ONION (*ALLIUM CEPA* L.) GROWTH, YIELD AND STORABILITY AS INFLUENCED BY RATE AND TIME OF NITROGEN APPLICATION

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DECLARATION

This thesis is my own original work and has not been submitted to this or any other academic institution for the award of any academic degree.

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DEDICATION

To my parents: Wanjira and the late Gateri,

My mentor, Dr. Anne W. Muriuki

and

My husband Makanga, My children Mumbi, Makanga Jr., Gateri, Kamari and Wambui

Your love, support and prayers have been amazing in this journey. To GOD be the Glory.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASTGS	Agriculture Sector Transformation and Growth Strategy
APG	Angiosperm Phylogeny Group
CAN	Calcium Ammonium Nitrate
CEC	Cation Exchange Capacity
cm	Centimeter
^{o}C	Degree Celsius
DNA	Deoxy-Nucleic Acid
et al.	And others
e.g.	For example
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Statistics
FINTRAC	Financial Transaction Report Analysis Centre of Canada
g	Gram
GOK	Government of Kenya
GA	Gibberellic Acid
GS-GOGAT	Glutamine Synthetase-Glutamate Synthase pathway
ha	Hectare
HCD	Horticultural Crops Directorate
IAA	Indole Acetic Acid
INM	Integrated Nutrient Management
KALRO	Kenya Agricultural and Livestock Research Organization
kg	Kilogram
LSD	Least Significant Difference
mg	Milligram
m	Metre
MOA	Ministry of Agriculture

MT	Metric Tones
NARL	National Agriculture Research Laboratories
NAA	Naphthalene Acetic Acid
N	Nitrogen
NH_4^+	Ammonium ion
NO_3^-	Nitrate ion
ns	None Significant
%	Percentage
PLW	Physiological Loss in Weight
pH	Power of Hydrogen
PPM	Parts Per Million
R/FR	Red: Far Red light
RCBD	Randomized Complete Block Design
RNA	Ribo-Nucleic Acid
SE	Standard Error
t	Tonne
TSP	Triple Supper Phosphate
UM	Upper Midland zone
UNESCO	United Nations Educational Scientific and Cultural Organization
USAID	United States Agency for International Development
USDA	United States Development Agency

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Abstract

Onion (*Allium cepa* L.) is an important commercial vegetable crop grown by small-holder farmers in Kenya, for both local and export markets. National average production is low and quality highly compromised due to use of low yielding varieties, low soil fertility and poor agronomic practices. Heavy loses estimated to be over 40% are also incurred in storage, mainly due to sprouting and rotting, further reducing the consumable yield. Nitrogen (N) is an important nutrient affecting onion growth and quality but with an impact on the shelf-life of the crop. This studywas therefore conducted to investigate the effect of nitrogen fertilizer and time of applicationon onion bulb growth, yield, quality and storage.

Two field experiments were conducted in 2014 and 2015 with five N rates (0, 26, 52, 78 and 104 kg N/ha), applied as Calcium Ammonium Nitrate at 3, 6, 9 and 12 weeks after transplanting. Two commonly grown varieties of onions, Red Creole and Red Tropicana F1 hybrid were used. The experiments were laid in a randomized complete block design (RCBD), with a split-split plot arrangement and replicated three times. The varieties were the main plots, the fertilizer rates the sub plots and the time of application the sub-sub plots. The experiments were conducted under natural rainfall conditions supplemented with drip irrigation. All other agronomic practices regarding weeding and crop protection were applied as recommended for farmers. Onion bulbs were stored at room temperature conditions for a period of three months.

Agronomic data collection commenced three weeks after transplanting while storage data started four weeks after storage. Field parameters included plant height, leaf number, bulb ratios, % bolters, % fallen plants, total yield, marketable yield, bulb weight, bulb diameter, bulb size, bulb neck size and split bulbs. Parameters taken during storage were physiological weight loss (PWL), sprouted bulbs, number and length of sprouts, rotted bulbs and severity of rotting (%). Data were subjected to analysis of variance (ANOVA)and means obtained separated using Fishers protected LSD at 5% probability level.

Interaction between N rates and time of application affected plant height in both seasons while number of leaves, bulbing ratios and % fallen tops increased significantly with increasing N rates. Late application of N decreased plant height, reduced the number of leaves and bulbing ratios but stimulated growth late in the season hence delaying crop maturity.

