GROWTH AND YIELD RESPONSE OF SWEET POTATO TO NITROGEN FERTILIZATION IN SOILS OF LADYSMITH, KWAZULU-NATAL, SOUTH AFRICA

by

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DECLARATION

I, NOMAKHISIMUSI GLORIA MVULA, hereby declare that the work presented in this Dissertation entitled "GROWTH AND YIELD RESPONSE OF SWEET POTATO TO NITROGEN FERTILIZER IN SOILS OF LADYSMITH, KWAZULU-NATAL, SOUTH AFRICA" is original work done by myself under the mentorship of my supervisors. Additionally, I declare that the work presented herein has not been published or submitted at any other institution as part of the requirements for any degree programme. All cited literature in this dissertation from other individuals or institutions has been acknowledged and listed in the reference section. I also certify that I have complied with the rules, requirements, procedures, and policies of the University of South Africa.

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DEDICATION

This work is dedicated to my mother Thokozile kaMthembu Mvula and my daughter Nokuthula Sinenhlanhla (Tutu) Mvula, who have always been a pillar of my strength through stormy times and calm, without them this stage would not have been reached. I also dedicate this work to my late grandfather, Gideon Mvula, late father Lymon Mvula, my two late grandmothers, Catherine kaShezi Mvula and gogo Kesia Kunene.

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ACRONYMS

ANOVA	Analysis of Variance
Al	Aluminium
ARC	Agricultural Research Council
C	Carbon
Ca	Calcium
Cu	Copper
DAFF	Department of Agriculture, Forestry and Fisheries
DAP	Days after Planting
DAT	Days after Transplanting
FAO	Food and Agriculture Organization
Fe	Ion
Ha	Hectare
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
LAN	Limestone Ammonium Nitrate
LAI	Leaf Area Index
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
P	Phosphorus
USA	United States of America
USDA	United States Department of Agriculture
Zn	Zinc

ABSTRACT

Sweet potato (*Ipomea batatas* L.) yield is low due to nitrogen constraints. This field study evaluated nitrogen fertilization on growth, yield and nutrient content of two sweet potato cultivars grown in soils of Ladysmith. Six nitrogen levels (0, 13, 23, 33, 43 and 53 kg N/ha) and two cultivars as treatments were arranged in a randomized complete block design with three replications. Generally, there was a steady increase in growth and yield as N fertilization increased from 0 kg/ha to 53 kg/ha. The interaction between cultivar and N level was significant for sweet potato's growth and yield. Tuberous roots number per plant was higher in Beauregard (12.00) fertilized with 53 kgN/ha compared to Ndou (8.00) without N. Sweet potato cultivar response to treatment was significant for shoot and tuber nutrient contents. High agronomic yield was observed with high N fertilization (53 kg N/ha) of sweet potato in soils of Ladysmith in KwaZulu-Natal Province.

CHAPTER 1: GENERAL INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

Globally, sweet potato (*Ipomoea batatas* L.) is an important source of carbohydrates and nutrients for many millions of people. However, the production of this crop is generally low in poor-nutrient soils due to several factors including nutrient deficiencies and cropping management systems. In South Africa, the crop is cultivated mostly by subsistence production-oriented smallholder farmers especially in rural areas in the KwaZulu-Natal Province. Most soils in the country are low in essential nutrients such as phosphorus and nitrogen (Smith, 1998; Sosibo et al., 2017). In particular, nitrogen is needed in large amounts for plant growth (Giller, Cadisch, Ehaliotis, Adams, Sakala & Mafongoya 1997; Chianu et al. 2012; Tully et al., 2015) and it is the most common deficient nutrient responsible for low agricultural yields in sub-Sahara African soils (Myers, 1988; Tully et al., 2015). In Ladysmith, KwaZulu-Natal Province, where sweet potato is mostly grown by majority of rural households, there are reports that the nitrogen levels are very low in soils for sweet potato cultivation (Smith, 1998: Sosibo et al., 2017). However, there are reports that application of optimum nitrogen fertilizer can increase yield and improve tuber quality of the crop (Smith, 1998: Sosibo et al., 2017). So far, little or no study has evaluated the growth of sweet potato under different levels of nitrogen fertilizer especially under field conditions to determine the crop's optimum N level in Ladysmith, KwaZulu-Natal Province.

The overall goal of this study was to assess nitrogen fertilization on the growth and yield of sweet potato in selected soils of Ladysmith in the KwaZulu-Natal Province. This chapter provides the study background, research problem, aim and objectives, significance of the study, research hypothesis, and the overall organization of the dissertation.

1.2 GENERAL BACKGROUND

Sweet potato is an important economic crop cultivated worldwide. The crop is a native of tropical America (central and northern), and it was transported to the Pacific Islands and Asia early in history (Hartmann, Kofranek, Rubatzky & Flocker, 1988; Roullier et al., 2013). The crop belongs to the morning-glory or Convolvulaceae family, and it is grown for its tuberous roots for human consumption and its vegetative parts for both human consumption and animal feed. This warm season crop does not tolerate frost. It requires a long warm growing season with monthly mean temperatures above 20^{o}C for at least three months. The soil requirement for sweet potato is a well-drained sandy or sandy loam with a clay subsoil. Sweet potato is a perennial crop but commonly grown as an annual and the plant grows prostrate on the ground. In tropical and much of subtropical regions, this crop is cultivated as a perennial while in temperate and some of the subtropical regions grown as an annual crop (Hartmann et al., 1988; Roullier et al., 2013).

Sweet potato is one of the most important staple food crops and carbohydrate source for many millions of people, particularly those in developing nations. However, the production of this crop is generally low in poor-nutrient soils but reports indicate that nitrogen (N) fertilizer application can increase yield and improve tuber quality of the crop (Ankumah, Khan, Mwamba & Kpomblekou, 2003). The effective use of N fertilizers to achieve optimum yields while reducing the amount of Nitrate-N in the soil is very important in both developed and developing countries (Ankumah et al., 2003).

The general recommendations are moderate amount of nitrogen with higher proportions of phosphorus and potassium. Nitrogen is the crucial factor in determining yield and nutrient composition of tuberous root crops, especially sweet potato. Nitrogen application to sweet potato has been shown to correlate linearly with increases in dry matter content, carotenoid and protein content of the plant (Constantine, Jones, Hammett, Hernandez & Kahlich, 1984). Nitrogen also play a major role in plant biochemistry as an essential constituent of cell wall, cytoplasmic proteins, nucleic acids, chlorophyll and other parts of the cell (Hay & Walker, 1989).

Villagarcia (1996) reported that the response of sweet potato to nitrogen fertilizer application depends highly on genotypic and environmental variations. High yields of good quality sweet potato require proper management of nitrogen fertilizer application. Inadequate or excessive amounts of nitrogen fertilizer can be detrimental to the sweet potato crop and can negatively affect its yield potential. In addition, excessive or improperly timed application of nitrogen fertilizer can result in added expense, leaching and thereby contamination of surface water and groundwater.

Informed decisions that consider cropping history and soil type are important factors to consider in determining the proper amount of nitrogen fertilizer to be applied in a sweet-potato production field (Hartmann et al., 1988; Smith & Villordon, 2009).

1.3 PROBLEM STATEMENT

Nitrogen is needed by plants in amounts greater than that of other nutrients for plant growth (Giller et al., 1997) and it is the most common deficient nutrient responsible for low agricultural yields in sub-Sahara Africa soils (Myers, 1988; Tully et al., 2015). Poor soil fertility due to very low concentration of nitrogen is responsible for low agricultural yields in most regions in sub-Sahara Africa. For example, soil assessment in KwaZulu-Natal showed nitrogen deficiency for the cultivation of sweet potato in the region (Smith, 1998; Sosibo et al., 2017). Specifically, previous soil analysis at the study site showed nitrogen and phosphorus as the main limiting nutrients for plant growth.

An extremely low yield in sweet potato production around Ladysmith in KwaZulu-Natal is one of the contributing factors to food insecurity and malnutrition as well as unemployment (Smith, 1998). Secondly, most crop farmers in this area who grow sweet potato do not grow it specifically for the market but only for their own consumption (Personal communication, Mr. B.D Sibisi, Agricultural Advisor-Plant Production, KwaZulu-Natal Department of Agriculture and Rural Development, Ladysmith).

It is expected that higher yields would encourage farmers to explore the option of supplying their produce to markets and chain stores within and around the province. However, the main problem of improving the extremely low sweet potato yield and tuber quality in soils of Ladysmith is due to little or lack of information on the proper management of nitrogen fertilizer application. So far, no study has investigated the effect of levels of nitrogen fertilizer application on growth and yield of sweet potato in the study area. Therefore, the question this research seeks to answer was, how best can the problem of extremely low sweet potato yield and tuber quality be improved through the application of optimum rates of nitrogen fertilizer in the soils of Ladysmith.

1.4 RESEARCH AIM

The aim of this study was to assess the effect of different levels of nitrogen fertilization on the growth and yield of sweet potato in soils of Ladysmith in the KwaZulu-Natal Province.

1.4.1 RESEARCH OBJECTIVES

The main objective of this study was to evaluate and compare the effect of different levels of nitrogen fertilization on growth and yield of two sweet potato cultivars in soils of Ladysmith, KwaZulu-Natal. Therefore, the specific objectives are:

- To assess the effect of nitrogen fertilization on vegetative growth/performance of two sweet potato cultivars (Beauregard and Ndou).
- To evaluate and compare the effect of different levels of nitrogen fertilization on yield of two sweet potato cultivars in soils of Ladysmith.
- To compare elemental compositions in shoot of two sweet potato cultivars treated with different levels of nitrogen fertilization.
- To compare tuber quality across cultivars and nitrogen levels.
- To compare the gross margins across treatments.

1.5 HYPOTHESIS

- The application of nitrogen fertilizer has no significant effect on vegetative growth and yield of sweet potato grown in soils of Ladysmith, KwaZulu-Natal.
- There is no significant difference in cultivar response (performance/elemental composition) to the treatments.
- Time/frequency of nitrogen fertilizer application has no effect on growth and yield of sweet potato.
- There is no significant difference in tuber quality and gross margins across treatments.

1.6 RATIONALE OF THE STUDY

For this study, these two cultivars, Beauregard and Ndou were selected because most households in Ladysmith prefer to grow them considering their various characteristics. Beauregard is a high-yielding cultivar with disease-resistance qualities. It is one of the orange fleshed cultivars with moist sweet taste whereas, Ndou is one of the creamy fleshed cultivars with dry sweet taste, therefore both of these cultivars represented the type of sweet potatoes that most people of the area prefer.

The vines of both cultivars were gratefully supplied by the Agricultural Research Council-Roodeplaat in Pretoria. However, the paucity of information on the application frequency and rate of nitrogen fertilizer on growth of sweet potato was a major constraint to maximizing the yields of this important crop in Ladysmith. Therefore, findings from this study will provide invaluable information on nitrogen fertilization management and possible ways to help farmers increase their yields to generate more income and make more profit to ensure household food security. In addition, proper management of N-fertilizer will help to prevent contamination of the environment (surface waters and groundwater).

1.7 DISSERTATION STRUCTURE

This dissertation is divided into six chapters and an overview of each chapter is presented here to guide the readers through the deliberations on topics discussed.

Chapter one (General Introduction and Background) – This chapter explains the title of the research study and explains why it is important doing it. Therefore, this chapter is consisting of the problem statement, research aim and objectives, hypothesis and the rational of the study.

Chapter two (Literature Review) - This chapter discusses the origin and cultivation of sweet potato, production of sweet potato and its challenges including soil characteristics and climatic requirements for sweet potato production, and the pests, diseases and disorders affecting the crop.

Chapter three (Materials and Methods) – This chapter explains the research methodology used during data collection for the research paper to answer research questions. Therefore, this chapter discusses the study area, soil sampling, planting materials, experimental design and layout, acquisition of ethical clearance, data collection and data analysis.

Chapter four (Results) - This chapter presents the results obtained from a field experiment, which investigated the effects of different nitrogen fertilizer levels on growth and yield of two sweet potato cultivars in soils of Ladysmith, KwaZulu-Natal. The results are arranged and presented in tables and figures format. This chapter focuses on growth data included vine (shoot) length, number of shoots per plant, data on yield determination included tuberous root diameter, tuberous root length, fresh and dry weight for the top growth, number of tuberous roots per plant, tuberous root weight and elemental analysis of dry matter from shoots and tuberous roots.

Chapter five (Discussions) – This chapter discusses the results and findings from the data collected from the experiment. This chapter discusses the findings on vegetative growth and yield response to different nitrogen fertilizer levels. The findings on elemental composition in shoots and tuberous roots of two sweet potato cultivars and gross margin per N-fertilizer level per hectare are also presented in this chapter.

Chapter six (General Conclusion and Recommendations) – This chapter presents an overview of the research findings with regards to the hypothesis of the research

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses the origin and cultivation of sweet potato, production of sweet potato and its challenges including soil characteristics and climatic requirements for sweet potato production, and the pests, diseases and disorders affecting the crop. Furthermore, the chapter evaluates research methods used in previous studies to assess nitrogen fertilization of sweet potato in other areas to acquire a better understanding of sweet potato production in Ladysmith.

2.2 ORIGIN AND CULTIVATION OF SWEET POTATO

Sweet potato *(Ipomoea batatas L.*) originated from Central America where it was found growing in the wild spreading across the Pacific from Central America and was transported to warmer regions of Asia and Africa by Spanish and Portuguese traders (Alleman, Laurie, Thiart & Vorster, 2004). Currently, the crop is grown in more than 100 countries under tropical, subtropical and temperate climatic conditions (Alleman *et al.,* 2004). Laurie & Niederwieser (2004) indicated that South Americans seemingly started producing sweet potatoes since 3000 years BC and distributed the crop to other parts of the world. Sweet potato was imported into South Africa in 1652 during the period when Jan Van Riebeeck colonized the Cape (Laurie & Niederwieser, 2004).

Over the years, the cultivation of sweet potatoes in different countries with different climatic conditions have been reported (Food and Agriculture Organization (FAO), 2012a). According to FAO (2012a), about 115 countries produced 108,274,685 tons of sweet potatoes in 2010 with China producing the largest (82,474,410 tons) followed by Indonesia (2,083,623 tons). Far behind, but ranked second in the world after Asia, is Africa with its contribution of up to 14% of global production put at 14,441,099 tons in 2010. Nigeria ranks second in Africa after Uganda with the production figure of 2,883,408 tons, which has shown an increasing trend over the years (FAO, 2012a). In East Africa, after Uganda, Tanzania ranks as the second largest producer of sweet potato with an annual production of just under one million tons (United Republic of Tanzania, 2011). Sweet potato is grown in almost all agro-ecological zones and it is cultivated mostly by smallholder farmers in approximately

14% of Tanzania's total arable land (Kapinga, Ewell, Jeremiah, & Kileo, 1995). In the country, the crop is a major staple food and is the third most important tuber and tuber crop after cassava and Irish potato (United Republic of Tanzania 2011). In Ethiopia, sweet potato is cultivated in all soil types that are fertile, moist, well drained and rich in nutrient and approximately, a total over 4,240 tons of the crop are produced annually over 53 thousand hectares of arable land (Alula, Zeleke & Manikandan, 2018).

Similarly, sweet potato is cultivated in different agro-ecological zones in the United States of America (USA) and on a vast arable land area (USDA Agricultural Statistics 1997; Food and Agriculture Organization (FAO), 2012b). Sweet potato can be grown throughout the state considering that all areas are favoured by the frost-free period of more than 150 days (Parvin, Walden, & Graves, 1999). In 2007, the USDA Agricultural Statistics reported that a yield of 100 million lbs. (50000 ton) of sweet potatoes with a value of $18 million was produced in 8,400 acres (3399 hectares) in Mississippi alone (USDA Agricultural Statistics, 1997; FAO, 2012b). Hence, in the United States, Mississippi was in fourth position among all the states in sweet potato production. Commercial production is currently concentrated in Calhoun and Chickasaw Counties in north central Mississippi, however, sweet potatoes are grown commercially in more than half of Mississippi's counties. However, recent reports by USDA Agricultural Statistics (2013a, b) indicated that in 2012, Mississippi ranked second and third in the nation for sweet potato production area of 24,000 acres that is equivalent to 9712.5 hectares with a crop value of $62.6 million.

In South Africa, sweet potato is now cultivated in almost all the provinces with different agro-ecological zones since the crop was imported in 1652 during the period when Jan Van Riebeeck colonized the Cape (Laurie & Niederwieser, 2004). The crop is cultivated both by commercial and subsistence small-scale farmers in the different provinces in the country. Among the nine provinces, Limpopo, Mpumalanga, Western Cape and KwaZulu Natal are the specific production areas in South Africa in which the largest quantity of sweet potato is cultivated on both commercial and subsistence bases. The average yield of sweet potato when grown commercially is approximately 49 t/ha, while on a subsistence farming the average yield is 5-10 t/ha

(Laurie, 2004). There are seven common commercial cultivars grown in South Africa namely, Beauregard, Jewel, Mafutha, Blesbok, Bosbok, Ribbok and Koedoe. Beauregard and Jewel are the orange-fleshed cultivars that originated in the USA. These common commercial cultivars except Mafutha are the moist textured but not sweet in taste as most consumers prefers sweet and dry taste cultivars such as the Mafutha (Laurie, 2004). Bosbok and Blesbok (cream-fleshed cultivars) as well as the Beauregard and Jewel (orange-fleshed cultivars) are grown for the for export market. In an attempt to meet consumer's demand, the Agricultural Research Council (ARC) in Roodeplaat, Pretoria, has developed and issued some new cultivars as augmentation of Mafutha, namely, Monate, Phala, Mamphenyane, Ndou, Lethlabula, Makone and Amasi (Laurie, 2004).

Availability of these high yield cultivars/varieties is however limited to commercial farmers due to the cost implications involved as small-scale farmers lack the required resources. Therefore, average yields are ten times lower for small-scale farmers compared with commercial growers (Laurie & Magoro, 2008). In a study aimed at evaluating the release of new sweet potato cultivars through farmer participatory selection that was conducted in four provinces of South Africa (North-West, KwaZulu-Natal, Mpumalanga and Limpopo), Laurie and Magoro (2008) reported mean yields of 3.9 to 9.5 t/ha on communal gardens compared with 25.2 t/ha at the experimental stations at Tompi Seleka (Limpopo Province). In addition, differences in the marketable yield and taste of sweet potato cultivars were reported in two different provinces during the sweet potato trials in 2001/2002. For example, the sweet potato varieties, Ndou and W-119, were reported to have the highest yield in Mafikeng (14.2 t/ha) and Vulindlela (14.4 t/ha) compared to A15 (3.9 t/ha) and Bosbok (5.3 t/ha), respectively. Based on the results of the 2001/2002 sweet potato trials in the different stations, Laurie and Magoro (2008) made cultivar recommendations for each specific production area within South Africa considering the yield and cooked taste acceptability (Tables 2.1 & 2.2).

Table 2.1 Marketable yield and taste results of sweet potato trials 2001/2002 at Mafikeng, Tompi Seleka and Venda, South Africa (Laurie & Magoro, 2008).

Mafikeng	Yield	Cooked	Tompi Seleka	Yield	Cooked	Venda	Yield	Cooked
Variety/Line	t/ha	Taste	Variety/Line	t/ha	Taste	Variety/Line	t/ha	taste
Ndou ~	14.2	Good	W-119 ~	48.2	Avg-Poor	Natal Red	9.5	Excellent
Blesbok	11.1	Poor	**Mokone** ~	34.6	Good	Mokone	9.4	Poor
Letlhabula ~	10.0	Avg – Poor	Phala	31.1	Poor	**Phala** ~	9.3	Avg-Good
W-119 ~	9.0	Good	1989-23-1	29.6	Poor	**Ndou** ~	9.0	Good
Monate ~	8.3	Good	**Excel** ~	29.6	Excellent	**Excel** ~	8.5	Good
Kenia	8.1	Avg	A45	27.2	Avg-Good	Kenya	8.1	Avg
1986-12-2	7.8	Very poor	**Mamphenyane**~	26.1	Good	Atacama	5.8	Poor
1989-23-1	6.9	Poor	Bosbok	25.7	Excellent	Mafutha	5.6	Excellent
Mafutha	6.9	Good	Natal Red	24.9	Excellent	Resisto	2.9	-
Bosbok	5.6	Good	Mafutha	22.8	Excellent	1997-18-1	2.8	-
Yan Shu 1	5.6	Excellent	Xushu 18	21.1	-	1987-17-3	1.8	-
1997-18-1	5.5	Avg	A2	20.9	-	Bosbok	1.5	-
CN1656-97	5.2	Poor	Ndou	18.2	-	ST87.030	1.4	-
1994-11-3	4.6	Avg – Poor	ST87.030	12.5	-	Amasi	0.9	-
A15	3.9	Good	1987-17-3	6.3	-	A59	0.7	-
Mean	7.51			25.26			5.14	
CV%	36.0			47.4			60.71	
LSD (P = 0.05)	4.52			16.64			5.23	

~ recommended varieties .

Table 2.2 Marketable yield and taste results of sweet potato trials at Vulindlela 2001/2002, Thembalethu (2002/2003) and Bushbuckridge (2002/2003), South Africa (Laurie & Magoro, 2008).

Vulindela	Yield	Cooked	Thembalethu	Yield	Cooked	Bushbuckridge	Yield	Cooked
Variety/Line	t/ha	taste	Variety/Line	t/ha	Taste	Variety/Line	t/ha	taste
W-119 ~	14.4	Avg	Blesbok	9.4	Very poor	**Monate** ~	9.5	Good-Avg
Letlhabula ~	14.4	Avg	**Phala** ~	8.3	Good-Avg	**Excel** ~	6.7	Very poor
Natal Red	14.1	Avg	1994-5-1	8.0	Avg-Poor	Phala	6.1	Good
A56	12.9	Poor	1994-8-1	7.0	Avg-Poor	**Serolane** ~	5.7	Good
Ndou ~	11.8	Excellent	**Ndou** ~	5.7	Excellent	**Ndou** ~	5.4	Avg-Good
A40	10.7	Avg - Good	1986-12-4	5.2	Poor	1994-5-1	5.5	Excellent
1989-23-1	9.8	Very poor	**Serolane** ~	4.8	Excellent	A15	5.2	Avg
Monate	9.8	Avg - Good	**W-119** ~	4.6	Excellent	Mokone	4.3	Avg-Poor
Amasi ~	9.7	Good	Monate	3.9	Good-Avg	W-119	3.7	Good- Excellent
ST87.030	6.9	Avg	Mafutha	3.7	Excellent	Mafutha	3.0	Excellent
Mafutha	6.1	Excellent	Mamphenyane	1.9	Excellent	1986-12-4	2.6	Good-Avg
Tacna	5.8	Avg	A-15	1.1	Excellent	Jewel	2.0	Very poor
Resisto	5.8	Excellent	Jewel	0.7	Avg-Poor	Blesbok	1.0	Avg-Poor
CN1656-97	5.7	Avg	Natal Red	0.0	Avg-Good	Natal Red	0.6	Good
Bosbok	5.3	Good				1994-8-1	0.0	Poor
Mean	9.54			4.6			3.93	
CV%	38.9			47.2			77.9	
LSD (P = 0.05)	6.2			3.65			5.12	

~ Recommended varieties.

In 2005, sweet potato production in South Africa was just above 54 300 tons but dropped by 14% in 2006 and the production volumes was found to be the lowest in a ten-year period, which was 2005 to 2014. The drop in production can be related to climatic conditions (drought) as well as the increased cost of production including pests and diseases (Department of Agriculture, Forestry and Fisheries (DAFF), 2015).

In Indonesia, low production of sweet potato has been attributed to climatic conditions (rainfall) as well as decrease of land area amongst other environmental and genetic factors (Saitama, Nugroho & Widaryanto, 2017). For example, a research study was done by Widaryanto and Saitama (2017) on plant growth analysis of ten sweet potato cultivars grown during the rainy season. The aim of their study was to determine the response of the ten sweet potato cultivars to climatic conditions (rainfall) in terms of plant growth and yield. The results demonstrated that the optimum Leaf Area Index (LAI) differed significantly among sweet potato cultivars at 90 days after planting (DAP). Rainfall significantly stimulated the vegetative growth (vine length) of some cultivars (Sari and Papua Sollosa) and vine pruning was recommended at this stage of plant growth to restrain the vegetative growth rate and boost the agronomic yield (tubers). The yield of sweet potato cultivars presented a negative correlation with leaf area and LAI, however, to achieve high yields, a low LAI value is required (Widaryanto & Saitama, 2017). In another related study, the growth and yield of ten sweet potato cultivars on dry land during the rainy season was found to differ significantly under field conditions (Saitama, Nugroho & Widaryanto 2017). These results clearly suggest that sweet potato cultivars respond differently to climatic and environmental conditions as well as adaptation to the same.

