutrients to plants, from the time they are applied, until when they are used by the plant. Fertilizer should be applied when plants need it, when it will be most effective, and when plants can readily take it up. The best way to ensure that added nutrients are used efficiently by plants and to reduce the risk of nutrient loss to the environment is to match nutrient availability to plant demand over time. Annual crops, perennial crops and pastures all have different patterns of nutrient demand over time, and respond differently according to soil moisture status and temperature.

2.7 Influence of nitrogen fertilizers on yield and quality

Nitrogen fertilizer is one of the most important factors influencing yield and the chemical composition of vegetables, as it has been identified as the major factor that influences the nitrate content in vegetables. Excessive amounts of nitrogenous fertilizer are usually applied to crops, as it is a reasonable insurance against yield losses and their economic consequences (Huang, 2002). Nevertheless, when nitrogen inputs exceed the demand, plants are no longer able to absorb it and it starts to build up in the soil mostly as nitrate. This will cause imbalances of nutrients in the soil and an increase in the nitrate level in the ground water supplies. There is conflicting evidence regarding the potential long-term health risks associated with nitrate levels encountered in the human diet. High nitrate accumulation in vegetables is, therefore, a concern because it might present a health hazard for humans (Goh & Vityakon, 1983; Lairon *et al.,* 1984).

Optimum use of fertilizer results in higher yield and better crop quality. For example, the protein content of cereals can be increased by proper management of nitrogen, in particular by providing adequate nitrogen for full growth. Similarly, a proper supply of phosphorus and potassium increases the sugar and starch contents of crops, while secondary and micronutrients also play important roles in improving crop quality (Lairon *et al*., 1984). Crop quality can be related to the nutritive values of the produce and to the commercial - or market value, which often depends on features such as appearance, taste, smell and keeping quality. Where crops are to be processed, either for food production or industrial use, the quality requirements depend essentially on the needs of the processor, in terms of both quantity and specifications of output from the processing plant (Fertilizer & plant nutrition guide, 1984).

The quality of crop products depends on inherited genetic makeup and on environmental (external) factors. The inherited factors determine the basic quality specific to the crop and variety while the environmental factors affect the realization of the inherited potential, by regulating it in different ways. Balanced use of plant nutrients plays a vital role in determining the quality of the produce. Frequently, quality is improved by fertilizer application up to an optimum level, while applications well in excess of this may lead to lower quality, either because of a straightforward nutrient excess or because of imbalance between nutrients (Marschner, 1986). The primary effect of nitrogen fertilizer is on plant dry matter production, much of which is eventually stored in the form of sugar. In soils which contain a large concentration of available nitrogen the addition of only a small amount of fertilizer causes a rapid decline in both characteristics.

2.8 Effect of nitrogen on pests and diseases

Pests and diseases are very important in crop production, in general, as they can pose a serious problem to farmers. These organisms can greatly reduce the yield and quality of the produce and consequently the produce will fetch a lower price in the market and give lower returns. These two problems are important in that money has to be spent in buying chemicals to combat them and this constitutes a financial loss to the farmer. Good husbandry practices are essential if good yields are to be achieved. The problem should be fully understood so that the most appropriate methods to affect satisfactory and economical control can be chosen. It has to be noted that the use of chemicals to fight diseases and pests should be employed as a last alternative as their effect can often pose a more serious long term threat to the survival of humans and the environment. Good husbandry and the use of resistant varieties can often reduce or eliminate the need for chemical control (Bok *et al*., 2003). Crop rotation helps to prevent the build-up of pest and disease populations in the soil. This will also ensure an efficient use of the nutrients as crops have different nutrient requirements and root depths.

2.9 Diagnosis of nitrogen deficiency

Nitrogen deficiency in plants can vary in severity, from slight with no visual symptoms, to acute with very obvious changes in appearance. The acute deficiency is an obvious signal that plant productive capacity has been affected. At the opposite end of the scale, some reduction in productivity can occur despite the absence of visual symptoms (Hauck, 1976).

Generally, with nitrogen deficiency, plant appearance is that of sparse growth with small leaves, thin stems, and fewer lateral branches, tillers, or shoots. In early growth stages, leaves are pale and yellowish-green in colour due to limited chlorophyll. The symptoms are more apparent on older leaves because nitrogen is mobile in the plant. Both inorganic forms and degradation products are translocated from the older tissue for re-use in the younger leaves. The leaves may develop yellow, red, or purple colours at later growth stages as pigments other than chlorophyll have a predominating effect. As nitrogen shortage becomes more acute, the older leaves turn brown, starting at the tip and progressing over the leaf until the entire leaf is dead. The younger leaves remain green until the stage when the deficiency is severe (Tomlinson, 1989)..

Although nitrogen deficiency symptoms are among the most reliable of those caused by nutrient shortage, other complexities can be confused with nitrogen deficiency (Tomlinson, 1989). For example, sulphur deficiency symptoms are easily confused with early symptoms of nitrogen deficiency, in that the leaves have a general pale green to yellowish appearance. Plant damage caused by disease, insects, or other environmental factors can be confused with nitrogen deficiency, as can other nutrient deficiencies at late stages of growth and development (Hauck, 1976).

In plants of the grass family, advanced stages of nitrogen deficiency symptoms are rather characteristic. In maize, the typical V- shaped pattern of dead tissue proceeds upward along the midrib. In other grass, the symptoms are less specific with general yellowing and firing of the lower leaves. In sorghum (*Sorghum bicolor* L.), the symptoms sometimes resemble potassium deficiency, in that the leaf tissue along the margins may deteriorate (Archer, 1988). With plants such as cotton (*Gossypium hirsutum* L.), nitrogen deficiency (N deficiency) symptoms are less pronounced. With early N deficiency, the plants show a lack of vigour and have small leaves, short petioles, and reduced internode elongation. The entire older leaves are pale to yellowish green in colour. As severity of nitrogen shortage intensifies, the lower leaves turn brown, die, and eventually fall to the ground.

Shedding of leaves is similar to natural leaf drop at maturity. A more specific effect of N deficiency is found in tobacco (*Nicotiana tabacum* L.) with a yellowing of lower leaves, followed by drying or firing of the yellowed leaves. The more acute the N shortage, the more leaves affected (Tomlinson, 1989).

Visual symptoms of N in vegetable crops are, in general, characterized by chlorosis progressing from light green to yellow. Under prolonged stress, the entire plant becomes yellow, growth is severely restricted, and some plants drop older leaves. Marketability of green, leafy vegetables is severely reduced by spindly appearance or lack of green colour (Archer, 1988).

In fruit and nut tree crops, the symptoms of N deficiency vary somewhat with specific crops. However, the leaves are generally small, pale green to yellowish green in colour, the foliage appears sparse and stunted, and twigs may die back. In various species, colours other than yellow appear, such as brown, orange, red, and purple. Older leaves fall, and fruit is sparse and small (Hauck, 1976).

Nitrogen deficiency in beetroot shows as either a purpling or yellowing of the older leaves, and this is coupled with poor plant growth. Ultimately the beets produced are small and the yields low (Weir & Cresswell, 1995).

2.10 Conclusion

An estimate of the fertilizer N needs of a particular crop cannot be determined quantitatively without knowledge of the crop's requirement for this element. The N requirements for a number of crops have been previously determined using data from N rate experiments in which the total N content of the plants was known. Application of large amounts of N fertilizer necessary to attain maximum yields of good quality may present problems for certain crops (toxicity, lodging, etc). Adequacy of N fertilizer applications can be determined best at the end of the growing season by an analysis of samples of the total dry matter produced to see if the internal N requirement has been met. In addition, an analysis of soil NO^-_3 after plants are mature would provide an estimate of excess N not utilized by the crop. It can be concluded that the high yields of good quality beetroot have not been fully exploited, and that continued research is required to elucidate the effects of high inputs of all factors, especially N, that contribute to the attainment of maximum yields of good quality beetroot (Stanford, 1966)

CHAPTER 3

MATERIALS AND METHODS

3.1 GENERAL

A pot trial was conducted to determine the effect of five nitrogen fertilizers (limestone ammonium nitrate (LAN), ammonium nitrate (AN), urea ammonium nitrate (UAN), ammonium sulphate nitrate (ASN) and urea at five nitrogen application rates (0, 50, 100, 150, 200 kg ha^{-1}) on the growth, yield and quality of beet. The trial was carried out in a glasshouse of the Department of Soil, Crop and Climate Sciences on the central campus of the University of the Free State in Bloemfontein, South Africa.

3.2 EXPERIMENTAL DESIGN AND TREATMENTS

Topsoil (0 - 20 cm depth) of a sandy loam (5% Cl) Bainsvlei soil was collected from the Kenilworth Experimental Farm for use in this trial. The chemical and physical properties of the soil was determined (Table 3.1) using standard procedures and the soil air-dried before being sieved through a 2 mm screen to remove stones and plant residues. Field capacity of the soil was determined gravimetrically to be 25% (m/m).

Table 3.1 Chemical properties* of the topsoil used in the pot trial

$pH_{(KCl)}$	P	K	Ca	Mg	Na	Zn
	(mg kg^{-1})					
4.4	18.3	98.7	194	68.3	1.5	0.5

***Determined with standard procedure (The Non-Affiliated Soil Analysis Working Committee, 1990)**

The amount of phosphorus (100 kg ha^{-1}) and potassium (80 kg ha^{-1}) that would be removed from the soil by a yield of 40 t ha^{-1} were applied to the soil in the form phosphoric acid and potassium hydrogen phosphate prior to filling the pots. The required amount of fertilizer to give the correct nitrogen application rate was mixed with the amount of soil necessary to fill each pot prior to filling. Application rates were calculated on the basis of the surface area of the pot (0.0963 m^2).

Polyethene pots (35 cm diameter by 28 cm high) were filled with soil and seeds of the cultivar Detroit Dark Red were planted at a depth of 2.5 cm. Seeds were spaced 7.5 cm apart in a single row arranged in the centre of the pot, and soil wet to field capacity. Plants were thinned to five per pot once the first true leaves appeared, approximately two weeks after planting (Figure 3.1), representing a plant population of 432 526 plants per ha^{-1}.

Figure 3.1 Layout of plants in the pots

After planting the pots were arranged in the glasshouse in a randomized complete experimental design with each treatment being replicated four times. The glasshouse was set to a day/night temperature regime of 22 / 15^{o}C, and the trial conducted under natural daylight conditions. The day length during the trial period was approximately 13 hours. Pots were weighed daily and water added when required to bring the water content in the pot back to 70% of field capacity. All weeds were removed by hand. Harvesting took place approximately three months after planting, when the middle three plants in each pot were removed and washed clean to ensure that roots were free of soil particles and other extraneous material and thereafter taken to the laboratory for further analyses.

3.3 DATA COLLECTION

3.3.1 Growth and yield parameters

Plant height was measured every 2nd week. It was measured from ground level to the highest natural point of the plant. The number of leaves per plant was counted at harvest. Leaf fresh mass (g) with attached petiole was measured at harvest. Leaves were placed in brown paper bags and dried in an oven at 60^{o} C for seven days. After drying, they were weighed to determine the dry mass. Total leaf area (cm^2 $plant^{-1}$) was measured using a LiCor leaf area meter (Model LI3100) at harvest. The mass of the entire plant (above and below ground portion) was weighed after washing to determine the total fresh mass. Plants were then separated into above and below ground portions after which each section was weighed separately.

3.3.2 Quality parameters

3.3.2.1 External quality parameters

3.3.2.1.1 Beet diameter

Beet diameter was measured at right angles to the longitudinal axis using a digital calliper, model CD 8.

3.3.2.1.2 Beet volume

Beet volume was determined by filling a measuring cylinder with water to a level that allowed space to insert the beetroot without spilling. The volume of water in the cylinder before the beetroot was inserted was recorded as (a). Volume b was recorded after the beetroot was inserted into the cylinder and all air bubbles removed. The volume of beetroot (cm^3) was calculated by subtracting volume a from volume b.

3.3.2.1.3 Defects

Beet defects such as cuts, bruises, diseases and physiological disorders were determined. During quality evaluation, the percentage of beet with each class of defect was determined as a guide to overall quality.

3.3.2.1.4 Grading according to size

At harvest, beetroot was graded in size according to grading standards as follows; small being below 5 cm in diameter, medium being around 5-7 cm and large being around 7.5-10 cm in diameter (National Department of Agriculture, 2009).

3.3.2.2 Internal quality parameters

3.3.2.2.1 Firmness

Beetroots were first washed to ensure that tissues were free of mud particles and other materials. Measure of beetroot texture that is related to sensory characteristics such as firmness was measured with a constant load penetrometer (Model 1719, Stanhope Seta Limited, England) that was automatically controlled by a Seta-Matic penetrometer controller (Model 1720). Beetroot was carefully sliced longitudinally to have a uniform horizontal surface at the bottom when resting on top of the penetrometer table surface. This was done to secure stability of beetroot samples when a constant load of 50 g was dropped automatically on top for penetration with a needle into the beetroot tissue. A constant load of

50 g was allowed for a record of 10 seconds to puncture beetroots and the depth of penetration in millimeter was recorded. Three measurements were made along the longitudinal axes for each treatment after which the average was calculated for each replication (Workneh *et al*., 2003).

3.3.2.2.2 Liquid fraction

Root pulp and peel were homogenized with a food blender after which they were centrifuged in a Beckman JA-21 centrifuge at a speed of 5000 rpm for 10 minutes to separate the liquid from the solid matter. The liquid was filtered through a tea sieve and used for analysis (Buitendag, 2004).

3.3.2.2.3 pH

The pH of the beetroot liquid fraction was determined using a pH meter (Model Hanna pH 210).

3.3.2.2.4 Total soluble solids

The total soluble solids were measured with a hand held refractometer (RFM 330, Bellingham & Stanley Ltd, England). Degrees Brix measurements were obtained by using two drops of the beetroot liquid fraction on the refractometer stage using a Pasteur pipette. Two readings per beetroot were recorded (de Bellie *et al*., 2003).

3.3.2.2.5 Colour

Colour of the roots was determined using a Minolta Chroma Meter CR-300 (C.I.E. systems). Parameters of colour were determined by light source [Instruction of Minolta, 1994]. Beetroot was carefully sliced longitudinaly in two and instrumental determination of colour was done three times per each half of beetroot (Czarniecka-Skubina *et al*., 2003).

3.3.2.2.6 Sugar (sucrose, glucose, fructose) and starch content

The sucrose, glucose and fructose content of the roots were determined enzymatically using test kits (Boehringer Mannheim, cat. No.10716260035). Calculations of sucrose, glucose and fructose levels were carried out according to the method given in the instructions supplied with the kits.

Starch content of the roots was determined using Boehringer Mannheim starch test kits (Boehringer Mannheim, cat. No.10207748035). Calculations of starch content were carried out according to the method provided with the kit.

3.3.2.3 Plant analysis

3.3.2.3.1 Mineral contents

The dried leaves were milled and the mineral contents (N, C, P, K, Ca, Na, Mg, Mn, Cu, Fe, and Zn) were analyzed using standard procedures (Agrilasa, 2002). The dried beets were also milled and analyzed for major minerals (P, K, Ca, Na, Mg, Mn, Cu, Fe and Zn) using standard procedures (Agrilasa, 2002). Ashing of the samples with nitric acid was used to obtain the P, K, Ca and Mg solution. The P was determined by colometry and K, Ca and Mg by atomic absorption.

3.3 STATISTICAL ANALYSIS

Data were analyzed statistically using the SAS ver.9.1 for windows statistical package (SAS Institute, 2003). Means of parameters showing significance at the 5% level were separated using Tukey's HSD test as described by S & T (1980). All analyses took place at 5% even if the ANOVA indicated a high level of significance.

CHAPTER 4

INFLUENCE OF NITROGEN FERTILIZERS ON GROWTH AND YIELD OF BEETROOT (*BETA VULGARIS* L.)

4.1 INTRODUCTION

Vegetables are sources of minerals (Russo, 1996) as well as vitamins and essential amino acids (Custic *et al*., 2002), and their consumption is thought to be beneficial to human health (Fridz *et al*., 1989; Vogel, 1996). Beet is often recommended for the prevention of the development or occurrence of cancer (Kapadia *et al*., 1996; Bobek *et al*., 2000). Because of that, nutrient removal by edible plant parts is a very important component of soil fertility (Alt & Wiemann, 1987). On the other side, fertilizers influence soil fertility and the environment. Lesic *et al*. (2004) reported that 150 kg N ha^{-1} is necessary for beet yield of 60 t ha^{-1}. Some authors (Michalik & Grzebellus, 1995; Ugrinovic, 1999) reported that the dry mass content in storage root varied from 80 to 164 g kg^{-1} and was decreased by nitrogen abundance.

Fertilizer is considered as a limiting factor for obtaining growth and yield of beet (Ouda, 2002). Thus, application of suitable fertilizers, such as nitrogen (N) may be favourable factors for the production of beet. Beet growth and yield are dramatically influenced by the level of available nitrogen. Also, nitrogen fertilization enhances absorption of the mineral from the soil (Nollar and Rhykerd, 1974). Nemeat Alla *et al*. (1997) and Abd EL-Hadi *et al*. (2002) reported that root dimensions were significantly affected by nitrogen levels and gave maximum root dimensions with high dose of N. Aboushady *et al*. (2007) concluded that maximum dry matter was obtained when beet was fertilized with micronutrients. Nitrogen is the most important fertilizer element for beet growth and yield (Badawi 1989a & b, Emara 1990 and EL-Kassaby and Leilah 1992b). Therefore, the aim of the present study was to determine the influence of nitrogen fertilizers on growth and yield of beet.

4.2 RESULTS AND DISCUSSION

4.2.1 GROWTH

4.2.1.1 Plant height

Plant height was monitored bi-weekly from planting to harvest, *i.e.* weeks 2-10. A summary of the analysis of variance to determine the effects of nitrogen source (NS) and nitrogen level (NL) on the plant height of beetroot during the growing season is shown in Table 4.1.

Table 4.1 Summary of results of analyses of variances conducted on plant height from 2 to 10 weeks after planting

Weeks after planting	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
2	*	*	ns
4	*	*	ns
6	*	*	ns
8	*	*	ns
10	*	*	ns

ns = no significant differences
*** = significant differences**

It can be seen that nitrogen fertilizer and application rate both had a significant effect on plant height throughout the season. The interaction effect between these two factors did not, however, significantly affect the height of plants, showing that plants reacted to increasing nitrogen application in the same way, irrespective of the fertilizer used.