Application of 104 kg N/ha increased total yields over the control by 59% in season one and 84% in season two. Marketable yield, average bulb weight and bulb diameteralso increased significantly with increasing N rates in both seasons. Nitrogen fertilizer decreased Size A bulbs (<40 mm in diameter) while increasing the most marketable bulbs in Size B (40 – 80 mm in diameter) and C (>80 mm in diameter). However, late application of N at 12 weeks resulted in low bulb weight and narrow bulb diameters increasing size A bulbs and reducing total yield by 23% in season one and 27% in season two. Marketable yield reduced by 25% in both seasons. The yields increased linearly up to the highest level of N applied hence optimal production was not reached.

Application of N significantly ($P \leq 0.001$) increased thick necked bulbs by 18% over the unfertilized check in season one and 32% in season two. Splitted bulbs increased with increasing N rates recording a 49% in season one. Late application of N at 12 weeks reduced necksizes but increased splitted bulbs by 42% in season one and 87% in season two. Bolted bulbs were not influenced by N or its time of application.

Nitrogen increased significantly PWL, the number of rotted bulbs and length of sprouts in both seasons. High early application (3 weeks) increased rotting and physiological loss in weight due to larger bulbs and neck sizes while high late application accelerated sprouting.

The Red Tropicana F1 hybrid performed better than the Red Creole variety, recording significant differences in growth and yield parameters. However, the Red Creole variety had a longer shelf life compared to the Red Tropicana F1 hybrid.

In conclusion, N fertilizer application improved growth and yield of onion but high rates from 78 kg N/ha had adverse effect on quality and storability of bulbs. Level 104 kg N/ha recorded the best growth and maximum yield for both varieties. Topdressing at 6 weeks after transplanting gave the best yields and quality. The yields increased linearly with N levels, warrantingtrials with higher levels to obtain an optimum and economic yield level. Application of 52 kg N/ha was best for bulbs intended for storage due to reduced rotting and sprouting. The Red Creole variety was a better option for storage.

Key words: Plant height, leaf number, crop maturity, marketable sizes, bulb ratios and diameters, bolted bulbs,PWL, accerated sprouting, increased splitting, increased rotting

CHAPTER ONE

GENERAL INTRODUCTION

1.1. Background Information

Onion (*Allium cepa* L.), is one of the oldest vegetables known to man, its cultivation dating back to more than 5000 years (Shultz, 2010). It is believed to have originated from central Asia (Brewster, 1994). Today the bulb onion is an important commercial vegetable grown worldwide, with a wide adaptation from the tropics to sub-arctic regions.

Although onion is used in small amounts, the vegetable is consumed in almost every household. The crop is grown for its pungent bulbs which are essential for seasoning a variety of dishes. Their nutrition is however quite low, while their medicinal value is widely acclaimed (Pareek *et al*., 2017). Majority of onions are cultivated for dry bulbs (Fritsch and Friesen, 2002). According to Food and Agriculture Organization (FAO, 2016), over 9 million acres are devoted to growing onions world over. In 2016, world total production was over 93 million MT with China being the largest producer (23.9 million), followed by India (19.1 million), Egypt (3.1 million) and United States (3.0 million) MT (FAOSTAT, 2016). About 170 countries grow onionsworldwide but only eight percent of the total production goes for trading (USA National Onion Association, 2011). India is the world's greatest exporter while Netherlands acts as an intermediary, importing and exporting onions (Brewster, 2008). The main exporting countries in Africa are Egypt, Tanzania, Morocco and Niger (Donna and Megan, 2007).

In Kenya, the bulbing onion is one of the most important vegetables after tomato and brassicas (MOA, 2004). It is mainly grown by small-scale farmers with very little on large scale. Records indicate that production does not meet the local market demand necessitating importation of about half the production capacity from India, Egypt and Tanzania (Tschirley *et al*., 2004; HCD, 2017). The yields vary between 5 – 20 tonnes/ha with an average of 15 tonnes /ha. Higher yields have been reported in other countries for example 65.3 MT/ha in Korea Republic, 56.4 MT/ha in USA, 56.2 in Australia and 54.1 MT/ha in Spain (FAOSTAT, 2016). Although the acreage under production has continued to increase over the years, the yields have remained low due to production challenges. On the other hand local demand has increased as a result of population increase, improved standards of living and diversification of eating habits. Kenya should target increasing the total production from its current average of 15 t/ha to over 60 t/ha to meet the growing demand (Fintrac, 2012).