In agreement with the above claim, Rolston et al. (1987) and Villordon et al. (2003) indicated that Beauregard B14 is the most preferred cultivar grown in Mississippi because of its superior qualities. The cultivar is a mericlone of ‘Beauregard’ that was developed by the Louisiana Agricultural Experiment Station and released in 1987. Beauregard B14 produces straight and tough slips that are suitable for mechanical transplanting. The tuberous roots are fusiform to ovoid in shape with a smooth, light rose skin and deep orange flesh. Dry matter is approximately 24%, and carotene content is 9.46 milligrams per 100 grams fresh weight. In addition, Beauregard B14 is resistant to fusarium wilt (*Fusarium oxisporum*) and moderately resistant to soil rot or pox (*Streptomyces ipomoea*) (Smith, 2012).

In addition to the lack of high yield sweet potato cultivars responsible for low production by small-scale farmers, soil characteristics have also been implicated in the cultivation of sweet potato. Sweet potato cultivation requires a soil that is sandy to loamy sand in texture, moderately fertile but well drained (Hartemink et al., 2000). The crop is fairly tolerant to soil pH variations but the optimum soil pH for high yields of quality sweet potatoes range from 5.8 to 6.0 (Kapinga et al.,1995). Low soil fertility is another important limiting factor for cultivation of sweet potatoes. Abd El-Aal, Abo El-Fadl, and Moussa (2010) carried out an experimental study on effect of mineral and organic potassium fertilization on sweet potato crop grown in the newly reclaimed land at Sadat city, Egypt, and they reported that 200 Kg potassium sulphate fertilizer/fed was the best level to increase vegetative growth, total tuber yield and quality compared to the other levels. In another study, Uwah, Undie, John & Ukoha (2013) assessed the growth and yield response of improved sweet potato varieties to different rates of potassium fertilizer in Calabar, Nigeria. Their results demonstrated that the application of potassium at the highest rate, which was 160 kg K/ha, significantly ($P<0.05$) increased vine length, number of leaves and branches per plant. However, the dry weight of vines, diameter of tubers per plant and weight of tubers per plant were statistically the same at 120 kg K/Ha and 160 kg K/Ha rates. Interestingly, the highest number of tubers per plant and highest yield per ha were reached at 120 kg K/Ha and 160 kg K/Ha, respectively. Aggregate tuber yield/ha obtained at 120 and 160 kg K/Ha rates were more than seven (7) and eight (8) times, respectively higher than the control treatments. Potassium fertilizer application at 120 to 160 kg/ha seemed suitable for optimum yield for Ex-Igbariam cultivar in the study area and was therefore recommended (Uwah et al., 2013). However, the most reported single nutrient that significantly influences growth and cultivation of sweet potato is nitrogen (Bourke, 1985; Vosawai, Halim & Shukor, 2015).

2.3 PRODUCTION OF SWEET POTATO AND ITS CHALLENGES

2.3.1 Nitrogen Fertilization of Sweet Potato

Nitrogen is a primary macronutrient needed by plants for many of their structural development, functioning and metabolic processes. Generally, nitrogen availability is a very important determinant of crop yield. It is also one of the most expensive inputs in crop production. Thus, the efficient management of nitrogen by farmers with limited resources is a very important part of successful soil and crop management systems. Sustainable and profitable commercial sweet potato production requires proper management of nitrogen fertilizer.

Sweet potato crop of 20 t/ha removes approximately 80 kg N/ha, if roots and vines are harvested (Niederwieser, 2004). The optimum rate of fertilization depends on the amount of plant-available nitrogen in the soil, and on yield potential, which might be dictated by the available soil water and rainfall. Reported recommendations for application of nitrogen fertilizer to sweet potato generally lies between 30 and 90 kg N/ha (De Geus, 1967; Pushpalatha, Vaidya, & Adsul, 2017). The recommended application rate of nitrogen fertilizer in sweet potato by the Department of Agriculture, Fisheries and Forestry (DAFF) (2011) is based on nutrients removal by crop from the soil, which is 100 kg N/ha under South African conditions. Therefore, 100 kg N/ha needs to be replaced in the soil before or at planting and through top dressing 4 to 6 weeks after transplanting vines. However, the levels of nitrogen nutrients in soil has to be considered for each particular region as differences between regions can affect nutrient uptake by sweet potato plants.

Notably, the maintenance of optimum level of nitrogen is crucial in sweet potato production because the application of high rates of nitrogen will result in abundant top growth at the expense of tuberous root development, while too little will result in limited vegetative growth and low yield (Allemann, 2004). Deficiency of nitrogen causes dramatic reductions in growth of sweet potato plants, and yet not easily recognized in the field, unless there is a well-fertilized crop for comparison. General symptoms are a uniform light green chlorosis of the leaves, and slow growth resulting in a delayed or sparse ground cover (O'Sullivan, Asher, & Blamey, 1997). The advancement of nitrogen deficiency symptoms diverges according to environmental circumstances experienced by the crop. When nitrogen is initially sufficient during the establishment phase but becomes depleted during crop growth, plants may appear normal or near normal in colour and habit, except for yellowing and premature shedding of older leaves due to remobilization of nitrogen from these tissues. In this case, the oldest leaves become uniformly yellow and slightly wilted. A light brown necrosis may spread from the tip or margins, but often the leaf shed before it develops extensive necrosis. Necrotic tissue is supple rather than brittle (O'Sullivan et al., 1997). Unlike, if nitrogen supply is low throughout the developmental stages of the crop, no senescence of older leaves may be visible. Symptoms of chronic nitrogen deficiency include uniformly pale colour, reduced leaf size, loss of the normal brilliance resulting in a blanch appearance of the leaves, thin weak elongated vines and reduced activity of axillary buds leading to less branching. In severe cases, small purple-pigmented flecks or ring spots observed on the surface of older leaves of some cultivars (O'Sullivan et al., 1997).

Inadequate or excessive amounts of nitrogen fertilizer can be detrimental to sweet potato crop and can negatively affect its yield potential. In addition, excessive or improperly timed nitrogen fertilizer can result in added expense, leaching and contamination of surface water and groundwater (Ankumah et al., 2003). Nitrogen management research conducted on the Beauregard variety in Louisiana, suggests that potential yields are achieved when nitrogen fertilizer applications is either delayed or split with the majority of the nitrogen applied three to four weeks following transplant (Smith & Villordon, 2009).

Ukom, Ojimelukwe & Okpara (2009) reported that increase in the application of nitrogen fertilizer from 0–80 kgN/ha increased Beta-Carotene yield with the highest numerical value. In a study on the effect of nitrogen fertilizer and vermicompost on vegetative growth, yield and NPK uptake by tuber of potato, Yourtchi, Hadi & Darzi (2013) reported that highest amount of plant height, leaf and stem dry weight, Leaf Area Index, fresh and dry weight of tuber, total tuber weight, total number of tuber, tuber diameter, and percentage of N, K & P in tuber were found from application of 150 kg N/ha. Their report also suggested that to gain highest yield and avoidance of environments pollution, use of 150 kg N/ha nitrogen fertilizer and vermicompost application of 12 tons per ha is recommended (Yourtchi et al., 2013).

An experimental research study conducted in Kharif by Pushpalatha, Vaidya, Sunil, & Adsul (2017) on the effect of graded levels of N and K on growth and yield of sweet potato (*Ipomoea batatas* L.) demonstrated that all growth and yield parameters of sweet potato significantly increased with increased levels of N and K content in earlier growth stages of sweet potato. A similar trend was observed in case of yield during harvesting. Application of 125 kg N/ha recorded significantly higher Leaf Area Index at harvest (1.26), leaf chlorophyll content like chlorophyll-a

(0.65 mg/g Fresh weight), chlorophyll-b (1.48 mg/g Fresh weight) and total chlorophyll (2.13 mg/g Fresh weight) content at 120 DAP and yield of sweet potato (22. 39 ton/ha) was significantly recorded in same manner (Pushpalatha et al., 2017).

Furthermore, Ankumah et al. (2003) reported that single application of nitrogen resulted in significantly ($P<0.05$) higher yield than split applications. Physiological efficiency values were highly correlated with total marketable yields. Their results also showed that the recovery rates increased with time as long growing-period cultivars tended to have higher nitrogen recovery and physiological efficiency than short growing-period cultivars (Ankumah et al., 2003). These results suggest that the growing period of cultivars do differ and should play an essential role in nitrogen fertilization recommendations for sweet potato production.

In a related study, the results of investigation on the effect of sulfur, phosphorus, and nitrogen application on the growth and yield of sweet potatoes grown on Fredensborg clay loam by Navarro & Padda (1981) demonstrated that yields increased significantly with N applications while P application did not significantly affect the yield. A noticeable increase in yield was achieved with the application of 280 kg N/ha, however, great reduction in yield resulted when the application of N increased to 560 kgN/ha, which indicates that high levels of N produced abundant vine growth at the expense of tuber formation (Navarro & Padda, 1981).

Furthermore, Osaki, Ueda, Shinano, Matsui & Tadano (1995) conducted a study on accumulation of carbon and nitrogen compounds in sweet potato plants grown under different N application rates and the study was done at the Hokkaido University, Sapporo, Japan. Sweet potato (*Ipomoea batatas* L. var. Beniazuma) was grown in a cold region at four N application rates. Their results showed that total dry weight and tuberous root dry weight decreased at a high N application rate of 300 kgN/ha. The growth at this N application rate was restricted from the early growth stage when the N content was higher. However, the appearance of plants did not show a notable difference when compared to those at low N application rate of 50 kgN/ha. Therefore, it was presumed that the carbon metabolism of sweet potato plants was interrupted by the high rate of N applied (Osaki et al., 1995). Secondly, they reported that the harvest index of dry weight and N for sweet potato ranged from 0.6 to 0.7, and 0.2 to 0.5, respectively. Thus, the distribution of nitrogen to tuberous roots was lower than that of carbon (dry weight). Therefore, sweet potato has capacity to achieve a high potential productivity at low N application rates because a high photosynthetic rate could be retained because of high distribution ratio of N to leaves when compared to other crops such as potato or grain crops. Lastly, they reported that the ratio of sporamine and *β*-amylase to total N in tuberous roots increased with growth until 105 DAP and then decreased. Main amino acids consisted of alanine, aspartic acid, asparagine, and glutamic acid in leaves, asparagine in stems, asparagine and glutamic acid in tuberous roots (Osaki et al., 1995).

An experimental study on effect of fertilizer and variety on the yield of sweet potato was conducted by Ali, Costa, Abedin, Sayed & Basak (2009) during the *rabi* season, which is the cropping season of India from October to March. The study was done in the farmer's field of Multi-location Testing (MLT) site at Melandah, Jamalpur, to assess the behavior of sweet potato cultivars as well as to discover the optimum application rate of fertilizer for sweet potato. In the study, two sweet potato cultivars were used, namely, BARI Sweet Potato-5 and BARI Sweet Potato-7 and five fertilizer treatments applied. The results revealed that the highest sweet potato yield (33.9 t/ha) was attained from BARI SP-7 with an Integrated Plant Nutrient System (IPNS) basis fertilizer treatment. The lowest sweet potato yield was attained from BARI SP-7 with control treatment, which was the zero fertilization (Ali et al., 2009). Taken together, these studies clearly indicate that the efficient management of N by farmers with limited resources is a very important part of successful, sustainable and profitable commercial sweet potato production. However, there are other challenges faced by farmers in the cultivation of sweet potato in soils with moderate to good N fertility.

2.3.2 Climatic Requirements

In addition to rainfall, temperature and radiation are the essential climatic factors that can influence the growth and development of sweet potato. Sweet potato is a warm season crop that do not tolerate frost nor grow well in cool weather but requires warm days and nights for optimum growth and development. Temperatures below $10^{o}C$ can cause chilling injury and can stop the growth and development of sweet potato crop (Hartmann et al., 1988; Van den Berg & Laurie, 2004). Heavy frost can kill all top growth over night. The growth season is 4 to 5 months with an average temperature of 20^oC usually required for acceptable yield. However, in areas whereby no frost occurring but cool temperatures do occur, a growth season of 5 to 6 months usually is required. Relatively low surrounding temperatures experienced during any growing stage of the crop will result in lower yield (Van den Berg & Laurie, 2004).

2.3.3 Soil Requirements

Sweet potato can grow in a diversity of soil types. However, the optimum soil for sweet potato is a well-drained sand or sandy loam with clay subsoil. Although, loams and clay loams grow good sweet potato if they are well drained (Hartmann et al., 1988). Van den Berg & Laurie (2004) indicated that the soil should be well drained considering that sweet potato is susceptible to prolonged exposure to excess moisture in the soil. For that reason, planting on ridges is recommended. Sweet potato crop is susceptible to alkaline soil conditions. Therefore, brackish soils should be avoided while soils with low pH should be treated with agricultural lime prior to planting according to the recommendations by soil analytic services (Van den Berg & Laurie, 2004). To achieve high yield, it is essential to maintain the ratio of potassium to nitrogen high (Van den Berg & Laurie, 2004).

Van den Berg & Laurie, (2004) mentioned some problems related to soil type and soil management. They suggested that in soils with compaction layer of about 200 to 300 mm deep, tubers tend to grow shallow and the shoulders of the tubers exposed above the soil surface, which result in greening and insects damage. In sandy soil, tubers are likely to grow long with pointed ends especially cultivars with naturally long tubers. They also indicated that in light soil with low water holding capacity, nutrients like nitrogen leach away rapidly. Moreover, such soils are susceptible to erosion due to wind, rain and irrigation that can cause the shoulders of the tubers to be exposed to sun and insects (Van den Berg & Laurie, 2004).

The problem with heavy clay soils is that it can lead to numerous physiological disorders such as malformed tubers, rotting and black watermarks. Hence, fertilization and irrigation need a major attention on these soils (Van den Berg & Laurie, 2004).

2.3.4 Weeds Problem

Weed refers to a plant that is growing where it is not wanted and in competition with desirable plant for plant nutrients, soil moisture and sunlight. Weeds are enduring with vigorous growth habit and they can shelter pests and diseases. Therefore, weed management process is crucial in sweet potato production especially during the crop establishment stage as it ensures that weed population and their growth is kept below level of economic injury to crop without polluting the environment. The study by Poole (1963) on chemical weed control in sweet potato production indicated that a small infestation of weeds would extremely reduce the yield of this crop and mainly during the first 40 DAP. Growing of some cultivars of sweet potatoes in ridges has been reported as good for weed management. Alleman et al. (2004) indicated that sweet potato vines grow quickly down the sides of the ridges; therefore, it suppressed weed growth and no further weed control measures are required.

Weeds can be controlled by using one of the most four common weed management techniques that is mechanical (use of tractor drawn implements), manual (use of hand hoes), chemical (application of herbicides) and biological (use proper crop rotation) or either two or more of these techniques integrated depending on how field is severely infested with weeds.

Most commercial sweet potato farmers rely on proper chemical weed control integrated with proper cultivation to minimize problematic weeds. Accurate use of these tactics are very effective. For each field, it is essential to understand the weed problems due, the soil type, the time of planting, and the cultural practices planned to use before selection of herbicides. In soils low in organic matter that is less than two percent (<2%) the lowest rates suggested in the herbicide label should be used (Wilson et al*.,* 1989).

Laurie, Maja, Ngobeni and Du Plooy (2014) reported that inorganic mulching (plastic and newspapers) and narrow plant spacing were the most effective weed management treatments compared to compost and grass mulching. A recommendation to smallholder farmers was the newspaper mulch to control weeds in sweet potato production to eliminate the cost of manual weed control.

2.3.5 Pests and Diseases Problem

Numerous fungal, viral and bacterial diseases invade sweet potatoes like any other crops. Hartmann et al. (1988) indicated that there are some critical diseases namely, fusarium wilt and stem rot, black rot, rhizopus soft rot, white rust, scarf, cercospora leaf spot, internal cork and russet crack virus, and several types of storage root diseases that affect sweet potato production. Thompson (2004) indicated that in South Africa, some sweet potato cultivars are normally resistant to diseases; however, some diseases invade these cultivars when environmental condition favours their development. Thompson & Domola (2004) described four mostly occurring viral diseases of sweet potato in South Africa and worldwide, namely; sweet potato feathery mottle virus (SPFMV), sweet potato mild mottle virus (SPMMV), sweet potato chlorotic stunt virus (SPCSV) and sweet potato virus disease (SPVD). These viral diseases commonly transmitted to sweet potato plant by aphids and whiteflies (*Bemisia tabaci*) in a non-persistent manner and semi-persistent manner respectively. To control the spread of these viral diseases, aphids, whiteflies and weed must be controlled chemically, and plant virus-free material only should be used for sweet potato cultivation (Thompson & Damola, 2004).

Sweet potato plants are attacked by various insects/pests, which can feed themselves on plant parts such as leaves, stems, flowers and roots. Douglas & Cowles (2011) indicated that flea beetles, leaf beetles, and young caterpillars are the type of leaf feeding by chewing insects that make holes on leaves. Various weevils, larger caterpillars and grasshoppers usually make irregular notches along the edges of leaves. An exact semicircular cut pieces of leaves demonstrate the existence of leaf cutter bees. When the insect feed entirely within leaves it is called leaf mining, and such insects can be found among beetles, flies, sawflies, and moths (Douglas & Cowles, 2011).

In South Africa, insects found predominantly in warm areas like Limpopo Province in Bushbuckridge were reported to cause a great sweet potato crop loss during an experimental study (Laurie & Magoro, 2008). In such warm areas, sweet potatoes are commonly attacked by insects/pests like sweet potato hawk moth (*Agrius Convolvuli*), Tortoiseshell beetles, Sweet potato weevils (*Blosyrus sp*) and (*Cylas Formicarius*), White grubs, leaf miner (*Bedellia spp*), White flies and Aphids (Visser, 2004). Therefore, it is essential to implement pests control measures in warm areas to prevent such great crop loss by using various chemicals (insecticides) recommended to control these insect/pests especially under field conditions (Visser, 2004).

2.3.6 Physiological Disorders

Physiological plant disorders also called abiotic plant disorders affect the functioning of any plant. Physiological disorders are caused by non-pathological conditions such as adverse weather, poor light, waterlogging, cultural practices, nutrient deficiency, chemical and mechanical injuries (Schutzki & Cregg, 2007). Van den Berg & Laurie (2004) reported that symptoms of physiological disorders simulate pathological diseases however; they are caused by a diversity of environmental, physiological and genetic factors but not pathogens. For example, in sweet potato, growth cracks commonly develop on large tubers than on small tubers due to uneven growing conditions. Water blisters are the small lumps formed on the outside of the tubers that were exposed in a very wet soil for a long period, which induces a lack of oxygen response in the tuber. Some other physiological disorders occurring in sweet potato production are mutations, chilling injury, souring and sun scalding (Van den Berg & Laurie, 2004).

2.4 SUMMARY

In this chapter, literature was reviewed on the origin and cultivation of sweet potato globally and locally, nitrogen fertilization of sweet potato, production of sweet potato and its challenges, which included the climatic requirement, soils requirement of sweet potato production, pests, diseases and disorders of sweet potato. This chapter further evaluated the reported research findings in the literature on effect of nitrogen fertilizers on growth and yield of sweet potato to enable the researcher to acquire a better understanding of sweet potato production in Ladysmith, KwaZulu-Natal. The next chapter presents the materials and methods used to achieve the aim and objectives of the study.

CHAPTER 3: MATERIALS AND METHODS

3.1 STUDY AREA

A field experiment was conducted in Zamani Madoda project at Ladysmith, Pieters area located at latitude $28^{o}36'40''$ S and longitude $29^{o}53'16''$ E (Fig. 3.1) in KwaZulu-Natal Province. The experimental site is at an elevation of 1372 m above sea level with the slope of 9 to 15% that is generally moderate. This area falls within the Bioresource Unit Vc9, which falls under the Moist Tall Grassveld that is in the Bioresource group 12. The vegetation type of this area is a Moist Tall Grassveld with vegetation pattern of grassland, wooded grassland, bushland and bushland thicket. According to the eleven-bioclimatic regions of Natal, this area falls under bioclimatic region 8, which is an upland-drier with moderately restricted growing season due to low temperatures, severe frost and moisture stress, during winter months. The soil is dominated by Oakleaf soil form of Buchuberg (1120) soil families that is well drained and well aerated with effective rooting depth of 600 mm. The soil horizons are of weak sub-angular blocky structure with sandy clay loam texture with clay content of 35%. The B-horizons are well drained with slightly hard soil consistency in dry stage. Therefore, this soil is suitable for irrigation without serious limiting factors as cropping potential under dryland conditions is limited due to a poor moisture regime. The serious problem with this soil is the soil compaction (Webster, 1990; MacVicar, 1991; Camp, Manson, Smith, Guy & Milborrow, 1994).

The study area has a mean annual rainfall of 779 mm with a range of 600 to 800 mm. Therefore, this is a high rainfall area during summer months (November-March). However, rainfall is very low or even absent in winter months therefore rain fed cropping sweet potato in winter is excluded, or generally, crops that requires too much water cannot be grown during this period. During summer months, community members in the study area prefer to grow sweet potato cultivars such as Beauregard and Ndou for their own consumption.

Figure 3 1 ArcView map of the study area Ladysmith, Pieters/Ezakheni – Zamani Madoda Project (Source: Google earth, 2018)

3.2 SOIL SAMPLING

Soil samples (0-30 cm depths) were collected from the experimental site prior fertilization. Soil samples were taken from the topsoil 15 cm and this sampling depth (15 cm) was considered standard regardless of tillage practices. The sampling equipment used was a soil sampler, which was considered appropriate because each core was of the same size and depth. A zigzag pattern was followed taking 24 cores from each replicate to ensure that the whole area was represented. The soil sampling area was 385 m^2. Three replicates of soil samples (20 g each) were taken from each of the three experimental blocks (represented as replicates in Fig. 3.2) and these samples were mixed thoroughly and one composite sample for each replicate was placed in a 500 g box and sent to the Agricultural Research Council (ARC) Laboratory – Institute for Soil, Climate and Water, Pretoria, Gauteng Province, for elemental composition and physical characteristics analysis.

3.3 PLANTING MATERIALS

Vine cuttings of two sweet potato cultivars (Beauregard and Ndou) were obtained from the Agricultural Research Council – Vegetable and Ornamental Plant Institute (ARC-VOPI) in Pretoria. The length of each vine cutting was between 25 and 30 cm. In Table 3.1 below, are the planting materials used and their characteristics, which consisted of an imported cultivar (Beauregard) grown in South Africa and one of the ARC breeding line cultivars (Ndou). Other inputs such as fertilizers, pesticides

(Cypermethrin) and herbicide (Focus® Ultra) were purchased from agricultural shops around Ladysmith, KwaZulu-Natal.

Table 3 1 Sweet Potato cultivars used and their characteristics (Laurie, 2004)

NO	CULTIVAR	ORIGIN	STORAGE ROOT SHAPE	SKIN COLOUR	FLESH COLOUR	ADVANTAGES	DISADVANTAGES
B1	Beauregard	USA	Long cylindrical to heavy elliptic	Orange with purple	Dark orange	Fairly quick grower High beta-carotene	May become too big with long growing season May vary in sizes Has not been planted widely locally
B2	Ndou	ARC in RSA	Long elliptic to obovate	Cream to creamy light orange	Cream, slight orange	Very good taste High yield	Some constriction

3.5 LAND PREPARATION, PLANTING TREATMENTS AND EXPERIMENTAL DESIGN

Mechanical land preparation was done by mouldboard-plough and disc plough to level the soil and plot demarcations in three replicate blocks was done manually (Fig. 3.2). Each block had six plots per cultivar. Each plot size within a block was 3.0 m x 2.0 m (6 m^2). Plots were separated by a path of 1.0 m. Planting was done on ridges/mounds about 25 cm high. Fertilizers (KCL (50% K) and Superphosphate (5% P + 8% C)) were used for pre fertilization at the rate of 0.132 and 0.72 kg/plot respectively following fertilizer recommendations from soil analytic services at Agricultural Research council, Pretoria. These fertilizers were band placed at 5 cm deep below the vines preventing vines to be burnt by fertilizer. Vine cuttings (between 25 and 30 cm) of two sweet potato cultivars (Beauregard and Ndou) were used in this study.