From Table 4.2 it can also be seen that all application rates of nitrogen resulted in a significant decrease in plant growth over that of the control treatment during the growth period, with plants receiving UAN being significantly smaller than those fertilized with other products. Nitrogen application only increased plant height significantly from Week 8 where the height of plants that received nitrogen, irrespective of the fertilizer used, were significantly taller than those that did not. At Week 8 no significant differences in height were noted between the various nitrogen application rates. However, by week 10 significant increases in plant height were noted between the 50 kg ha^{-1} and 150 kg ha^{-1} or 200 kg ha^{-1} application rates. Plant height at the 100 kg ha^{-1} N application was intermediate to that at 50 and 150 kg ha^{-1} N.

Significant differences in plant reaction to the various fertilizers used also occurred from Week 8. At this stage plants fertilized with urea and ASN were significantly taller than those fertilized with other products. The least reaction took place in plants fertilized with AN, these plants were also significantly shorter than those receiving UAN. Height of plants fertilized with LAN were intermediate to those fertilized with AN and UAN. Plants that were fertilized with ASN were significantly taller than those that received any of the other products by Week 10. At this stage the shortest plants were still those fertilized with AN, which were also significantly shorter than those fertilized with UAN, while plants that received either LAN or urea did not differ statistically in height from those receiving AN or UAN.

When analyzed as a percentage of the control treatments no increase in plant height was noted from Weeks 2 to 6 due to N-application. From week 6-8, however, sudden increases occurred, ranging from 44% in plants treated with LAN and AN, through 100% for LAN treated plants to 121% and 126% for plants that received urea and ASN respectively. Between Weeks 8 and 10 plant height increased by 90% over those of control treatments, 82% for AN, 61% for urea, 122% and 104% for plants that received LAN, AN, urea, ANS and UAN respectively. These findings show that beet plants reacted better to N-fertilization with ASN and UAN than from other sources, although LAN and AN application also produced improvements in plant growth, the growth of plants that received urea slowed down at this stage. Once urea has been incorporated into cellular components, it probably becomes relatively immobile; this would contribute to the explanation of slow growth at later growth stages (Bondada *et al*., 1997).

It was also noted that plant growth response to the various N-application rates only started after Week 6, although plants on the LAN treated soils (50 kg ha^{-1}) showed on immediate reaction. All other source and application rates resulted in an inhibition of growth during this period when compared to the control treatments.

Height of plants can be considered as one of the indices of plant vigour ordinarily, and it depends upon vigour and growth habit of the plant (Pervez *et al*., 2004). Soil nutrients are also very important for the height of plants (Mohammad *et al.,* 2012). Contrary to the present findings, Nemeat (2001) reported that AN as a nitrogen source surpassed urea or ammonium sulphate in beetroot and produced the tallest plants. Badawi (1996) also indicated that urea as foliar nutrition had an active role in enhancing growth and yield of beetroot. The influence of nitrogen as ammonium nitrate on agronomic efficiency is mainly due to their effect on soil reaction and nutrient availability. Sharma & Rastogi (1992) found that 150 kg ha^{-1} or higher of UAN increased plant height. This correlates positively with the present findings.

Table 4.2 Effect of nitrogen source and nitrogen level on the plant height(percentage of the control) of beetroot from 2 to 10 weeks after planting

Weeks After Planting	Nitrogen Level (kg ha^{-1}) (NL)	Nitrogen Source (NS) Limestone ammonium nitrate (LAN)	Ammonium nitrate (AN)	Urea	Ammonium sulphate nitrate (ASN)	Urea ammonium nitrate (UAN)	Mean
2	0	100.00	100.00	100.00	100.00	100.00	100.00^{a}
	50	116.65	76.43	72.38	64.60	53.38	76.69^{b}
	100	79.58	63.45	64.90	91.43	38.85	67.64^{b}
	150	73.65	90.70	55.63	59.73	50.70	66.08^{b}
	200	82.80	79.48	93.68	69.58	53.80	75.87^{b}
Mean	**Mean**	**90.54^{a}**	**82.01^{a}**	**77.32^{a}**	**77.07^{a}**	**59.35^{b}**	**77.26**
$LSD_{T(0.05)}$		**NS = 13.85**		**NL = 13.85**		**NS x NL = ns**	
4	0	100.00	100.00	100.00	100.00	100.00	100.00^{a}
	50	116.65	76.43	72.38	64.60	53.38	76.69^{b}
	100	79.58	63.45	64.90	91.43	38.85	67.64^{b}
	150	73.65	90.70	55.63	59.73	50.70	66.08^{b}
	200	82.80	79.48	93.68	69.58	53.80	75.87^{b}
Mean	**Mean**	**90.54^{a}**	**82.01^{a}**	**77.32^{a}**	**77.07^{a}**	**59.35^{b}**	**77.26**
$LSD_{T(0.05)}$		**NS = 13.85**		**NL = 13.85**		**NS x NL = ns**	
6	0	100.00	100.00	100.00	100.00	100.00	100.00^{a}
	50	116.65	76.43	72.38	64.60	53.38	76.69^{b}
	100	79.58	63.45	64.90	91.43	38.85	67.64^{b}
	150	73.65	90.70	55.63	59.73	50.70	66.08^{b}
	200	82.80	79.48	93.68	69.58	53.80	75.87^{b}
	Mean	**90.54^{a}**	**82.01^{a}**	**77.32^{a}**	**77.07^{a}**	**59.35^{b}**	**77.26**
$LSD_{T(0.05)}$		**NS = 13.85**		**NL = 13.85**		**NS x NL = ns**	
8	0	100.00	100.00	100.00	100.00	100.00	100.00^{b}
	50	127.68	145.53	222.54	203.03	168.58	173.47^{a}
	100	132.28	129.63	231.13	196.15	159.88	169.81^{a}
	150	146.95	123.00	201.90	261.33	181.60	182.96^{a}
	200	165.93	116.28	235.05	254.95	188.05	192.05^{a}
	Mean	**134.57^{bc}**	**122.89^{c}**	**198.12^{a}**	**203.09^{a}**	**159.62^{b}**	**163.66**
$LSD_{T(0.05)}$		**NS = 32.72**		**NL = 32.72**		**NS x NL = ns**	
10	0	100.00	100.00	100.00	100.00	100.00	100.00c
	50	188.20	240.03	214.28	293.03	262.70	239.65b
	100	231.90	224.30	303.58	386.38	321.73	293.58ab
	150	296.68	240.20	338.20	429.13	290.48	318.94a
	200	308.10	220.80	340.68	417.63	343.58	326.16a
	Mean	**224.98^{bc}**	**205.07^{c}**	**259.35^{bc}**	**325.23^{a}**	**263.70^{b}**	**255.67**
$LSD_{T(0.05)}$		**NS = 58.58**		**NL = 58.58**		**NS x NL = ns**	

Means followed by the same letter in either row or column do not differ significantly from each other.

The observations at Weeks 2, 4 and 6, although not statistically significant, is in agreement with the findings of Boroujerdnia & Ansari (2007) who found that in the first stages of growth, differences between nitrogen levels were not significant because plants are in rosette stage and growth of plants is typically low at this stage. Once the seedling has become established, the plant enters a period of leaf initiation, during which there is very little growth. Thus, when the plant is six weeks old, it has 8-10 leaves while the root system is still small (Milford & Thorne, 1973; Scott *et al*., 1974). Detailed studies by Milford & Thorne (1973) showed that up to about Leaf 12, mature leaves become progressively larger, but later-formed leaves achieve smaller final sizes. Early leaves senesce in the order in which they are produced, and leaf area index (LAI) reaches a maximum close to the time at which the largest leaf reaches its full size, after which LAI declines. Leaves appear and expand in a linear relationship with thermal time. From the 8-10 leaf stage onward, leaf and root growth occur simultaneously with roots making up an increasing proportion of total plant dry mass. Mohammed *et al.* (2012), however, observed that nitrogen fertilizer application leads to increased plant height during early vegetative stages. Similar results were obtained in radish by Sharma & Kanuzia (1994). The findings in the present study concur with these findings. Khan & Suryanarayana (1978) and Aman *et al*. (2002) reported that 100-150 kg N ha^{-1} produced taller plants. Hemmat *et al*. (2010) discovered that most leafy vegetables preferred obtaining N from nitrate sources than from ammonium or urea, and that the application of nitrate fertilizer usually promoted growth of these species. Olayini *et al.* (2008) reported that the plant height of amaranthus increased as the nitrogen application increased from lower to higher levels. A higher application of nitrogen increased plant height (Pervez *et al*., 2004).

A summary of the analysis of variance (ANOVA) that was conducted to determine the effect of nitrogen source, nitrogen level as well as NS x NL interaction on the growth parameters (number of leaves, leaf area, leaf fresh mass and leaf dry mass) of beetroot is given in Table 4.3.

Table 4.3 Summarised ANOVA showing the significant effects on the nitrogen source and level as well as NS x NL interaction on the growth parameters of beetroot

Growth	**Nitrogen source (NS)**	**Nitrogen level (NL)**	**NS x NL**
Number of leaves	ns	*	ns
Leaf area	*	*	ns
Leaf fresh mass	*	*	ns
Leaf dry mass	*	*	*

ns = no significant differences
*** = significant differences**

Table 4.3 shows that the interaction between nitrogen source and nitrogen level significantly influenced the leaf dry mass of beetroot. Nitrogen level significantly influenced beetroot leaf number, while nitrogen source and nitrogen level significantly influenced the leaf area and leaf fresh mass of beetroot.

4.2.1.2 Number of leaves

The nitrogen level had a highly significant ($P < 0.0001$) effect on the number of beetroot leaves. Leaf number increased from 8.50 at 0 kg N ha^{-1} to 13.02 at 100 kg N ha^{-1} (Table 4.4). The number of leaves for plants that received 50, 100, 150 and 200 kg N ha^{-1} was significantly higher than that of plants that received no nitrogen (0 kg N ha^{-1}). Nitrogen levels of 50, 100, 150 and 200 kg ha^{-1} did not differ significantly in influencing the number of beetroot leaves. The data in Table 4.4 shows that application of nitrogen at 100 kg N ha^{-1} influenced plants to produce significantly more leaves (13.02) than the control level (0 kg ha^{-1}). However, this application level did not differ significantly with other levels in influencing the number of leaves. Urea significantly influenced the number of beet leaves (12.35) as compared to ASN (10.77).

These findings contradict those of Karic *et al.,* (2005) who applied four nitrogen levels (0, 50, 100 and 200 kg N ha^{-1}) to leek culture and reported that the application of 200 kg N ha^{-1} resulted in a maximum number of leaves per plant (14.4), but no effect was observed on the number of leaves up to 100 kg N ha^{-1}. Boroujerdnia & Ansari (2007) also found that nitrogen fertilizer level significantly affected the beet leaf number, and the highest leaf number was related to the treatment (120 kg N ha^{-1}) while the lowest was related to the control treatment.

Table 4.4 Effect of nitrogen source and nitrogen level on the number of beetroot leaves at harvesting

Nitrogen levels kg ha^{-1} (NL)	Nitrogen source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	9.55	9.08	7.83	8.00	8.05	**8.50b**
50	11.75	11.75	10.93	10.73	13.50	**11.73a**
100	11.25	12.15	16.93	11.10	13.68	**13.02a**
150	12.08	13.05	13.08	11.28	12.00	**12.30a**
200	11.98	13.10	13.00	12.73	13.66	**12.89a**
Mean	**11.32ab**	**11.83ab**	**12.35a**	**10.77b**	**12.18ab**	

$LSD_{T(0.05)}$NS=ns
$LSD_{T(0.05)}$NL=1.49
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other.

These findings are also similar to the results reported by Elia *et al.* (1999) who stated that number of leaves of spinach was increased by higher rates of nitrogen fertilizers. Gulser (2005) reported that increments in the nitrogen rate of fertilizers from 0 kg N ha^{-1} to 200 kg N ha^{-1} increased the number of leaves in spinach, but these increases were not statistically significant. Shahbazi (2005) showed that there was a significant difference in the number of beet leaves among nitrogen levels (0, 50, 100, 150 and 200 kg N ha^{-1} increasing from 9.50 to 14.35.

Hemmat *et al*. (2010) found that the number of spinach leaves per plant increased by increasing urea fertilizer rate from zero to 200 kg N ha^{-1}. Hemmat *et al.* (2010) also found that the highest number of leaves (21.47) and the lowest (17.8) were found at 200 kg N ha^{-1} and the control, respectively. Maximum number of leaves might be due to regular supply of N which enhanced vegetative growth, while deficiency of N resulted in poor growth. Similar results were found by Vas & Riemond (1992) who reported that nitrogen promoted total number of leaves in potato.

The increase in number of leaves as nitrogen rates increased reconfirmed the role of nitrogen in promoting vigorious vegetative growth in leafy vegetables (Olaniyi *et al*., 2008). Findings by Akoumianakis *et al.* (2011) also showed that by increasing nitrogen application the number of leaves per plant at harvest increased significantly. Previous studies showed that increasing the rate of nitrogen fertilization caused a small increase in the number of leaves per plant, but significantly increased leaf growth, in particular at 150 kg N ha^{-1} (Guvenc, 2002; El-Desuki *et al*., 2005).

4.2.1.3 Leaf area

Nitrogen source had a highly significant ($P < 0.0001$) effect on the leaf area of plants. From Table 4.5 it can be seen that plants receiving UAN produced a significantly larger leaf area (739.87 cm^2) than those fertilized with urea (602.98 cm^2), ASN (513.64 cm^2) and LAN (502.79 cm^2). Application of AN resulted in significantly a larger leaf area (681.52 cm^2) than application of ASN (513.64 cm^2) and LAN (502.79 cm^2). Urea also produced plants with a larger leaf area (602.98 cm^2) of compared to ASN (513.64 cm^2) and LAN (502.79 cm^2). However, UAN as nitrogen source performed better than other nitrogen sources (739.87 cm^2) in influencing larger leaf area of beetroot, whereas LAN had the lowest effect (502.79 cm^2) on leaf area.

Table 4.5 Effect of nitrogen source and nitrogen level on the leaf area (cm^2) of beetroot at harvesting

Nitrogen levels ($kg\ ha^{-1}$) (NL)	Nitrogen source (NS): Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	Mean
0	218.28	222.82	156.68	154.55	192.84	**189.03d**
50	448.76	636.13	468.29	436.11	728.08	**543.47c**
100	556.20	786.77	670.27	470.58	861.31	**669.03b**
150	659.26	892.99	770.98	727.71	910.99	**792.39a**
200	631.45	868.87	948.68	779.23	1006.11	**846.87a**
Mean	**502.79c**	**681.52ab**	**602.98b**	**513.64c**	**739.87a**	**608.16**

$LSD_{T(0.05)}$NS = 87.02
$LSD_{T(0.05)}$NL= 87.02
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other.

The application rate of nitrogen had a highly significant ($P < 0.0001$) effect on the leaf area of beetroot. Allen *et al*. (1972) also reported that the leaf area of beetroot was significantly affected by nitrogen level. The data in Table 4.5 indicates that leaf area of beetroot increased with increasing levels of nitrogen. Boroujerdnia & Ansari (2007) stated that the increase in leaf area in response to an increase in N fertilizer is probably due to enhanced availability of nitrogen to produce more leaves resulting in higher photo assimilates thereby in more dry matter accumulation. Also, Square *et al.* (1987) established that the main effect on N fertilizer was to increase the rate of leaf expansion, leading to increased interception of daily solar radiation by the canopy.

In this experiment beet leaf area increased from 189.03 cm^2 with 0 kg N ha^{-1} to 846.87 cm^2 with 200 kg N ha^{-1}. Beetroot plants that received higher levels of nitrogen (200 kg ha^{-1}) recorded a significantly larger leaf area (846.87 cm^2) than plants that received no nitrogen and those that received 50 and 100 kg N ha^{-1}. These results are in agreement with Dorobantu *et al*. (1989) who reported an increase in leaf area of potato with increase in N levels. Demir *et al*. (1996) also reported that the rate of nitrogen fertilizers increased the leaf surface area of spinach. The increase in nitrogen concentration also promoted an increase in mean leaf area (Akoumianakis *et al*., 2011).

The data in Table 4.5 also indicates that nitrogen application at 100 kg N ha^{-1} resulted in a significantly greater leaf area than plants that received 0 and 50 kg N ha^{-1}. Nitrogen level at 50 kg ha^{-1} resulted in a significantly larger leaf area of beetroot than the control level.

Findings by Ali and Ali (2011) showed broader leaves on beetroot plants provided with 140 kg N ha^{-1} while minimum leaf area was found at the control.

4.2.1.4 Leaf fresh mass

Nitrogen source and nitrogen level both had a highly significant ($P < 0.0001$) effect on the fresh mass of leaves produced by beetroot plants. The interaction effect between these two factors was, however, not significant (Table 4.6). The data shows that application of UAN as nitrogen source significantly influenced leaf fresh mass (68.17 g) of beetroot more than ASN (45.46 g), LAN (45.79 g), urea (51.12 g) and AN (58.01 g). AN as nitrogen source also influenced leaf fresh mass of beetroot significantly more (58.01 g) than ASN (45.46 g) and LAN (45.79 g). El-Tantawy *et al.* (2009) also found that AN significantly increased fresh weight of beetroot leaves. Barsoum & Zeinab (1995) revealed that foliar application of urea at 4% concentration produced the highest fresh mass as well as top and root yields of beetroot. However, application of UAN as a nitrogen source outclassed other nitrogen sources (68.17 g) in influencing beetroot leaf fresh mass whereas ASN as a nitrogen source resulted in the lowest leaf fresh mass (45.46 kg).

The data in Table 4.6 indicates that leaf fresh mass of beetroot increased with increasing levels of nitrogen. Leaf fresh mass of beetroot increased from 14.90 g $plant^{-1}$ at no N application to 77.83 g $plant^{-1}$ at an application rate of 200 kg N ha^{-1}. Application of nitrogen level at 200 kg N ha^{-1} significantly influenced leaf fresh mass (77.83 g $plant^{-1}$) of beetroot more than plants that received no nitrogen (14.90 g $plant^{-1}$) and plants that received 50 (46.13 g $plant^{-1}$) and 100 kg N ha^{-1} (59.23 g $plant^{-1}$).