Economically, onions rank second after tomato among vegetable crops in the world (Griffiths *et al.*, 2002; Mallor *et al*., 2011). They are found present in most markets of the world at all seasons of the year. They have good price elasticity, being consumed in about the same amounts when the prices are high or low, with the demand remaining fairly constant. In Kenya, the onion is important for food security, commercial production and employment. Per capita consumption is about2 kg per annum (Helgi analytics, 2014). Most of the onions are consumed locally with very little exports. A highly specialized market allows exportation of 602.5 MT to EU market as vegetable mixes and prepacks. However, due to the high demand, Kenya is a net importer of onions which presents a good opportunity for growers. Market prices and demand show immense potential for increasing incomes of the local farmers.

Although favourable conditions for production exists in Kenya, several constraints impede onion production leading to low yields and poor quality.. The major biotic constraints include pests and diseases especially weeds which pose a major problem during cultivation leading to high yield losses (Waiganjo*et al*., 2009). Abiotic constraints contributing to low production include low soil fertility and inadequate moisture for production where irrigation is not available.The high cost of hybrid seed is another challenge as most farmers cannot afford hybrid seed. Added to these challenges is climate change. Selection of cultivars to be grown in various areas is not well done and husbandry is not adequate resulting to poor crop yield and quality of bulbs. Technical information regarding plant density, fertilizer, water application, diseases and pest control is limited due to inadequate research(Kibanyu, 2009; MOA, 2013).

Despite the achievements made in production, high post-harvest losses (40 -60%) pose another challenge. Onions are in production all year round and bulbs are stored due to seasonal glut in the market. Significant losses in quality and quantity are incurred due to physiological weight loss, sprouting and rotting (Maini *et al*., 1984). This results to poor supply of bulbs and hiking of prices during lean periods.

1.2. Statement of the Problem

Low yields(5 – 20 t/ha) and low acreages lead to low National total production necessitating importation of large amounts to meet the growing demand (HCD, 2017). Quality is also compromised so that the commodity is not competitive in the market. Post-harvest losses estimated to be over 40%, further compound the problem, leading to poor seasonal distribution, escalation of prices during lean periods and reduction of marketable yield.

Despite a continuous increase in acreage over the years, the productivity continuous to be low due to limited availability of quality seed and associated technologies (Fintrac, 2012). Low soil fertility and inappropriate cultural practices contribute to the low yields and quality of bulbs. The old National recommended fertilizer rates of 78 kg N/ha have been overtaken by loss of soil fertility as a result of continuous crop cultivation. Growers are known to fertilize the crop at the late stages of bulb growth perhaps to compensate for losses incurred through leaching or merely from anxiety that the yields will be less than needed to maintain profitability (MOA, 2013). Improper application of fertilizers can have negative results on yield and quality of onion bulbs.

The problem of bulb splitting and thick necks is common in the onion growing areas and may be due to excess irrigation and application of high doses of nitrogen fertilizers. The extent of bulb splitting is estimated at 30 to 40% which greatly affects quality hence the marketable yield (MOA, 2013). Splitting of onion bulbs is a physiological disorder resulting from shoots coming from multiple growing points which could be influenced by cultural or environmental factors. Cultural factors such as application of high soil moisture or excessive nitrogen in the early stages of bulb formation can lead to the malformation (Abdissa *et al*., 2011; Valenzuela *et al*., 1999). Varieties also show great differences in bulb splitting with some exhibiting a higher degree of the malformation(Eltayeb, 2006;Jilanand Ghaffor, 2003;Steer, 1980)

The high post-harvest losses incurred in storage due to sprouting and rotting greatly reduce the consumable yield and farmers are forced to sell their onions at low prices in the glut period (Abate, 2012). Storage losses of onions have been reported to reduce considerably by treatment of maleic hydrazide, ultraviolet radiation, controlled atmosphere storage, low and high temperature storage. Although these techniques work well to control post-harvest losses, most of them involve costly investment with specialized equipment and storage structures not feasible for the small-scale Kenyan farmer. Low-cost farm level technology is required to extend the shelf life of the crop. Manipulation of certain preharvest factors such as plant nutrition and time of bulb lifting can be done to extend shelf-life and increase marketability of the commodity.

Nitrogen is one of the primary macronutrients necessary for plant growth, development and good yields. Different levels of this nutrient have been reported to affect differently the yields, marketable quality, taste and even shelf-life of the crop in storage. In view of this, the current study was carried out to investigate the influence of varying rates of N and time of top dressing on growth, yield, quality and shelf-life of two onion varieties commonly grown in Kenya.