Figure 3 2 Plot demarcation and ridging

Figure 3 3 Transplanting of sweet potato vines

During transplanting, vine cuttings of between 25 to 30 cm in length with 5-6 nodes from the terminal shoots but without lower leaves were inserted to half their length with slanting at an angle of 45°. A common spacing of 0.3 m between plants and 0.5 m between rows was used to give around 42 plants per plot (see experimental layout below). Manual transplanting of sweet potato vines was carried out on 22 December 2017 (Fig. 3.4). Limestone Ammonium Nitrate (NH_4NO_3) 28% N was used as a top dressing fertilizer. For the nitrogen fertilizer treatments, the fertilizer was applied as two split applications of 0, 13, 23, 33, 43 and 53 kg/ha at half rate of each respectively. The choice of the N fertilization was informed by a similar study by Pushpalatha, Vaidya, & Adsul, (2017, however, the levels were reduced due to the cost implications. Half of each amount of fertilizer (0, 13, 23, 33, 43 and 53 kg/ha) was dissolved in water as micronutrients and applied as irrigation water during the first split application(Table 3.2). The first split application of each N fertilization were applied 4 weeks after transplanting sweet potato vine cuttings. Four weeks later, the remaining half of each N fertilization level was also dissolved in water and applied as the second split application. Treatments consisted of six (6) levels of nitrogen fertilizer (0, 13, 23, 33, 43 and 53 kg N/ha denoted as N1, N2, N3, N4, N5, N6 respectively) for each of the two cultivars (Beauregard (B1) and Ndou (B2)) with each treatment replicated three times for both cultivars. The different treatments with the details of application rates are given in Table 3.2 below. The crop was grown under rain-fed condition, however supplementary irrigation was provided during the dry hot days, especially during the crop establishment.

In this study, there were three incidences of insect /pest’s attack that occurred during the test crop’s growing stages and it was controlled by using pesticide, Cypermenthrin - 200 EC, at 40 ml/10L of water. Seven days after transplanting, the first incidence of the rough sweet potato weevils (*Blosyrus sp*.), which are problematic in the study area, attack occurred. One and two months after transplanting, the second and third incidences of sweet potato hawk moths (*Agrius convolvuli*), late instar larvae of sweet potato hawk moths and tortoiseshell beetles, attacks occurred respectively. There were no signs of fungal and viral diseases identified during the growing season.

One month after transplanting, weed control was done using both manual and chemical (post-emergent herbicide) weed control methods, whereby hand hoes and herbicide, Focus® Ultra, at the rate of 200 mL/10L water, were used respectively.

Table 3 2 Different nitrogen fertilization treatments with their respective doses

TREATMENTS	**APPLICATION RATES (DOSES)** **Limestone Ammonium Nitrate (NH_4NO_3) 28% N (kgN/ha)**	**1ST SPLIT PER PLOT (kg)**	**2ND SPLIT PER PLOT (kg)**
B1N1	0	0	0
B1N2	13	0.0139	0.0139
B1N3	23	0.0246	0.0246
B1N4	33	0.0353	0.0353

B1N5	43	0.0461	0.0461
B1N6	53	0.0567	0.0567
B2N1	0	0	0
B2N2	13	0.0139	00139
B2N3	23	0.0246	0.0246
B2N4	33	0.0353	0.0353
B2N5	43	0.0461	0.0461
B2N6	53	0.0567	0.0567

The calculation of application rates (doses) per plot was calculated using this formula:

- Plot size = 3 m × 2 m
  = 6 m^2 ÷ 10000 m^2
  = 0.0006 ha
- The amount of fertilizer required for 1 kg nutrient = 100 ÷ 28
  = 3.57 kg

Then, the applied amount of fertilizer for each treatment was calculated as follows:

For treatment- B1N2 & B2N2 = 13 kg N/ha × 3.57

= 46.41 kg/ha × 0.0006 ha plot size

= 0.0278 kg ÷ 2 split applications

= 0.0139 kg / split application

For treatment- B1N3 & B2N3 = 23 kg N/ha × 3.57

= 82.11 kg /ha × 0.0006 ha plot size

= 0.0492 kg /plot ÷ 2 split applications

= 0.0246 kg / split application

For treatment- B1N4 & B2N4 = 33 kg N/ha × 3.57

= 117.81kg /ha × 0.0006 ha plot size

= 0.0706 kg /plot ÷ 2 split applications

= 0.0353 kg / split application

For treatment- B1N5 & B2N5 = 43 kg N/ha × 3.57

= 153.51 kg/ha × 0.0006 ha plot size

= 0.0921 kg /plot ÷ 2 split applications

= 0.04605 kg / split application

For treatment- B1N6 & B2N6 = 53 kg N/ha × 3.57

= 189.21 kg/ha × 0.0006 ha plot size

= 0.1135 kg /plot ÷ 2 split applications

= 0.0567 kg / split application

3.6 EXPERIMENTAL LAYOUT

A factorial experiment was laid out with a randomized complete block design. The experimental treatments (six nitrogen levels (N1-N6) and two cultivars (B1 & B2) layout is displayed below (Fig. 3.4) in a representation manner and in the real order in which the treatments were assigned to the three (3) blocks in the field. All the treatments were each randomly assigned to the sub plots. All agronomic measures were observed during planting and harvesting leaving the buffer rows out but used the harvest rows for sample collection.

Replicate 1											
B1N2	B1N6	B1N5	B1N3	B1N5	B1N4	B2N5	B2N2	B2N4	B2N6	B2N3	B2N1

Replicate 2											
B1N5	B1N2	B1N6	B1N4	B1N1	B1N3	B2N2	B2N5	B2N3	B2N1	B2N4	B2N6

Replicate 3											
B1N2	B1N1	B1N4	B1N6	B1N5	B1N3	B2N3	B2N6	B2N4	B2N5	B2N1	B2N2

Figure 3 4 Field experimental layout

- Total experimental area = 35 m x 11 m
- Two cultivars = Beauregard (B1) and Ndou (B2)
- Six levels of nitrogen (kg N/ha) = N1 (0), N2 (13), N3 (23), N4 (33), N5 (43) and N60 (53).
- Treatment / Plot size = 3.0 m x 2.0 m
- Spacing between the plots = 1 m
- Spacing in-between row = 0.5 m
- Spacing in-between plants= 0.3 m

- No. of rows/treatment = 6
- No. of plants/row = 7

3.7 ACQUISITION OF ETHICAL CLEARANCE

Before the commencement of data collection, ethics approval was obtained from the University of South Africa's Ethics Committee to carry out the study. The ethics approval (Ref. no. 2017/CAES/109) was granted specifically for the research project entitled "The effect of nitrogen fertilizer on growth and yield of sweet potato in soils of Ladysmith, KwaZulu-Natal". The ethics approval was valid for 12 months and it was renewed for another 12 months to enable completion of the experiment as per the university's ethics policy. In addition, permission to carry about the study was sorted from all relevant authorities within the municipality.

3.8 DATA COLLECTION

After transplanting, growth stages of the crop (crop establishment, vegetative growth and tuber formation) were monitored on a weekly basis until the harvesting period. The data were collected from the four harvest rows leaving out two buffer rows using the quantitative methods. Data collected included vine length, number of vines per plant, wet and dry weight for the top growth (shoot), crop yield, tuberous root weight, number of tuberous roots per plant, and nutrient analysis of dry matter from shoot and tuberous root. All data collection was done manually, namely hand picking of shoots, use of garden forks to harvest tuberous roots, scale to weigh fresh and dry shoots and tuberous roots, and tape measure for length of vines (Fig. 3.5). A vine length range of 2.3-4.0 m was considered to be long and a range of 1.0-2.2 m was short. Both types of vine lengths were measured for each plant per treatment. The number of vines per plant was counted and those with less than five vines were considered to have low number of vines and those with more than five vines were high. A minimum of six plants were sampled for each treatment for data collection. For yield determination, six plants were randomly harvested at 115 days after transplanting (DAT). The total number of tuberous roots per plant was counted (Fig. 3.6) and weighed. The number of tubers per plant was regarded as high when it was greater than five and low when below five. The weights of root tuber considered to be large (1.0 – 2.2 kg) and small (0.1 – 0.9 kg) were determined and their lengths and diameters measured using a measure tape (Fig. 3.7). Tuberous roots with a length range of 17 – 24 cm were regarded as long and those with a range of 9 - 16 cm were considered as short. Root tubers with a diameter range of 17 – 24 cm were regarded as large and those with a range of 7- 16 cm were considered as small. Data for the following growth and yield parameters were collected:

- Vine length every two weeks until harvesting
- Vine number per plant at harvesting
- Shoot fresh/dry weight at harvesting
- Tuberous root length/diameter at harvesting
- Tuberous root number and fresh weight per plant per treatment

The dry matter percentage was calculated using this formula:

$$\text{Dry matter \%} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}} \times 100$$

Figure 3 5 Measurement of vine length

Figure 3 6 Harvesting of tuberous roots at 115 DAT

Figure 3 7 Measurement of tuberous root length/diameter at harvesting (115 DAT)

3.9 NUTRIENTS DETERMINATION IN LEAF, VINE AND TUBER

3.9.1 Procedure for Determination of Al, Fe, Mn, Zn, Cu, Ca, Mg, Na, P & K

For elemental composition analysis, the fresh leaves, vines (shoots) and tubers were harvested, placed in labelled brown paper bags and dried at 75^{o}C in an air-forced oven for 48 h. The elemental (Al, Fe, Mn, Zn, Cu, Ca, Mg, Na, P & K) composition in plant organs was analysed with Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) using Hunter's method (1975). Beakers/crucibles were stored overnight (12 h) in an oven at 110^{o}C and in the next morning were cooled in a desiccator for 30 min.

About 0.5 g of each sample was measured and milled to pass through a 1 mm sieve into beakers (100 mL) and placed in an oven set at 110^{o}C for 2 h. After 2 h, the beakers were removed from the oven using a pair of tongs and cooled in a desiccator for 30 min. Together, the mass of sample and beaker was recorded for later calculations and beakers/crucibles were taken to the furnace room for ashing.

3.9.2 Furnace Ashing

The beakers/crucibles with samples and blank crucibles were put into the furnace set at 450^{o}C to dry-ashed for 4 h and left inside the furnace overnight. The timer was set so that the furnace would cool off before the next working day. During the next day the beakers/crucibles with samples and blank crucibles were removed using a pair of tongs. Thereafter, the ashed samples were taken for digestion and filtration.

3.9.3 Digestion and Filtration

The cool beakers with ash contents were then wet with few drops of distilled water and 2 ml of concentrated HCl was added to each sample. The wet ashed contents were then evaporated slowly to dryness on a water bath in the fume cupboard with the extractor fan on. Twenty-five millilitre (25 mL) of freshly prepared 1.9 HCl solution (approx..TM HCl) was added to each sample using a Fortuna Optifix dispenser. Thereafter, each sample was stirred using a rubber policeman, rinsing the rod in a beaker of distilled water in between samples. The content of each sample was then filtered through Advantec 5B: 90 mm diameter filter papers into a clean rack of sample cups.

3.9.4 Inductively Coupled Plasma Atomic Emission Spectroscopy Procedure

The filtrate was diluted with de-ionized water, ratio 5:20. Then the diluted solution was taken for elemental analysis using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-OES). The calibration standards were also done through a similar dilution procedure used for the samples. Lastly, the raw data from the ICP-OES was taken for further calculations using dry matter determined earlier and together with the weight of sample weighed.

3.9.5 Determination of C and N

The elemental composition in plant (C & N) was analysed on TruSpec using dry combustion based on Duma's method (1831). The furnace was set to 950^{o}C to burn samples. The gases (Oxygen and Helium) in the tanks where checked and confirmed to be sufficient to analyse the whole batch of samples and the procedure for system calibration was followed as stated in Duma's method (1831). Zero point one two five grams (0.125 g) of each dried sample was measured and milled to pass through a 1 mm sieve into weighing boats and taken to Carbon, Nitrogen & Sulphur (CNS) room for analysis. The actual weight for each sample was recorded and analysed in approximately five drift of samples in small tin foil cups recommended for plant samples. The number of drift standards used and the actual weight were also recorded. Thereafter, the samples were loaded into the carousel and the analysis process was carried out.

3.10 DETERMINATION OF GROSS MARGIN ANALYSIS ASSOCIATED WITH THE APPLICATION OF DIFFERENT FERTILIZATION LEVELS

After the experiment was conducted, the Gross Margin analysis was done to determine the potential revenue associated with the use of different levels of nitrogen in accordance with Kelly (2012). The gross margin analysis was calculated by subtracting the total variable costs (TVC) from total gross income. Gross margin as explained by Maoba (2016) is the net sales of produced goods, less the production cost of the goods sold. Maoba (2016) further explained that Gross Margin is frequently expressed as a percentage, called the Gross Margin Percentage and is calculated using the following formula where estimated figures will be used. The formula used to calculate Gross Margin according to Kelly (2012) was as follows:

Gross Margin (GM) = Gross income (GI) - Total Variable Cost (TVC)

Where:

GM = Gross Margin

GI = Gross Income

VC = Variable Cost of Inputs (i.e. Production Input Cost + Fertilizer Cost + Labour)

3.10.1 Sweet Potato Gross Margin

Table 3 3 Yield factors used to calculate Gross Income per hectare

Yield Factors	**Gross Income Per Hectare**
Plant population	33 300 plants/ha (plant spacing: 0.3 m x 1.0 m)
AVG Tuber weight/plant (Kg)	0.6 kg/plant x 33300 = 19 980 /1000 = 20.00 ton
Price/ton	R 5 481.34
Total revenue (estimated)/ha(A)	**R 109 626.80/ha**

Total Revenue/ha = AVG Tuber weight/plant (kg) *Price/ton

Table 3 4 Sweet potato production inputs with relevant production costs in Rands per hectare (2018).

Inputs Per Hectare	Unit	Price Per Unit (R)	Quantity	Total variable costs Per Hectare (R)
DIRECTLY ALLOCATED VARIABLE COSTS				
PRE-HARVEST COST (B)				
Plant Material:				
Sweet Potato Seedlings	Kg	432.55	30.00	12 976.50
Fertilizers				
2:3:4 (30) + 0.5% Zn	Ton	6 089.40	0.50	3 044.70
LAN 28%	Ton	5 124.44	0.25	1 281.11
Herbicides				
Eptam Super	Litre	140.74	4.00	562.96
Linuron	Litre	241.80	2.00	483.60
Pesticides				
Decis	Litre	91.52	0.25	22.88
Wetting Agent				
Summit Super	Litre	59.56	0.75	44.67
Irrigation	mm	3.93	200.00	786.00
Casual Labour	Days	138.52	10.00	1385.2
TOTAL (B)				**20 570.62**
Harvesting (C)				
Casual Labour	Days	138.52	32.00	4 432.64
Packaging 10 kg Pockets (Spinach pockets)	Each	1.31	2 000.00	2 625.00
Marketing Cost				
Agents Commission	7.50%	411.10	20.00	8 222.01
Market Commission	5.00%	274.07	20.00	5 481.34
Transport : Contract	Ton	288.75	20.00	5 775.00
TOTAL (C)				**26 535.99**
INDIRECTLY ALLOCATED V C				
PRE-HARVEST COST (D)				
Fuel	Litre	12.71		1 588.75
Repairs & Maintenance				1 429.88
TOTAL (D)				**3 018.63**
TOTAL PRE-HARVEST COSTS (B + D)				22 689.04
TOTAL HARVEST COSTS (C)				26 535.99
TOTAL DIRECTLY ALLOCATED V C (B + C = E)				46 206.41
TOTAL INDIRECTLY ALLOCATED V C (D)				3 018.63
TOTAL ALLOCATED V C (D + E = F)				**49 225.03**
GM ABOVE TOTAL ALLOCATED VC (A - F)				**61 318.97**

Table 3 5 Estimated Gross Margins (GM) per nitrogen level per hectare

Nitrogen level (kg)	**Nitrogen cost/ha (R5 124.44/ton)**	**Production costs/ha**	**Total variable cost**	**Total revenue**	**Gross margin/ha** (i.e. Total revenue – total variable costs)
N1 (0 kg/Ha)	R5124.44 x 0 kg/ha ÷ 1000 = R0.00	R49 225.03	R49 225.03	R109 262.80	R60 037.77
N2 (13 kg/Ha)	R5124.44 x 46.41 kg/ha ÷ 1000 = R237.83	R49 225.03	R49 462.86	R109 262.80	R59 799.94
N3 (23 kg/ha)	R5124.44 x 82.11 kg/ha ÷ 1000 = R420.77	R49 225.03	R49 645.80	R109 262.80	R59 617.00
N4 (33 kg/ha)	R5124.44 x 117.81 kg/ha ÷ 1000 = R603.71	R49 225.03	R49 828.74	R109 262.80	R59 434.06
N5 (43 kg/ha)	R5124.44 x 153.51 kg/ha ÷ 1000 = R786.65	R49 225.03	R50 011.68	R109 262.80	R59 251.12
N6 (53 kg/ha)	R5124.44 x 189.21 kg/ha ÷ 1000 = R969.60	R49 225.03	R50 194.63	R109 262.80	R59 068.17

The formula used to calculate the estimated Gross Margin percentage in Table 3.4 according to (Anonymous, 2016) was as follows:

Gross Margin Percentage

$$= \frac{Estimated\ Net\ Sales\ of\ sweet\ potato\ tuber - Estimated\ Input\ Costs\ of\ sweet\ potato\ tuber}{Estimated\ Net\ Sales\ of\ sweet\ potato\ tuber}\ x\ 100$$

Table 3 6 The estimated Gross Margin Percentage per hectare

Nitrogen Level per Ha (kg)	Gross Margin per Ha (R)	Gross margin Percentage per Ha
N1 (0 kg)	R60 037.77	54.95 %
N2 (13 kg)	R59 799.44	54.06 %
N3 (23 kg)	R59 617.00	54.56 %
N4 (33 kg)	R59 434.06	54.40 %
N5 (43kg)	R59 251.12	54.23 %
N6 (53 kg)	R59 068.17	54.06 %

3.11 DATA ANALYSIS

All data collected for growth and yield parameters from the different plots were analyzed using two-way analysis of variance (ANOVA). All parameter means were compared and where differences were significant, the Duncan multiple range test (DMRT) was used for separation between treatment means. Statistica v. 10, StatSoft (USA) was used for all statistical analysis.

CHAPTER 4: RESULTS

4.1 INTRODUCTION

This chapter provides and describes results obtained from a field experiment, which investigated the effects of different nitrogen fertilization on growth and yield of two sweet potato cultivars in soils of Ladysmith, KwaZulu-Natal. The study focused on the effect of different N fertilization levels on the vegetative growth of sweet potato, which included vine (shoot) length, number of vines per plant, and fresh and dry weight of plant shoot, and yield data such as tuberous root diameter, tuberous root length, number of tuberous roots per plant and tuberous root weight. The results are presented in this chapter. The elemental analysis of shoot and tuberous root dry matter at 110 days after transplanting is also presented and described. The chapter concludes with presentation of key findings on the N fertilization effect on growth, tuber yield and nutrient content of sweet potato grown in soils of Ladysmith.

4.2 SOIL PROPERTIES OF THE EXPERIMENTAL AREA

The mineral in soils of the experimental area was analyzed in this study before the experiment commenced. The results of the soil analysis are presented in Table 4.1. The sandy soil samples were found to be slightly acidic (pH 5.91) with a pH range of 5.67- 6.26. In general, the minerals (P, K, Ca, Mg, Na and Total N) analyzed were found to be relatively in low concentrations (mg/kg) in the soil samples. For example, total N percentage ranged from 0.47 to 0.55 %. The P and K contents in soil sample were 18.13 mg/kg and 121.33 mg/kg respectively (Table 4.1). To address the observed nutrient deficiencies, Limestone Ammonium Nitrate (NH_4NO_3) 28% N, KCL (50% K) and superphosphates (5% P + 8% C), were added as a top dressing fertilizer before the experiment. as per recommendations from the soil analytic services at Agricultural Research council, Pretoria.

Table 4.1 Chemical characteristics of soil in experimental site

Properties	Concentration	Units
pH (water)	5.91	
P	18.13	mg/kg
K	121.33	mg/kg
Ca	767.67	mg/kg
Mg	190.00	mg/kg
Na	15.27	mg/kg
Total N	0.51	%

4.3 VEGETATIVE GROWTH RESPONSE TO NITROGEN FERTILIZATION

In this study, one objective was to evaluate the effect of nitrogen fertilization on growth and performance of two sweet potato cultivars grown in soils of Ladysmith. In this regard, the following growth parameters; vine length and vine numbers per plant and shoot biomass (fresh and dry weights), were measured in response to N fertilization. Although data was collected on a weekly basis, significant changes were only noted after 110 days of transplanting (DAT). Therefore, only results obtained for each growth parameter after 110 DAT are presented and described below.

4.3.1 Vine Length per Plant

At 110 DAT, N fertilization significantly affected vine length of sweet potato cultivars grown in soils of Ladysmith. For example, the mean long (3.21 m) and short (2.21 m) vines of Beauregard (B1) were different compared to those of Ndou (B2) (1.83 m and 1.28 m respectively) at 110 DAT (Table 4.2).

Similarly, the level of nitrogen fertilization had a significant effect on the vine length of sweet potato plants. Regardless of the variety, plants treated with the highest (53 kg/ha) N level (N6) showed vine length of 2.83 m (long) and 2.10 m (short) compared to control (N1), which had 2.42 m (long) and 1.50 m (short) vine lengths respectively. Generally, there was a steady increase in vine length (long & short) as the nitrogen level was increased from 0 kgN/ha through to 53 kgN/ha (Table 4.2).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and N fertilizer level. For example, Beauregard fertilized with 53 kgN/ha (B1N6) had a long vine length of 3.63 m compared to Beauregard fertilized with 26 kg/ha (B2N2), which had a long vine length of 2.89 m. Similarly, the long vine length

(2.02 m) of Ndou fertilized with 53 kgN/ha (B2N6) was longer than that of Ndou fertilized with 26 kgN/ha (B2N2), which had a long vine length of 1.64 m (Fig. 4.1). With regards to short vine lengths, a similar pattern was noted. Beauregard fertilized with 53 kgN/ha (B1N6) had a short vine length of 2.75 m compared to Beauregard not fertilized 0 kgN/ha (B2N1), which had a short vine length of 1.87 m (Fig. 4.2). In general, regardless of the treatment, the vine length (long and short) of Beauregard was longer than that of Ndou (Figs. 4.1 and 4.2).