Leilah *et al*. (2007) also stated that foliage fresh mass of beetroot was increased with each increase in nitrogen level up to the highest rate (216 kg ha^{-1}). The increase in yield may be due to high availability of nitrogen as the data shows that at lower levels the nutrient was not available to plants in sufficient quantities that suppressed the growth. Contrary to these findings, Boroujerdnia & Ansari (2007), working on lettuce, found that the application of N fertilizer up to 120 kg N ha^{-1} increased the fresh mass of leaves significantly, but as the application rate increased above 180 kg N ha^{-1} leaf fresh mass decreased. Application of nitrogen at 100 kg N ha^{-1} also resulted in a leaf fresh mass (59.23 g $plant^{-1}$) that was significantly higher than that of the control (14.90 g $plant^{-1}$) and at 50 kg N ha^{-1} (46.13 g $plant^{-1}$). Nitrogen application of 50 kg ha^{-1} increased leaf fresh mass significantly over that of control plants (14.90 g $plant^{-1}$).

Table 4.6 Effect of nitrogen source and nitrogen level on the fresh mass (g) of beetroot leaves at harvesting leaves at harvest

Nitrogen levels (kg ha^{-1}) (NL)	Nitrogen source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	17.35	18.02	12.39	12.55	14.21	**14.90d**
50	33.29	55.94	38.42	37.59	65.40	**46.13c**
100	46.43	74.59	56.61	40.41	78.09	**59.23b**
150	64.23	70.45	62.93	67.26	87.43	**70.46a**
200	67.64	71.06	85.25	69.48	95.73	**77.83a**
Mean	**45.79c**	**58.01b**	**51.12bc**	**45.46c**	**68.17a**	**53.71**

$LSD_{T(0.05)}$NS = 7.80
$LSD_{T(0.05)}$NL= 7.80
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other.

The same findings regarding fresh yield as influenced by N levels have been obtained by Mrkovic *et al*. (1988) who reported that spinach yield increased with increasing N levels. The same trend of increases in yield of different leafy vegetables was reported by Sharma & Kansal (1984), Boon *et al*. (1986) and Weier & Scharrpf (1989). Elia *et al*. (1999) also reported that by increasing nitrogen level, yield of spinach increased. This result was also supported by Ibrahim (1998) and Basha (1999) who concluded that application of nitrogen significantly increased the leaf fresh mass. Mahmoud *et al*. (1990) also found that leaf fresh mass was increased due to increasing nitrogen level and Nemeat Alla *et al.* (2002) showed the same trend. The present results are in agreement with the findings of Muthuswamy & Muthukirshnan (1984) who reported that fresh mass was markedly increased with nitrogen application in radish. The production of heavier leaves with 200 kg N ha^{-1} was due to balanced fertilization, necessary for growth and development versus the control where no fertilizer was used (Jilani *et al*., 2010).

4.2.1.5 Leaf dry mass

The interaction effect between fertilizer and application rate was not significant, indicating that leaf dry mass reacted to increasing application rate in the same way for all fertilizers used. Both fertilizer and nitrogen level had a highly significant effect ($P < 0.0001$) on the leaf dry mass (Table 4.7). Using UAN as a nitrogen source significantly increased leaf dry mass (397.35%) compared to other nitrogen sources. Urea, ASN and AN did not differ significantly in influencing leaf dry mass. However, leaf dry mass was significantly increased by urea at an average of 275.58% as compared to LAN that increased leaf dry mass by an average of 139.42%. ASN, AN and LAN did not differ significantly in influencing the leaf dry mass of beet. UAN had the greatest influence on leaf dry mass with an average increase of 397.35% while the lowest leaf dry mass increase of 139.42% was obtained after application of LAN as a nitrogen source.

The data in Table 4.7 also shows that leaf dry mass increased as the application levels increased from the lower to the higher level. The present findings show that application of nitrogen at 150 and 200 kg N ha^{-1} significantly increased the leaf dry mass by average of 416.79% and 358.94% respectively as compared to other nitrogen sources. Application of nitrogen at 100 and 50 kg N ha^{-1} also increased the leaf dry mass significantly more than the control level, by an average of 264.75% and 199.38% respectively. These results shows that the highest leaf dry mass was observed at the highest rate of nitrogen application (200 kg ha^{-1}) and the lowest leaf dry mass was observed at the control level (0 kg N ha^{-1}).

Table 4.7 Effect of nitrogen source and level on the leaf dry mass (percentage of control) of beetroot

Nitrogen levels (kg ha^{-1}) (NL)	**Nitrogen Source (NS)**					**Mean**
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	100.00	100.00	100.00	100.00	100.00	**100.00^{c}**
50	186.40	371.55	286.50	245.65	406.78	**299.38^{b}**
100	215.60	371.38	391.65	287.88	557.23	**364.75^{b}**
150	302.32	413.73	497.80	415.28	665.58	**458.94^{a}**
200	392.78	298.98	601.95	533.08	757.18	**516.79^{a}**
Mean	**239.42^{c}**	**311.13^{bc}**	**375.58^{b}**	**316.38^{bc}**	**497.35^{a}**	**347.97**

$LSD_{T(0.05)}$NS = 84.45
$LSD_{T(0.05)}$NL = 84.45
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other.

Similarly to the present results, Tei *et al.* (2000) reported that increasing the rate of nitrogen fertilizer from 0 to 155 kg ha^{-1} significantly increased the dry weight of lettuce leaves. Increasing the rate of nitrogen fertilizer affected leaf dry mass because nitrogen stimulates plant vegetative growth and increases leaf area. As a result increments in leaf area increase the rate of plant photosynthesis and thus increases dry matter production. Khogali *et al*. (2011) found that raising nitrogen fertilization levels from 40 to 120 kg ha^{-1} resulted in a significantly higher leaf dry mass, possibly due to an increase in the amount of metabolites synthesized by plants due to the effect of nitrogen in enhancing photosynthesis.

Boroujerdnia & Ansari (2007) found that the dry mass of leaves increased as nitrogen fertilizer application rate increased but the difference in leaf mass between 60, 120 and 180 kg N ha^{-1} was not statistically significant. They also found that the highest dry mass of leaves was obtained at 120 kg N ha^{-1} application while the lowest leaf mass was obtained in the control. Similarly, Magdatena (2003) reported that leaf dry matter content increased as nitrogen rate increased. However, this result is in disagreement with the findings of Akoumianakis *et al.* (2011) who found that leaf dry mass showed a reduction with the application of nitrogen fertilization at 150 kg ha^{-1}, although this was not significant. This result differs with the present findings.

4.3 Yield parameters

In order to establish the yield of beetroot, total fresh mass (root + leaves) root fresh mass and total yield were measured. A summary of the analysis of variance (ANOVA) that was done to determine the effect of nitrogen source and nitrogen level as well as NS x NL interaction on the yield (total fresh mass, root fresh mass and total yield) of beetroot is shown in Table 4.8.

Table 4.8 Summarised ANOVA showing the significant effects on the nitrogen source, nitrogen level and the NS x NL interaction on the yield of beetroot

Yield	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
Total fresh mass	*	*	ns
Root fresh mass	ns	*	ns
Total yield	*	*	ns

ns = no significant effect between treatments

*** = differences significant at the 5% level of significance**

As shown in Table 4.8 both the nitrogen source and level significantly influenced the total fresh mass and the total yield of beetroot. The root fresh mass of beetroot was significantly influenced by nitrogen level.

4.2.1 Total fresh mass

The interaction between nitrogen source x nitrogen level did not significantly influence the total fresh mass of beetroot. However, nitrogen source did influence the total fresh mass of beetroot significantly ($P < 0.0024$). From Table 4.9, it can be seen that application of UAN as nitrogen source resulted in a significantly higher total fresh mass (116.48 g) of beetroot than application of LAN (86.67 g) and ASN (89.19 g) respectively. AN as nitrogen source influenced the total fresh mass (103.42 g) of beetroot significantly more than LAN (86.67 g). UAN outperformed other nitrogen sources in influencing the total fresh mass of beetroot (116.48 g) and the lowest total fresh mass (86.67 g) was obtained with LAN as nitrogen source. Field results of Goh *et al.* (1983) showed that significantly higher spinach yields were obtained with ammonium form of fertilizer compared with nitrate form, with the maximum yield occurring after application of 300 kg N ha^{-1}. Gulser (2005) reported that the yield of spinach was significantly influenced by ammonium sulphate and urea as nitrogen sources.

Nitrogen level had a highly significant effect on the total fresh mass of beetroot ($P < 0.0001$). The total fresh mass of beetroot increased from 28.72 g with 0 kg N ha^{-1} to 139.40 g with 200 kg N ha^{-1}. The data shows that the total fresh mass of beetroot increased with increasing levels of nitrogen. Application of nitrogen at 200 kg ha^{-1} affected the total fresh mass (139.40 g) of beetroot significantly more than plants that received no nitrogen and those that received 50 and 100 kg N ha^{-1} respectively. Application of nitrogen at 100 and 150 kg ha^{-1} affected the total fresh mass of beetroot significantly more than beetroot plants that received no nitrogen and those that received 50 kg ha^{-1}. A nitrogen level of 50 kg N ha^{-1} significantly increased total fresh mass of beetroot plants over that of the control.

Khogali *et al.* (2011) also stated that increasing nitrogen level up to 120 kg N ha^{-1} significantly increased the total fresh mass of beetroot over the control level. This result was supported by Mahmoud *et al.* (1990), Ibrahim (1998), Basha (1999) and Nemeat Alla *et al.* (2002), finding that application of nitrogen significantly increased total fresh mass. As shown in Table 4.9, nitrogen level at 200 kg N ha^{-1} outclassed other nitrogen levels in influencing the total fresh mass (139.40 g) of beetroot while the lowest total fresh mass of beetroot (28.72 g) was obtained at the control level. The increase of marketable yield with higher N levels was not only due to increased total yield but also due to increased weight of marketable yield, mostly as an effect of increased root size at higher N levels as shown in Table 4.14.

Table 4.9 Effect of nitrogen source and level on the total fresh mass (roots and leaves)

Nitrogen levels (kg ha^{-1}) (NL)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	33.59	30.57	23.39	30.00	26.05	**28.72^{d}**
50	69.06	105.24	74.55	79.40	123.05	**90.26^{c}**
100	98.22	126.54	135.29	79.59	135.04	**114.94^{b}**
150	114.61	118.43	115.76	130.06	148.00	**125.37^{ab}**
200	117.86	136.33	160.60	126.91	150.28	**138.40^{a}**
Mean	**86.67^{c}**	**103.42^{ab}**	**101.92^{abc}**	**89.19^{bc}**	**116.48^{a}**	**99.54**

$LSD_{T(0.05)}$NS=15.87
$LSD_{T(0.05)}$NL=15.87
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other.

These results are in agreement with findings of Elia *et al.* (1999), Gulser (2005) and Stagnari (2007) who indicated that spinach yield was increased by increasing nitrogen fertilizer rate. However, the results are in disagreement with Aminifard *et al*. (2012) who discovered that the total yield of sweet pepper decreased as the nitrogen fertilizer increased up to 150 kg N ha^{-1}. Aminifard *et al.* (2012) found that the highest yield was obtained at 100 kg N ha^{-1} while the minimum yield was recorded at 150 kg N ha^{-1}. Total fresh mass is directly proportionate to number of leaves, length of leaves, beet length, beet diameter, beet fresh mass and weight of leaves per plant (Pervez *et al*., 2004).

4.3.2 *Beet fresh mass*

The nitrogen level had a highly significant ($P < 0.0001$) effect on this parameter, while the interaction effect with nitrogen source was not significant. Beet fresh mass increased with increasing levels of nitrogen (Table 4.10). The beet fresh mass increased from 12.49 g with 0 kg N ha^{-1} to 59.16 g with 200 kg N ha^{-1}. Beetroot plants that received 100, 150 and 200 kg N ha^{-1} had significantly higher beet fresh mass than plants that received no nitrogen and those that received 50 kg N ha^{-1}. However, no significant differences in beet fresh mass were found between three levels, namely 100, 150 and 200 kg N ha^{-1}. Comparing means of average beet fresh mass of nitrogen fertilizer applications, the highest fresh mass (59.16 g) was obtained from 200 kg N ha^{-1}, whereas the lowest (12.49 g) was obtained at the control level.

These results confirm those of Albayrak and Yeksel (2010) who found that the highest beet fresh mass was obtained at 200 kg N ha^{-1}. However, Turk (2010) reported that supplying beetroots with nitrogen fertilizer up to 100 kg significantly increased beet fresh mass. Similar trend was observed by El-Shafai (2000), Ismail (2002) and Ibrahim *et al*. (2005). Turk (2010) findings also showed that application of nitrogen fertilizer had a significant effect on beet fresh mass. In beetroot cultivated in Greece under semi arid conditions, beet fresh mass was maximized at high nitrogen rates (180-240 kg N ha^{-1}), but acceptable at 120 kg N ha^{-1} (Tsialtas & Maslaris, 2008). Muhammad *et al.* (2010) findings showed that root fresh mass of radish increased gradually with an increase in nitrogen level up to 200 kg N ha^{-1} and then it started to decline.

Table 4.10 Effect of nitrogen source and level on root fresh mass (g) of beetroot

Nitrogen levels (kg ha^{-1}) (NL)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	16.12	12.30	10.80	12.17	11.04	**12.49^{c}**
50	34.42	46.70	37.69	44.37	51.48	**42.93^{b}**
100	51.50	51.84	65.35	39.13	56.89	**52.94^{a}**
150	50.41	46.15	53.19	62.78	70.60	**56.63^{a}**
200	48.43	56.35	75.39	57.39	58.24	**59.16^{a}**
Mean	**40.18^{b}**	**42.67^{ab}**	**48.48^{ab}**	**43.17^{ab}**	**49.65^{a}**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL= 9.26
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other.

4.3.3 Total Yield

Yields of beet were significantly affected by both the N-application rate and the source. The insignificant interaction between these two factors showed that the plants reacted to increasing N-application rates in the same way irrespective of the source used.

Beet yields were found to increase as the N application rate increased from 2.99 t ha^{-1} in the control treatments (0 kg N ha^{-1}) to 14.37 t ha^{-1} in treatments that received 200 kg N ha^{-1}, (Table 4.11). Application of 50 kg N ha^{-1} (9.37 t ha^{-1}) increased yields significantly over that of the control, while applying 100 kg N ha^{-1} resulted in a further significant yield increase (11.94 t ha^{-1}). At 150 kg N ha^{-1} the yields were not significantly different from those obtained at the 100 or 200 kg N ha^{-1} application rates. Fertilizing with UAN gave the highest yields (12.17 t ha^{-1}), while using LAN gave the lowest (9.00 t ha^{-1}). No significant difference in yields between N-sources were found between LAN, ASN and urea, or between urea, AN and UAN.

The results showed that there was a positive correlation between plant height, leaf dry mass and total yield of beet. Beet yield, plant height and leaf dry mass were significantly affected by both the N application rate and the N-source whereas the interaction effect between the two factors did not significantly affect these parameters. The interaction effect between these two factors did not significantly affect these parameters, that plants reacted to increasing nitrogen application in the same way, irrespective of the fertilizer used. UAN as a nitrogen source resulted in higher beet yields and higher leaf dry mass than other nitrogen sources.

Table 4.11 Effect of nitrogen source and level on the total yield (t ha^{-1}) of beetroot

Nitrogen levels (kg ha^{-1}) (NL)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	3.49	3.18	2.43	3.12	2.71	**2.99^{d}**
50	7.17	10.93	7.74	8.25	12.78	**9.37^{c}**
100	10.20	13.14	14.05	8.26	14.03	**11.94^{b}**
150	11.90	12.30	12.02	13.51	15.70	**13.09^{ab}**
200	12.24	14.16	16.68	13.18	15.61	**14.37^{a}**
Mean	**9.00^{c}**	**10.74^{ab}**	**10.58^{abc}**	**9.26^{bc}**	**12.17^{a}**	**10.35**

$LSD_{T(0.05)}$NS=1.65
$LSD_{T(0.05)}$NL=1.65
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other.

A number of papers (Cerne, 1981; Goh & Vityakon, 1983; Stopar *et al.,* 1988; Fridz *et al*., 1989; Salo *et al*., 1992; Vogel, 1996) deal with the influence of nitrogen fertilization (from 120 to 600 kg N ha^{-1}) on beetroot yield (from 20 to 70 t ha^{-1}). Ugrinovic (1999) and Cerne *et al.* (2000) determined that mineral fertilization with 150 kg N ha^{-1} could result in good beet yield. Similar findings regarding the influence of nitrogen on yield were obtained by Mrkovic *et al.* (1988) who reported that spinach yield increased as nitrogen application increased up to 150 kg N ha^{-1}. The same trend of increase in yield of different vegetables was observed by Sharma and Kansal (1984), Boon *et al*. (1986) and Weier and Scharrpf (1989).

For example, Rincon *et al.* (1998) reported that increasing nitrogen up to 100 kg N ha^{-1} increased the yield of lettuce, up to 53.4 t ha^{-1}, while the application of 150 and 200 kg N ha^{-1} caused a decrease in yield. Zarei (1995) reported that by increasing the nitrogen fertilizer rate to 200 kg ha^{-1} increased the yield of spinach but that the corresponding increase in yield was not economical at this level. Also, Bestash (1995), during experiments on cabbage and celery, found that the application of nitrogen fertilizer increased yield over that of control treatments, but that the economic best yield was obtained at an application of 100 kg N ha^{-1}.

4.4 External quality

A summary of the analysis of variance that was conducted to determine the effect of nitrogen source and nitrogen level on the external quality of beetroot is shown in Table 4.12.

Table 4.12 Summary of the analyses of variances showing the effect of nitrogen source and nitrogen level on the external quality of beetroot

External quality parameters	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
Beet diameter	*	*	ns
Beet volume	ns	*	ns

ns = no significant difference

*** = significant differences**

Both the nitrogen source and level significantly influenced the beet diameter. Nitrogen level also significantly influenced the beet volume of beetroot.

4.4.1 Beet diameter

The data in Table 4.13 shows that nitrogen source influenced the beet diameter significantly ($P < 0.0493$). Application of UAN as nitrogen source resulted in significantly larger beet diameter (41.99 mm) than AN (37.27 mm), ASN (37.82 mm) and LAN (38.38 mm). UAN and urea as nitrogen sources did not differ significantly in influencing beet diameter. Inspection of Table 4.13 shows that LAN, AN, urea and ASN did not differ significantly in influencing the beet diameter. However, larger beet diameter was obtained after application of UAN (41.99 mm) whereas the lowest diameter was obtaind after application of AN.