1.3. Justification

The onion is a horticultural crop which is an important source of income for small-holder farmers and business communities involved in cross border trade (Kimani *et al*., 1991). Although Kenya exports about 602.5 MT of onions annually, it is a net importer of the commodity. Local production does not meet the domestic demand necessitating importation of about half the production capacity from Tanzania (Tschirley *et al.*, 2004; MOA, 2004).

Although favourable conditions for production exist in Kenya, yields are still very low, averaging 15 tons/ha compared to 50-60 tons/ha in countries like China, Korea, USA and Spain (FAOSTAT, 2016). The low yield is attributed to use of low yielding varieties, poor agronomic practices and pests and disease infestation. Post-harvest losses contribute to further reduction of marketable yield due to poor keeping quality and handling practices. Quality of onions particularly bulb splitting is another factor that greatly affects competitiveness of Kenyan onions in the market.

Through the Agriculture Sector Transformation and Growth Strategy (ASTGS), the government aims to boost house hold food resilience, increase small-scale farmer incomes and increase overall agricultural output for economic growth (GoK, 2019-2029). Onion production presents a real opportunity for enhancing rural farm incomes, reduce poverty and improve Kenyan economy. There is huge unmet demand for the crop and focus is on research opportunities as well as the constraints that are impeding production. This study sought to improve production and quality to curb post-harvest losses.

1.4. Research objectives

1.4.1. Broad objective

To improve yield, quality and storability of onions for food and nutrition security and improved livelihoods.

1.4.2. Specific objectives

1. To determine the effect of different rates of N and time of application on growth, yield, and quality of onion.
2. To determine the influence of N and time of application on storability of onion.

1.5. Hypotheses

1. Nitrogenand its time of applicationhas no effect on growth, yieldand quality of onion.
2. Nitrogen and its time of application has no effect on shelf life of onion bulbs.

CHAPTER TWO

LITERATURE REVIEW

2.1. Origin, botany and nutritional value of onion

The onion crop has been in cultivation for more than five thousand years in the central Asian mountaneous region where it it was first domesticated (Brewster, 1994). Though a biennial plant, the crop is adopted in the tropics as an annual vegetable. Its close relatives include the garlic, shallot, leek, chives and Chinese bunching onion. The centre of origin is central Asia where nearly 200 of the 500 species of *Allium*have been documented (Brewster, 2008). Another centre of origin is located in Western North America, where majority of the species are found in the mountainous regions (Hanelt, 1990).

The bulb onion is classified under*Monocotyledoneae*, super order *Liliiflorae*, order *Asparagales*, family *Alliaceae*, genus *Allium*, species *Cepa* and variety *Cepa* L. (Firtsch and Friesen, 2002). The genus *Allium* had been placed in both families *Liliaceae* and *Amaryllidaceae*. It resembles the lilies in its ovary placement above other floral parts and the Amaryllidaceae in its umbellate inflorescence surrounded by spathe. In the APG III classification system, molecular phylogenetic studies have placed it in family *Amaryllidaceae* and subfamily *Alliaceae*, having shown that *Liliaceae* is not monophyletic (Chase *et al.*, 2009). Like most *Alliums*, the onion is diploid, with a chromosome number of eight (2n = 16) (Hanelt, 1990)

Allium cepa is a group of onions that form bulbs at the base of very young leaves. The leaf bases form a stem-like structure usually called the pseudostem (false stem). The true stem is a flattened disc (short and cone shaped) found underneath the soil (Nonnecke, 1989). The foliage leaves that are continuously formed during bulb development are alternately arranged on the pseudostem and elongate to a height of 45cm. The fleshly formed blades are bluish green in colour, cylindrical but flattened on the adaxial surface and are hollow inside (DeMason, 1990). Each leaf consists of a blade and a sheath. Leaves continue to grow until bulbing sets after which new leaves cease to form (Rubtzky and Yamaguchi, 1997).

The onion has a relatively short primary root that emerges from the seed at germination. This is followed by emergence of adventitious roots (DeMason, 1990). The roots have no root hairs and grow shallowly (not extensive), up to a radius of 30 cm from the bulb and rarely more than 30 cm below the soil surface (Pursegrove, 1985).