Table 4.2 Effect of N fertilization level on vine length (m) of sweet potato at 110 DAT. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Treatment	**Vine Length per plant (m)**	
	Long	**Short**
Cultivar		
Beauregard (B1)	3.21±0.07a	2.21±0.09a
Ndou (B2)	1.83±0.08b	1.28±0.04b
N level (kgN/ha)		
N1	2.42±0.29b	1.50±0.17c
N2	2.27±0.29c	1.59±0.18c
N3	2.42±0.31b	1.68±0.18c
N4	2.53±0.34b	1.75±0.24b
N5	2.64±0.34a	1.87±0.26b
N6	2.83±0.39a	2.10±0.30a
F-Statistics		
Cultivar (C)	212.16***	154.45***
N level	2.91**	5.55***
C x N interaction	0.56*	1.52*

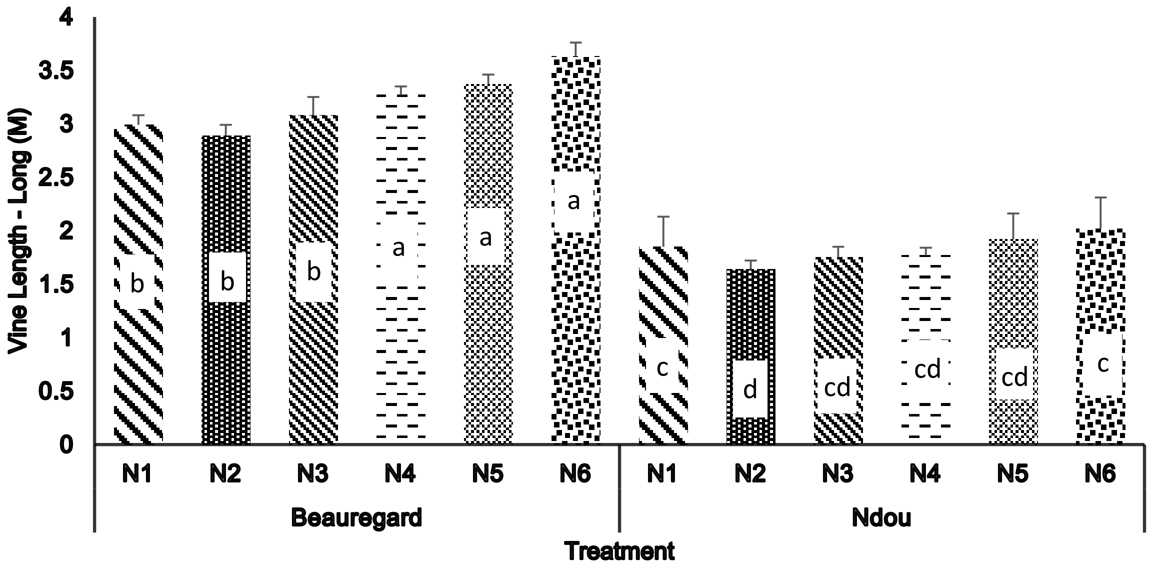

Figure 4.1 Effect of nitrogen level and cultivar interaction on long vine length (m) of sweet potato at 110 DAT

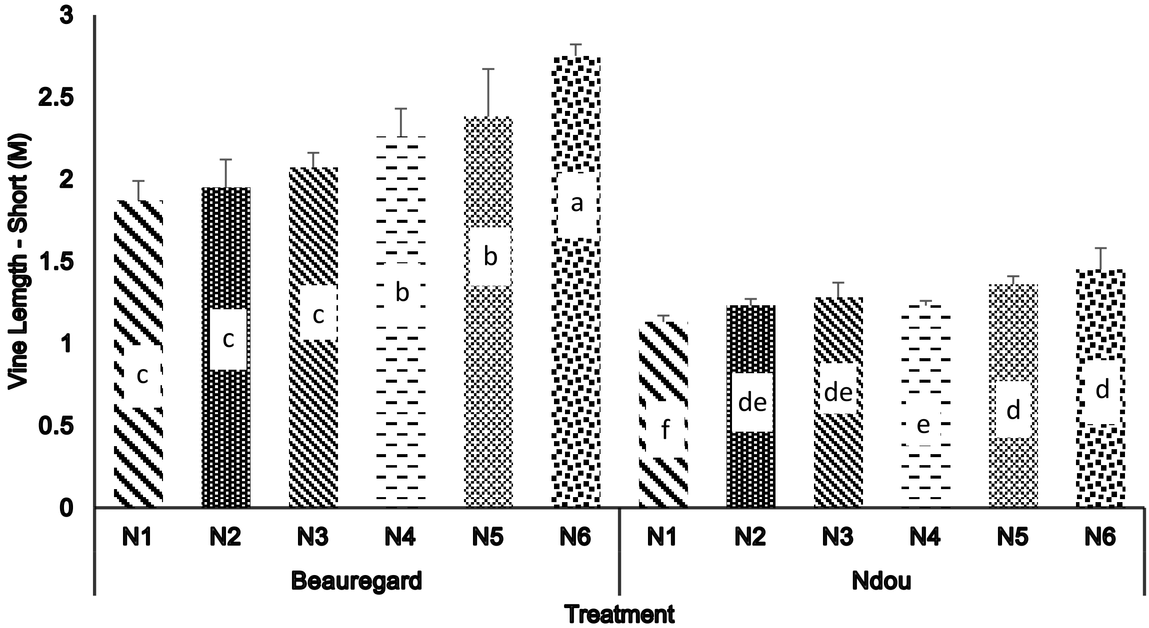

Figure 4.2 Effect of nitrogen level and cultivar interaction on short vine length (m) of sweet potato at 110 DAT

4.2.2 Number of Vines (shoot) per Plant

According to Table 4.3, at 110 DAT, sweet potato cultivar response to N fertilization was significantly ($p \leq 0.001$) affected with respect to the number of vines per plant. For example, Ndou exhibited more vines (7.94 (high) and 3.56 (low)) per plant compared to Beauregard (5.44 (high) and 2.89 (low)), (Table 4.3).

Similarly, the N fertilization level affected number of vines per plant of sweet potato. Regardless of the variety, plants treated with 23 kgN/ha had more vines (7.33 (high) and 3.50 (low)) per plant compared to control, which had 7.00 (high) and 3.17 (low) vines per plant at 110 DAT. In general, there was an increase and a decrease in vines with the application of 23 and 33 kgN/ha, and a steady increased with the supply of 43 and 54 kgN/ha (Table 4.3).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and N fertilization level, for example, Ndou fertilized with the highest N (53 kgN/ha) (B2N6) had more vines (8.67 (high)) compared to Beauregard fertilized with highest N (53 kgN/ha) (B1N6), which had 5.33 (high) vines (Fig. 4.3). Similarly, the low number of vines per plant was significantly affected by cultivar and N level interaction. Ndou fertilized with 23 kgN/ha (B2N3) had 4.33 vines (low) compared to Beauregard fertilized with the same amount of N (23 kg/ha) (B1N3), which had 2.67 vines (low) (Fig. 4.4).

Table 4.3 Effect of nitrogen fertilization level on number of vines of sweet potato at 110 DAT. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$.

Treatment	**Number of vines (per plant)**	
	High	**Low**
Cultivar		
Beauregard (B1)	5.44±0.22b	2.89±0.58b
Ndou (B2)	7.94±0.34a	3.56±0.26a
N level (kgN/ha)		
N1	7.00±1.00b	3.17±0.31b
N2	6.50±0.76c	3.17±0.40b
N3	7.33±0.67a	3.50±0.72a
N4	5.83±0.60d	3.00±0.26b
N5	6.50±0.43c	3.33±0.31b
N6	7.00±0.82b	3.17±0.75b
F-Statistics		
Cultivar(C)	39.71***	4.50***
N level	1.20*	0.20*

C x N interaction	0.98*	0.90*

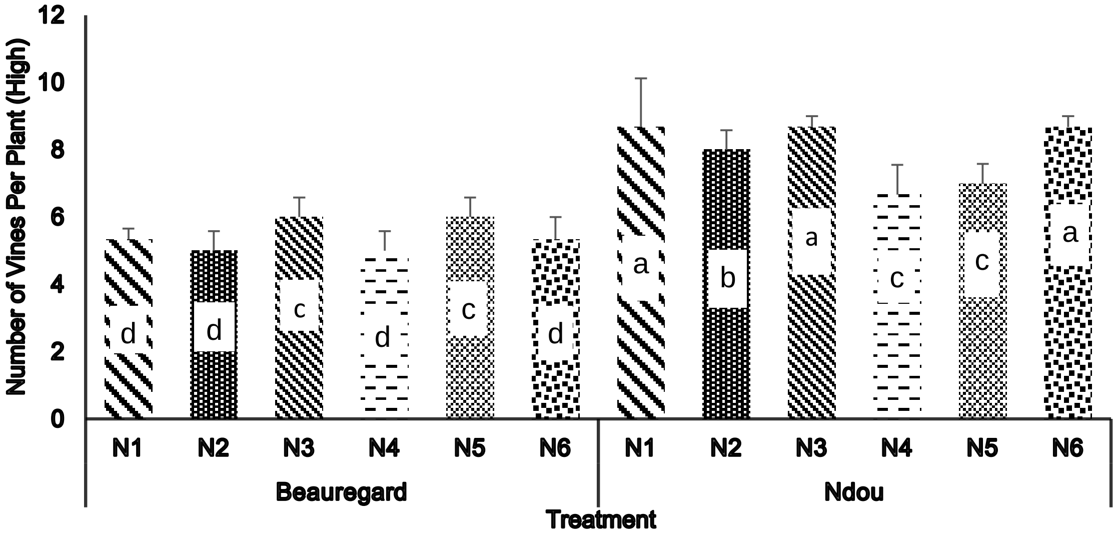

Figure 4.3 Effect of nitrogen level and cultivar interaction on number (high) of vines per plant of sweet potato at 110 DAT

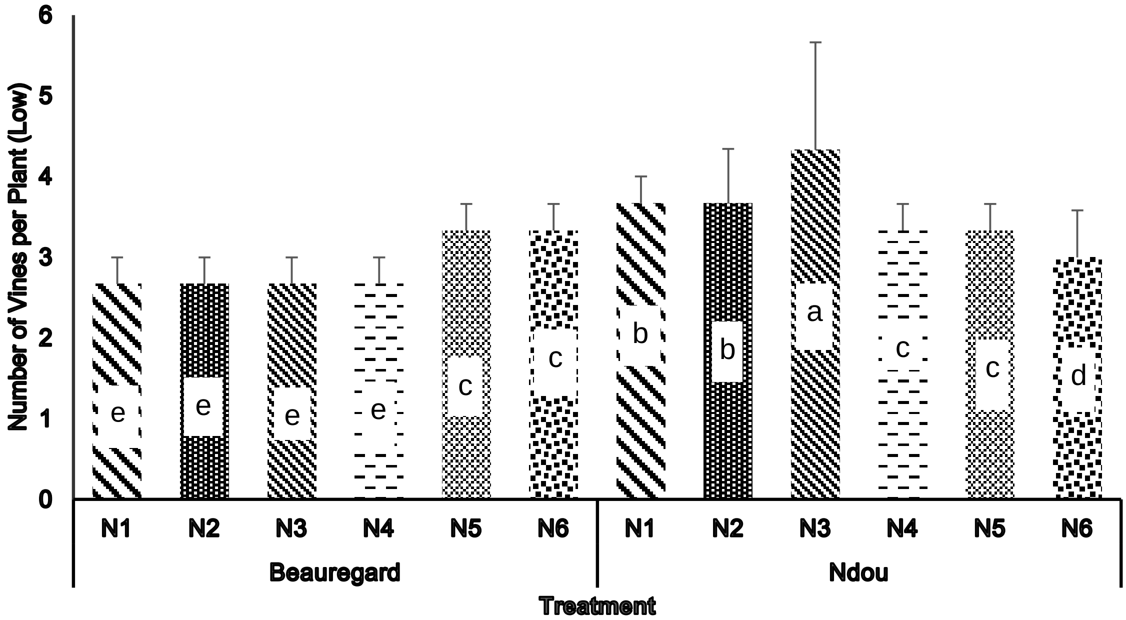

Figure 4.4 Effect of nitrogen level and cultivar interaction on number (low) of vines per plant of sweet potato at 110 DAT

4.2.3 Shoot biomass

For biomass determination, plants were harvested at 115 DAT. According to Table 4.4, cultivar response to N fertilization was not significant in terms of sweet potato shoot biomass, however, at 115 DAT, the shoot weight, fresh (398.13 g) and dry (75.18 g) of Ndou were slightly higher compared to Beauregard (355.28 g and 61.74

g, respectively). Interestingly, shoot moisture percentage was significantly affected. For example, shoot of Ndou had a moisture content of 81.35% compared to Beauregard with 82.59% (moisture) per plant (Table 4.4).

Nitrogen fertilization level had a significant effect on the fresh and dry shoot weight of sweet potato plants. Plants treated with highest N (53 kgN/ha) (N6) showed greater fresh and dry shoot weights of 422.84 g and 75.70 g compared to control (N1), which had 337.45 g and 64.26 g, respectively, per plant. In general, the application of 13 kgN/ha increased vines, followed by a decrease with the supply of 23, 33, and 43, but an increase was noted with the application of 53 kgN/ha (Table 4.4). Overall, there was a steady increase in the moisture as N level increased from 0 to 53 kgN/ha (Table 4.4). Regardless of the variety, plants with higher N fertilization had more shoot biomass and moisture. For example, the shoot of plants fertilized with 13 kgN/ha (N2) had a moisture percentage of 82.56 compared to control (N1) with 81.25% moisture in shoot (Table 4.4).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and N fertilization level for sweet potato shoot biomass. For example, Ndou fertilized with the highest N (53 kgN/ha) (B2N6) had a higher fresh shoot weight of 519.89 g compared to control (Ndou fertilized with 0 kgN/ha) (B2N1), which had a fresh shoot weight of 332.46 g per plant (Fig. 4.5). As was expected, Ndou fertilized with the highest N (B2N6) had a higher dry shoot weight of 95.15 g compared to control (Ndou fertilized with 0 kgN/ha) (B2N1), which had a dry shoot weight of 65.79 g per plant (Fig. 4.6). Notably, the fresh and dry shoot weights of Ndou (519.89 g and 91.15 g, respectively) fertilized with the highest N (B2N6) was higher than that of Beauregard fertilized with the same N level (B1N6), which had 325.79 g (fresh) and 56.24 g (dry) (Figs. 4.5 and 4.6, respectively) shoot weights per plant.

Table 4.4 Effect of nitrogen fertilization level on fresh and dry shoot weights of sweet potato cultivars at 115 DAT. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p≤0.05, ** p≤0.01, *** p≤0.001.

Treatment	Shoot biomass per plant		
	Fresh weight (g)	**Dry weight (g)**	**Moisture (%)**
Cultivar			
Beauregard (B1)	355.28±26.11a	61.74±4.26a	82.59±0.31a
Ndou (B2)	398.13±29.49a	75.18±6.45a	81.35±0.40b
N level (kgN/ha)			
N1	337.45±29.78c	64.26±8.57bc	81.25±0.95b
N2	424.99±80.23a	74.51±14.03a	82.56±0.67a
N3	353.75±30.68bc	64.13±5.64bc	81.84±0.44ab
N4	378.80±52.06b	71.65±12.08ab	81.38±0.58b
N5	342.41±19.44c	60.50±5.73c	82.47±0.65a
N6	422.84±59.00a	75.70±11.96a	82.32±0.68ab
F-Statistics			
Cultivar	ns	ns	4.99*
N level	0.61*	0.39*	0.71*
C x N interaction	0.84*	0.75*	0.27*

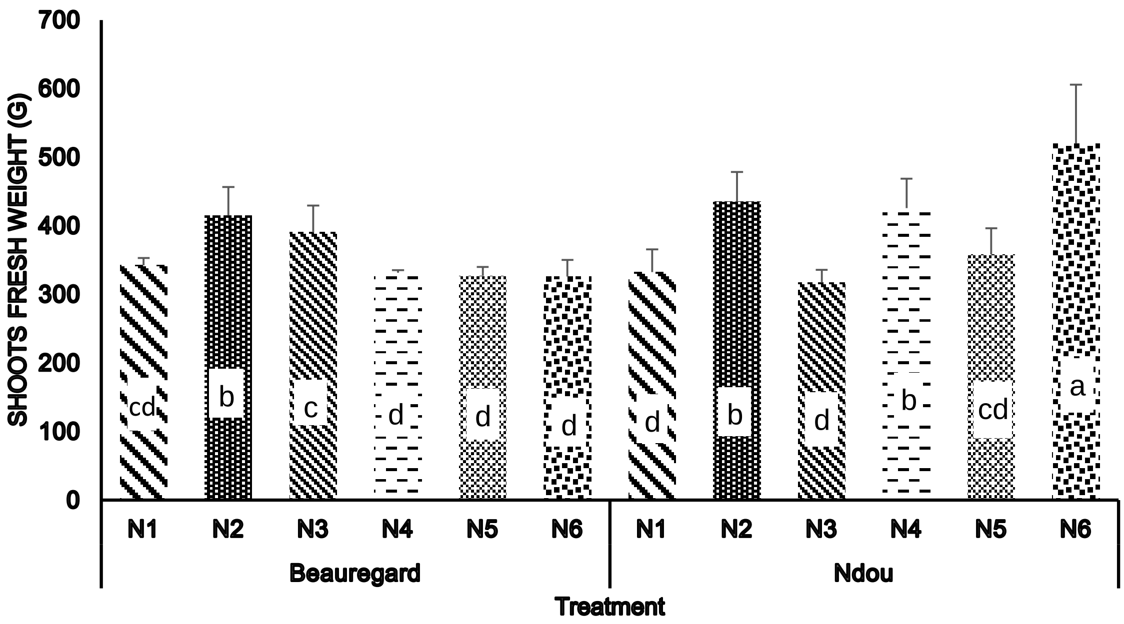

Figure 4.5 Effect of nitrogen level and cultivar interaction on mean fresh shoot weight (g) of sweet potato at 115 DAT

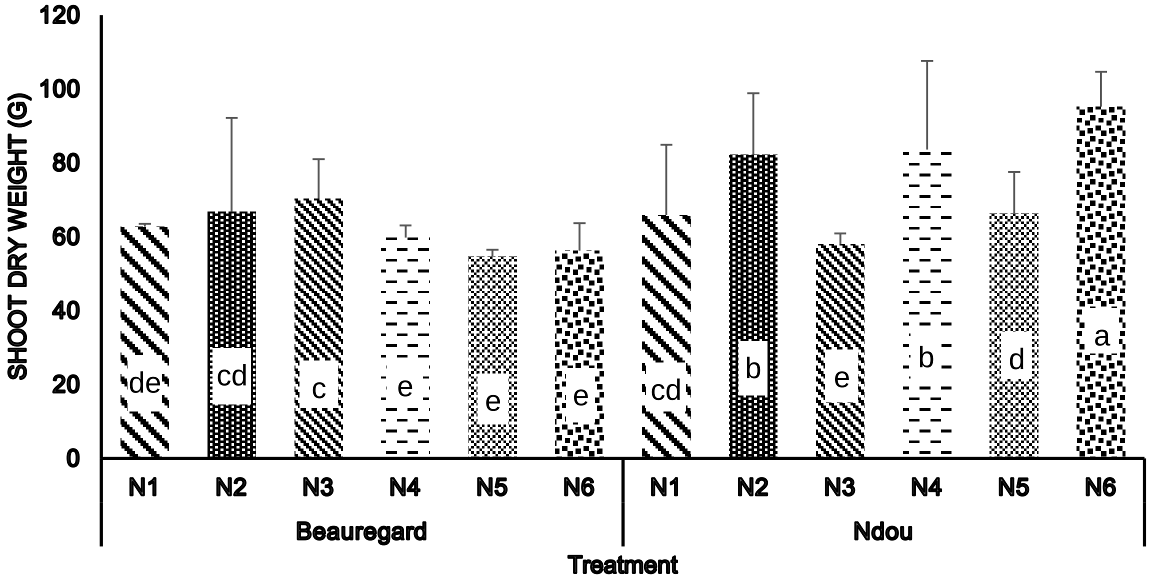

Figure 4.6 Effect of nitrogen level and cultivar interaction on shoot dry shoot weight (g) of sweet potato at 115 DAT

Similarly, the moisture percentage in shoot of sweet potato was significantly affected by the interaction of cultivar and N level. For example, the moisture (83.76%) in shoot of Beauregard fertilized with 13 kgN/ha (B1N2) was higher than that of Ndou (81.36%) fertilized with the same N level (B2N2) (Fig. 4.7).

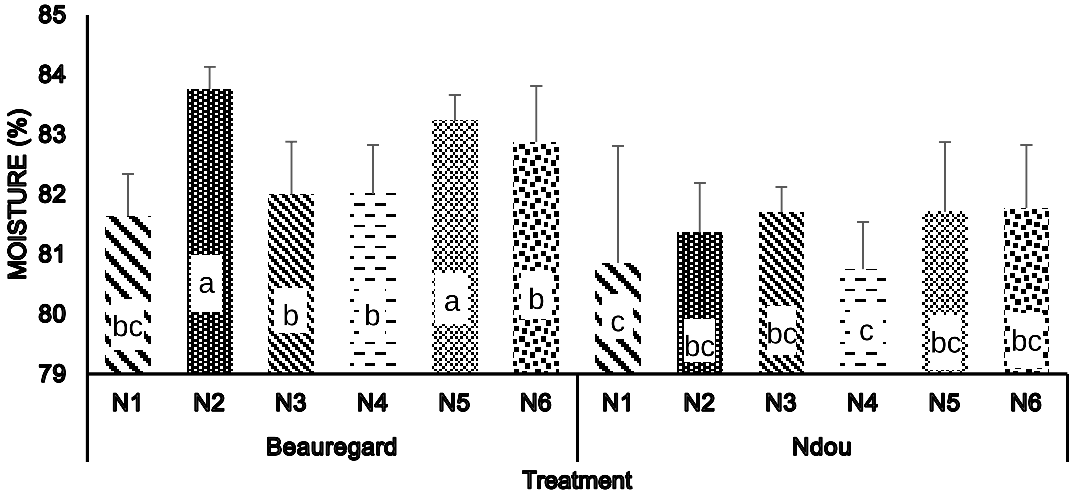

Figure 4.7 Effect of nitrogen level and cultivar interaction on mean shoot moisture percentage (%) of sweet potato at 115 DAT

4.3 YIELD RESPONSE TO DIFFERENT NITROGEN FERTILIZER LEVELS

4.3.1 Number of Tuberous Roots per Plant

Sweet potato cultivar response to N fertilization in terms of yield (number of tuberous roots) per plant at 115 DAT was significantly ($p<0.05$) affected. For example, Beauregard (B1) had more tuberous roots (11.38 (high) and 4.67 (low)) compared to the tuberous roots per plant of Ndou (B2) with 5.94 (high) and 2.33 (low) respectively (Table 4.5).

In this field experiment, N fertilization level had a significant effect on number of tuberous root per plant of sweet potato. Regardless of the variety,, plants treated with highest N (53 kg/ha) (N6) showed more tuberous roots (10.37 (high) and 4.50 (low) compared to control (0 kgN/ha), which had 10.00 (high) and 3.30 (low) number of tuberous roots, respectively. In general, there was a steady increase in number of tuberous roots (high and low) per plant as N fertilization level was increased from 0 kg/ha through to 53 kg N/ha (Table 4.5).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and N fertilization level, for example, Beauregard fertilized with 53 kgN/ha (B1N6) had more tuberous roots of 12.00 (high) compared to the same cultivar not fertilized (B1N1), which had 11.33 tuberous roots (high) per plant (Fig. 4.8). In contrast however, regardless of N fertilization level, the number of tuberous roots (high) in Ndou was not significantly affected (Fig. 4.8).

Table 4.5 Effect of nitrogen fertilization on yield (number of tuberous roots) of sweet potato cultivars (115 DAT). Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p≤0.05, ** p≤0.01, *** p≤0.001.