Table 4.13 also shows that nitrogen level had a highly significant ($P < 0.0001$) effect on the diameter of beetroot. Beetroot diameter increased with increasing levels of nitrogen. Beetroot diameter increased from 23.91 mm (0 kg N ha^{-1}) to 44.83 mm (200 kg N ha^{-1}).

Diameter of plants receiving 150 and 200 kg N ha^{-1} was significantly larger than those that received no nitrogen and those that received 50 kg N ha^{-1}. These results concur with the findings of Albayrak and Yuksel (2010) who reported that the greatest beet diameter was found after application of nitrogen fertilizer at the rates of 150 and 200 kg N ha^{-1}. Nitrogen at 100 kg N ha^{-1} level resulted in larger beetroot diameter than the control level. Application of nitrogen at 100, 150 and 200 kg ha^{-1} did not differ significantly in influencing the beet diameter. Nitrogen at 50 and 100 kg ha^{-1} did not differ significantly in influencing the beet diameter. However, plants that received 200 kg N ha^{-1} resulted in significantly larger sized roots (44.38 mm) while smaller beet diameter were obtained at the control level (23.91 mm) (Fig. 4.1).

Figure 4.1 Small beetroot diameter found with no extra N application

Amin (2005) reported that increasing nitrogen levels significantly increased root length and its diameter. Turk (2010) also found that increasing the nitrogen fertilizer doses caused an increase in beet diameter. Mean values in relations to different nitrogen levels indicated significant superiority of 200 kg N ha^{-1} nitrogen level over 100 kg N ha^{-1} and 0 kg N ha^{-1} and was found at par with 150 kg N ha^{-1} (Pervez *et al.,* 2004). These results are confirmed by the findings of Kolota and Orlowski (1984) and Lenka *et al.* (1990). Muthuswamy and Muthukrishnan (1984) also reported that beet diameter markedly increased with nitrogen application. The reason for maximum beet diameter in plants receiving more nitrogen may be due to the fact that these plants were more healthy and vigorous than others (Jilani *et al*., 2010).

Table 4.13 Effect of nitrogen source and level on the diameter (mm) of beetroot

Nitrogen levels ($kg\ ha^{-1}$) (NL)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	26.47	24.83	21.74	23.20	23.29	**23.91^{c}**
50	36.04	41.52	39.13	38.92	42.08	**39.54^{b}**
100	43.26	41.30	45.28	35.38	47.14	**42.47^{ab}**
150	43.38	38.82	45.76	46.43	47.35	**44.35^{a}**
200	42.77	39.90	46.22	45.16	50.08	**44.83^{a}**
Mean	**38.38^{b}**	**37.27^{b}**	**39.63^{ab}**	**37.82^{b}**	**41.99^{a}**	**39.02**

$LSD_{T(0.05)}NS = 3.34$
$LSD_{T(0.05)}NL = 3.34$
$LSD_{T(0.05)}NSxNL =$ ns

Means followed by the same letter in either row or column do not differ significantly from each other.

4.4.2 Beet volume

Nitrogen level had a highly significant ($P < 0.0001$) effect on beet volume, while nitrogen source and the interaction between level and source had no significant effect on beet volume (Table 4.14). Beet volume increased as the nitrogen application increased from 0 to 200 kg ha^{-1}. Beetroot volume increased from 14.70 cm^3 with 0 kg N ha^{-1} to 63.42 cm^3 with 200 kg N ha^{-1}. Beet volume increased significantly with each increase in N application from 0 to 100 kg N ha^{-1}. Although root volume continued increasing up to the 200 kg N ha^{-1} rate no significant differences were noted in root volume from plants receiving 100, 150 and 200 kg N ha^{-1}.These results are consistent with those of Bar-Tal *et al*. (2001), Magdatena (2003), Akanbi *et al*. (2007) and Aujla *et al*. (2007) who reported that increasing the rate of nitrogen fertilizers increases the average fruit volume of pepper.

Table 4.14 Effect of nitrogen source and level on the beet volume (cm^3) of beetroot

Nitrogen levels (kg ha^{-1}) (NL)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	19.17	13.50	14.18	13.75	13.33	**14.79^c**
50	34.58	47.50	38.75	48.75	54.17	**44.75^b**
100	52.92	56.67	65.42	40.83	60.42	**55.25^a**
150	53.34	48.33	57.92	65.97	72.09	**59.53^a**
200	56.67	65.84	73.33	59.58	61.67	**63.42^a**
Mean	**43.34**	**46.37**	**49.92**	**45.78**	**52.34**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 9.51
$LSD_{T(0.05)}$NSxNL = ns

Means followed by the same letter in either row or column do not differ significantly from each other.

4.5 CONCLUSION

The findings from this study clearly show that nitrogen fertilizers influenced the growth, yield and external quality parameters of beetroot. The results showed that all fertilizers, with the exception of LAN, used resulted in a reduction in plant height for the first six weeks of growth. Nitrogen application only increased plant height significantly from Week 8 where the height of plants that received nitrogen, irrespective of the fertilizer used, were significantly taller than those that did not. By Week 10, significant increases in plant height were noted between 50 kg N ha^{-1} and 150 kg N ha^{-1} or 200 kg N ha^{-1} application rates. Plants fertilized with urea and ASN were significantly taller than those fertilized with other products at Week 8. Plants that were fertilized with ASN were significantly taller than those that received any other products by week 10.

Nitrogen application at 100 kg ha^{-1} resulted in more beetroot leaves than application of nitrogen at other levels. UAN as a nitrogen source significantly increased leaf area, leaf fresh mass, total fresh mass and root diameter. UAN increased leaf dry mass by an average of 397.35% while the lowest leaf dry mass was increased by an average of 139.42% after application of LAN as a nitrogen source. Greatest dry mass was obtained at the highest rate of nitrogen application and the lowest leaf dry mass was obtained at the control level. These results also indicates that application of nitrogen at 200 kg ha^{-1} resulted in larger leaf area, greater leaf fresh mass, greater total fresh mass, larger beet diameter and greater beet volume.

Beet yields were found to increase from 2.99 t ha^{-1} in the control treatments to 14.37 t ha^{-1} in treatments that received 200 kg N ha^{-1}. Fertilizing with UAN gave the highest yields (12.17 t ha^{-1}) while using LAN gave the lowest (9.00 t ha^{-1}). These results are useful in preliminary studies in determining the preferred nitrogen source and application levels of nitrogen that affect the growth, yield and quality of beetroot. However, the findings must be verified in the field.

CHAPTER 5

INFLUENCE OF NITROGEN FERTILIZER ON THE PHYSICO-CHEMICAL PROPERTIES OF BEETROOT (*BETA VULGARIS* L.)

5.1 INTRODUCTION

The influence of plant nutrition on vegetable quality has recently been studied and there is still much to be learned. Although supply of nutrients above the optimum levels may not reduce the quantity or yield, it may have either negative or positive effects on aspects of quality that are not readily apparent. Adequate nitrogen (N) is essential for optimal plant growth and development and it is the mineral element most used by plants. Adequate nitrogen usually allows plants to grow, develop and produce maximum yields with at least the potential for a high quality product with desired color, flavour, texture, and nutritional composition.

Nitrogen has the greatest influence of all the mineral elements on root quality and sucrose production of beets (*Beta vulgaris* L.). Beets grown with inadequate levels generally have a high sucrose percentage and low impurities. Too much N increases root impurities while reducing glucose, sucrose and fructose percentages. Optimum amounts of soil and fertilizer N are desirable for adequate top and root growth, while maintaining sufficiently high carbohydrate percentage. Excessive soil nitrogen can negatively impact on quality in several ways. Higher amount of nitrogen can result in compositional changes such as reduced ascorbic acid content, lower sugar content, lower acidity and altered ratios of essential amino acids. High doses of nitrogen decrease not only starch content but also dry matter content and spoil the taste of potato tubers after cooking (Vokal and Radil, 1996).

An adequate supply of N is essential for optimum yield but excess N may result in an increase in yield of roots with lower sucrose content. Yield increased with applied N, but TSS and sucrose % yield per ha were significantly decreased as N level increased (Lauer, 1995; Badawi *et al*., 1995; Salama & Badawi, 1996; El-Hennawy *et al*., 1998). According to Huett (1989), for most vegetable species the nitrogen level producing the highest yield produces the best quality edible plant part. In tomato, the high nitrogen levels produced the firmest fruit with the highest total soluble solids and dry matter content and in the case of cabbage and lettuce; crispness of heads was reduced at low and high nitrogen levels. Hedau (1998) found that higher doses of N reduced total soluble solids (TSS) in tomato fruits. Nitrogen fertilization had little effect on glucose but increased fructose and lowered sucrose levels in cabbage (Hicks *et al.,* 1986). Nilsson (1988) found a decrease in sucrose content with N application while hexose and starch remained unchanged. Mukkun *et al*. (2001) observed that nitrogen nutrition affects fruit firmness, quality and shelf life of strawberries. In leaves of cabbage, for example, nitrogen deficiency caused an increase in free sugar content, especially that of sucrose (Hara, 1989). Conversely, sugar content in spinach has been observed to decrease in response to increased application of nitrogen fertilizer (Watanabe *et al*., 1988; Takebe *et al*., 1995).

A summary on the analysis of variance (ANOVA) that was done to determine the effect of nitrogen source (NS), nitrogen level (NL) as well as NS x NL interaction on the defects and internal quality (firmness, colour, pH, TSS, starch, and sugars) of beetroot is shown in Table 5.1.

Table 5.1 ANOVA for the effects of nitrogen source, level as well as NS x NL interaction on the defects and internal quality of beetroot

Physico-chemical properties	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
Defects	*	*	ns
Firmness	ns	*	ns
L* (Lightness)	ns	*	ns
A +a -red	ns	*	ns
-a -green			
B +b -red	ns	*	ns
-b -green	ns	*	ns
pH	ns	ns	ns
TSS	ns	*	ns
Starch	ns	*	ns
Glucose	ns	*	ns
Sucrose	ns	ns	ns
Fructose	ns	ns	ns

ns = no significant differences

*** = significant difference**

As shown in Table 5.1, the interaction between nitrogen source x nitrogen level (NS x NL), as well as nitrogen source (NS) did not significantly influence the internal quality (physico-chemical properties) of beetroot. Nitrogen source also significantly influenced beet defects. Nitrogen level did not significantly influence pH, sucrose and fructose content of beet. The physico-chemical properties, including defects, firmness, colour (L^*, A and B), total soluble solids, starch and glucose content) of beet were significantly influenced by nitrogen level.

5.2 Physical parameters

5.2.1 Defects

Beet marketability (absence of defects) was not significantly influenced by the interaction between nitrogen source x nitrogen level, although both nitrogen source and nitrogen level had a significant effect on defects. All application rates of N significantly reduced the occurrence of defects relative to the control treatment, although no significant differences were noted with increasing N applications from 50-200 kg ha^{-1} (Table 5.2). Significant differences in the relative reduction in defects were found between the N-sources used. Application of LAN resulted in significantly fewer defects with an average of 9.47%, compared to ASN, urea and UAN that had 22.94%, 25.55% and 41.73% defects, respectively.

The data also showed that AN, ASN and urea did not differ significantly from each other in influencing beet defects. However, UAN resulted in significantly fewer defects than the other sources. LAN and AN did not differ from each other in reducing beet defects. The findings showed that UAN was better than other nitrogen sources in reducing defects, while LAN resulted in the lowest reduction of defects. An example of a defective beetroot is shown in Fig. 5.1. Findings by Hailu *et al*. (2008) showed that the increased rates of pre-harvest urea application resulted in uniform decreases in percentage defects of carrots, although the differences were not significant. Bose and Som (1990), showed reduced defects of carrots due to nitrogen fertilizer application and their report showed more cracking of carrot roots with increased levels of nitrogen.

Table 5.2 Effect of nitrogen source and nitrogen level on defects expressed as a percentage of the control

	Nitrogen Source (NS)					
Nitrogen level (NL) kg ha^{-1}	**Limestone ammonium nitrate**	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	**Mean**
0	100.00	100.00	100.00	100.00	100.00	**100.00[a]**
50	116.65	76.43	72.38	64.60	48.03	**75.62[b]**
100	79.58	63.45	50.60	91.43	38.85	**64.78[b]**
150	73.65	90.70	55.63	59.73	50.70	**66.08[b]**
200	82.80	79.48	93.68	69.58	53.80	**75.87[b]**
Mean	**90.54[a]**	**82.01[ab]**	**74.46[b]**	**77.07[b]**	**58.28[c]**	**76.47**

$LSD_{T(0.05)}$NS = 13.25
$LSD_{T(0.05)}$NL = 13.25
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other.

Figure 5.1 Symptoms of beetroot defects (cracks, patches and discolouration)

5.2.2 Firmness

The interaction between nitrogen source x nitrogen level, as well as the nitrogen source (Table 5.3) did not significantly influence the firmness of beetroot. However, the nitrogen level significantly influenced the beetroot firmness. Plants that did not receive any nitrogen (control) were significantly softer than plants that received nitrogen at 50, 100, 150 and 200 kg N ha^{-1}. Plants that received 50 kg N ha^{-1} had significantly firmer beets (26.91 mm) as compared to the control. Though not significantly different, the firmness of beetroots decreased as the nitrogen level was increased from 100 (28.84 mm), 150 (29.28 mm) to 200 kg N ha^{-1} (30.91 mm).

The results are in conformity with Akoumianakis *et al.* (2011) who reported that firmness of radish decreased under the influence of N application. Akoumianakis *et al.* (2011) also showed that increasing nitrogen levels caused a higher water uptake by the radish, which was thus responsible for the increase in fresh root weight but at the expense of root firmness. Irrespective of N level, the loss of firmness represents a serious loss of quality and may enhance sponginess or softness of the roots as water is lost during storage. This result also concurs with the studies on canning tomatoes by Moore *et al*. (1957) where firmness was reduced by fertilizer applications and Samaila (2011) where tomato fruits were firmest in plots with low fertilizer and the fruits became softer with corresponding increase in fertilizer rates.

Table 5.3 Effect of nitrogen source and nitrogen level on firmness (mm) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	40.75	35.88	31.44	39.50	34.38	**36.39a**
50	19.31	29.56	32.56	24.81	28.33	**26.91b**
100	34.69	29.00	30.06	30.13	20.31	**28.84b**
150	26.94	30.38	31.00	26.44	31.63	**29.28b**
200	32.00	33.63	33.13	26.50	29.31	**30.91b**
Mean	**30.74**	**31.69**	**31.64**	**29.48**	**28.79**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 5.12
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in the row or column do not differ significantly from each other.

In other experiments (Park & Fritz, 1990), radish sponginess was related to increased rates of fertilizer application. Nitrogen fertilization has also been linked with fruit flesh softening (Rettke *et al*., 2006; Jia *et al*., 2006) and their results showed that firmness of apricot fruit was significantly reduced as the rate of applied nitrogen increased. This might be due to the effect of nitrogen in diminishing the cell wall thickness, which in consequence decreases the flesh texture (Muramatsu, 1996; Jia *et al*,. 2006). This undesirable decrease in firmness due to excess nitrogen fertilization is well documented in several crops (Prasad *et al*., 1988; SAMS, 1999). Mukkun *et al*. (2001) observed that nitrogen nutrition affects fruit firmness, quality and shelf life of strawberries.

The softening and decline in root firmness are accompanied by increased expression of numerous cell wall degrading enzymes, including polysaccharide hydrolases, transglycosylates, lyases and all other wall loosening proteins (Harker *et al*., 1997; Rose *et al*., 2003; Brummell, 2006). It has been reported that factors such as turgor and cell morphology contribute to aspects of texture (Lin & Pitt, 1986; Schackel *et al*., 1991) and invariably attribute to softening and disassembly of polysaccharide networks (Rose *et al*., 2003; Brummel, 2006).

5.2.3 Colour

5*.2.3.1 L* (Lightness)*

The interaction between nitrogen source x nitrogen level did not significantly influence the lightness of beetroot. The data in Table 5.4 indicates that nitrogen level significantly influenced the lightness of beetroot. Plants that did not receive any nitrogen differed significantly from plants that received nitrogen. The darkening of colour (decrease of L*) was observed at the control level and the highest changes of colour was obtained at the highest nitrogen level (200 kg N ha^{-1}). Nitrogen source did not significantly influence the lightness of beetroot.

Table 5.4 Effect of nitrogen source and level on lightness (L*) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	19.55	19.30	18.58	18.37	19.16	**18.99b**
50	19.82	21.44	21.25	20.71	22.89	**21.22a**
100	21.21	21.27	20.07	20.39	21.63	**20.91a**
150	20.63	21.52	21.31	21.97	20.45	**21.18a**
200	21.32	25.87	19.95	22.14	20.64	**21.98a**
Mean	**20.51**	**21 .88**	**20.23**	**20.72**	**20.95**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 1.64
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other

Because of its high dietary value and good flavor and the many different ways it can be processed, beet is one of the most popular vegetables. It owes its organoleptic properties mainly to the beautiful colour derived from the presence of betalains, among which there are red and purple betacyanins and yellow betaxanthines (Felczynski & Elkner, 2008). The concentration of these compounds in beet is influenced by genetic factors, degree of plant maturity, cultivation conditions, root size, the extent of fertilization and the type of fertilizers used (Nilsson, 1973, Michalik & Grzebelus, 1995, Elkner *et al*. 1997, 2006). The lightness of raw beet as reported by Czarniecka-Skubina *et al*. (2003) ranges around 27.0 ± 0.9 and the present findings showed colour lightness of the same trend, although a little lower. However, there are not many studies on the effect of nitrogen source and nitrogen level on the lightness of beetroot colour.