The onion's inflorescence is a globular umbel of greenish white flowers, totaling from 50 to 2000 (DeMason, 1990). All flowers open over a period of two to four weeks with those near the tip of the umbel opening first (Rabinowitch, 1990). They are protandrous sheddingpollen within three days. Onions are outcrossing and are pollinated by insects (Peters, 1990). Ripe umbels give rise to glossy black seeds (Encyclopedia of Garden Plants, 1996).

The bulbs are always tunicate, but differ in shape, size, colour, flavour, keeping quality as well as time ofmaturity depending on cultivar or hybrid (Brewster, 2008). They are made of leaf scales which are bladeless with the outer scales protected by a thick cuticle. During bulb formation, photosynthates are channeled to these leaf scales with the innermost scales acting as the strongest sinks. Bulbs formed assume various shapes including globular, ovoid, flattened disc form, bottle like and pear shaped (Hanelt, 1990).

At maturity, the pseudostem weakens due to leaf senescence and loss of photosynthates from the leaves. Eventually the pseudostem fails to support the weight of leaf blades and the foliage falls. The bulbs are harvested when at least 50% of the plants have fallen (Brewster, 1994). The bulb is the primary organ of commercial interest in onion. The common bulb onion which forms large

Table 1: Nutritional value of raw onion per 100g serving

Nutrient	**Amount**	**%Daily value**
Water	89.11g	
Protein	1.1g	2%
Fat	0.1g	0%
Carbohydrate	9.3g	3%
Dietary fiber	1.7g	6%
Vitamin C	7.4mg	8%
Vitamin B_6	0.12mg	9%
Thiamin	0.046mg	4%
Riboflavin	0.027mg	2%
Niacin	0.118mg	1%
Mangnese (Mn)	0.129mg	6%
Phosphorus (P)	29mg	4%
Potassium (K)	146mg	3%
Calcium (Ca)	23mg	2%
Magnesium (Mg)	10mg	2%
Zinc (Zn)	0.17mg	2%
Iron (Fe)	0.21mg	1%
Selenium (Se)	0.50mcg	1%
Sodium (Na)	4.00mg	0%

Daily values are based on 2000 calorie diet.Source: USDA Nutrient Data Base, 2014

bulbs is the most world economically important of the *Alliums*, being cultivated and traded all over the world (Brewster, 1994).

The onion has a distinctive flavor which makes it popular for preparation of different dishes. The green leaves are eaten at its young stage while the bulb is consumed at maturity. Table 1 above gives the nutritional value of onions. For their medicinal value, onions contain bioactive compounds such as flavonoids which impart health benefits to humans. These health benefits include reduction of factors that cause cancer, diabetes, cardiovascular and inflammatory diseases (Augusti, 1996;Grifith *et al.*, 2002; Lanzotti, 2006; Pareek *et al.*,2017).

2.2. Onion ecology, growth and nutrition

2.2.1 Onion ecology

Onion thrives best in cool climate with day temperatures ranging between 13 and 29^{o}C (Brewster, 1994). Cool temperatures are desired during early growth while at maturity a warmer climate is favourable. It requires rainfall ranging from 750 – 1000 mmbelow which supplemental irrigation is given to get good yields. It also requires bright sunny weather during bulb development stage. Day length of at least ten hours andoptimal temperatures are required for onion growth and production.

In Kenya, the bulbing onion grows well in both short and long rain seasons. However, it is grown in different climatic zones, stretching from the coastal regions to the highlands over 2500 m above sea level (Kimani *et al*., 1993). Most of the onions are grown in dry areas with government's effort of irrigation schemes. Some of the important schemes include Perkerra, Kibirigwe, Mwea and Bukura irrigation schemes but only Perkerra grows onions as a major crop. The major growing counties include Bungoma (23%), Meru (11%), Taita taveta (7%), Isiolo (7%), Siaya (6%) and Narok (4%) (HCD, 2017). Varieties commonly grown in Kenya are short day varieties including Red Creole, Red Tropicana, Red Tropicana F1 Hybrid, Texas Early Grano, Bombay Red, Yellow Bermuda, Yellow Granex F1 Hybrid, White Creole, some local hybrids and the Green bunching onions (Farmers Pride International, 2014).

Soils best for onions are fertile alluvial, loamy (Sandy or silt loams) type of soils with high organic matter content. They should be loose, friable and well drained. Best soil pH ranges from 5.8 to 6.5 for optimum growth but can be grown up to pH of 4. Heavy clays, poorly drained and alkaline soils (above 8.0) are not suitable for onions (Nikus and Mulugeta, 2010).