Treatment	Number of Tuberous Roots per Plant	
	High	Low
Cultivar		
Beauregard (B1)	11.38±0.41a	4.67±0.25a
Ndou (B2)	5.94±0.46b	2.33±0.32b
N level (kgN/ha)		
N1	10.00±1.01c	3.30±0.58c
N2	10.17±1.25b	3.38±0.60c
N3	10.19±0.72b	4.00±0.62b
N4	10.22±0.65b	4.50±0.58a
N5	10.33±0.71a	4.53±0.72a
N6	10.37±1.22a	4.50±0.24a
F-Statistics		
Cultivar(C)	11.13***	9.00***
N level	0.03*	0.83*
C x N interaction	0.35*	0.68*

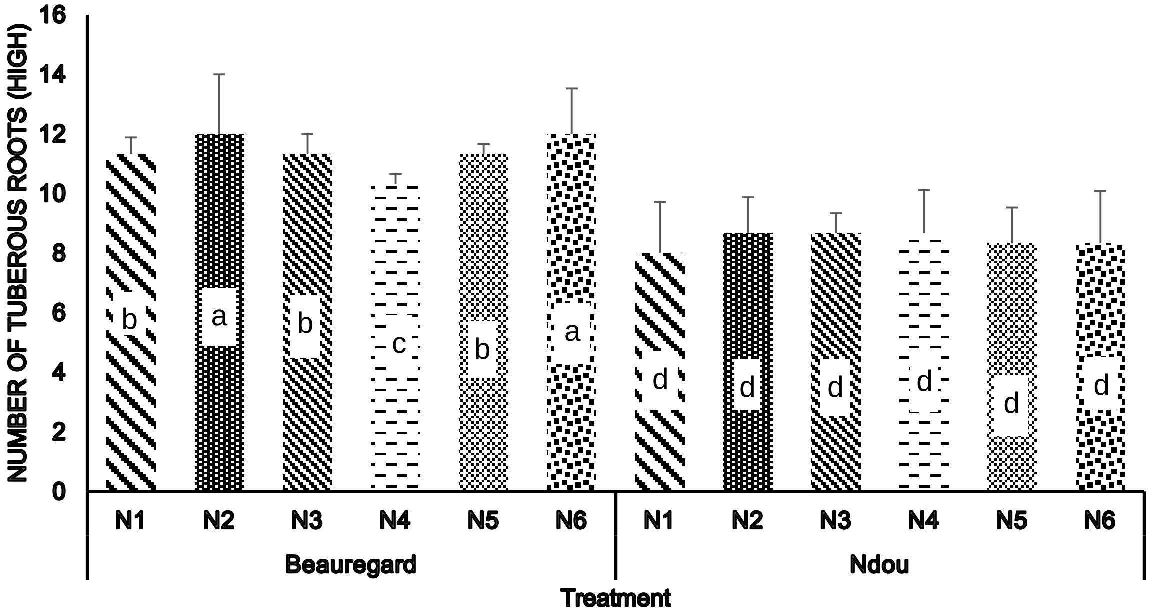

Figure 4.8 Effect of nitrogen level and cultivar interaction on mean number (high) of tuberous roots of sweet potato at 115 DAT

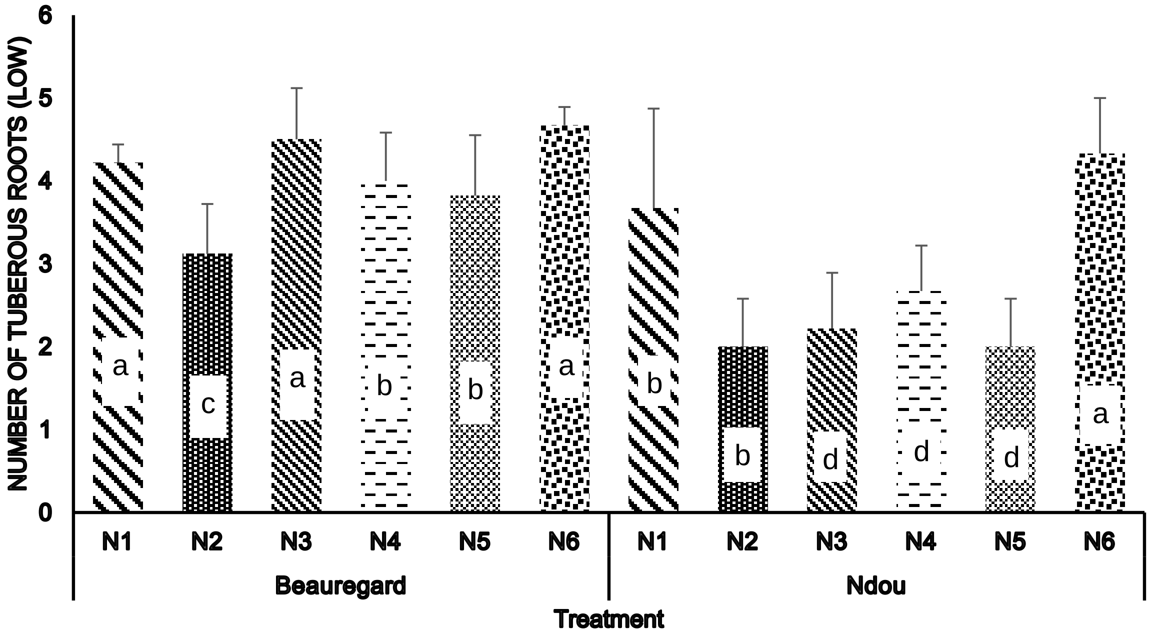

Figure 4.9 Effect of nitrogen level and cultivar interaction on mean number (low) of tuberous roots of sweet potato at 115 DAT

With regards the low number of tuberous roots, both cultivars responses to N fertilization were significantly different. Beauregard fertilized with the highest N (B1N6) had more low number of tuberous roots per plant (4.46) compared to those fertilized with 13 kgN/ha (B1N2), which had 3.12 tuberous roots (Fig. 4.9). Similarly, Ndou fertilized with the highest N (B2N6) had more low number of tuberous roots (4.33) compared to those fertilized with 13 kgN/ha (B2N2), which had 2.00 tuberous roots per plant (Fig. 4.9).

4.3.2 Tuberous Root Weight

Sweet potato cultivar response to N fertilization was not significant for tuberous root weight per plant at 115 DAT; however, Beauregard had a slightly high tuberous root weight (1.79 kg (large) and 0.53 kg (small) per plant compared to Ndou with 1.21 kg (large) and 0.52 kg (small) per plant, respectively (Table 4.6).

In contrast, N fertilization level has no significant effect on large tuberous root weight per plant. However, N fertilization level had a significant effect on the small weights of tuberous roots per plant of sweet potato. For example, regardless of the variety, plants treated with the highest N (N6) showed tuberous root weight of 0.66 kg (small) compared to control (N1), which had 0.42 kg (small) per plant. In general, there was a steady increase in tuberous root weight (small) per plant as N fertilization level was increased from 13 kg N/ha through to 53 kg N/ha (Table 4.6).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and N fertilization level. For example, Beauregard fertilized with 23 kgN/ha (B1N3) had the largest weight of 1.92 kg for large tubers compared to control (B1N1) (1.58 kg) per plant and similarly, the tuberous roots of Ndou fertilized with 23 kgN/ha (B2N3) (1.45 kg) was heavier compared to those fertilized with 13 kgN/ha (1.25 kg) (Fig. 4.10). Small seized tuberous root weight was similarly affected by the interaction between cultivar and N fertilization level. The small tuberous roots weights of both Beauregard and Ndou fertilized with the highest N (B1N6 & B2N6) were heavier compared to their respective controls (B1N1 & B2N1) (Fig. 4.11).

Table 4.6 Effect of nitrogen fertilization on yield (tuberous root weight) of sweet potato cultivars at 115 DAT. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Treatment	**Tuberous roots weight per plant (kg)**	
	Large	**Small**
Cultivar		
Beauregard (B1)	1.79±0.10a	0.53±0.06a
Ndou (B2)	1.21±0.10a	0.52±0.04a
N level (kgN/ha)		
N1	1.53±0.11a	0.42±0.05b
N2	1.47±0.15a	0.62±0.10a
N3	1.52±0.24a	0.62±0.12a
N4	1.58±0.15a	0.51±0.07b
N5	1.59±0.24a	0.47±0.07b
N6	1.71±0.12a	0.66±0.12a
F-Statistics		
Cultivar(C)	ns	ns
N level	ns	1.44*
C x N interaction	0.64*	1.42*

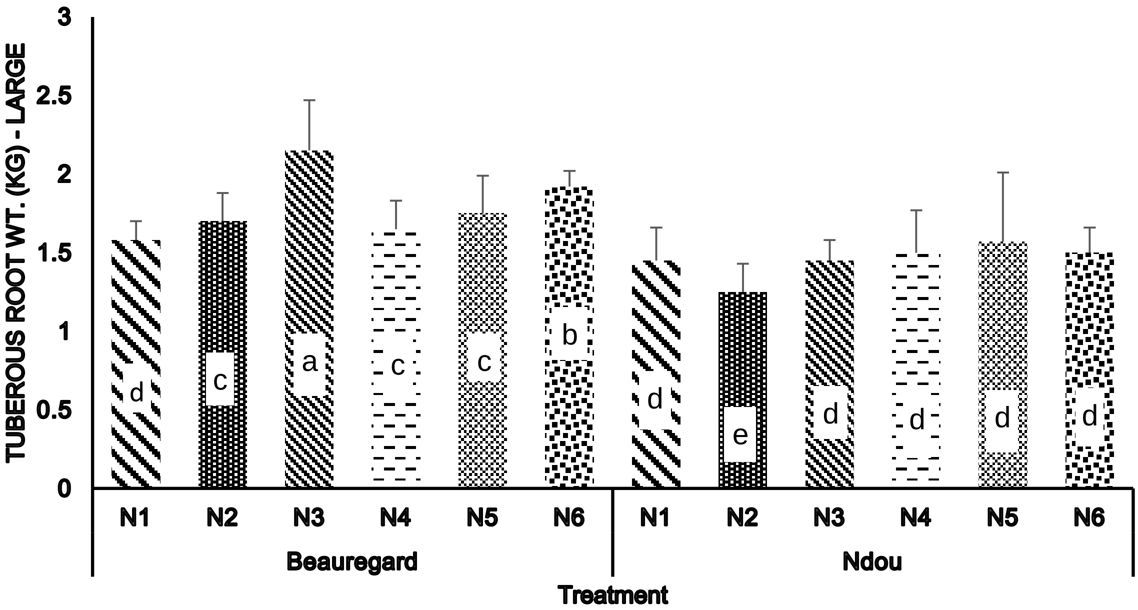

Figure 4.10 Effect of nitrogen level and cultivar interaction on mean tuberous root weight (kg) (large) of sweet potato at 115 DAT

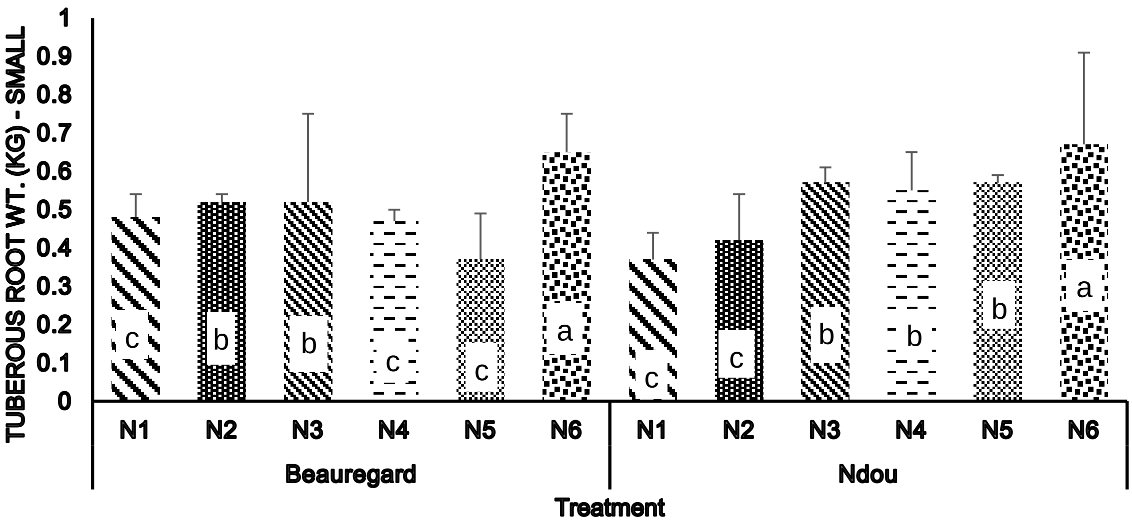

Figure 4.11 Effect of nitrogen level and cultivar interaction on mean tuberous root weight (g) (small) of sweet potato at 115 DAT

4.3.3 Tuberous Root Length (cm)

Sweet potato cultivar response to N fertilization was significant for tuberous root length per plant at 115 DAT. For example, Beauregard (B1) had longer (long (21.76 cm) and short 11.41 cm) tuberous root length compared to Ndou (B2) with 18.23 cm (long) and 10.80 cm (short) root tubers respectively (Table 4.7).

Similarly, N fertilization level had a significant effect on the long tuberous root length but not on the short tuberous root length. Regardless of the variety, plants treated with 23 kgN/ha (N3) showed the longer tuberous length (20.47 cm) compared to control (N1), which had 17.75 cm (Table 4.7). In general, there was increase in tuberous root length (long & short) as the N level was increased from 0 kg/ha through to 53 kg N/ha (Table 4.7).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and nitrogen fertilization level. For example, Beauregard fertilized with highest N (B1N6) had the longest tuberous root of 23.28 cm (long) compared to Beauregard not fertilized (B1N1) which had a long tuberous root length of 19.89 cm (Fig. 4.12). Similarly, Ndou fertilized with highest N (B2N6) had a longer tuberous root of 18.11 cm (long) compared to Ndou not fertilized (B1N1), which had a shorter tuberous root length of 15.61 cm (Fig. 4.12). Short tuberous root length was similarly affected by the interaction between cultivar and N fertilization level. The short tuberous roots length of Beauregard not fertilized (12.45 cm) (B1N1) was longer compared with Beauregard fertilized with the highest N (B1N6), which had a short tuberous roots length of 10.61 cm (Fig. 4.13). The short tuberous roots length of Ndou fertilized with 33 kgN/ha (B2N3) was longer compared to control (B2N1) with a length of 9.27 cm (Fig. 4.13).

Table 4.7 Effect of nitrogen fertilization on root length of sweet potato cultivars at 115 DAT. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p≤0.05, ** p≤0.01, *** p≤0.001, ns = not significant.

Treatment	Tuberous root length (cm)	
	Long	Short
Cultivar		
Beauregard (B1)	21.76±0.52a	11.41±0.48a
Ndou (B2)	18.23±0.49b	10.80±0.47b
N level (kgN/ha)		
N1	17.75±1.10b	10.86±1.10a
N2	20.20±1.06a	10.37±1.20a
N3	20.47±0.53a	10.89±1.01a
N4	20.50±1.79a	11.89±1.02a
N5	20.69±0.92a	10.88±0.66a
N6	20.83±1.00a	10.95±0.30a
F-Statistics		
Cultivar(C)	28.73***	ns
N level	1.77*	ns
C x N interaction	1.64*	0.84*

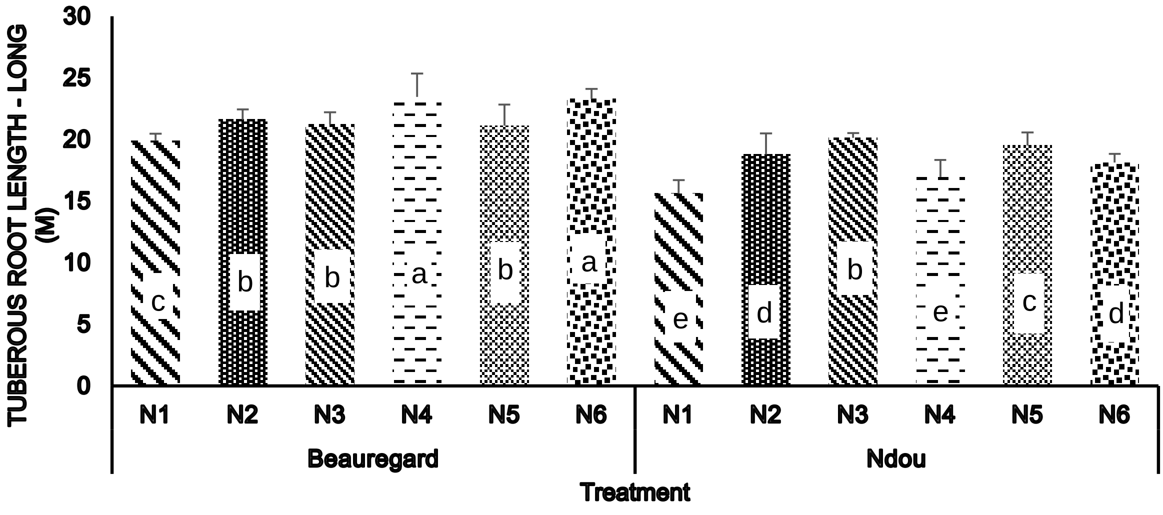

Figure 4.12 Effect of nitrogen level and cultivar interaction on mean tuberous root length (long) of sweet potato at 115 DAT

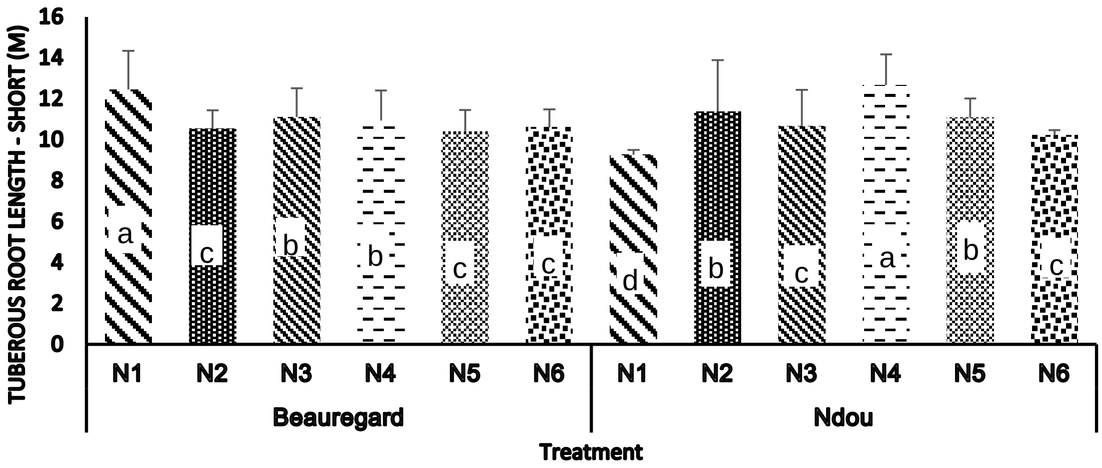

Figure 4.13 Effect of nitrogen level and cultivar interaction on mean tuberous root length (short) of sweet potato at 115 DAT

4.3.4 Tuberous Root Diameter

Sweet potato cultivar response to N fertilization was significant for tuberous root diameter per plant at 115 DAT. Ndou (B2) had bigger (large (20.52 cm) and small (10.82 cm) tuberous root diameter compared to Beauregard (B1) with 17.90 cm (large) and 8.67 cm (small) root tuber diameters respectively (Table 4.8).

Similarly, N fertilization level had a significant effect on the tuberous root diameter of sweet potato at 115 DAT. Regardless of the variety, plants treated with the highest N (N6) showed a bigger tuberous diameter (20.44 cm (large) compared to control (N1), which had 18.31 cm (Table 4.8). Similarly, the size of small tuberous root diameter was affected by N fertilization. For example, plants treated with 33 kgN/ha (N4) had a bigger tuberous root diameter (10.03 cm (small)) compared to control (N1) with a tuber diameter of 9.58 cm (Table 4.8). In general, there was increase in tuberous root diameter (large & small) as the N level was increased from 0 kg/ha through to 53 kg N/ha (Table 4.8).

A two-way analysis of variance (ANOVA) revealed a significant interaction between cultivar and nitrogen fertilization level. For example, Beauregard fertilized with highest N (B1N6) had a bigger tuberous root diameter of 18.5 cm (large) compared to Beauregard not fertilized (B1N1) which had a large tuberous root diameter of 17.05 cm (Fig. 4.14). Ndou fertilized with highest N (B2N6) had a bigger tuberous root diameter of 22.39 cm (large) compared to Ndou not fertilized (B2N1), which had a large tuberous root diameter of 19.55 cm (Fig. 4.14). Tuberous root diameter considered to be small was similarly affected by the interaction between cultivar and N fertilization level. For example, Beauregard fertilized with highest N (B1N6) had a bigger tuberous root diameter of 9.91 cm (small) compared to Beauregard not fertilized (B1N1), which had a small tuberous root diameter of 8.81 cm (Fig. 4.15). Ndou fertilized with 33 kgN/ha (B2N4) had a bigger tuberous root diameter (12.36 cm) compared to control (B2N1), which had a small tuberous root diameter of 10.36 cm (Fig. 4.15).

Table 4.8 Effect of nitrogen fertilization on the tuberous root diameter of two sweet potato cultivars (115 DAT). Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p≤0.05, ** p≤0.01, *** p≤0.001.

Treatment	**Tuberous root diameter (cm)**	
	Large	**Small**
Cultivar		
Beauregard (B1)	17.90±0.46b	8.67±0.24b
Ndou (B2)	20.52±0.50a	10.82±0.39a
N level (kgN/ha)		
N1	18.31±0.85d	9.58±0.57b
N2	18.90±0.71c	9.87±0.32a
N3	19.79±1.14b	9.85±0.71a
N4	19.76±1.32b	10.03±1.37a
N5	18.06±0.68d	9.55±0.70b
N6	20.44±1.04a	9.58±0.48b
F-Statistics		
Cultivar(C)	14.12***	20.40***
N level	1.21*	0.12*
C x N interaction	0.33*	1.49*

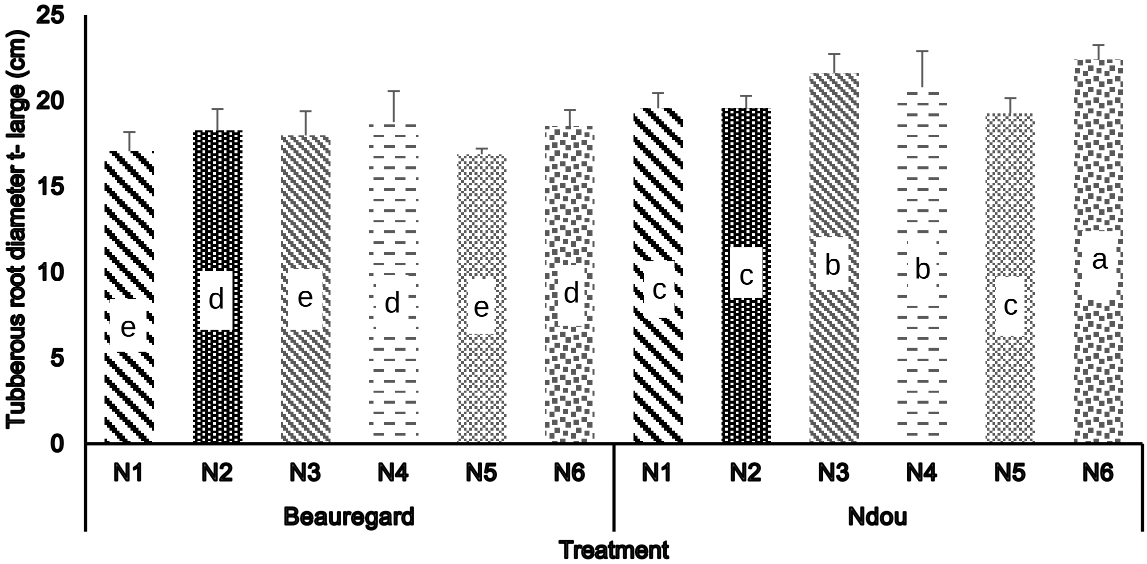

Figure 4.14 Effect of nitrogen level and cultivar interaction on mean tuberous root diameter (large) of sweet potato at 115 DAT

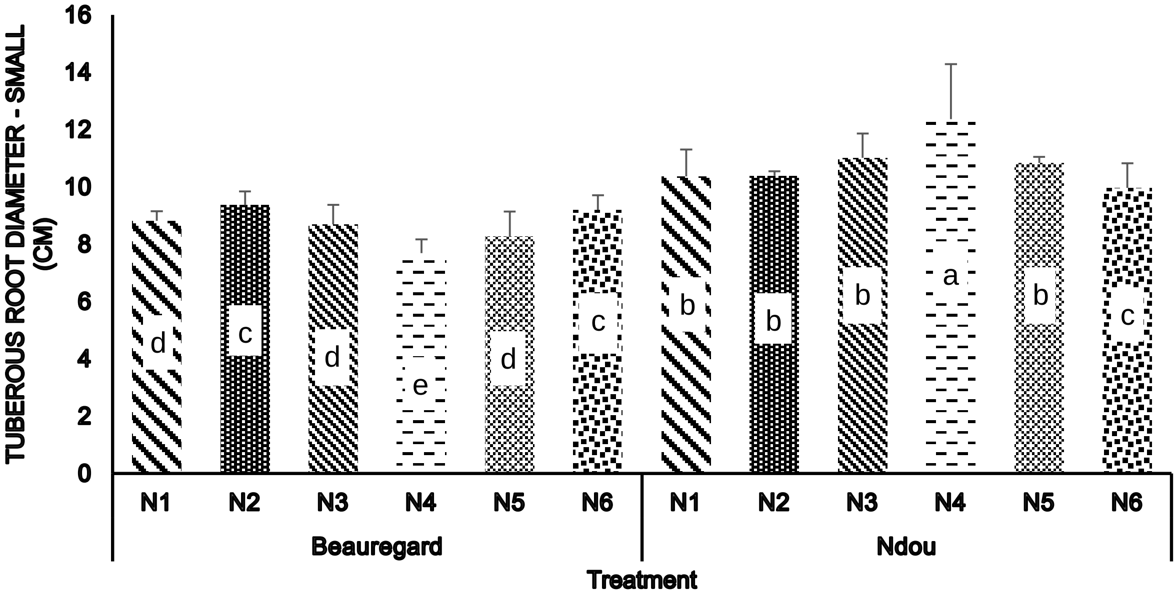

Figure 4.15 Effect of nitrogen level and cultivar interaction on mean tuberous root diameter (small) of sweet potato at 115 DAT

4.4 ELEMENTAL COMPOSITION IN SHOOT OF SWEET POTATO CULTIVARS

Nitrogen fertilization significantly affected the elemental composition (macro- and micro-nutrients) in shoot of sweet potato cultivars at 115 DAT. For example, the concentration of macronutrients such as C, Ca, Mg and K were significantly different when the two cultivars were compared. The shoot of Beauregard was found to have more C (43.91 mg/kg), Ca (0.69 mg/kg), and K (1.59 mg/kg) compared to Ndou with

44.25 mg/kg, 0.61 mg/kg, and 1.28 mg/kg, respectively and the shoot of Ndou had higher Mg concentration. However, the concentrations of N, Na and P were not different between the two sweet potato cultivar (Table 4.9).