Tuncay *et al.* (2011) found that nitrogen source did not have a statistically significant effect on leaf lightness values of garden cress (*Lepidium sativum* L.). However, although not significantly different, AN influenced lightening of colour (increase of L*) more than urea, that influenced the darkening of colour (decrease of L*). Leon *et al*. (2007) reported that leaf lightness values are strongly correlated with leaf chlorophyll content of butter head lettuce (*Lactuca sativa* Lores). When colour values were examined for crispy salad, there was a difference only in lightness value and the highest value was obtained from intercropped plants (Demir & Polat., 2011). Tunkay *et al*. (2011) also discovered that mineral fertilizers produced darker coloured leaves of garden cress (*Lepidium sativum* L.) as compared to farmyard manure and although the results were not statistically significant, lightness values showed a similar trend. Leaf nitrogen concentration is directly related to leaf chlorophyll content and therefore to leaf greenness (Chapman & Barreto, 1997). As a result, there are several researchers who report on the prediction of crop nitrogen status via chlorophyll measurements or analysis (Sandoval – Villa *et al*., 1999; Shaahan *et al*., 1999,; Sandoval – Villa *et al*., 2002; Westerveld *et al*., 2004; Liu *et al*., 2006).

5.2.3.2 A +a -red, -a -green

Nitrogen level had a significant influence on changes of trichromatic coefficient a (Table 5.5). Coefficient a changes from red into green colour. The data indicates that nitrogen at the control level (0 kg N ha^{-1}) significantly resulted in more intensive change of coefficient a from red into green than application of nitrogen level at 50, 100, 150 and 200 kg N ha^{-1}. Nitrogen level at and above 100 kg N ha^{-1} significantly caused the lowest change of coefficient a from red to green while the control level (0 kg N ha^{-1}) resulted in more intensive change. Application of nitrogen at 50, 100, 150 and 200 kg N ha^{-1} did not differ significantly in influencing the change of coefficient a from red into green colours. Though not significantly different, LAN resulted in more intensive change of coefficient a from red into green colours and AN influenced the least change of coefficient a.

A healthy colour value of red beet is determined by a high content of betalain pigments (Elbe *et al*., 1974), including red violet betacyanins (mainly betanin) and yellow betaxanthins (mainly vulgaxanthin). Experiments have shown that pigment compounds of red beet have cytotoxic properties against cancer cells (Bujanowska, 2003). Beet nutrition contain betalain which is a nutrient important for cardiovascular health and it functions in conjuction with folic acid and vitamins B6 and B2 to reduce homocysteine build up in the blood. Too much homocysteine build up can lead to heart disease, stroke and peripheral vascular disease. The concentration level of betalain pigments in beetroots determines to a great extent their quality, particularly as a raw material for processing (Felczynski & Elkner, 2008). A predominance of red pigments over yellow ones imparts a beautiful purple red colour to beetroot juice (Wolyn & Gabelman, 1986).

Table 5.5 Effect of nitrogen source and level on trichromatic coefficient (a) of beetroot

Nitrogen level (NL) ($kg\ ha^{-1}$)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	20.31	20.64	20.84	20.39	20.59	**20.55b**
50	20.66	28.04	26.25	25.64	26.43	**25.40a**
100	28.20	27.84	24.59	24.88	30.15	**27.13a**
150	26.26	27.63	29.16	26.92	25.65	**27.12a**
200	26.67	24.76	24.70	28.56	26.01	**26.14a**
Mean	**24.42**	**25.78**	**25.11**	**25.28**	**25.77**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 1.64
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other.

Czarniecka-Skubina *et al*. (2003) reported that raw beet colour changes of trichromatic coefficient a ranges around +24.9 ± 0.9 and the present results showed the same trend although the present results are a bit higher (20.31-30.15). Findings by Felczynski and Elkner (2008) showed that as the application level of mineral fertilizers increased, the betanin content in the roots decreased while the vulgaxanthine content increased, resulting in a less favourable colour of the roots. Michalik and Grzebelus (1995) and Ugrinovic (1999) found an unfavourable effect of high nitrogen fertilization rates on the betanine content in the roots of beetroot, except that according to these authors, the ratio of red to yellow pigments was influenced more by the genetic properties of the cultivars. Similar to the present findings, results of Ugrinovic (1999) showed that betanin (betacyanin pigment) units increased from 59.3 at 225 kg N ha^{-1} to 66.1 at 0 kg N ha^{-1}.

In agreement with the present findings, Michalik and Grzebelus (1995) also showed that medium levels of nitrogen tend to increase betanin content of the beetroot sap, while high nitrogen supply may cause a decrease in betanin concentrations. The decrease of betanin with later harvesting and higher nitrogen supply and the dependence of betanine content on genotype have been reported before (Watson & Gabelman, 1982; Michalik & Grzebelus, 1995). For that reason, considerable differences in the ratio of red to yellow pigments had been observed in different years (Nilsson 1973, Sobkowska & Kaczmarek 1991, Michalik & Grzebelus 1995).

5.2.3.3 B +b-yellow, -b- blue

Table 5.6 shows that the interaction between nitrogen source x level did not significantly influence coefficient b. However, nitrogen level significantly influenced coefficient b. Coefficient b changes from yellow into blue colours. The data shows that coefficient b at the control level (0 kg N ha^{-1}) resulted in significantly more intensive changes from yellow to blue colours than application of nitrogen at 100, 150 and 200 kg N ha^{-1}. Nitrogen at the control and 50 kg N ha^{-1} level did not differ significantly in influencing changes of coefficient b from yellow to blue colours. Application of nitrogen at 100, 150 and 200 kg N ha^{-1} did not differ significantly in influencing changes of coefficient b. Nitrogen at the control level (0 kg N ha^{-1}) resulted in more intensive changes of coefficient b from yellow to blue and application of nitrogen at the highest level (200 kg N ha^{-1}) resulted in less intensive changes of coefficient b from yellow to blue. Though the effect of nitrogen source was not significant, LAN resulted in more intense changes of coefficient b while AN resulted in less intense changes.

Colour is one of the most important attributes in foods, being considered as a quality indicator and frequently determining frequently their acceptance (Azeredo, 2009). Ugrinovic (1999) also found that the content of vulgoxantine I (yellow betaxanthin pigment) in beetroot decreased with higher nitrogen levels. Vulgoxantine decreased from 22.3 at 0 kg N ha^{-1} to 26.1 at 225 kg N ha^{-1} (Ugrinovic, 1999). In agreement to the present findings, Czarniecka-Skubina *et al*. (2003) showed that the normal trichromatic coefficient b readings of raw beet range around +5.4 ± 0.8; however, the readings of Ugrinovic (1999) were not in the same range. This might be due to different genetic factors, degree of plant maturity, cultivation conditions, root size, extent of fertilization and type of fertilizers used (Nilsson 1973; Michalik & Grzebelus 1995; Elkner *et al*. 1997, 2006). Higher concentrations of betanin and lower concentrations of vulgaxanthine in beetroot were also found by Litka (1996) in a two year-long study. Many researchers are of the opinion that the biosynthesis of betanin and vulgaxanthine in beetroot, apart from other factors, is also greatly influenced by weather conditions during vegetation (Felczynsky & Elkner, 2008).

Table 5.6 Effect of nitrogen source and level on trichromatic coefficient (b) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	3.39	3.26	3.39	3.14	3.13	**3.26b**
50	3.33	6.32	4.95	4.55	4.54	**4.74ab**
100	5.67	5.81	4.25	4.61	6.56	**5.38a**
150	4.44	5.75	5.69	5.53	4.69	**5.22a**
200	4.66	9.32	4.11	6.22	5.06	**5.87a**
Mean	**4.30**	**6.09**	**4.48**	**4.81**	**4.80**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 1.57
$LSD_{T(0.05)}$NSxNL=ns
Means followed by the same letter in the row or column do not differ significantly from each other

5.3 Chemical parameters

5.3.1 pH

As shown in Table 5.7, the interaction between nitrogen source x nitrogen level did not significantly influence the pH of beetroot, and neither did the nitrogen source nor nitrogen level. Although the nitrogen level did not significantly influence the pH of beetroots, plants that received no nitrogen (0 kg N ha^{-1}) had higher pH values (6.58) while plants that received 150 kg N ha^{-1} recorded lower pH values (6.48). ASN as nitrogen source influenced pH values to be higher (6.55) than other nitrogen sources though the differences were not significant.

The pH of beetroot is a very important parameter in determining taste (Hailu *et al*., 2008) and may vary depending on cultivar type, etc. Beet pH and carbohydrate content are the main factors influencing taste and the interaction of these two factors influence beet taste dramatically (Gul *et al*., 1967). Hailu *et al*. (2008) also recorded an elevated pH value of 6.42 for carrots treated with pre-harvest 309 kg orga (an organic fertilizer containing 1% N and 23 % P_2O_5) ha^{-1} with no urea combined, while on the other hand, the lowest pH value of 6.27 was observed in carrots treated with the recommended rate of orga combined with 150 % recommended rate of urea i.e. 309 kg orga ha^{-1} combined with 411 kg urea ha^{-1}. In general, there was a decrease in pH values of carrots with increasing application of inorganic nitrogen fertilizer at the time of harvest (Hailu *et al*., 2008). Findings of Gul *et al*. (1967) showed that different nitrogen levels did not significantly influenced tomato pH and it varied in a range of 4.24 to 4.26. Results of Leilah *et al.* (2005) showed that tomato pH increased from 4.20 at 300 kg N ha^{-1} to 4.22 at 100 kg N ha^{-1}.

Table 5.7 Effect of nitrogen source and level on pH of beetroot

Nitrogen level (NL) (kg ha^{-1})[1]	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	6.52	6.67	6.58	6.57	6.54	**6.58**
50	6.62	6.48	6.39	6.56	6.50	**6.51**
100	6.44	6.47	6.52	6.61	6.43	**6.49**
150	6.50	6.45	6.49	6.44	6.51	**6.48**
200	6.60	6.55	6.55	6.58	6.51	**6.56**
Mean	**6.54**	**6.52**	**6.51**	**6.55**	**6.50**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other

5.3.2 *TSS*

The interaction between nitrogen source x nitrogen level did not significantly influence total soluble solids of beetroot. Table 5.8 indicates that nitrogen source did not significantly influence the total soluble solids. Nitrogen level significantly influenced total soluble solids of beetroot. Application of nitrogen at 50 kg N ha^{-1} resulted in significantly more total soluble solids than the control level (0 kg N ha^{-1}). However, no significant difference was found between 50, 100, 150 and 200 kg N ha^{-1}. Nitrogen at the highest level (200 kg N ha^{-1}) did not differ significantly from the control in influencing the total soluble solids of beetroot. Increasing the nitrogen level of the fertilizers up to 150 kg N ha^{-1} increased the total soluble solids of beetroot and the trend decreased at the highest level (200 kg N ha^{-1}).

The °Brix index gives an indication on total dissolved soluble solids (TSS) within the beet. The °Brix index may be the single most important parameter in determining beet quality and taste (Nemeat, 2001). Leilah *et al.* (2007) found that the highest level of nitrogen (216 kg N ha^{-1}) resulted in a marked reduction in total soluble solids in beetroot (25.93%) while the lowest level (120 kg N ha^{-1}) resulted in higher concentrations of total soluble solids (26.18%). On the other hand, an increase in nitrogen level was also associated with marked reduction in total soluble solids. Leilah *et al.* (2005) also showed that total soluble solids of beetroot decreased from 23.87% to 23.33% and 22.78%, respectively with an increase in nitrogen from 150 to 200 and 250 kg N ha^{-1}, respectively. The decrease in total soluble solids with the increase of nitrogen level might be due to the role of nitrogen in increasing moisture content in the root tissues. Salama and Badawi (1996) and Mahasen Fahmi (1999) came to similar conclusions.

Table 5.8 Effect of nitrogen source and level on TSS (°Brix) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	6.00	4.63	4.63	4.48	5.23	**4.99b**
50	4.00	7.50	7.75	8.00	6.48	**6.75a**
100	7.88	7.50	6.25	6.85	6.75	**7.05a**
150	6.25	7.58	7.75	7.25	6.75	**7.12a**
200	6.00	5.00	5.48	7.25	6.26	**6.00ab**
Mean	**6.03**	**6.44**	**6.37**	**6.77**	**6.29**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 1.29
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other

The present results are in disagreement with Nemeat (2001) who reported that AN as a nitrogen source surpassed other nitrogen fertilizer sources in producing higher total soluble solid content of beetroot. Contradictory to the findings of Nemeat (2001), El-Tantawy and Eisa (2009) found that application of AS as a nitrogen source increased total soluble solids in beetroot as compared to AN. High rates of nitrogen were also found to decrease the total soluble solids thereby impairing root quality of beetroot (Liao *et al*., 2009). Nemeat - Alla *et al*. (2009) reported that the increase in total soluble solids of beetroot caused by the lowest nitrogen level may be attributed to the fact that it gave the lowest root size and lowest root moisture, thus causing increased concentration of total soluble solids in the roots.

The present findings are in disagreement with those reported by Hailu *et al.* (2008) who found that total soluble solids of carrots were not significantly affected by nitrogen fertilizer treatments. Nitrogen being a constituent of protein and amino acids directly affects total soluble solids (Kirimi *et al*., 2011) and these indicate the reason for low total soluble solids in the zero nitrogen application in the current study. Saha (1985) as cited by Erdal *et al*. (2007) reported that total soluble solids were higher with tomato fruits that received higher nitrogen than those that received lower nitrogen. Raupp (1996) also discovered that increasing the application of urea had no significant effect on total soluble solids of vegetables.

5.3.2 *Starch*

The interaction between nitrogen source x nitrogen level did not significantly influence the starch content of beetroot. As shown in Table 5.9, nitrogen source did not significantly influence the starch content of beetroot. However, the nitrogen level significantly influenced the starch content of beetroot. Starch content of beetroot plants that received no nitrogen (0 kg N ha^{-1}) was significantly higher than those that received nitrogen (50, 100, 150 and 200 kg N ha^{-1}). An increase in nitrogen 50 to 150 kg N ha^{-1} tended to reduce the starch content of the roots from (5.18 g/100 g to 3.45 g/100 g starch) and the content increased slightly (3.89 g/ 100 g) at the highest level of application. Although not significant, urea application resulted in more beetroot starch content than other nitrogen sources. The data indicates that urea recorded 7.49 g/100 g of starch and the lowest (3.86 g/100 g) was obtained when using UAN.

The current result is consistent with the findings of Rop *et al.* (2009) who reported that increasing nitrogen in the soil led to a statistically significant decrease in starch content of potato tubers. Vokal and Radil (1996) stated that high doses of nitrogen decreases not only starch content but also dry matter content and spoil the taste of potato tubers after cooking. Starch stores energy in the form of disaccharides, it is a source of human nutrition and beet contains 0.6 g of starch. High starch levels are well correlated with high levels of soluble solids in a number of tomato lines (Dinar & Stevens, 1981; Sun *et al*., 1992). The decrease in starch is accompanied by an accumulation of reducing sugars (Dinar & Stevens, 1981).

Table 5.9 Effect of nitrogen source and level on starch content (g/100g) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	14.08	5.96	21.49	10.61	6.09	**11.65a**
50	3.84	3.43	6.48	8.50	3.64	**5.18b**
100	6.03	6.60	5.75	4.41	2.59	**5.07b**
150	2.84	4.38	2.33	4.54	3.15	**3.45b**
200	3.58	12.60	1.41	4.01	3.83	**5.09b**
Mean	**6.07**	**6.60**	**7.49**	**6.41**	**3.86**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 4.02
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other

5.3.4 Sucrose

The data in Table 5.10 indicates that the interaction between nitrogen source x nitrogen level did not significantly influence the sucrose content of beetroot, and neither did the nitrogen source nor nitrogen level. ASN application as a nitrogen source had a higher sucrose content in the roots while UAN resulted in the lowest content, although the differences were not significant. Although the nitrogen level did not significantly influence the sucrose content of beetroot, the findings show that the control level had higher sucrose content in the roots while the highest N level (200 kg N ha^{-1}) resulted in the lowest sucrose content of the beet.

Proper nitrogen fertilization is of utmost importance in producing quality beetroot (Campbell, 2008). High levels of nitrogen reduce the sucrose portion of dry root weight (Milford & Watson, 1971). High rates of nitrogen increase root cell volumes, but have no effect upon number of cambial rings, and the amount of sucrose entering a root is not affected by excess nitrogen; however, more sucrose is metabolized for root growth than when nitrogen is limited (Campbell, 2008). Decreases in sucrose percentage in the beetroot with increasing nitrogen fertilization have been reported by Smith *et al*. (1973). They also stated that too much nitrogen decreases the sucrose content of beetroot and decreases sucrose recovery. Other authors have reported that high levels of mineral nitrogen supply may result in lower content of sugar compounds (Evers, 1994). Findings by Blumenthal *et al*. (2008) showed that excessive nitrogen supply, especially late in the growing season, has in general two main effects on the quality of the harvested beetroot (1) it decreases the concentration of sucrose in the beets; and (2) it increases the impurities. However, the decrease in sucrose concentration in beetroots is mainly caused by dilution, that is, the roots retain more water, which in turn reduces the concentration of sucrose per unit fresh matter (Wieninger & Kubadinow, 1973). Leila *et al*. (2007) also found that the highest level of nitrogen resulted in marked reduction in sucrose content of beetroot (17.67%) while the lowest level of nitrogen resulted in higher sucrose content (18.36%).

Table 5.10 Effect of nitrogen source and level on sucrose content (µmol per fresh weight) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS) Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	Mean
0	134.39	53.87	59.31	153.43	106.64	**101.53**
50	62.69	54.36	165.94	79.81	41.07	**80.77**
100	47.677	116.63	56.31	79.90	27.11	**65.53**
150	48.20	31.22	63.67	85.27	36.35	**52.94**
200	29.47	68.94	15.22	36.72	43.25	**38.72**
Mean	**64.48**	**65.00**	**72.09**	**87.03**	**50.88**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

Schaller & Schnitzler (2000) stated that sucrose is the reserve carbohydrate and it is generated in the vegetative phase of the plant's development and is stored in the root. Mengel (1979) also reported that high nitrogen supply during the filling period of vegetative storage tissues favours the growth of the storage organs but reduces the filling of the cells with carbohydrates. A high nitrogen level influences plant growth and yield, not only directly by providing the element nitrogen for synthesis of amino acids, but also for the formation of phytohormones, especially cytokinins (Shaller & Schnitzler, 2000). Although this result is not significant, apparent sucrose was significantly reduced by nitrogen fertilization (Cole *et al.,* 1973). Nilsson (1988) also found a decrease in sucrose content of cabbage with nitrogen application. Freyman *et al.* (1991) discovered that sucrose content declined linearly, while glucose and fructose of winter cabbage increased to a plateau with increasing nitrogen application.