2.2.2. Onion growth and nutrition

Of all the biological and physiological factors involved in onion production, nutrition is likely the most significant factor in its growth and development. In the tropics especially, bulbing is no longer a photoperiod phenomenon (Abdalla, 1967). Nutrition therefore seems to play a major role. Research has shown that organic matter is important and soils with high levels of organic matter e.g alluvium or sandy loams are very good for onion production. Adding manure or any organic matter is often advised during planting.

Research has also shown that adequate reserves of the major nutrients are also important. In particular nitrogen and potassium are needed in larger amounts to optimize production. A few trace elements e.g. iron, boron, copper, zinc and sulphur are also important. Among these nutrients, nitrogen is given particular emphasis because it is important from development to maturity. Minolti and Stone, (1988) found no yield reduction when Phosphorus and Potassium were omitted from a fertilizer programme. The crop on the other had responded well to N most of the times. Nitrogen was noted to stimulate early vigorous growth and hastened maturity.

The conclusion drawn from this was that Phosphorus and Potassium application was not necessary if substantial amounts were indicated by a soil test but monitoring the levels was essential with time. Eliminating N was going to be detrimental especially in the early stages ofthe crop. Since onion rootsare shallow, adequate application of nitrogen is required to meet crop demand. Application early in the season is important as peak demand is during vegetative growth. However, very high applications result to delayed maturity (crop extends vegetative growth) and storage problems such as softening of bulbs and rotting (Sorensen and Grevsen, 2001).

Potassium (K) is the next macro nutrient needed in large quantities. A comprehensive study by Singh and Verma, (2001), showed yield increases in onion production as a result of K application up to 100 kg/ha. Peak demand for Potassium is later than that for N, occurring during bulb formation and expansion. It is important in sugar accumulation and hence in bulb enlargement and good yield attainment. Deficiency leads to burning of leaf tips, slowed growth, softening of bulbs and thinning of skins (Yara International, 2015)

Phosphorus (P) is needed at the earliest of growth as foundby Heneriksen, (1987). Supply of P at early stages gave rapid growth, high yields and good bulb maturity. Phosphorus is required to promote early root and leaf development. The research showed the results to be best when P is combined with N, the latter being applied as a top dressing. Growth, yield and quality improvement are commonly seen using Phosphorus starter fertilizers in onions. Phosphorus is important for DNA and RNA formation and energy transfer within the plant hence it has a direct effect on yield and quality. Deficiency results in slow establishment of the crop, especially rooting is adversely affected. Leaves are mottled and maturity in onions is delayed resulting to thicker necks at harvest (Yara International, 2015)

Among the micronutrients, Iron and Boron have been found to have the greatest influence on quality and yields of the bulbs. Iron is however needed in greater a mounts. Copper and Sulphur are needed in lesser quantities, the former being required for skin finish and the latter for enhancing pungency of the bulbs. Zinc which is needed in much smaller quantities is required during seed germination. An important factor in micronutrient availability is pH. Application of soil improving chemicals such as lime (Stevens *et al*., 2003; Sullivan *et al*., 2013) gave significant increases in leaf length and area resulting to increased yields perhaps due to enhanced uptake of these nutrients.

2.3. Nitrogen nutrition and metabolism

Nitrogen is the most abundant mineral in plants constituting up to 5% dry weight of plants. It is found in chlorophyll, proteins, cytochrome, nucleic acids and hormones. The uptake by the roots is in the forms of nitrate (NO_3^-) and ammonium (NH_4^+). The form taken largely depends on the plant species and soil reactions. However, the nitrate (NO_3^-) form is more preferred. For example in most aerated soils, (NO_3-) is the most available form (Xu *et al*., 2012) and plants adapted to such soils grow well with it as the sole source of nitrogen. Also the arable crops (onion included) mainly take the nitrate form even when the ammonium fertilizers are applied, the (NH_3^+) form being converted to the nitrate form through microbial oxidation. Ammonium form is predominant in grasslands (Jackson *et al*., 1989) and flooded anaerobic soils like rice paddies (Ishii *et al*., 2011). Plants suffer various impairments when only ammonium ions furnish nitrogen. For example the structure of chloroplasts are affected under conditions of ammonium toxicity (Puritch and Barker, 1967; Mengel and Kirby, 1979). However some plants such as rice utilize ammonium nitrogen more effectively than nitrate at all stages of growth (Mengel and Kirby, 1979).