Nitrogen fertilization level significantly affected the concentrations of Ca and Na in the shoot of sweet potato at 115 DAT. Regardless of the variety, shoot of plants fertilized with 13 kgN/ha (N2) had higher concentration of Ca (0.77 mg/kg) and Na (222.50 mg/kg) compared to control with 0.61 mg/kg and 182. 86 mg/kg respectively. However, N fertilization did not significantly affect concentrations of C, N, Mg, K, and P in shoot of sweet potato under field conditions (Table 4.9).

A two-way analysis revealed a significant interaction effect of cultivar and nitrogen fertilization level on the concentrations of Ca and Na in shoot of sweet potato. For example, the concentration of Ca (0.91 mg/kg) was significantly higher in shoot of Beauregard fertilized with 13 kgN/ha (B1N2) compared to Ndou not fertilized (B2N1) (0.60 mg/kg) (Fig. 4.16).

Similarly, the concentration of Na (224.43 mg/kg) was significantly high in shoot of Beauregard fertilized with 13 kgN/ha (B1N2) compared to Ndou not fertilized (B2N1) (128.89 mg/kg) (Fig. 4.17).

Table 4. 9 Effect of nitrogen fertilization on macronutrients in sweet potato shoot. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * $p \leq 0.05$ ** $p \leq 0.01$, *** $p \leq 0.001$.

Treatment	Macronutrient in shoots (mg/kg)						
	C	N	Ca	Mg	K	Na	P
<u>Cultivars</u>							
Beauregard (B1)	43.91±0.11a	1.02±0.07a	0.69±0.03a	0.40±0.01b	1.59±0.06a	192.96±20.05a	0.22±0.01a
Ndou (B2)	44.25±0.06b	0.98±0.06a	0.61±0.01b	0.52±0.01a	1.28±0.05b	173.57±13.85a	0.23±0.01a
<u>N level (Kg N/ha)</u>							
N1	44.03±0.09a	0.88±0.04a	0.61±0.01c	0.45±0.03a	1.29±0.11a	182.86±25.92b	0.23±0.01a
N2	43.89±0.28a	1.13±0.20a	0.77±0.10a	0.48±0.02a	1.56±0.19a	222. 50±49.60a	0.25±0.03a
N3	43.98±0.11a	0.97±0.03a	0.62±0.03c	0.43±0.03a	1.41±0.08a	184.19±11.53b	0.22±0.01a
N4	44.08±0.19a	0.93±0.03a	0.62±0.02c	0.46±0.02a	1.46±0.14a	188.67±20.75b	0.22±0.01a
N5	44.22±0.15a	1.17±0.12a	0.63±0.03c	0.43±0.02a	1.56±0.06a	174.41±38.88bc	0.22±0.01a
N6	44.28±0.08a	0.93±0.06a	0.65±0.02b	0.45±0.03a	1.33±0.07a	146.98±19.29c	0.21±0.02a
<u>F-statistics</u>							
Cultivar	7.5*	ns	6.98*	108.47***	17.90***	ns	ns
N level	ns	ns	3.23*	ns	ns	0.83*	ns
C x N Interaction	ns	ns	2.67*	ns	ns	2.89*	ns

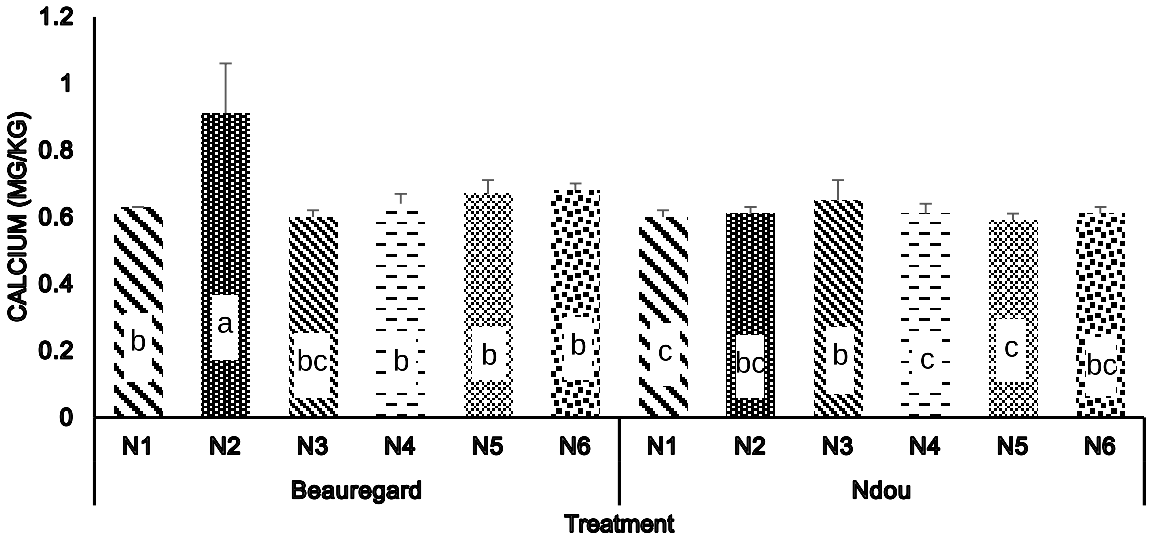

Figure 4.16 Effect of nitrogen level and cultivar interaction on mean concentration of calcium (mg/mg) in shoot of sweet potato at 115 DAT

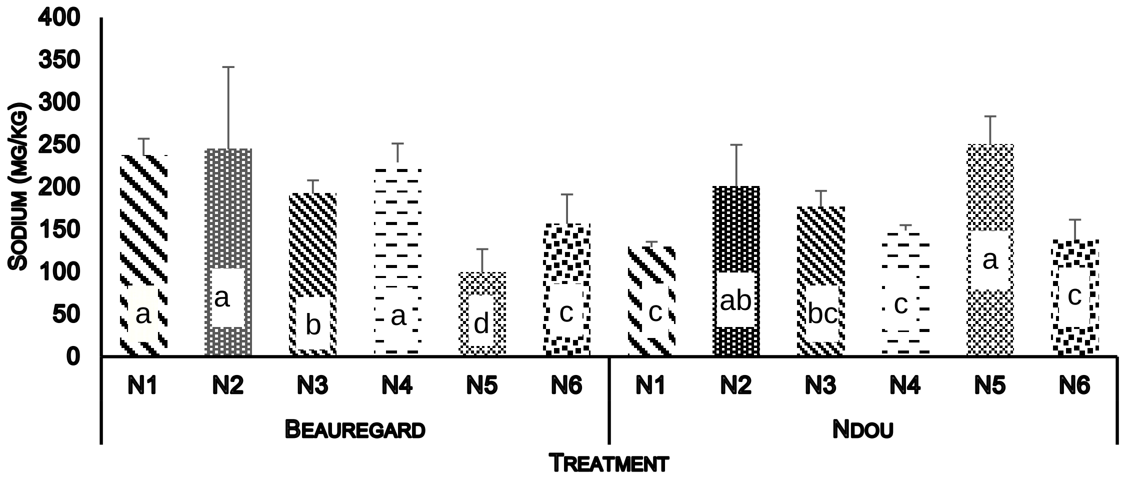

Figure 4.17 Effect of nitrogen level and cultivar interaction on mean concentration of sodium (mg/kg) in shoot of sweet potato at 115 DAT

Similarly, sweet potato cultivar response to N fertilization was significant with regards to micronutrient concentrations in plant shoot at 115 DAT. For example, shoot concentrations of Cu, Fe and Al were significantly different when the two cultivars were compared. The concentrations of Cu (10.09 mg/kg), Fe (333.43 mg/kg) and Al (107.43 mg/kg) in shoot of Beauregard were higher compared to the Cu (8.89 mg/kg), Fe (105.90 mg/kg) and Al (47.69 mg/kg) in shoots of Ndou respectively.

However, shoot concentrations of Zn and Mn were not significantly different between the two cultivars (Table 4.10).

Nitrogen fertilization level significantly affected concentrations of micronutrients such as Cu, Fe and Al in sweet potato shoot; however, the concentrations of Zn and Mn were not affected. Regardless of the variety,, the concentrations of Cu (10.6 mg/kg), Fe (652.1 mg/kg) and Al (152.5 mg/kg) in shoot of plants fertilized with 13 kgN/kg (N2) were significantly higher compared to their respective controls (Table 4.10).

Table 4.10 Effect of nitrogen fertilization on micronutrients in sweet potato shoot. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p≤0.05, ** p≤0.01, *** p≤0.001.

Treatment	**Micronutrients in shoots (mg/kg)**				
	Zn	**Cu**	**Mn**	**Fe**	**Al**
Cultivars					
Beauregard (B1)	16.85±0.91a	10.09±0.28a	42.65±3.75a	333.43±61.82a	107.43±24.85a
Ndou (B2)	15.70±0.80a	8.89±0.17b	43.75±5.01a	105.90±23.46b	47.69±4.10b
N level (KgN/ha)					
N1	15.79±1.43a	9.58±0.23b	36.65±3.32a	87.90±5.61f	52.81±6.37f
N2	17.97±2.23a	10.60±0.83a	47.39±11.07a	652.03±83.27a	152.52±73.10a
N3	16.42±1.42a	9.83±0.38b	38.88±1.88a	155.33±47.75c	82.78±22.59b
N4	15.60±0.53a	9.39±0.13b	34.36±1.81a	166.23±17.44b	56.12±9.24e
N5	17.50±1.71a	9.21±0.30b	49.36±12.93a	105.90±14.15e	59.17±6.03d
N6	14.38±1.20a	8.77±0.40c	43.54±2.39a	153.52±45.33d	61.98±7.97c
F-statistics					
Cultivar	ns	18.46***	ns	2.17*	6.10*
N level	ns	3.22*	ns	1.27*	1.67*
C & N Interactions	2.91*	1.54*	ns	1.48*	0.91*

A two-way analysis revealed a significant interaction between cultivar and nitrogen fertilization level on concentrations of micronutrients in shoot of sweet potato. For example, Zn concentration (20.73 mg/kg) was significantly high in shoot of Ndou fertilized with 43 kgN/ha (B2N5) compared to Beauregard fertilized with the same amount of N (B1N5) (14.27 mg/kg) (Fig. 4.18). Copper concentration (11.96 mg/kg) was significantly high in shoot of Beauregard fertilized with 13 kgN/ha (B1N2) compared to Ndou fertilized with same N level (B2N2) (9.24 mg/kg) (Fig. 4.19). Similarly, concentrations of Fe (1228.51 mg/kg) and Al (236.77 mg/kg) were significantly higher in shoot of Beauregard fertilized with 13 kgN/ha (B1N2) compared to Ndou fertilized with same N level (B2N2) (75.56 mg/kg (Fe) and 60.26 mg/kg (Al)) (Figs. 4.20 and 4.21, respectively).

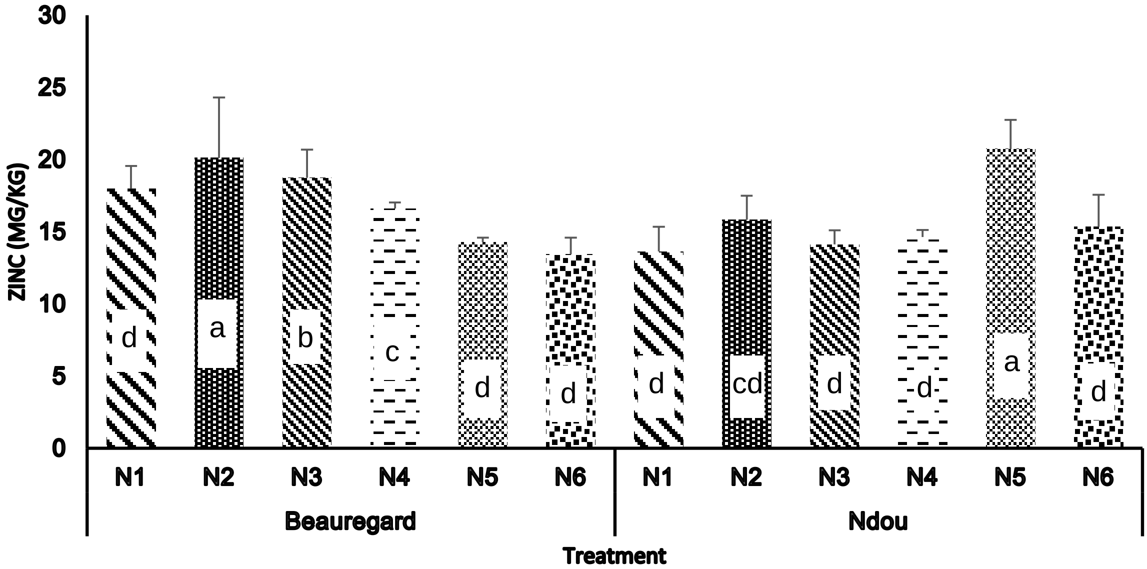

Figure 4.18 Effect of nitrogen level and cultivar interaction on mean concentration of zinc (mg/kg) in shoot of sweet potato at 115 DAT

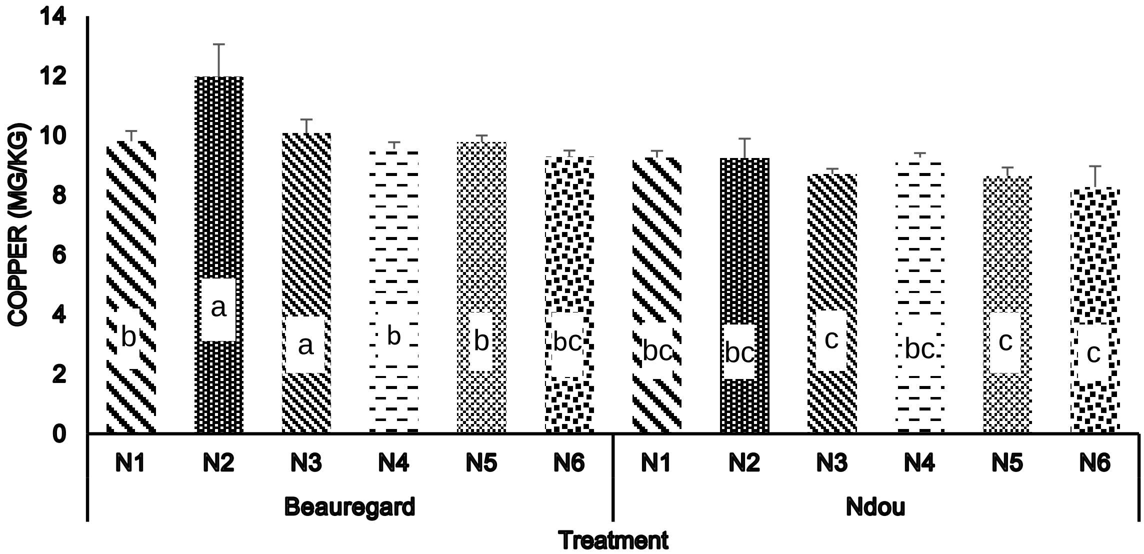

Figure 4.19 Effect of nitrogen level and cultivar interaction on mean concentration of copper (mg/kg) in shoot of sweet potato at 115 DAT

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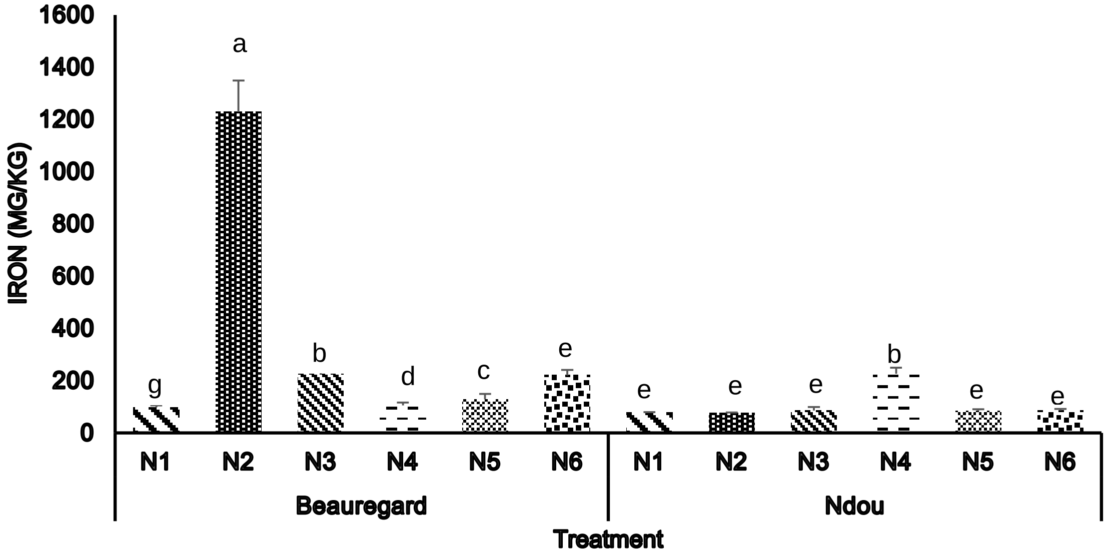

Figure 4.20 Effect of nitrogen level and cultivar interaction on mean concentration of iron (mg/kg) in shoot of sweet potato at 115 DAT

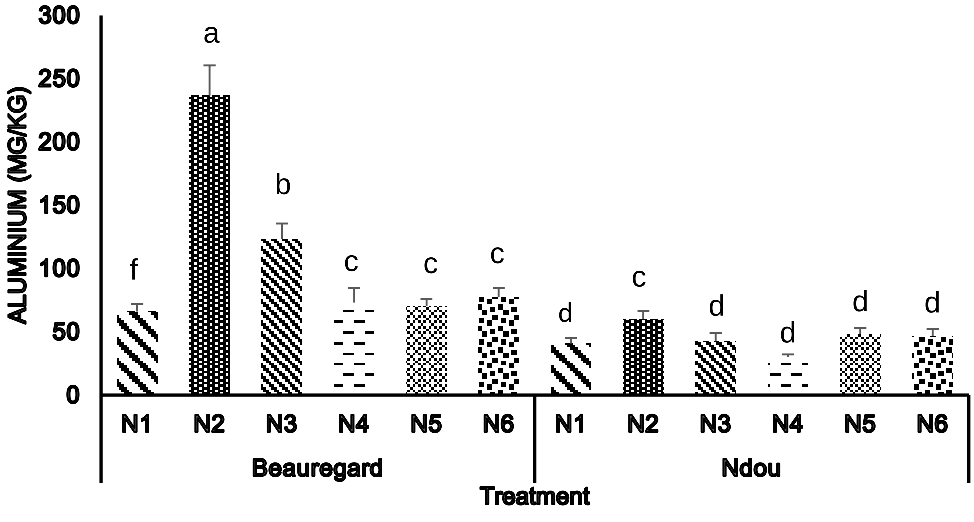

Figure 4.21 Effect of nitrogen level and cultivar interaction on mean concentration of aluminium (mg/kg) in shoot of sweet potato at 115 DAT

4.5 ELEMENTAL COMPOSITION IN TUBEROUS ROOT OF SWEET POTATO CULTIVARS

Similar to the elemental composition of shoot, N fertilization significantly affected the elemental composition (macro- and micro-nutrients) in tuberous root of sweet potato cultivars at 115 DAT. The concentrations of C, N, Ca, Mg, K, and Na were significantly different when sweet potato cultivars were compared. For example, concentrations of C (43.43 mg/kg), N (0.49 mg.kg), Ca (0,1 mg/kg), K (1,3 mg/kg) and Na (1142.65 mg/kg) in tuberous root of Beauregard were higher compared to those in tubers of Ndou (42.99 mg/kg. 0.42 mg/kg, 0.08 mg/kg, 1.12 mg//kg, 993.29 mg/kg, and 0.11 mg/kg, respectively) (Table 4.11). In contrast, the concentration of Mg (0.07 mg/kg) was higher in the tuberous root of Ndou compared to Beauregard (0.06 mg/kg) (Table 4.11).

Nitrogen fertilization level significantly affected the concentrations of macronutrients (N, Ca, Mg, & Na) in the tuberous root of sweet potato at 115 DAT. Regardless of the variety, tuberous root of plants fertilized with 43 kgN/ha (N5) had higher concentration of N (055 mg/kg) and Mg (0.08 mg/kg) compared to their controls with 0.38 mg/kg and 0.06 mg/kg respectively. However, N fertilization did not significantly affect concentrations of C, K, and P in tuberous root of sweet potato under field conditions (Table 4.11).

A two-way analysis revealed a significant interaction effect of cultivar and nitrogen fertilization level on the concentrations of N and Na in tuberous root of sweet potato. For example, the concentration of N (0.6 mg/kg) was significantly higher in tuberous root of Ndou fertilized with 43 kgN/ha (B2N5) compared to Beauregard fertilized with same amount of N (B1N5) (0.5 mg/kg) (Fig. 4.22).

Similarly, the concentration of Na (1379.38 mg/kg) was significantly high in tuberous root of Beauregard fertilized with 33 kgN/ha (B1N4) compared to Ndou fertilized with amount of N (B2N4) (1259.64 mg/kg) (Fig. 4.23).

Table 4.11 Effect of nitrogen fertilizer level on macronutrients in tuberous roots of two sweet potato cultivars. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001.