5.2.5 Glucose

Table 5.11 indicates that the interaction between the nitrogen source x nitrogen level did not significantly influence the glucose content of beetroot. Nitrogen source did not influence the glucose content of beetroot significantly; however, it was significantly influenced by nitrogen level. These findings indicates that nitrogen at the control level (0 kg N ha^{-1}) and at 100 kg N ha^{-1} significantly influenced a higher glucose content of the roots than its application at 50, 150 and 200 kg N ha^{-1}, respectively. These results show that the control level (0 kg N ha^{-1}) influenced higher glucose content in the roots while the lowest glucose content was found at 150 kg N ha^{-1}. Although nitrogen source did not significantly influence the glucose content of beetroot, the data shows that ASN as a nitrogen source influenced the roots to have higher glucose content while the lowest glucose content was found when using urea as a nitrogen source.

Table 5.11 Effect of nitrogen source and level on glucose content (µmol per fresh weight) of beetroot

Nitrogen level (NL) (kg ha^{-1})	**Nitrogen Source (NS)**					**Mean**
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	22.221	29.394	31.179	12.334	20.229	**23.071a**
50	6.063	18.984	5.010	13.903	5.174	**9.827b**
100	21.025	11.706	1.717	64.445	3.596	**20.498ab**
150	3.254	5.242	2.119	10.765	3.846	**4.276b**
200	6.043	41.291	2.394	4.929	3.402	**11.612b**
Mean	**11.721**	**21.323**	**8.484**	**21.272**	**6.569**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL=10.638
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in either row or column do not differ significantly from each other

Sugars (mainly glucose and fructose) and acids (mainly citric and malic acid) play an important role in determining the taste of beet and other fruits and vegetables (Stevens, 1979; Malundo *et al*., 1995; Granges, 2002). Glucose and fructose are products of metabolism and are formed through sucrose hydrolysis (Campbell, 2008). An equal molar mixture of these two hexoses is referred to as invert sugar (Hartmann, 1977). In accord with the present findings, some research has found increased levels of nitrogen fertilizer to decrease the content of glucose in vegetables (Knorr & Vogtmann, 1983). Consistent with the present result, Evers (1989) observed that unfertilized treatments had tendencies to yield higher glucose, fructose and thus also higher sugar contents of carrots than the nitrogen fertilizer treatments.

Contrary to this results, Shaller and Schnitzler (2000) found that the lower the nitrogen fertilization, the lower were the contents of glucose and fructose in the roots of carrots. There was a reported advantageous effect of intensive nitrogen fertilization on total and reducing sugars of radicchio chicory (Biesida & Kolota, 2010). According to Hoque *et al*. (2005) increasing nitrogen gradually elevated glucose content in lettuce. High nitrogen application to the soil caused a decrease in glucose and fructose in the leaves of cabbage (Yano *et al.,* 1981). Conversely, the content of sucrose, glucose and fructose in cabbage plants all increased in response to decreased nitrogen levels (Hara, 1989) while in spinach leaves, sugar content also increased with decreased nitrogen application (Takebe *et al.,*1995). Nitrogen fertilization had little effect on glucose levels in cabbage (Hicks *et al.* 1986).

5.3.6 Fructose

The data in Table 5.12 shows that the interaction between nitrogen source x nitrogen level did not significantly influence the fructose content of beetroot. Nitrogen source and nitrogen level also did not significantly influence the fructose content of the root. However, these results indicate that the control level resulted in higher fructose contents in the beets than application of nitrogen at other levels, although the differences were not significant. The lowest fructose level was observed after application of nitrogen at 100 kg N ha^{-1}. UAN as a nitrogen source resulted in a higher fructose content in the roots than other nitrogen sources, although the differences were not significant.

Findings by Cole *et al*. (1973) also showed that application of nitrogen fertilizer at the highest level (330 kg N ha^{-1}) did not significantly alter fructose levels of beetroot. According to Granges (2002) fructose contributes to flavor and taste on account for greater sweetness compared to glucose and sucrose. Sugars (mainly glucose and fructose) and acids (mainly citric and malic acids) play an important role in determining the taste of tomatoes and other vegetables (Stevens, 1979; Malundo *et al*., 1995; Granges, 2002). Findings by Heeb *et al*. (2006) showed that fructose concentration in tomatoes at high nitrogen level was significantly higher (340 mg (g $DM)^{-1}$ in the inorganic treatments than in the organic treatments.

Table 5.12 Effect of nitrogen source and level on fructose content (µmol per fresh weight) of beetroot

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	29.95	47.60	46.60	68.14	154.25	**69.31a**
50	28.69	14.93	21.54	66.50	25.59	**31.45ab**
100	14.94	7.28	9.92	18.47	7.90	**11.70b**
150	15.19	42.63	12.60	41.08	22.84	**26.87b**
200	22.10	46.25	15.22	14.95	25.72	**24.85ab**
Mean	**22.17**	**31.74**	**21.18**	**41.83**	**47.26**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 1.29
$LSD_{T(0.05)}$NSxNL= ns
Means followed by the same letter in either row or column do not differ significantly from each other

5.4 CONCLUSION

Results from this study indicated that nitrogen source as well as the interaction between nitrogen source x nitrogen level did not have any influence on the physico-chemical properties of beetroot. Nitrogen level did not influence pH, nor the sucrose and fructose content of beet. Defects, firmness, colour, total soluble solids, starch and glucose were significantly influenced by nitrogen level. Nitrogen source also significantly influenced the beet defects. Application of UAN was better than other nitrogen sources in reducing beet defects while LAN resulted in the lowest reduction of defects. The data also shows that nitrogen level significantly influenced the firmness of beetroots. Application of nitrogen at 50 kg N ha^{-1} resulted in firmer beets than application of nitrogen at other levels. These findings showed that plants that did not receive any nitrogen were significantly softer than plants that received nitrogen. The darkening of beetroot colour (decrease of L*) was observed at the control level while the highest changes of colour was obtained at the highest nitrogen level (200 kg N ha^{-1}). The data from this study indicated that nitrogen at 100 kg N ha^{-1} influenced the lowest change of coefficient a from red to green while the control level resulted in more intensive change.

The data also revealed that nitrogen at the control level led to more intensive changes of coefficient b from yellow to blue and nitrogen at the highest level (200 kg N ha^{-1}) resulted in less intensive changes of coefficient b from yellow to blue. The beetroot pH was not influenced by the interaction between nitrogen source x level, and neither did the nitrogen source nor nitrogen level significantly influenced the pH. These findings also show that increasing nitrogen up to 150 kg N ha^{-1} increased the total soluble solids and the trend decreased at the highest application level (200 kg N ha^{-1}). Application of nitrogen at 150 kg N ha^{-1} resulted in a higher total soluble solid content of the roots. Starch content of beetroot plants that received no nitrogen was significantly higher than those that received nitrogen. Application of nitrogen at 100 kg N ha^{-1} and at the control level significantly influenced the glucose content of beetroot more than application of nitrogen at 50, 150 and 200 kg N ha^{-1}; however, the highest glucose content was obtained at the control level. The interaction between nitrogen source x nitrogen level, nitrogen source and nitrogen level did not significantly influence the sucrose and fructose content of the beetroot. These results are useful in preliminary studies in determining the preferred sources and levels of nitrogen that affect the physico-chemical properties of beetroot; however, they must be confirmed in field studies.

CHAPTER 6

INFLUENCE OF NITROGEN FERTILIZER ON THE NUTRIENT CONTENT OF BEETROOT (*BETA VULGARIS* L.)

6.1 INTRODUCTION

Vegetables are a source of minerals whose consumption is thought to be beneficial to human health (Fridz *et al*., 1989; Russo, 1996; Vogel, 1996; Custic *et al*., 2002). Beetroot is often recommended for prevention of development or occurrence of cancer, as well as for anaemia and kidney stone therapy (Kapadia *et al*., 1996; Bobek *et al*., 2000; Lesic *et al*., 2004). Because of that, nutrient removal by edible plant parts is a very important component of soil fertility (Alt and Wiemann, 1987). Custic *et al*. (2007) reported beet yield up to 4.59 kg m^{-2} and Lesic *et al*. (2004) up to 50 t ha^{-1}. However, yield is no more the most important factor in today's agricultural production. Vegetables are important sources of carbohydrates and minerals. It has been observed that nitrogen fertilizer is an essential component of any system in which the aim is to maintain good yield Custic *et al*. (2007).

Lesic *et al.* (2004) reported that 150 kg N ha^{-1} is necessary for red beet yield of 60 t ha^{-1}. Some authors (Michalik and Grzebelus, 1995; Ugrinovic, 1999) reported that the dry weight content in storage root varied from 80 to 164 g kg^{-1} and was decreased by nitrogen abundance (Salo *et al*., 1992; Michalik & Grzebellus, 1995). A number of papers (Cerne, 1981; Goh & Vityakon, 1983; Stopar *et al*., 1988; Fritz *et al*., 1989; Salo *et al*., 1992; Vogel, 1996) dealt with the influence of nitrogen fertilization (from 120 to 600 kg N ha^{-1}) on the beet yield and nutrition. Cerne *et al*. (2000) and Ugrinovic (1999) determined that the mineral fertilization with 150 kg N ha^{-1} could result in a good yield.

Food nutritional quality is very important. Microelements, as enzyme activators, play a notable role in human nutrition. According to Ugrinovic (1999), there is 0.9 mg Fe 100 g^{-1} fresh weight in edible beet part, and Lesic *et al.* (2004) and Lisiewska *et al.* (1996) reported that Fe in edible beet part ranged from 0.5 to 1.73 mg 100 g^{-1} fresh weight. Lisiewska *et al.* (1996) reported 0.387 mg Mn 100 g^{-1} in fresh weight of broccoli.

Minerals are responsible for building structures in the body like bones and teeth and they can help regulate bodily processes (Ugrinovic, 1999). They can be classified as macro elements and micro elements. Some macro elements that are needed for development of strong bones and teeth are calcium, phosphorus, magnesium, sodium, potassium, chlorine and sulfur (Lisiewska *et al.,* 1996). Calcium is also important in regulating blood clotting, muscle tone and nerve function. Phosphorus helps in providing energy to work. Sodium is an osmoregulator and helps muscles to contract and relax. Potassium has similar functions but it is also responsible for regulating heart burn. Chlorine is part of hydrochloric acid which is important for digestion of protein in the stomach. Sulfur is an important constituent of all proteins. Iron transports oxygen in the blood while manganese is important for the development of bones (Lisiewska *et al.* (1996). For this reason, the goal of these investigations was to determine the influence of nitrogen fertilization on the mineral content of beet leaves and roots. This investigation might suggest some new solutions, methods and levels for fertilizing beet.

6.2 LEAVES

A summary of the analysis of variance (ANOVA) that was done to determine the effect of nitrogen source (NS), nitrogen level (NL) as well as NS x NL interaction on the mineral status of beetroot leaves is given in Table 6.1.

Table 6.1 ANOVA (analysis of variance) showing significant effects of the nitrogen source, N level as well as NS x NL interaction on the mineral content of beetroot leaves

Mineral	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
N	ns	*	*
C	ns	ns	ns
P	ns	ns	ns
K	*	ns	ns
Ca	ns	*	ns
Na	ns	*	ns
Mg	ns	ns	ns
Mn	*	ns	ns
Cu	ns	ns	ns
Fe	ns	*	ns
Zn	ns	ns	ns

ns = no significant differences

* = significant differences

Table 6.1 indicates that the interaction between nitrogen source x nitrogen level significantly influenced only the nitrogen content of the beetroot leaves. Neither nitrogen source nor level significantly influenced the carbon, phosphorus, magnesium, copper and zinc content of beetroot leaves. The potassium and manganese contents of beetroot leaves were significantly influenced by nitrogen source. Nitrogen level significantly influenced the nitrogen, calcium, sodium and iron content of beetroot leaves.

6.2.1 Mineral contents of beetroot leaves

6.2.1.1 Nitrogen

Data in Table 6.2 indicates that the interaction between nitrogen source x nitrogen level, as well as nitrogen level, significantly influenced the nitrogen content of roots. However, nitrogen source did not significantly influence nitrogen content. The findings show that application of LAN as a nitrogen source at levels of 100, 150 and 200 kg N ha^{-1} significantly increased the nitrogen content in the leaves than its application at 0 and 50 kg N ha^{-1}.

AN as a nitrogen source resulted in significantly higher nitrogen content in leaves when applied at 50 kg N ha^{-1} than when it was applied at 0, 100, 150 and 200 kg N ha^{-1}. The data also shows that application of AN as a nitrogen source at 0, 150 and 200 kg N ha^{-1} significantly increased the nitrogen content in leaves compared to application at 100 kg N ha^{-1}.

Table 6.2 Effect of nitrogen source and level on nitrogen content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	1.545	2.481	1.509	2.273	2.121	**1.986b**
50	1.855	3.329	1.217	1.694	1.806	**1.980b**
100	2.391	1.461	2.018	2.340	2.658	**2.174ab**
150	2.762	2.318	2.057	2.161	2.541	**2.368ab**
200	2.586	2.411	3.197	1.743	3.451	**2.678a**
Mean	**2.228**	**2.400**	**2.000**	**2.042**	**2.515**	**2.237**

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 0.52
$LSD_{T(0.05)}$NSxNL= 0.41

Means followed by the same letter in either row or column do not differ significantly from each other

With urea, the nitrogen content of beetroot leaves increased from 1.509% to 3.197% as nitrogen increased from 0 kg N ha^{-1} to 200 kg N ha^{-1}. When urea was applied at 200 kg N ha^{-1}, it influenced the nitrogen content in the leaves to be significantly higher than its application at 0, 50, 100 and 150 kg N ha^{-1}. Also, urea application at 100 and 150 kg N ha^{-1} significantly influenced higher nitrogen content in the leaves than at 0 and 50 kg N ha^{-1}.

The results in Table 6.2 also show that application of ASN as a nitrogen source at 0, 100 and 150 kg N ha^{-1} resulted in significantly higher nitrogen content of the leaves than its application at 50 and 200 kg N ha^{-1}. UAN as a nitrogen source increased nitrogen content in the leaves when applied at 200 kg N ha^{-1} than when applied at 0, 50, 100 and 150 kg N ha^{-1}. Application of UAN as a nitrogen source also significantly increased nitrogen content in leaves when applied at 100 and 150 kg N ha^{-1} than when applied at 0 and 50 kg N ha^{-1}. The results show that application of UAN at a level of 200 kg N ha^{-1} outperformed the other nitrogen sources at different levels of application by increasing the nitrogen content of beetroot leaves to 3.451%.

Smith *et al*. (1973) also found that nitrogen percentages of beetroot tops were increased by nitrogen fertilizer application. This concurs with the findings of Hellal *et al.* (2009) who reported that nitrogen application significantly increased nitrogen content in shoot and root of beetroot than those in the control plants. They also stated that the increment in nitrogen percentage may be due to fixed nitrogen fertilizers used as a nitrogen source. Khogali *et al*. (2011) reported that nitrogen content of beetroot leaves increased from 1.59% at 0 kg N ha^{-1} to 1.64% at 80 kg N ha^{-1}. Higher rates of nitrogen fertilizer (214 and 285 kg N ha^{-1}) had significant positive effects on nitrogen content of beetroot leaves (Fathy *et al*., 2009). In a study of Goh and Vityakon (1986), total nitrogen content of spinach increased with increasing levels of nitrogen fertilizers. Similar results were obtained by Lopez-Bellido *et al.* (1994) who found a maximum nitrogen uptake with increasing nitrogen fertilizer levels.

6.2.1.2 Carbon

Results in Table 6.3 show that the interaction between nitrogen source x nitrogen level did not significantly influence carbon content of the leaves. Neither nitrogen source nor nitrogen level influenced the carbon content of the leaves. Contradictory to the present results, Ibrahim *et al.* (2011) reported that nitrogen fertilization significantly influenced the carbon content of *Labisia pumila* blume. Their results showed that the carbon content of the leaves was higher under 0 kg N ha^{-1} than under the 90, 180 and 270 kg N ha^{-1} treatments by (18%, 38% and 62%, respectively). Similar to the findings of Ibrahim *et al*. (2011), Anderson *et al*. (2011) also reported similar increases in carbon content in plants fertilized with low nitrogen.

Ibrahim *et al*. (2011) also reported that the increase in leaf nitrogen content had lead to reduced leaf carbon content under high nitrogen fertilization.

Table 6.3 Effect of nitrogen source and level on carbon content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	30.65	39.33	31.28	34.70	33.90	**33.97**
50	28.70	35.08	27.13	32.15	29.53	**30.52**
100	40.48	23.18	31.53	38.15	27.43	**32.15**
150	31.68	31.43	28.53	31.75	31.55	**30.99**
200	33.83	32.40	38.35	26.78	33.00	**32.87**
Mean	**33.07**	**32.28**	**31.36**	**32.71**	**31.08**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.3 Phosphorus

Table 6.4 indicates that the interaction between nitrogen source x nitrogen level did not significantly influence the phosphorus content of the beetroot leaves; neither did the nitrogen source significantly influence it. Although the nitrogen level did not significantly influence the phosphorus content of the beetroot leaves, plants that did not receive nitrogen (0 kg N ha^{-1}) had higher phosphorus contents (0.936%) than plants that received nitrogen. LAN as nitrogen source increased phosphorus content of the beetroot leaves more than other nitrogen sources.

Khogali *et al*. (2011) stated that nitrogen caused an inconsistent increase in phosphorus content of beetroot with a significant effect in the second season. Anac *et al*. (1999) reported a non steady change in leaf phosphorus under different nitrogen levels. Contrary to the present results, phosphorus content of beetroot leaves increased significantly from 0.12% at 0 kg N ha^{-1} and 80 kg N ha^{-1} to 0.15% at 120 kg N ha^{-1} (Khogali *et al*., 2011). Gulser (2005) also reported that increasing nitrogen levels of fertilizers significantly decreased the phosphorus content of spinach. Similarly, Cil and Katkat (1995) stated that application of high nitrogen rates decreased the phosphorus content of spinach. Although not significant, this result concurs with conclusions reported by Zarei (1995), Elia *et al.* (1999), Gulser (2005) and Stagnari *et al.* (2007), who reported that application of high nitrogen levels decreased the phosphorus absorption in spinach plants. Ukom *et al*. (2009) also found that application of nitrogen fertilizer significantly decreased phosphorus contents in sweet potato.