Mengel and Kirby, 1979 also reported that (NH_3^+) can also be absorbed by plants roots particularly under high pH conditions where the presence of (NH_3^+) is favoured. Urea Co $(NH_2)_2$ may also be absorbed by plants according to Tisdale and Nelson, (1966); Braun, (2012). The urea is rapidly and directly absorbed through the leaf epidermis. But it is unlikely that large quantities of urea nitrogen can as such be absorbed by plant roots, for urea hydrolyses to ammonium nitrogen in most soils. There are also complex materials, such as water soluble amino acids and nucleic acids which may be absorbed and utilized by higher plants (Tisdale and Nelson 1966)

Various factors are reported to affect the uptake of both the nitrate and Ammonium forms. For example pH greatly affects their rate of uptake, their sensitivity showing a marked difference. Rao and Rains, (1976) showed that the ammonium uptake is best at neutral pH, the uptake falling drastically as pH falls while the reverse is true for the nitrate uptake. A more rapid (NO_3^-) uptake takes place when pH is low than when it is high, the uptake being decreased due to competition with the OH^- ions. Temperature has also been shown to affect uptake, the highest uptake taking place at high temperatures. Moisture availability is also known to be important in that uptake takes place in solution form. However the NO_3^- form which is negatively charged is readily leached below the root zone with excess rain or irrigation water especially on sandy soils (Whiting *et al.*, 2014). The NH_4^+ form being positively charged is attracted to the soil particles and thus is resistant to leaching and can be available even in flooded conditions.

After uptake, the translocation depends on the source of nitrogen and the root metabolism. According to Kiyomiya *et al.*, (2001), nearly all the (NH_3^+) form is assimilated in the roots and distributed as amino acids. In contrast, the (NO_3^-) form can translocate unaltered to the shoots and leaves by use of action potentials (Tischner, 2000). Once in the shoots, the nitrates are reduced to the ammonium form which are assimilated by Glutamine Synthetase (GS) for the synthesis of amino acids through the GS-GOGAT pathway (Miflin and Habash, 2002). The translocation of nitrogen in the phloem only takes place in amino acid form. The translocation occurs according to demand from 'Source to Sink' (Marcelis, 1996). Plant organs that form rapidly act as important sinks (Braun. 2012). Once translocated, the nitrogen is metabolized to form proteins and nucleic acids.

Nitrogen is quite mobile in the plant. The young leaves are continually supplied with amino acids until they have reached maturity (Milthorpe and Moorby, 1969). When the supply of nitrogen from the root media is inadequate, its supply from the older leaves is mobilized and fed to the young ones (Chapin III, 1991). Hence the deficiency of nitrogen first shows in the older leaves, through chlorosis or yellowing of the leaves as the chlorophyll content declines.

Nitrogen deficiency in onion is characterized by poor growth rate, stunted plants, small leaves and restricted root development. Older leaves are observed to fall prematurely due to N deficiency. In most cases plants mature early when N is deficient and this has been reported to occur in onion

(Sorensen and Grevisen, 2001; Abdisa *et al*., 2011). It has been observed that N supply is related to cytokinins which maintain the plant in a juvenile stage (Garnica *et al.,* 2012). The synthesis of cytokinins is depressed by N deficiency resulting to early plant maturity and senescence.

On the other hand, good supply of N in onions results to a healthy plant with vigorous vegetative growth. This is essential for photosynthesis which is the main machinery for food processing in the plant and results to good yields. Excessive quantities can be detrimental in the sense that toxic compounds may result or the plant can have prolonged growing period resulting in delayed maturity (Brewster, 1994). The latter is likely to occur when adequate supplies of plant nutrients are not present (Beevers, 1976). Excessive quantities beyond crops demand also have negative implications for the environment (Mansouri *et al*., 2014).

2.4. Bulb development and factors that affect bulbing

2.4.1 Bulb development

The formation of an onion bulb is as a result of mobilization of the carbohydrates into the base of young leaves. When this commences, growth of apical meristems, roots and even cell division generally ceases and swelling of the young leaves slowly become pronounced (Brewster, 1990).. However, the complex process of bulb germination cannot be sufficiently explained by accumulation of sugars alone.

Like most developmental processes, the formation of bulbs is genetically controlled. Research into the histological changes that occur during bulb formation speculates the existence of a bulbing hormone. The onset of sugar accumulation and swelling of leaves was thought to be controlled by a hormone originated from the leaves or shoot apex.