Treatment	**Macro nutrient in tuberous roots (mg/kg)**						
	C	N	Ca	Mg	K	Na	P
Cultivar							
Beauregard (B1)	43.43±0.08a	0.49±0.02a	0.10±0.00a	0.06±0.000b	1.30±0.02a	1142.65±49.00a	0.12±0.00a
Ndou (B2)	42.99±0.06b	0.42±0.03b	0.08±0.00b	0.07±0.00a	1.12±0.03b	993.29±52.19b	0.11±0.00b
N level (KgN/ha)							
N1	42.99±0.13b	0.38±0.02d	0.08±0.00f	0.06±0.00c	1.21±0.05a	980.49±52.07c	0.11±0.01a
N2	43.18±0.11a	0.43±0.01c	0.08±0.01e	0.07±0.00b	1.27±0.05a	919. 99±74.99c	0.12±0.00a
N3	43.25±0.18a	0.42±0.03c	0.09±0.01c	0.07±0.00b	1.22±0.04a	932.09±61.46e	0.11±0.01a
N4	43.45±0.12a	0.45±0.04c	0.11±0.01a	0.08±0.00a	1.15±0.05a	1319.51±82.87a	0.11±0.01a
N5	43.45±0.10a	0.55±0.06a	0.10±0.01b	0.08±0.00a	1.23±0.06a	1081.10±86.19b	0.12±0.01a
N6	43.28±0.19a	0.49±0.04b	0.09±0.01d	0.07±0.00b	1.21±0.06a	1174.64±89.38b	0.11±0.01a
F-statistics							
Cultivar	32***	9.58**	52.98***	16.88***	35.65	6.51*	8.81**
N level	3*	4.00**	5.94**	2.74*	ns	4.78**	ns
C x N Interaction	ns	3.24*	ns	ns	ns	0.59*	ns

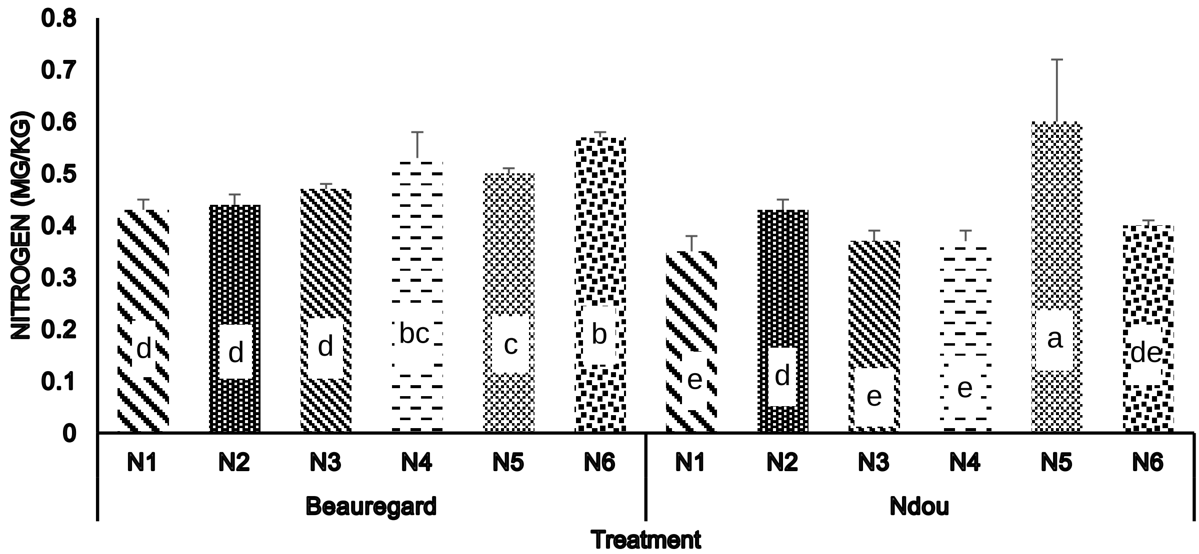

Figure 4.22 Effect of nitrogen level and cultivar interaction on mean concentration of nitrogen (mg/kg) in tuberous root of sweet potato at 115 DAT

Similar to micronutrient concentrations in sweet potato shoot, cultivar response to N fertilization was significant with respect to the micronutrient concentrations in tuberous root at 115 DAT (Table 4.12). The concentrations of Zn, Cu, Fe, and Al in tuberous root of sweet potato were significantly different when both cultivars were compared. For example, concentrations of Zn (7.21 mg/kg), Fe (51.28 mg/kg) and Al (66.46 mg/kg) were higher in tuberous root of Beauregard compared to Ndou (4.98 mg/kg, 19.30 mg/kg and 40.39 mg/kg, respectively. In contrast, Cu concentration was higher in tuberous root of Ndou (8.88 mg/kg) compared with Beauregard (7.62 mg/kg) (Table 4.12). However, N fertilization did not significantly impact Mn concentration in tuberous roots when both cultivars were compared.

Nitrogen fertilization level had a significant effect on micronutrient concentrations in tuberous roots of sweet potato plants at 115 DAT. The concentrations of Zn, Cu, Mn, Fe and Al were significantly different in tuberous roots of sweet potato plant in response to N fertilization levels. For example, plants fertilized with 43 kgN/ha (N5) had higher Zn (7.9 mg/kg), Mn (17.2 mg/kg), Fe (49.65 mg/kg) and Al (63.86 mg/kg) in their tuberous root compared to control (6.51 mg/kg, 8.34 mg/kg, 35.56 mg/kg, and 51.78 mg/kg, respectively (Table 4.12).

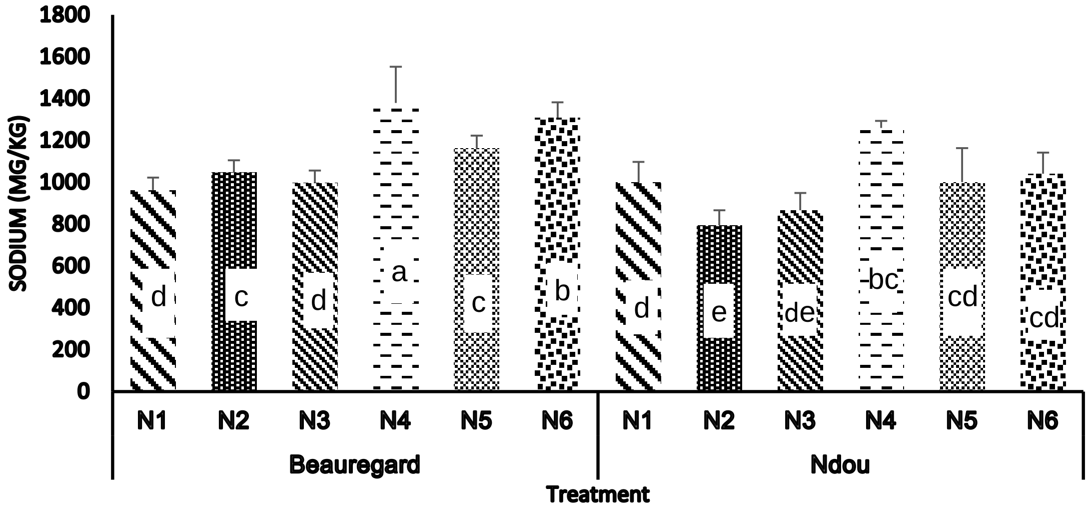

Figure 4.23 Effect of nitrogen level and cultivar interaction on mean concentration of sodium (mg/kg) in tuberous root of sweet potato at 115 DAT

A two-way analysis revealed a significant interaction between cultivar and N fertilization level on the micronutrient (Zn, Cu, Mn, Fe and Al) concentrations in the tuberous root of sweet potato. For example, the concentrations Zn (8.5 mg/kg), Cu (13.1 mg/kg), Fe (70.66 mg/kg) and Al (90.0 mg/kg) in tuberous root of Beauregard fertilized with 43 kgN/ha (B1N5) were higher compared Ndou fertilized with same amount of N (B2N5) (7.3 mg/kg, 2.54 mg/kg, 28.65 mg/kg, and 37.7 mg/kg) (Figs. 4. 24, 4.25, 4.26 & 4.27 respectively). Similarly, the tuberous root of Ndou fertilized with 43 kgN/ha (B2N5) had higher concentration of Mn (23.6 mg/kg) compared to Beauregard fertilized with the same amount of N (B1N5) (10.6 mg/kg) (Fig. 4.28).

Table 4 12 Effect of nitrogen fertilization on micronutrients in tuberous roots of two sweet potato cultivars. Values (M±S.E.) followed by dissimilar letters in a column are significantly different * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001.

Treatment	**Micronutrients in tuberous roots (mg/kg)**				
	Zn	**Cu**	**Mn**	**Fe**	**Al**
Cultivar					
Beauregard (B1)	7.21±0.29a	7.62±1.03b	10.56±0.48a	51.28±3.22a	66.46±4.37a
Ndou (B2)	4.98±0.56b	8.88±1.94a	11.64±2.00a	19.30±2.55b	40.39±2.62b
N level (Kg N/ha)					
N1	6.51±0.34b	13.40±4.84a	8.34±0.49d	35.02±4.95b	51.78±6.47bc
N2	5.51±0.70e	5.67±1.64d	10.24±0.86c	38.70±10.58b	45.75±4.96d
N3	6.08±0.42c	6.92±1.66cd	8.58±0.74d	32.72±6.30b	50.07±6.11c
N4	5.62±1.23d	9.71±0.95b	12.02±1.01b	30.41±7.72b	58.90±6.89b
N5	7.90±0.99a	7.82±3.14c	17.20±5.47a	49.65±9.77a	63.86±12.36a
N6	4.96±1.07f	5.97±1.20d	10.34±0.85c	25.25±8.83c	50.17±11.20c
F-statistics					
Cultivar	21.54***	0.49*	ns	93.34***	33.57***
N level	3.07*	1.74*	2.07*	4.25**	1.47*
C x N Interaction	3.83*	3.48*	1.77*	1.42**	2.45*

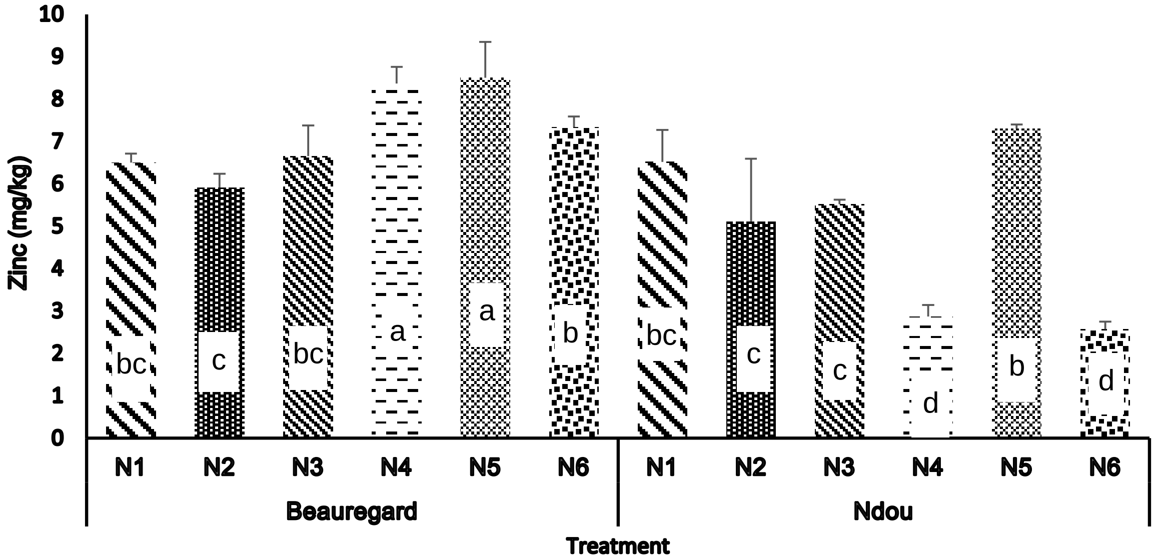

Figure 4.24 Effect of nitrogen level and cultivar interaction on mean concentration of zinc (mg/kg) in tuberous root of sweet potato at 115 DAT

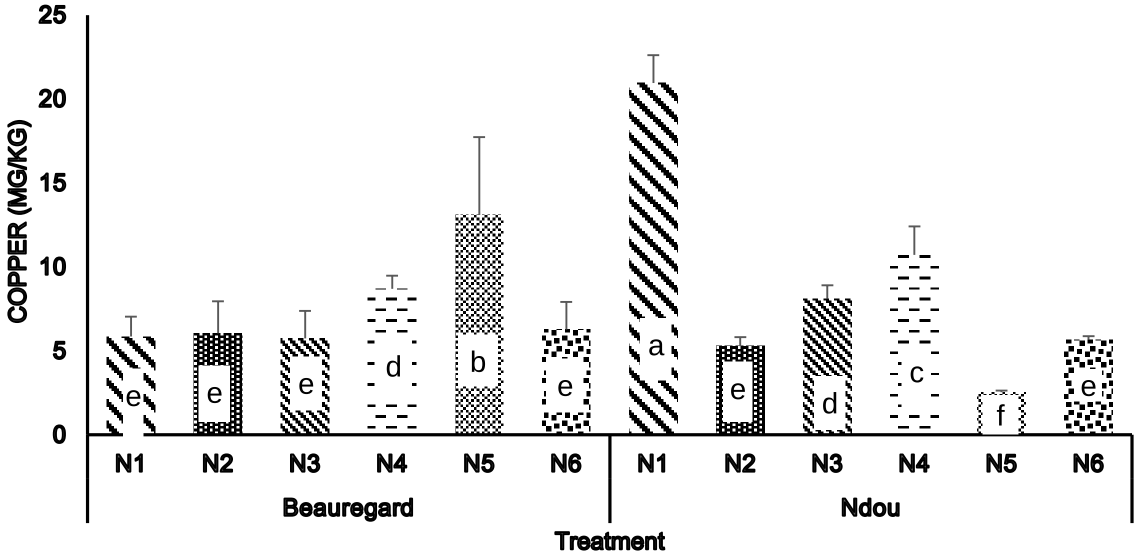

Figure 4.25 Effect of nitrogen level and cultivar interaction on mean concentration of copper (mg/kg) in tuberous root of sweet potato at 115 DAT

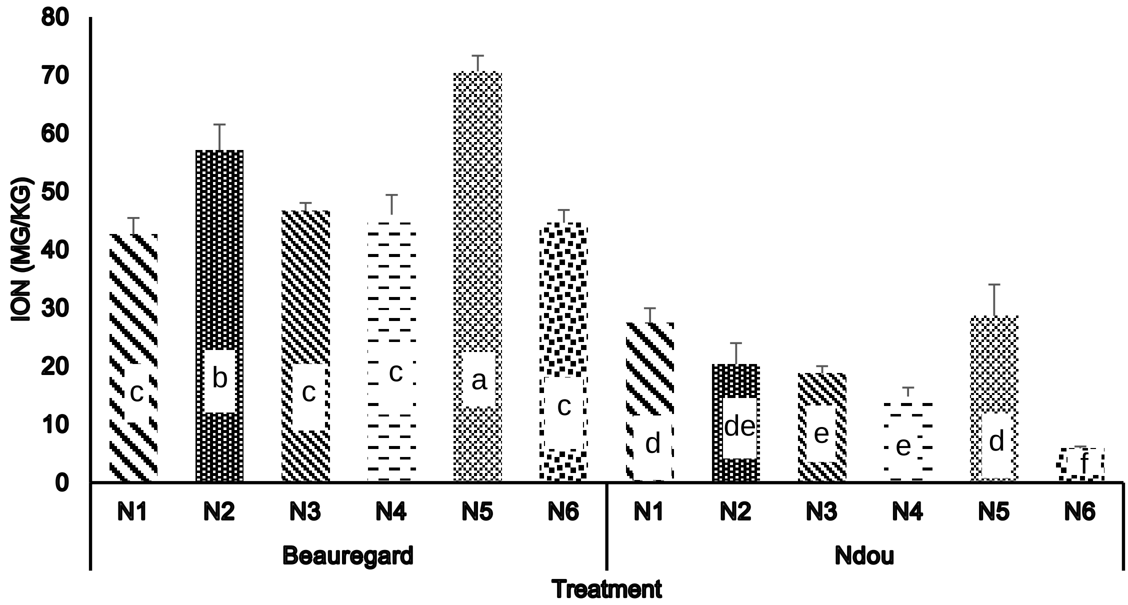

Figure 4.26 Effect of nitrogen level and cultivar interaction on mean concentration of iron (mg/kg) in tuberous root of sweet potato at 115 DAT

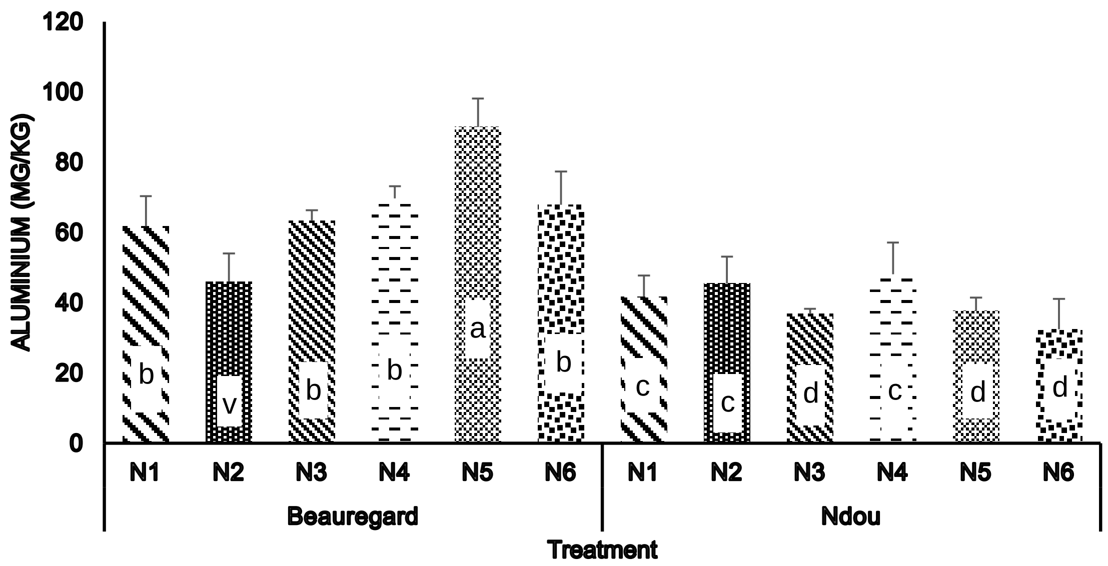

Figure 4.27 Effect of nitrogen level and cultivar interaction on mean concentration of aluminium (mg/kg) in tuberous root of sweet potato at 115 DAT

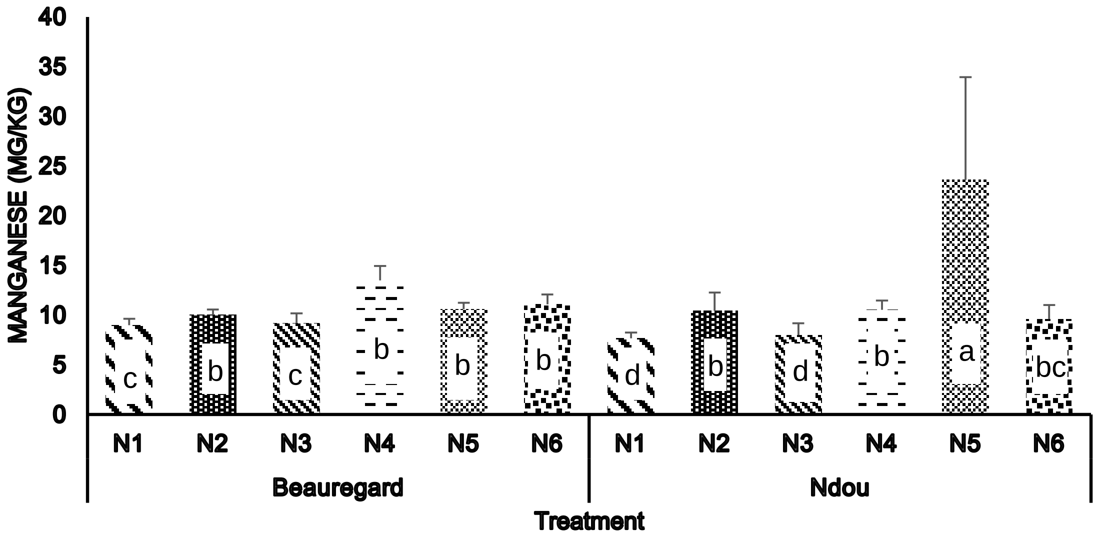

Figure 4.28 Effect of nitrogen level and cultivar interaction on mean concentration of manganese (mg/kg) in tuberous root of sweet potato at 115 DAT

4.6 SWEET POTATO GROSS MARGINS ANALYSIS

The Gross Margin analysis was done to determine the potential revenue associated with the use of different levels of nitrogen in accordance with Kelly (2012). The gross margin analysis was calculated by subtracting the total variable costs (TVC) from total gross income. Gross margin as explained by Maoba (2016) is the net sales of produced goods, less the production cost of the goods sold. Maoba (2016) further explained that Gross Margin is frequently expressed as a percentage, called the Gross Margin Percentage and is calculated using the following formula where estimated figures will be used. Visagie & Ghebretsadik (2005) also explained that Gross margin is the difference between the Gross Income (GI) derived from each enterprise minus the total variable costs (TVC). The formula for calculating Gross margin can be shown as GM = (GI – TVC). The formula used to calculate Gross Margin according to Visagie & Ghebretsadik (2005) was as follows: Gross Margin (GM) = Gross Income (GI) - Total Variable Cost (TVC).

In this study, after determination of tuberous yield of sweet potato grown in the field and the cost of tuberous estimated based on current prices in local markets in Ladysmith, the cross income per hectare was estimated. Table 4.13 below shows that the total estimated revenue per hectare was two hundred and nineteen thousand, two hundred fifty-three rands and sixty cents (R 219 253.60).

Table 4.13 Yield factors used to calculate Gross Income per hectare

Yield Factors	Gross Income Per Hectare
Plant population	66 600 plants/ha (plant spacing: 0.3 m x 0.5 m)
AVG Tuber weight/plant (Kg)	0.6 kg/plant x 66600 = 39960 kg /1000 = 40.0 ton
Price/ton	R5 481.34 /ton
Total revenue(estimated)/ha	**R 219 253.60 /ha**

According to Table 4.14, the total estimated production cost per hectare was one hundred and thirty-seven thousand, nine hundred and sixty rands and seventy-eight cents (R 137 960.78).

Table 4.14 Sweet Potato Production Inputs with relevant production costs per hectare.

Inputs Per Hectare	Price Per Unit (R)	Total variable costs Per Hectare (R)
Plant material:		
Sweet Potato Vine cuttings	1.00	66 600.00
Fertilizers:		
Super phosphate 5% P + 8% C (1.2 ton)	7 500.00	9 000.00
KCL 50% (0.22 ton)	6 216.21	1367.57
Transplanting sweet potato vines (Labour: 2 man days)	450.00	900.00
Cultural Practices (Labour: 3 man days)	450.00	1 350.00
Herbicides:		
Focus Ultra (0.6 Litre)	454.08	272.45
Pesticides:		
Cypermethrin 200 EC (1.5 Litre)	245.00	367.50
Harvesting (3 man days)	450.00	1 350.00
Packaging (10kg pockets x 2000)	1.31	2 620.00
Marketing costs:		
Agents Commission 7.50%	411	29 014.96
Markets commission 5.00%	274.07	19 343.30
Transport (contract)	81.80	5 775.00
Production costs per hectare (Total variable cost)	**16 534.47**	**137 960.78**
Average Gross Margin		**81 292.82**

In addition, the Gross Margins per nitrogen level per hectare was estimated and Table 4.15 shows the analysis. According to Table 4.15, the Gross Margins per hectare of nitrogen applied were not different from each other and the cost ranged from R80 323.22 for highest N level to R81 292.82 for no fertilization per hectare.

Table 4.15 Gross Margins (GM) per nitrogen level per hectare.

Nitrogen level per ha (kg)	**Nitrogen cost/ha (R5 124.44/ton)**	**Production costs/Ha (R)**	**Total variable cost/Ha (R)**	**Total revenue per Ha (R)**	**Gross margin/ha** (i.e. Total revenue – total variable costs)/Ha **(R)**
N1 (0 kg/	R5124.44 x 0 kg/ha ÷ 1000 = R0.00	R137 960.78	R137 960.78	R219 253.60	R81 292.82
N2 (13 kg/Ha)	R5124.44 x 46.41 kg/ha ÷ 1000 = R237.83	R137 960.78	R138 198.61	R219 253.60	R81 054.99
N3 (23 kg/ha)	R5124.44 x 82.11 kg/ha ÷ 1000 = R420.77	R137 960.78	R138 381.55	R219 253.60	R80 872.05
N4 (33 kg/ha)	R5124.44 x 117.81 kg/ha ÷ 1000 = R603.71	R137 960.78	R138 564.49	R219 253.60	R80 689.11
N5 (43 kg/ha)	R5124.44 x 153.51 kg/ha ÷ 1000 = R786.65	R137 960.78	R138 747.43	R219 253.60	R80 506.17
N6 (53 kg/ha)	R5124.44 x 189.21 kg/ha ÷ 1000 = R969.60	R137 960.78	R138 930.38	R219 253.60	R80 323.22

Similarly, no differences were noted in the Gross Margin Percentages per hectare according to Table 4.16.