Table 6.4 Effect of nitrogen source and level on phosphorus content (%) of beet leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	1.093	0.991	0.588	1.024	0.983	**0.936**
50	0.823	1.047	0.642	0.733	0.585	**0.766**
100	0.943	0.820	0.925	1.058	0.622	**0.874**
150	0.703	0.965	0.884	0.859	0.774	**0.837**
200	1.268	0.721	0.631	0.574	0.535	**0.746**
Mean	**0.966**	**0.909**	**0.734**	**0.850**	**0.700**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.4 Potassium

As shown in Table 6.5, the interaction between nitrogen source x nitrogen level, as well as nitrogen level, did not significantly influence potassium content of the leaves. However, nitrogen source significantly influenced the potassium content. Plants that received LAN as nitrogen source had significantly higher potassium contents in the leaves (5.00%) than AN (4.42%), urea (4.30%) and UAN (4.01%). The lowest potassium content (4.01%) in the leaves was obtained when using UAN as a nitrogen source. AN, urea, ASN and UAN as nitrogen sources did not differ significantly in influencing the potassium content of the leaves. These results also indicate that LAN and ASN did not differ significantly in influencing the potassium content of the beetroot leaves. However, LAN outclassed other nitrogen sources in influencing the potassium content of the leaves. Potassium percentage of beetroot leaves was insignificantly increased by nitrogen application as was reported by Mustafa (2007). This result is not consistent with that reported by Stagnari *et al.* (2007). These authors expressed that potassium content in spinach plants was decreased by increasing nitrogen rate up to 200 kg N ha^{-1}.

Table 6.5 Effect of nitrogen source and level on potassium content (%) of beetroot leaves

Nitrogen level (NL) ($kg\ ha^{-1}$)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	4.68	5.17	3.78	4.58	4.91	**4.62**
50	5.48	4.71	5.13	4.86	4.02	**4.84**
100	4.52	3.70	4.62	4.56	4.27	**4.33**
150	4.87	4.51	4.16	4.19	3.24	**4.19**
200	5.44	4.01	3.82	4.38	3.61	**4.25**
Mean	**5.00a**	**4.42b**	**4.30b**	**4.51ab**	**4.01b**	

$LSD_{T(0.05)}$NS = 0.55
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.5 Calcium

Table 6.6 shows that the interaction between nitrogen source x nitrogen level, as well as nitrogen source, did not significantly influence the calcium content of the beetroot leaves. The nitrogen level, however, significantly influenced the calcium content of the leaves. The calcium content of the leaves increased from 0.913% with an application of 0 kg N ha^{-1} to 1.381% with 200 kg N ha^{-1}. These data show that application of nitrogen at 150 and 200 kg N ha^{-1} influenced calcium content of the beetroot leaves to be significantly higher than the control level (0 kg N ha^{-1}). Nitrogen at 200 kg N ha^{-1} influenced the calcium content to be significantly higher in the leaves (1.381%) than application of 100 kg N ha^{-1} (1.031%). Nitrogen application at 0, 50 and 100 kg N ha^{-1} did not differ significantly in influencing the calcium content of the beetroot leaves. The data also indicates that nitrogen application at 50, 150 and 200 kg N ha^{-1} did not differ significantly in influencing the calcium content of the leaves. However, nitrogen level at 200 kg N ha^{-1} outperformed other nitrogen levels in increasing the calcium content of the beetroot leaves.

Contrary to this result, Abd EL Gwad *et al*. (1989) found that the calcium percentage of beetroot was reduced by nitrogen application. Ukom *et al.* (2009) found that calcium content of sweet potato leaves was significantly increased at different levels of nitrogen fertilizer application. These results are in agreement with those reported by other researchers (El-Fadaly & Mishriky, 1990; Cil & Katkat, 1995) that high nitrogen levels increased calcium contents in spinach.

Table 6.6 Effect of nitrogen source and level on calcium content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	0.782	0.994	0.851	1.023	0.915	**0.913c**
50	0.928	1.251	1.256	0.921	1.293	**1.130abc**
100	0.992	1.038	1.098	0.855	1.172	**1.031bc**
150	1.061	1.544	1.314	1.045	1.469	**1.287ab**
200	1.762	0.781	2.206	0.921	1.234	**1.381a**
Mean	**1.105**	**1.122**	**1.345**	**0.953**	**1.217**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 0.322
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.6 Sodium

The interaction between nitrogen source x nitrogen level, as well as nitrogen source, did not significantly influence the sodium content of beetroot leaves. Sodium content of beetroot leaves was significantly influenced by nitrogen level (Table 6.7). The data shows that the sodium content increased from 2.348% with 50 kg N ha^{-1} application to 3.810% with 150 kg N ha^{-1} applied. Application of nitrogen at 150 and 200 kg N ha^{-1} significantly influenced the sodium content in the beetroot leaves to be higher than application of 50 kg N ha^{-1}. Nitrogen application at 150 kg N ha^{-1} resulted in significantly higher sodium content in leaves (3.810%) than in the control leaves (2.738%). The results of the present study showed that nitrogen application at 0, 50 and 100 kg N ha^{-1} did not differ significantly in influencing the sodium content of beetroot leaves.

Nitrogen at 200 and 100 kg N ha^{-1} and the control level did not differ significantly in influencing the sodium content of leaves. Application of nitrogen at 100 kg N ha^{-1}, 50 kg N ha^{-1} and the control level did not differ significantly in influencing the sodium content of beetroot leaves. However, the highest sodium content in the beetroot leaves (3.810%) was obtained at 150 kg N ha^{-1}, while the lowest sodium content (2.348%) was obtained at 50 kg N ha^{-1}.

In higher nitrogen fertilizer levels, which were followed by a yield increment, sodium content decreased. It might be the result of a dilution effect by plant biomass increment (Ahmadi *et al*., 2010). Contradictory to this result, Ahmadi *et al.* (2010) also showed that the highest sodium content of beetroot leaves (14.26 g kg^{-1} DW) was obtained at the highest fertilizer rate (200 kg N ha^{-1}) while the lowest (7.02 g kg^{-1} DW) was experienced with the control level (0 kg N ha^{-1}). Fathy *et al*. (2009) also showed that higher rates of nitrogen fertilizer (214 and 285 kg N ha^{-1}) resulted in significant increases in the sodium content of beetroot leaves.

Table 6.7 Effect of nitrogen source and level on sodium content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	3.173	2.435	2.198	3.145	2.738	**2.738bc**
50	2.415	2.263	2.188	3.165	1.710	**2.348c**
100	3.285	3.325	3.975	2.318	2.455	**3.072abc**
150	3.900	4.450	2.638	2.963	5.100	**3.810a**
200	4.560	3.000	3.605	2.990	3.205	**3.472ab**
Mean	**3.467**	**3.095**	**2.921**	**2.916**	**3.042**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = 0.805
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in teither row or column do not differ significantly from each other

6.2.1.7 Magnesium

As shown in Table 6.8, the interaction between nitrogen source x nitrogen level did not significantly influence magnesium content in beetroot leaves. Neither nitrogen source nor nitrogen level significantly influenced the magnesium content of beetroot leaves. This result is not consistent with the findings of Cil and Katkat (1995) who stated that there was a positive correlation between high levels of nitrogen fertilizer and magnesium increase. Furthermore, the results also do not concur with the findings of Ahmadi *et al*. (2010) who observed that application of different nitrogen levels had a significant effect on magnesium content of beetroot leaves. Findings by Khogali *et al.* (2011) showed that the magnesium content of beetroot leaves significantly increased by the same amount under different nitrogen levels (40, 80 and 120 kg N ha^{-1}) in the first season. They stated that nitrogen application may have depleted magnesium in the soil through higher plant growth, so that no further increase in magnesium occurred at higher nitrogen levels.

Table 6.8 Effect of nitrogen source and level on magnesium content (%) of beetroot leaves

Nitrogen level (NL) ($kg\ ha^{-1}$)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nirate	
0	1.374	1.295	2.093	1.353	1.048	**1.433a**
50	1.185	0.910	1.760	1.580	1.903	**1.468a**
100	1.500	1.490	2.318	0.938	1.443	**1.538a**
150	1.845	1.625	1.995	1.870	1.398	**1.747a**
200	1.535	1.895	1.670	1.470	1.563	**1.627a**
Mean	**1.488**	**1.443**	**1.967**	**1.442**	**1.471**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.8 Manganese

Table 6.9 indicates that the interaction between nitrogen source x nitrogen level, as well as nitrogen level, did not significantly influence the manganese content in the beetroot leaves. However, nitrogen source significantly influenced the manganese content in the leaves. These findings show that application of UAN as nitrogen source significantly increased manganese content in beetroot leaves (0.109%) more than application of LAN (0.056%), AN (0.055%) and urea (0.077%). UAN as a nitrogen source did not differ significantly from ASN in influencing manganese content of beetroot leaves. The data in Table 6.9 also show that application of ASN, urea, AN and LAN as nitrogen sources did not differ significantly in influencing the manganese content of beetroot leaves. These results showed that UAN as nitrogen source outclassed other nitrogen sources in influencing manganese content of beetroot leaves. Voth and Christenson (1980) found that an increase in nitrogen fertility decreased manganese concentrations in beetroot leaf blades.

Table 6.9 Effect of nitrogen source and level on manganese content (%) of beetroot leaves

Nitrogen level (NL) ($kg\ ha^{-1}$)	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.047	0.062	0.054	0.141	0.065	**0.074**
50	0.052	0.051	0.070	0.554	0.068	**0.159**
100	0.046	0.047	0.073	0.068	0.072	**0.061**
150	0.066	0.057	0.080	0.081	0.182	**0.093**
200	0.070	0.057	0.109	0.071	0.158	**0.093**
Mean	**0.056b**	**0.055b**	**0.077b**	**0.083ab**	**0.109a**	

$LSD_{T(0.05)}$NS = 0.031
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.9 Copper

As shown in Table 6.10, the interaction between nitrogen source x nitrogen level did not significantly influence copper content of beetroot leaves. Neither nitrogen source nor nitrogen level significantly influenced the copper content of beetroot leaves. These results are contradictory to those found by Gulser (2005) who reported that copper content in spinach usually increased with increasing nitrogen levels. This present results also contradict those found by Cil and Katkat (1995) who indicated that a decrease in copper content in spinach was associated with increasing nitrogen fertilizer levels.

Table 6.10 Effect of nitrogen source and level on copper content (%) of beetroot leaves

Nitrogen level (NL) ($kg\ ha^{-1}$)	Nitrogen Source(NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.002	0.002	0.001	0.002	0.001	**0.002**
50	0.001	0.002	0.002	0.001	0.001	**0.001**
100	0.002	0.002	0.002	0.001	0.002	**0.002**
150	0.001	0.002	0.002	0.002	0.002	**0.002**
200	0.002	0.002	0.002	0.001	0.002	**0.002**
Mean	**0.002**	**0.002**	**0.002**	**0.001**	**0.002**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either ow or column do not differ significantly from each other

6.2.1.10 Iron

Table 6.11 indicates that the interaction between nitrogen source x nitrogen level, as well as nitrogen source, did not significantly influence iron content of beetroot leaves. However, nitrogen level significantly influenced iron content in the leaves. These findings indicated that the control level (0 kg N ha^{-1}) had significantly more iron content in leaves (0.102%) than all other nitrogen levels. Nitrogen at 50, 100, 150 and 200 kg N ha^{-1} did not differ significantly in influencing iron content of the beetroot leaves (0.075%, 0.062%, 0.064% and 0.076%, respectively). In disagreement with the present results, Khogali *et al.* (2011) reported that increasing nitrogen levels to 120 kg N ha^{-1} significantly increased iron content of beetroot leaves in the first season, while in the second season the increase was highly significant up to levels of 80 kg N ha^{-1}. This may indicate the enhancing role of nitrogen in the absorption of the mineral from the soil (Nollar & Rhykerd, 1974). Hellal *et al*. (2009) also reported that iron content in shoots of beetroot was found to be significantly affected by the application of nitrogen fertilizer. These results are in accordance with those reported by El-Fadaly and Mishriky (1990) who stated that iron content of spinach was not significantly affected by increasing nitrogen doses.

Table 6.11 Effect of nitrogen source and level on iron content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.083	0.102	0.102	0.102	0.121	**0.102a**
50	0.071	0.089	0.086	0.067	0.062	**0.075b**
100	0.070	0.053	0.058	0.058	0.071	**0.062b**
150	0.094	0.064	0.060	0.056	0.048	**0.064b**
200	0.086	0.098	0.082	0.055	0.060	**0.076b**
Mean	**0.081**	**0.081**	**0.078**	**0.068**	**0.072**	

$LSD_{T(0.05)}$NS = ns

$LSD_{T(0.05)}$NL = 0.018

$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.11 Zinc

The data in Table 6.12 shows that the interaction between nitrogen source x nitrogen level did not significantly influence zinc content of leaves; neither did nitrogen source nor nitrogen level. Bravo *et al.* (1992) also found that nitrogen level had little effect on zinc concentrations in the beet petioles.These results are in disagreement with those found by Raymond and Spedding (1966) who confirmed that there was an increase in zinc content of the beetroot leaves with increasing nitrogen level. Contrary to the current results, Marshner (1998) reported that the higher contents of zinc recorded for beetroot leaves, under nitrogen fertilization, was expected because of the positive effect of nitrogen application in increasing the zinc content, as well as the fact that leaves are the main sink for zinc. Findings by Fuehring and Finkner (1973) also confirmed that increasing nitrogen level has an effect on the total zinc content of leaf blades.

Table 6.12 Effect of nitrogen source and level on zinc content (%) of beetroot leaves

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.008	0.009	0.009	0.009	0.009	**0.009**
50	0.008	0.007	0.008	0.009	0.007	**0.008**
100	0.008	0.006	0.008	0.007	0.009	**0.008**
150	0.009	0.007	0.008	0.009	0.008	**0.008**
200	0.009	0.006	0.007	0.008	0.008	**0.008**
Mean	**0.008**	**0.007**	**0.008**	**0.008**	**0.008**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.3 STORAGE ROOTS

A summary on the analysis of variance (ANOVA) that was done to determine the effect of nitrogen source, nitrogen level as well as NS x NL interaction on the mineral status of the roots is given in Table 6.13.

Table 6.13 indicates that interaction between nitrogen source x nitrogen level did not significantly influence nutrient contents of beets. Neither nitrogen source nor N level significantly influenced the phosphorus, potassium, sodium, magnesium, manganese, copper, iron and zinc contents of beets. Only calcium content of beets was significantly influenced by nitrogen source.

Table 6.13 ANOVA (analysis of variance) showing the significant effects of nitrogen source (NS) and nitrogen level (NL) as well as NS x NL interaction on mineral content of beetroots

Mineral	Nitrogen source (NS)	Nitrogen level (NL)	NS x NL
P	ns	ns	ns
K	ns	ns	ns
Ca	*	ns	ns
Na	ns	ns	ns
Mg	ns	ns	ns
Mn	ns	ns	ns
Cu	ns	ns	ns
Fe	ns	ns	ns
Zn	ns	ns	ns

ns = no significant differences

* = significant differences

6.3.1 Mineral contents of the storage roots

6.3.1.1 Phosphorus

Data in Table 6.14 shows that interaction between nitrogen source x nitrogen level did not significantly influence phosphorus content of beets. Neither nitrogen source nor N level significantly influenced phosphorus content of beets. Although the nitrogen source did not significantly influence the phosphorus content in the beets, plants that received ASN as nitrogen source had higher phosphorus contents (0.401%) while those that received AN as nitrogen source resulted in lower phosphorus contents in the beets (0.375%). Beetroot plants that received 200 kg N ha^{-1} tended to have higher phosphorus contents (0.403%) while those that received nitrogen at 100 kg N ha^{-1} tended to have lower phosphorus contents (0.382%).

Magat and Goh (1990) reported a variation in chemical composition of tops and roots of beet plants as a result of nitrogen fertilization. Contents of phosphorus in beetroot affected by different farming systems were studied by Mader *et al*. (1993) who found lower phosphorus contents in beets from mineral systems. In disparity to the present results, Rajasree and Pillai (2012) reported that enhancing the levels of nitrogen from 200 to 250 or 350 kg N ha^{-1} significantly increased the phosphorus content of bitter gourd. They showed that the total phosphorus content in fruits was higher (1.08%) during the initial year of experimentation when 300 kg N ha^{-1} was given when compared to the application of 250 kg N ha^{-1} or 200 kg N ha^{-1} which recorded total phosphorus contents of 1.05 and 1.00%, respectively.

Table 6.14 Effect of nitrogen source and level on phosphorus content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.368	0.373	0.403	0.397	0.373	**0.383**
50	0.404	0.379	0.364	0.401	0.392	**0.388**
100	0.381	0.356	0.383	0.371	0.421	**0.382**
150	0.410	0.381	0.398	0.373	0.371	**0.387**
200	0.377	0.386	0.410	0.465	0.379	**0.403**
Mean	**0.388**	**0.375**	**0.392**	**0.401**	**0.387**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.3.1.2 Potassium

As shown in Table 6.15, the interaction between nitrogen source x nitrogen level did not significantly influence potassium content of beets. Data also showed that both nitrogen source and nitrogen level did not significantly influence the potassium content of beets. Similarly, potassium percentage of beetroot was not increased by nitrogen application as was reported by Mustafa (2007). Khogali *et al.* (2011) stated that roots are the main sinks of potassium because they translocate assimilates from leaves to storage roots. The uptake and utilization of potassium (the element) greatly depends on the supply of other minerals, especially nitrogen (Tisdale *et al*., 1995). Nitrogen nutrition promoting the total potassium content in cauliflower heads was previously reported by Singh *et al*. (1970) and Funda *et al*., 2008 in broccoli.

6.3.1.3 Calcium

Data in Table 6.16 indicates that the interaction between nitrogen source x nitrogen level, as well as nitrogen level, did not significantly influence calcium content of beets. Nitrogen source significantly influenced calcium content of beets significantly. These results show that beetroot plants that received AN as a nitrogen source resulted in a significantly higher calcium content in the roots (0.241%) than those plants that received urea, ASN and UAN (0.200%, 0.194%, and 0.181%, respectively) as nitrogen sources.