Table 4.16 Gross Margin Percentage per nitrogen level per hectare

Nitrogen Level per Ha	**Application Rate per Ha (kg)**	**Gross Margin per Ha (R)**	**Gross Margin Percentage per Ha (%)**
N1	0	81 292.82	37.07
N2	13	81 054.99	36.97
N3	23	80 872.05	36.89
N4	33	80 689.11	36.80
N5	43	80 506.17	36.72
N6	53	80 323.22	36.63

The operating capital ratio was calculated in order to determine the percentage of the gross income that goes to cover the cost of production of sweet potato in the area (Khuliso, 2017). The operating capital ratio was calculated using the following formula:

OR = TOC ÷ GI,

Where: OR = Operating Capital Ratio

TOC = Total Operating Costs

GI = Gross Income

Table 4.17 The estimated Operating Capital Ratio per hectare

Nitrogen Level per Ha	Application Rate per Ha (kg)	Total Operating Costs per Ha (R)	Operating Capital Ratio per Ha (%)
N1	0	137 960.78	62.92
N2	13	138 198.61	63.03
N3	23	138 381.55	63.11
N4	33	138 564.49	63.20
N5	43	138 747.43	63.28
N6	53	138 930.38	63.37

CHAPTER 5: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 VEGETATIVE GROWTH RESPONSE TO NITROGEN FERTILIZATION

The growth and yield of sweet potato (*Ipomea batatas* L.) is generally low partly due to nitrogen constraints in soils of Ladysmith, KwaZulu-Natal. In this field study, the effect of nitrogen fertilization on vegetative growth of two sweet potato cultivars (Beauregard and Ndou) was undertaken. Prior to carrying out the field experiment, soil samples of the experimental site (Fig. 3.1) were analyzed. The soil samples were slightly acidic (pH 5.91) and generally, the minerals (P, K, Ca, Mg, Na and Total N) analyzed were relatively in low concentrations (mg/kg) including total N percentage (0.51 %) (Table 4.1). Therefore, pre-fertilization of the experimental site was done using fertilizers (KCL (50% K) and Superphosphate (5% P + 8% C))at rate of 0.132 and 0.72 kg/plot respectively as per recommendations from the soil analytic services at Agricultural Research council, Pretoria. Vine cuttings (between 25 and 30 cm) of two sweet potato cultivars (Beauregard and Ndou) were transplanted in the experimental site in December during the summer season in KwaZulu-Natal Province. To evaluate the vegetative growth response of sweet potato to N fertilization in soils in Ladysmith, the following growth parameters; vine length and vine numbers per plant and shoot biomass (fresh and dry weights) were determined. At 115 DAT, the results showed that N fertilization significantly affected the growth of sweet potato under field conditions and cultivar differences were noted with respect to each of the measured growth parameters. In general, the growth of sweet potato increased with N fertilization increase from 0-53 kgN/ha, a finding that is in agreement with reports of other studies on effect of N on growth of sweet potato (De Geus, 1967; Navarro & Padda, 1981; Osaki et al., 1995; Allemann, 2004; Ali et al., 2009; Smith & Villordon, 2009; Ukom et al., 2009; Yourtchi et al., 2013; Pushpalatha et al., 2017).

In this study, sweet potato response to different levels of nitrogen fertilization during vegetative growth was positive for vine length and number of shoots per plant. Plants with vine length range of 2.3-4.0 m were considered to be long and a range of 1.0-2.2 m was short. Plants with more than five vines were regarded as having high number of vines and those with less than five were low. At 110 DAT, the longest vine (long & short) length per plant was observed in Beauregard cultivar while the highest number of vines (high & low) per plant was observed in Ndou cultivar. These responses were attributed to the role of nitrogen fertilizer in supplying essential nutrient for plant growth, which resulted to greater length of vines and number of vines per plant. In general, there was a steady increase in vine length (long & short) and number of vines (high & low) as the nitrogen level was increased from 0 kg/ha through to 53 kg/ha (Tables 4.2 & 4.3). It is not clear if the noted differences in cultivar response (vine length and numbers per plant) to N fertilization could have been due to their genetic predisposition, as each has some remarkable characteristics (Table 3.1). However, clearly, positive responses were noted in the growth characteristics (vine length and numbers) of plants treated with the highest N dose (53 kg N/kg) compared to control (0 kgN/ha). Interestingly, the interaction of cultivar and N fertilization was significant for these parameters as well. For example, Beauregard fertilized with the highest N (53 kgN/ha) had a longer vine length of 3.63 m compared to Beauregard fertilized with 26 kg/ha, which had a length of 2.89 m (Fig. 4.1). A similar response was shown by Ndou, however, generally regardless of the treatment, the vine length of Beauregard was longer than that of Ndou (Figs. 4.1& 4.2), a finding that suggest differences in their genetic dispositions.

In contrast, at 115 DAT, cultivar response to nitrogen fertilization was not significantly affected with respect to shoot fresh and dry weight, however, shoot moisture percentage was significantly affected. Moisture percentage in shoot of Beauregard was at 82.59% and Ndou at 81.35% per plant (Table 4.4). Nitrogen fertilization level had a significant effect on the shoot biomass of sweet potato plants. Plants treated with highest N (53 kgN/ha) had higher fresh and dry shoot weights (422.84 g and 75.70 g) compared to control (337.45 g and 64.26 g, respectively), per plant. In general, there was a steady increase in the shoot biomass per plant as N level increased from 0 kgN/ha through to 53 kg N/ha (Table 4.4). The interaction between cultivar and nitrogen fertilization level was significant in terms of shoot biomass. Notably, the fresh (519.89 g) and dry (91.15 g) shoot weights of Ndou fertilized with the highest N (53 kgN/ha) was higher than that of Beauregard fertilized with the same N level (325.79 g (fresh) and 56.24 g (dry)) (Figs. 4.5 and 4.6, respectively).

Taken together, increases in N fertilization positively influenced growth of sweet potato and the highest dose of N (53 kgN/ha) seems to be optimum for growth of the crop in nutrient-poor soils of Ladysmith in the Kwazulu-Natal Province. These results are in agreement with findings of Pushpalatha et al. (2017) who reported that all growth and yield parameters of sweet potato significantly increased with increased levels of N content in earlier growth stage.

5.2 YIELD RESPONSE TO NITROGEN FERTILIZATION

In this field study, the response of two sweet potato cultivars in terms of yield (tuberous root number, length, diameter and weight) per plant following application of 53 kg N/ha Limestone Ammonium Nitrate (NH_4NO_3) 28% N is notable. For yield determination per plant, the number of tubers was regarded as high when it was greater than five and low when below five. The weight of root tuber range 1.0 – 2.2 kg considered to be large and 0.1 – 0.9 kg as small. Tuber with a length range of 17 – 24 cm was regarded as long and a range of 9 - 16 cm as short. Root tuber with a diameter range of 17 – 24 cm was regarded as large and a range of 7- 16 cm was small. At 115 DAT, the number of tuberous roots per plant was significantly affected by N fertilization. Beauregard had more tuberous roots (11.38 (high) and 4.67 (low)) compared to Ndou (B2) with 5.94 (high) and 2.33 (low) respectively (Table 4.5) and plants treated with highest N (53 kg/ha) had more tuberous roots (10.37 (high) and 4.50 (low) compared to control (10.00 and 3.30, respectively). In general, there was a steady increase in number of tuberous roots (high and low) per plant as N fertilization level was increased from 0 kg/ha through to 53 kg N/ha (Table 4.5). However, cultivar and N level interaction was significant. For example, Beauregard fertilized with 53 kgN/ha had more tuberous roots (12.00) per plant compared to the same cultivar not fertilized, control (8.00) (Fig. 4.8). Although sweet potato cultivar response to N fertilization was not significant for tuberous root weight, however, differences were noted. Beauregard had a slightly higher tuberous root weight (1.79 kg (large) and 0.53 kg (small)) per plant compared to Ndou (1.21 kg (large) and 0.52 kg (small), respectively) (Table 4.6). N fertilization level significantly affected the weight of tuberous roots of sweet potato. At 115 DAT, plants treated with the highest N (53 kgN/ha) has heavier tuberous root weight (1.71 kg (large) and 0.66 kg (small)) compared to control (1.53 kg and 0.42 kg, respectively). In general, the tuberous root weight (large and small) per plant increased steadily as N fertilization level was increased from 13 kg N/ha through to 53 kg N/ha (Table 4.6). The interaction between cultivar and N fertilization level significantly affected tuber weight of sweet potato. For example, Beauregard and Ndou fertilized with 23 kgN/ha had heavier (1.92 kg and 1.45 kg) tubers per plant compared to when fertilized with the lowest N (13 kgN/ha) (1.7 kg and 1.25 kg, respectively) (Fig. 4.10). Similarly, sweet potato cultivar response to N fertilization was significant for tuberous root length and diameter per plant at 115 DAT. Beauregard had longer (long (21.76 cm) and short 11.41 cm) tuberous roots per plant compared to Ndou (18.23 cm and 10.80 cm, respectively) (Table 4.7). In contrast, Ndou had bigger (large (20.52 cm) and small (10.82 cm) tuberous roots compared to Beauregard (17.90 cm (large) and 8.67 cm (small), respectively) (Table 4.8). In general, the tuberous root length (long & short) and diameter (large and small) increased as the N level was increased from 0 kg/ha through to 53 kg N/ha (Tables 4.7 & 4.8) and the highest applied N (53 kgN/ha) increased the tuberous root diameter of sweet potato by 53% (from 9.58 cm to 20.44 cm) per plant. The interaction between cultivar and nitrogen fertilization level was also significant for tuber length and diameter. For example, Beauregard and Ndou fertilized with highest N had bigger tuberous root (18.5 cm and 22.39 cm) compared to their respective controls (17.05 cm and 19.55 cm respectively) (Fig. 4.14).

In this study, the increased length, diameter, weight and number of tuberous roots in response to increased level of nitrogen fertilization could be attributed to availability of balanced nutrients in the soil available for plant use, which stimulated improved yield compared to control. The N fertilization level applied at 53 kg N/ha in split applications seems to be the optimum application rate to increase yield of sweet potato cultivars (Beauregard and Ndou) in soils of the present study area. These findings are in agreement with results of a similar study conducted by Masibuka (2016) in loamy sand soils at Tumbi, Tabora, Tanzania. Furthermore, the findings are in agreement with results obtained in a study conducted by Yourtchi et al. (2013), where the authors reported the highest amount of plant height, leaf and stem dry weight, leaf area index, total tuberous root weight, total number of tuberous roots and tuberous root diameter were found from the highest N application (150 kg N/ha). Similarly, Najim et al. (2010) reported that the maximum sweet potato plant height of 73 cm was obtained by using 150 kgN plus 15 tons of manure per hectare, and maximum LAI of 5.36 was obtained by using 150 kgN plus 20 tons of manure per hectare. The maximum tuberous root yield of 36.8 tons/ha was obtained by the utilization of 150 kgN/ha plus 20 tons' manure.

Notably, nitrogen nutrition is noted to play critical role in many physiological processes related to plant growth and development (Sedano-Castro et al., 2011). For example, N influences leaf area (AF) and leaf area index (LAI) and chlorophyll content responsible for photosynthesis in plants and in addition, it is a major constituent of vital cellular components (amino acids, proteins and nucleic acids) involved in plant growth and development (Torres-Olivar et al. 2014).

5.3 ELEMENTAL COMPOSITION IN SHOOTS OF SWEET POTATO IN RESPONSE TO NITROGEN FERTILIZATION

5.3.1 Macronutrient (C, N, Ca, Mg, K, Na & P) in shoot

Sweet potato cultivar response to nitrogen fertilizer was significant for macronutrients in plant shoot at 115 DAT. For example, C, Ca, Mg and K concentrations in sweet potato shoot were significantly different when the two cultivars were compared. Beauregard shoot had more C (43.91 mg/kg), Ca (0.69 mg/kg), and K (1.59 mg/kg) compared to Ndou with 44.25 mg/kg, 0.61 mg/kg, and 1.28 mg/kg, respectively and the shoot of Ndou had higher Mg concentration. However, the concentrations of N, Na and P were not different between the two sweet potato cultivar (Table 4.9). The N fertilization level significantly exaggerated Ca and Na concentrations in shoot of sweet potato at 115 DAT. For example, shoot of plants fertilized with 13 kgN/ha had higher concentration of Ca (0.77 mg/kg) and Na (222.50 mg/kg) compared to control (0.61 mg/kg and 182. 86 mg/kg respectively). The highest Na concentration (222. 50 mg/kg) was observed in plants treated with 13 kg N/ha, followed by plants treated with 33 kg N/ha (188.67 mg/kg) compared to control. However, N fertilization did not significantly affect concentrations of C, N, Mg, K, and P in shoot of sweet potato under field conditions (Table 4.9). The interaction of cultivar and N level was significant macronutrient concentrations in sweet potato shoot. For example, Ca concentration (0.91 mg/kg) was higher in shoot of Beauregard fertilized with 13 kgN/ha compared to Ndou not fertilized (control) (0.60 mg/kg) (Fig. 4.16). and similarly, Na concentration (224.43 mg/kg) was more in shoot of Beauregard fertilized with 13 kgN/ha compared to Ndou not fertilized (128.89 mg/kg) (Fig. 4.17).

5.3.2 Micronutrients (Zn, Cu, Mn, Fe & Al) in shoot

Cultivar response to nitrogen fertilization was significant for micronutrient composition in shoot of sweet potato plants at 115 DAT. For example, Cu, Fe and Al concentrations were significantly different between cultivar shoots. The concentrations of Cu (10.09 mg/kg), Fe (333.43 mg/kg) and Al (107.43 mg/kg) in Beauregard shoot were higher compared to Ndou (Cu (8.89 mg/kg), Fe (105.90 mg/kg) and Al (47.69 mg/kg), respectively). However, shoot concentrations of Zn and Mn were not different when the two sweet potato cultivars used in this study were compared (Table 4.10).

Similarly, N fertilization level affected micronutrients (Cu, Fe and Al) concentrations in sweet potato shoot at 115 DAT but the concentrations of Zn and Mn were not affected. Concentrations of Cu (10.6 mg/kg), Fe (652.1 mg/kg) and Al (152.5 mg/kg) in shoot of sweet potato plants fertilized with 13 kgN/kg (N2), were significantly higher compared to the control (Table 4.10). Sweet potato cultivar response to N fertilization differed with respect to shoot micronutrients. Ndou fertilized with 43 kgN/ha had more Zn (20.73 mg/kg) in shoot compared to Beauregard (14.27 mg/kg) fertilized with the same amount of N (Fig. 4.18). Copper concentration (11.96 mg/kg) was higher in shoot of Beauregard fertilized with 13 kgN/ha compared to Ndou (9.24 mg/kg) fertilized with same N level (Fig. 4.19). Similarly, Fe (1228.51 mg/kg) and Al (236.77 mg/kg) concentrations were higher in shoot of Beauregard fertilized with 13 kgN/ha compared to Ndou fertilized with same N level (75.56 mg/kg (Fe) and 60.26 mg/kg (Al)) (Figs. 4.20 and 4.21, respectively).

Similar to shoot elemental composition, N fertilization affected the macro- and micro-nutrients in tuberous root of sweet potato cultivars at 115 DAT. For example, C (43.43 mg/kg), N (0.49 mg.kg), Ca (0,1 mg/kg), K (1,3 mg/kg), Na (1142.65 mg/kg) and P (0.12 mg/kg) concentrations in tuberous root of Beauregard were higher compared to Ndou (42.99 mg/kg. 0.42 mg/kg, 0.08 mg/kg, 1.12 mg//kg, 993.29 mg/kg, and 0.11 mg/kg, respectively) (Table 4.11). However, Mg (0.07 mg/kg) concentration was higher in the tuberous root of Ndou compared to Beauregard (0.06 mg/kg) (Table 4.11).

In addition, N fertilization affected N, Ca, Mg, Na and P concentrations in the tuberous root of sweet potato at 115 DAT. Sweet potato plants fertilized with 43 kgN/ha had higher concentration of N (055 mg/kg) and Mg (0.08 mg/kg) in tubers compared to their respective controls (0.38 mg/kg and 0.06 mg/kg, respectively). However, N fertilization did not significantly affect C, K, and P concentrations in sweet potato tubers under field conditions (Table 4.11).

The differences in nutrients in shoot of sweet potato cultivars noted in this study are in agreement with reports by Osaki et al (1995) that different concentrations of carbon and nitrogen accumulated in the leaf, stem and root of sweet potato plants grown under different nitrogen application rates. The authors found higher concentrations of N in the leaf, stem and roots of sweet potato fertilized with higher dosages of nitrogen fertilizer (100, 300 & 500 kgN/ha) compared to control (0 kgN/ha) at 65 DAT.

5.4 ELEMENTAL COMPOSITION IN TUBEROUS ROOTS OF SWEET POTATO IN RESPONSE TO NITROGEN FERTILIZATION

5.4.1 Macronutrients (C, N, Ca, Mg, K, Na & P) in tuberous root

Similarly, sweet potato cultivar response to nitrogen fertilizer was significant for macronutrients in tuberous root. At 115 DAT, elemental analysis of tuberous root dry matter showed that C (43.43 mg/kg), N (0.49 mg.kg), Ca (0,1 mg/kg), K (1,3 mg/kg), Na (1142.65 mg/kg) and P (0.12 mg/kg) concentrations in Beauregard were higher compared to Ndou (42.99 mg/kg. 0.42 mg/kg, 0.08 mg/kg, 1.12 mg//kg, 993.29 mg/kg, and 0.11 mg/kg, respectively) (Table 4.11). In contrast, Mg (0.07 mg/kg) concentration was higher in the tuberous root of Ndou compared to Beauregard (0.06 mg/kg) (Table 4.11). In addition, N fertilization affected concentrations N, Ca, Mg, Na and P in the tuberous root of sweet potato at 115 DAT. Sweet potato plants fertilized with 43 kgN/ha (N5) had higher concentration of N (055 mg/kg) and Mg (0.08 mg/kg) in tuberous roots compared to control. However, N fertilization did not significantly affect C, K and P concentrations in tuberous root of sweet potato under field conditions (Table 4.11). Sweet potato cultivar and N fertilization interaction was significant with respect to macronutrients in tubers. At 115 DAT, elemental analysis of the dry matter of tuberous root of Ndou fertilized with 43 kgN/ha revealed that N concentration (0.6 mg/kg) was higher compared to N in Beauregard (0.5 mg/kg) fertilized with same amount of N (Fig. 4.22). Similarly, Na concentration (1379.38

mg/kg) was higher in tubers of Beauregard fertilized with 33 kgN/ha compared to Ndou (1259.64 mg/kg) fertilized with same N (Fig. 4.23).

5.4.2 Micronutrients (Zn, Cu, Mn, Fe & Al) in tuberous root

Similar to micronutrient concentrations in shoot, cultivar response to N fertilization was significant with respect to the micronutrient concentrations in sweet potato tubers. At 115 DAT, the concentrations of Zn (7.21 mg/kg), Fe (51.28 mg/kg) and Al (66.46 mg/kg) were higher in tuberous root of Beauregard compared to Ndou (4.98 mg/kg, 19.30 mg/kg and 40.39 mg/kg, respectively). However, in contrast, Cu concentration was higher in tuberous root of Ndou (8.88 mg/kg) compared with Beauregard (7.62 mg/kg) (Table 4.12). In addition, N fertilization affected micronutrient concentrations in tuberous roots of sweet potato plants at 115 DAT. Sweet potato plants fertilized with 43 kgN/ha had higher Zn (7.9 mg/kg), Mn (17.2 mg/kg), Fe (49.65 mg/kg) and Al (63.86 mg/kg) in their tuberous root compared to control (6.51 mg/kg, 8.34 mg/kg, 35.56 mg/kg, and 51.78 mg/kg, respectively) (Table 4.12). Similarly, the interaction between cultivar and N fertilization affected Zn, Cu, Mn, Fe and Al concentrations in tuberous root of sweet potato. For example, Zn (8.5 mg/kg), Cu (13.1 mg/kg), Fe (70.66 mg/kg) and Al (90.0 mg/kg) concentrations in tuberous root of Beauregard fertilized with 43 kgN/ha were higher compared Ndou fertilized with same amount of N (7.3 mg/kg, 2.54 mg/kg, 28.65 mg/kg, and 37.7 mg/kg) (Figs. 4. 24, 4.25, 4.26 & 4.27 respectively). The tubers of Ndou fertilized with 43 kgN/ha had higher Mn (23.6 mg/kg) compared to Beauregard (10.6 mg/kg) fertilized with the same amount of N under field conditions (Fig. 4.28).

The effect of N fertilization on macro- and micro-nutrients in tuberous root of sweet potato noted in this field experiment was expected because N is known to influence concentrations of P, K and other nutrients in plant organs (Sedano-Castro, et al., 2011). Yourtchi et al. (2013) reported that the concentrations of nitrogen, phosphorus and potassium in tuberous roots of sweet potato were significantly influenced by the nitrogen fertilizer and vermicompost applied. In their study, the highest concentration of nitrogen, phosphorus and potassium were found in tuberous roots of sweet potato plants fertilized with 100 kgN/ha and 150 kgN/ha. Furthermore, the form of N supplied can also positively influence the concentrations of minerals in plant organs. example, McCrimmon et al. (1993) reported that the form of N supplied significantly affected nutrients concentrations in the shoot, root, and verdure of creeping bentgrass. In their study, higher P, Ca, and Mg concentrations were found in roots of bentgrass plants treated with nitrate- and urea-treated compared to those treated with ammonium and urea-treated, which had higher P, Ca, and Mg concentrations in the verdure. Similarly, differences in micronutrients (B, Fe & Mn) were noted in the shoot, root and verdure of bentgrass plants treated with either nitrate or urea or ammonium (McCrimmon et al., 1993).

5.5 SWEET POTATO GROSS MARGIN PER NITROGEN LEVEL PER HECTOR

Gross Margin analysis was done in the present study to compare gross margins across treatments. Khuliso (2017) indicated that gross margin analysis enables farmers to assess the profitability of the crop, and hence allow farmers to compare with other crops and then chose the most efficient type of crop to produce. Furthermore, Kelly (2012) reported that the gross margin analysis was done to determine the potential revenue associated with the use of different levels of nitrogen. The gross margin analysis in the present study revealed that the control treatment had the average gross margin of R81282.82 calculated as 37.07% of gross income, which means that sweet potato cultivars with zero nitrogen fertilizer applied had retained a portion of 37.7% of gross income and had more to cover for other costs. The operating capital ratio of sweet potato cultivars treated with zero nitrogen fertilizer was 62.92% of the gross income that means that total costs of production was covered. The gross margin of the nitrogen fertilizer levels (13, 23, 33, 43 and 53 kg N/ha) showed a steady decrease with the increased nitrogen fertilizer levels from 13 kg N/ha to 53 kg N/ha while the production costs increased with increased levels of nitrogen fertilizer applied per hectare. The lowest gross margin percentage of 36.63% was recorded from sweet potato cultivars treated with 53 kg N/ha when the six nitrogen fertilizer levels per ha were compared. The highest production cost percentage of 63.37% was recorded from two sweet potato cultivars treated with 53 kg N/ha when six nitrogen fertilizer levels per hectare were compared.

5.6 CONCLUSION

The present study has revealed that nitrogen fertilization at a rate of 53 kg N/ha improved sweet potato growth, yield and net revenue obtained under good management practices. Both cultivars, Beauregard and Ndou were more responsive to high level of nitrogen fertilizer application rate in terms of growth and yield. The agronomic yield observed in this study was high and efficient with high nitrogen fertilization application rates particularly at 53 kg N/ha.

5.7 RECOMMENDATIONS

Based on results of nitrogen fertilizer application rates under field conditions, the following recommendations were made:

- Farmers should top-dress sweet potato with nitrogen fertilizer (LAN 28%) at the rate of 53 kg N/ha for optimum yields and economic returns of sweet potato cultivation in soils of Ladysmith, KwaZulu-Natal.
- Beauregard and Ndou cultivars are recommended for use by farmers of Ladysmith, KwaZulu-Natal. However, farmers should consider differences in cultivar responses to N fertilization in their sweet potato N management practices.
- More studies on nitrogen fertilizer management in sweet potato production are needed to develop sustainable soil nutrients replenishment program for the sandy clay loam soils of Ladysmith, KwaZulu-Natal, as a single study is not enough to answer all questions and problems specifically related to the production areas in the province.

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