Table 6.15 Effect of nitrogen source and level on potassium content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	1.228	1.655	1.363	1.363	1.343	**1.390**
50	1.850	1.338	1.608	1.740	1.288	**1.565**
100	1.263	1.348	1.330	1.700	1.508	**1.430**
150	1.675	1.188	0.945	1.313	1.038	**1.232**
200	0.773	1.173	1.855	1.470	1.195	**1.293**
Mean	**1.358**	**1.340**	**1.420**	**1.517**	**1.274**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

Application of LAN as a nitrogen source increased calcium content in beets (0.235%) more than the application of ASN (0.194%) and UAN (0.181%) as nitrogen sources; however, UAN as a nitrogen source did not differ significantly from AN and urea in influencing calcium content. ASN and UAN also did not differ significantly in influencing calcium content in the beets. These findings show that AN as a nitrogen source outperformed other nitrogen sources in increasing calcium content in the storage roots.

Table 6.16 Effect of nitrogen source and level on calcium content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.198	0.286	0.217	0.159	0.227	**0.217**
50	0.273	0.234	0.187	0.195	0.149	**0.208**
100	0.259	0.235	0.168	0.191	0.166	**0.204**
150	0.176	0.206	0.199	0.227	0.168	**0.195**
200	0.267	0.246	0.229	0.198	0.193	**0.227**
Mean	**0.235ab**	**0.241a**	**0.200cb**	**0.194c**	**0.181c**	

$LSD_{T(0.05)}$NS = 0.039
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

Contrary to the present results, Ugrinovic (1999) reported that calcium content of beetroots increased from 1.87% at 150 kg N ha^{-1} to 2.12% at 0 kg N ha^{-1}. Contents of calcium and other chemical elements in different farming systems were studied by Mader *et al*. (1993). Their findings showed that calcium content of beetroots produced under mineral fertilizers ranged between 0.21 – 0.29% in all years of their trial. The contents of calcium from 0.24 – 0.31% in different cultivars of beetroot are also given by Jasnic *et al*. (1975).

6.3.1.4 Sodium

Table 6.17 indicates that the interaction between nitrogen source x nitrogen level did not significantly influence sodium content of beets. Nitrogen source as well as nitrogen level also did not significantly influence sodium content of beets. Although not significant, application of AN as nitrogen source increased sodium content of beets more (0.442%) than all other nitrogen sources. Application of nitrogen at 50 kg N ha^{-1} resulted in higher sodium content (0.342%) of the beets than applications of nitrogen at all other levels, although the result was not significant.

Contrary to these results, Khogali *et al.* (2011) reported that nitrogen fertilization significantly increased sodium content of beetroot. Gutstein (1968) reported that nitrogen fertilizer increased absorption of sodium. Marschner (1998) reported that nitrogen has a positive effect on sodium uptake and that the roots are the main sink of sodium.

Table 6.17 Effect of nitrogen source and level on sodium content (%) of beets

Nitrogen level (NL) kg ha^{-1}	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	0.476	0.101	0.090	0.088	0.281	**0.207**
50	0.313	0.971	0.152	0.039	0.233	**0.342**
100	0.086	0.200	0.075	0.103	0.297	**0.152**
150	0.086	0.808	0.200	0.295	0.300	**0.338**
200	0.052	0.128	0.124	0.284	0.310	**0.180**
Mean	**0.203**	**0.442**	**0.128**	**0.162**	**0.284**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL=ns

Means followed by the same letter in the row or column do not differ significantly from each other

6.3.1.5 Magnesium

As shown in Table 6.18 interaction between nitrogen source x nitrogen level did not significantly influence magnesium content of beets; neither did the nitrogen source nor nitrogen level influence the magnesium content. Contrary to the present findings, Khogali *et al*. (2011) found that the magnesium content of beetroot was significantly ($p < 0.05$) increased by nitrogen fertilization. These authors also reported that magnesium contents in beetroot leaves were slightly higher than that in the roots. Similar observations were made by Nadaf *et al*. (1998a).

Table 6.18 Effect of nitrogen source and level on magnesium content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.175	0.195	0.203	0.215	0.168	**0.191a**
50	0.195	0.225	0.163	0.188	0.173	**0.189a**
100	0.188	0.183	0.170	0.160	0.208	**0.182a**
150	0.178	0.158	0.198	0.213	0.218	**0.193a**
200	0.165	0.158	0.195	0.200	0.143	**0.172a**
Mean	**0.180**	**0.184**	**0.185**	**0.195**	**0.182**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.3.1.6 Manganese

Data in Table 6.19 indicates that interaction between nitrogen source x nitrogen level did not significantly influence manganese content of beets. Nitrogen source and nitrogen level also did not significantly influence manganese content. However, although not significant, application of AN as nitrogen source resulted in higher manganese content (0.033%) in beets than all the other nitrogen sources. Application of nitrogen at 50 kg N ha^{-1} tended to result in higher manganese content (0.031%) in beets than application of nitrogen at other levels. Bravo *et al*. (1992) reported that when nitrogen application was increased, the average manganese concentration of all beetroot parts decreased. Petek *et al*. (2003) found that at harvest time the manganese values in beetroot ranged from 0.51 to 0.69 mg Mn 100 g^{-1} fresh weight, without statistical differences.

Table 6.19 Effect of nitrogen source and level on manganese content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.014	0.014	0.011	0.011	0.013	**0.013**
50	0.017	0.098	0.013	0.011	0.014	**0.031**
100	0.012	0.010	0.010	0.010	0.012	**0.011**
150	0.012	0.011	0.013	0.011	0.017	**0.013**
200	0.011	0.031	0.017	0.017	0.010	**0.017**
Mean	**0.013**	**0.033**	**0.013**	**0.012**	**0.013**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.7 Copper

Table 6.20 shows that the interaction between nitrogen source x nitrogen level did not significantly influence copper content of beets. Neither nitrogen source nor nitrogen level significantly influenced copper content in beets. Bravo *et al.* (1992) also found that application of nitrogen did not affect average concentrations of copper contents in beetroot.

Table 6.20 Effect of nitrogen source and level on copper content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.0006	0.0009	0.0007	0.0009	0.0005	**0.0007**
50	0.0008	0.0008	0.0005	0.0007	0.0006	**0.0007**
100	0.0015	0.0008	0.0007	0.0006	0.0005	**0.0008**
150	0.0045	0.0006	0.0009	0.0006	0.0006	**0.0014**
200	0.0073	0.0007	0.0008	0.0009	0.0004	**0.0020**
Mean	**0.0029**	**0.0008**	**0.0007**	**0.0007**	**0.0005**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.3.1.8 Iron

The interaction between nitrogen source x nitrogen level did not significantly influence iron content of beets (Table 6.21). Nitrogen source and nitrogen level also did not significantly influence iron content. Contradictory to these results, Fathy *et al*. (2009) reported that iron content of roots and foliage was decreased by increasing nitrogen fertilization rates. This observation was expected since high nitrogen rates enhanced vegetative growth and consequently the absorption of other nutrients to meet the growth demand (Fathy *et al*. 2009). A significant decrease in iron content of foliage and roots with increasing nitrogen fertilization rates may be attributed to the dilution caused by high vegetative growth in the presence of the high nitrogen fertilization rates (El-Shahawy *et al*., 2002; Attia, 2004).

Table 6.21 Effect of nitrogen source and level on iron content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	Ammonium nitrate	Urea	Ammonium sulphate nitrate	Urea ammonium nitrate	
0	0.028	0.025	0.031	0.022	0.023	**0.026**
50	0.023	0.026	0.023	0.040	0.022	**0.027**
100	0.019	0.026	0.026	0.027	0.027	**0.025**
150	0.030	0.022	0.025	0.028	0.027	**0.026**
200	0.035	0.026	0.028	0.027	0.023	**0.028**
Mean	**0.027**	**0.025**	**0.027**	**0.029**	**0.024**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxNL= ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.2.1.9 Zinc

Results in Table 6.22 indicate that the interaction between nitrogen source x nitrogen level did not significantly influence zinc content of beets, and neither did the nitrogen source nor nitrogen level. These results concur with that of Bravo *et al.* (1992) who found that nitrogen level had little effect on zinc concentrations in the petioles of beetroot.

Table 6.22 Effect of nitrogen source and level on zinc content (%) of beets

Nitrogen level (NL) (kg ha^{-1})	Nitrogen Source (NS)					Mean
	Limestone ammonium nitrate	**Ammonium nitrate**	**Urea**	**Ammonium sulphate nitrate**	**Urea ammonium nitrate**	
0	0.0039	0.0032	0.0040	0.0036	0.0036	**0.0037**
50	0.0038	0.0038	0.0034	0.0037	0.0037	**0.0037**
100	0.0037	0.0034	0.0040	0.0035	0.0039	**0.0037**
150	0.0035	0.0034	0.0036	0.0044	0.0033	**0.4000**
200	0.0034	0.0039	0.0036	0.0041	0.0032	**0.0036**
Mean	**0.0037**	**0.0035**	**0.0037**	**0.0037**	**0.0035**	

$LSD_{T(0.05)}$NS = ns
$LSD_{T(0.05)}$NL = ns
$LSD_{T(0.05)}$NSxN = ns

Means followed by the same letter in either row or column do not differ significantly from each other

6.4 CONCLUSION

The results from this study showed that interaction between nitrogen source x nitrogen level significantly influenced nitrogen content of leaves. Application of UAN at 200 kg N ha^{-1} resulted in a higher nitrogen content in the beetroot leaves as compared to other nitrogen sources. Nitrogen source significantly influenced potassium content of beetroot leaves. The findings also showed that LAN as a nitrogen source outperformed other nitrogen sources in increasing potassium content of leaves. Application of nitrogen at 200 kg N ha^{-1} outclassed other nitrogen levels in influencing the calcium content of leaves. These results showed that the highest sodium content in leaves was obtained at 150 kg N ha^{-1}, while the lowest sodium content was obtained at 50 kg N ha^{-1}. UAN as a nitrogen source outperformed other nitrogen sources in increasing manganese content of beetroot leaves. The obtained results showed that the control level (0 kg N ha^{-1}) significantly influenced the iron content to be higher in the leaves than all other nitrogen application levels.

The data also revealed that nitrogen source significantly influenced calcium content of beets. AN as a nitrogen source, increased calcium content of beets more than other nitrogen sources. However, most nutrients in beets such as phosphorus, potassium, sodium, magnesium, manganese, copper, iron and zinc were not significantly influenced by interaction between nitrogen source x nitrogen level, and neither did the nitrogen source nor nitrogen level had any influence. These results are useful in determining the preferred sources and levels of nitrogen that affect nutrient contents of roots. However, they must be confirmed in field studies because of widely different plant, soil and environmental factors that are too different from the pot trials done in glasshouse conditions.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

7.1 Influence of nitrogen fertilizer on growth, yield and external quality

The study revealed that application of various nitrogen sources at different nitrogen levels influenced the growth of beetroot when plant height, number of leaves, leaf area, leaf fresh mass and leaf dry mass were used as indices. The results also showed that all fertilizers resulted in a slower growth of plants for the first six weeks of growth. Nitrogen application only increased plant height significantly from Week 8 where the height of plants that received nitrogen, irrespective of the fertilizer used, were significantly taller than those that did not. At Week 10 significant increases in plant height were noted between the 50 kg N ha^{-1} and 150 kg N ha^{-1} or 200 kg N ha^{-1} application rates. At Week 8 plants that received urea and ASN were significantly taller than those fertilized with other products while by Week 10, plants that were fertilized with ASN were significantly taller than those that received any of the other products.

Nitrogen level had a highly significant effect on number of beetroot leaves. The results showed that the number of beetroot leaves increased from 8.50 with 0 kg N ha^{-1} to 13.02 with 100 kg N ha^{-1}. Application of nitrogen at 100 kg N ha^{-1} resulted in more beetroot leaves than at any other level.

Leaf area was also significantly affected by nitrogen source. UAN as a nitrogen source had a greater effect on increasing leaf area of beetroot than any of the other sources, whereas LAN had the least influence on leaf area. Leaf area of plants was also significantly affected by nitrogen application, with the greatest leaf area being obtained with addition of 200 kg N ha^{-1}, while the least area was obtained where no additional N was applied.

Using UAN as a nitrogen source produced the greatest mass of fresh leaves, significantly greater than that produced by the application of ASN, LAN, urea or AN. The greatest mass of fresh beetroot leaves was obtained at the highest nitrogen application (200 kg N ha^{-1}) while the lowest leaf fresh mass was obtained at the control level. UAN increased leaf dry mass by an average of 397.35% while the lowest leaf dry mass increase of 139.42% was obtained after application of LAN as a nitrogen source. Nitrogen application had a significant effect on the area and mass of leaves, both fresh and dry. In both cases the greatest leaf mass was produced when plants received 200 kg N ha^{-1} and the lowest where no additional N was applied.

The interaction between nitrogen source and nitrogen level did not influence total fresh mass of beetroot significantly, although both nitrogen source and application rate significantly affected the total fresh mass. Application of UAN as a nitrogen source resulted in higher total fresh mass as compared to other products and the lowest fresh mass was observed with LAN. The data shows that total fresh mass of beetroot increased from 28.78 g $plant^{-1}$ at 0 kg N ha^{-1} to 139.40 g $plant^{-1}$ at 200 kg N ha^{-1}. Application of nitrogen at 200 kg ha^{-1} produced plants with a significantly greater total fresh mass than those that received no or up to 100 kg ha^{-1}.

The beetroot fresh mass also increased as nitrogen application rate increased, from 12.49 g $plant^{-1}$ at 0 kg ha^{-1} to 59.16 g $plant^{-1}$ at the 200 kg ha^{-1} level. Using UAN as a nitrogen source produced beets with a significantly larger diameter than using AN, ASN and LAN, with the lowest beet diameter being found when AN was used as a nitrogen source. Beet yield increased from 2.99 t ha^{-1} in the control treatments (0 kg N ha^{-1}) to 14.37 t ha^{-1} in the treatments that received 200 kg N ha^{-1}. Fertilizing with UAN gave the highest yields (12.17 t ha^{-1}), while using LAN gave the lowest yields (9.00 t ha^{-1}).

Nitrogen application increased beetroot diameter significantly, from 23.91 mm with no additional N to 44.83 mm with 200 kg N ha^{-1}. The diameter of beets from plants that received 150 to 200 kg N ha^{-1} was significantly greater than those that received no nitrogen or those that received 50 kg N ha^{-1}. The volume of beets increased as nitrogen application increased, from 14.70 cm^3 with 0 kg N ha^{-1} to 63.42 cm^3 with 200 kg N ha^{-1}. These results are similar to those found with beet diameter.

7.2 Influence of nitrogen fertilizers on the physico-chemical properties

Using UAN resulted in fewer defects on beets than other N sources, while using LAN gave the highest percentage of defects. Beet firmness was significantly influenced by the nitrogen level, with beets from plants that received nitrogen being significantly firmer than those from plants that had no nitrogen. However, the firmest beets were obtained from plants with a nitrogen application rate of 50 kg ha^{-1}. The best developed colour of beets (darker) was obtained in the control plants and the lightest colours found where plants received the most nitrogen (200 kg ha^{-1}).

Coefficient b at the control level resulted in significantly more intensive change from yellow to blue colours than application of nitrogen at 100, 150 and 200 kg ha^{-1}. Nitrogen at the control level resulted in more intense changes of coefficient b from yellow to blue and the results showed that application of nitrogen at the highest level resulted in less changes of coefficient b from yellow to blue.

The interaction between nitrogen source x nitrogen level did not significantly influence the pH of beetroot, neither did the nitrogen source nor nitrogen level. The findings showed that application of nitrogen at 150 kg ha^{-1} resulted in higher total soluble solids of beetroot. Starch content of beetroot plants that received no nitrogen was significantly higher than those that received higher levels of nitrogen. The control level also resulted in a higher glucose content in beetroot than application of nitrogen. However, the interaction between nitrogen source x nitrogen level did not significantly influence the sucrose and fructose content of the beetroot, neither did the nitrogen source nor nitrogen level.

7.3 Influence of nitrogen fertilizers on mineral content of beetroot

The findings showed that application of UAN as a nitrogen source at 200 kg N ha^{-1} outclassed other nitrogen sources at different levels of application in influencing the nitrogen content of beetroot leaves. The interaction between nitrogen source and nitrogen level did not influence the carbon, phosphorus, magnesium, copper and zinc contents of the beetroot leaves significantly, neither did the nitrogen source nor nitrogen level. These results also revealed that beetroot plants that received LAN as a nitrogen source had significantly higher potassium content in the leaves than those that received AN, urea and UAN as nitrogen sources.

Application of nitrogen at 150 and 200 kg ha^{-1} significantly increased the calcium content of beetroot leaves over those of the control rates, with the greatest calcium content being found at the highest rate of N application. The highest sodium content on the leaves was obtained with a nitrogen application of 150 kg ha^{-1} while the lowest was found at the 50 kg ha^{-1} level. The results also showed that using UAN as a nitrogen source significantly increased the manganese content of leaves versus the use of LAN, AN and urea as N sources. Plants that received no additional nitrogen contained significantly more iron than plants receiving any additional nitrogen.

The interaction between nitrogen source and nitrogen level did not significantly affect the phosphorus, potassium, sodium, magnesium, manganese, copper, iron and zinc content of beets, nor did the nitrogen source or nitrogen level. However, the calcium content of the beets was significantly influenced by nitrogen source. Plants that received AN as a nitrogen source had a significantly higher calcium content in the beets than those that received urea, ASN or UAN as nitrogen sources. LAN as a nitrogen source also significantly increased calcium content of beets more than using ASN and UAN as nitrogen sources.

7.4 Recommendations

- The response of beetroot plants to different nitrogen fertilizers at different application levels showed that the optimum fertilizer application rate for ASN was 150 kg N ha^{-1} and for UAN was 200 kg N ha^{-1} on the soil type used in this study.
- Considering the response of beetroot in terms of yield parameters, 200 kg N ha^{-1} appeared to be the optimum level for the type of soil used in this study.
- Application of UAN at 100 kg N ha^{-1} is considered as the best optimum level for producing the lowest percentage of defective beets.
- Higher total soluble solids content of the beetroot will be obtained with application of nitrogen at 150 kg N ha^{-1}.

These results were obtained from a single pot trial conducted under protected conditions on a Bainsvlei type of soil using the cultivar Detroit Dark Red. The present findings showed that the best nitrogen source for growth, yield and quality of beetroot was UAN at 200 kg N ha^{-1}. However, these results would need to be confirmed in field trials conducted in different areas, using a variety of beetroots planted on various soils.

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