It is believed that a gene for bulbing is responsible for turning on indole acetic acid (IAA) synthesis which promotes cell division and enlargement of the onion scales prior to accumulation of the storage carbohydrates. The swelling of the young leaves is characterized by lateral swelling of cells which suggested that Auxins were involved in the increase. However, it was unusual for Auxins to cause renewed growth in cells that had ceased to grow and such a growth would have been an elongation and not a lateral extension. Investigating this scenario Clark and Heath (1961), reported an elevated level ofIAA content after induction just before swelling of the leaves. The IAA content reduced drastically 5-7 days later suggesting involvement of other hormones. Studies with different hormones, giberrelic acid (GA), IAA and naphthalene acetic acid (NAA) showed a positive effect with GA being most effective in enhancing bulb yield, bulb weight and vertical diameter in onions (Singh, 2006). These studies show clearly that not one hormone is involved, as part of the regulatory mechanism, in the peculiar process of bulb formation.

2.4.2 Environmental factors that affect bulbing

While the genetic constitution of an organism dictates the type of development to take place, the course of such development is profoundly influenced by environmental factors. The expression of the organisms heredity can therefore be significantly changed by the environment (Whaley, 1965). Such is the case with bulbing of onions. The process of bulbing is greatly affected by environmental factors such as light intensity, photoperiod, temperature, moisture and nutrition. Under different conditions of these factors, scallions, sets, large normal, double or split bulbs as well as bolting plants are produced.

Bulb development in the onion plant starts with the formation of scales and this begins in the response to an induction phenomena which occurs in the leaves and transmitted to the leave base. Bulb initiation is greatly influenced by length of days and nights, i. e. Photoperiod (Savonen, 2006; Brewster, 2008). There are short days, intermediate and long day varieties with bulb initiation requiring a critical minimum day length of 11, 13 and 14 hours respectively (Brewster 2008). Thus bulbing in onions is dependent upon a suitable length of day. This gives a better understanding on adaptation of cultivars, some being well adapted to tropical regions with shorter days and others to temperate regions where the day length is longer.

Investigations by Khokhar (2008), established an interaction between day-length and temperature. It was found that temperatures affected the minimum day length for bulb formation and that bulbing would not occur if temperatures were too low. Longer day lengths were required for bulb formation at low temperatures. If day length is sufficiently short, no bulbing occurs even at high temperature (Steer, 1980). However, bulbs will form at a slightly shorter day length if plants accumulate at least 600 degree days (Lancaster *et al.,* 1996). High temperatures (25^{o} -27^{o}C) favour bulbing and enhance earlier bulb initiation and maturation (Bosekeng, 2012). Bulbing ratios increase curve-linearly and time to maturity shortens with increasing temperatures and day-lengths (Khokhar, 2008). Thus for bulb formation to start, both temperature and day-length must go beyond a critical minimum and bulb ratios and maturity time are influenced positively by their increase.

The phytochrome system controls the photoperiodic triggering of bulb formation. The system detects the changes of red/far red ratios so the photomorphogenic responses resulting from this shows its control over the bulbing process. However, it is not known what effect temperature has on the phytochrome mediation of bulbing. Sobeih and Wright (1987) were able to show some interaction between these, temperatures having an effect on bulbing at lower ratios than at high ratios.

Sobeih and Wright (1986) also showed that the photoperiodic stimuli is received by young leaves. The sensitivity to the photoperiod increases with age and that bulbing cannot take place prior to achievement of a specific age irrespective of plant size. When day onion sets of the same age were planted at the same time, plants from the large sets matured first, indicating that the amount of stored food may play a definite role. Thus age, size, or stored food, possibly all three, play some unknown part in triggering the mechanism that initiates bulbing. Mondal *et al.,* (1986a), was able to show that other factors affecting bulbing particularly size and shape include cultivar, plant size, nutrition and plant density.

When onion plants were subjected to photoperiod which were well above those that are critical for the cultivar, bulbing started immediately (Scully *et al*., 1945). Within the critical range however, bulbing is somewhat slower and the plant is more susceptible to the influence of these other environmental factors.

In their experiments, nitrogen nutrition was shown not to influence the bulbing response with photoperiod that were much above the critical range.But when plants were grown near the critical photoperiod a deficient nitrogen supply had the same effect as shortening photoperiod. At critical photoperiod then, a deficiency of N will hasten bulbing and an excess of N will slow the bulbing process. However, adequate reserves are needed during early development because faster development leads to earlier cessation of green leaf formation for onset of bulbing (Brewster *et al.*, 1987)

The critical photoperiod, as used here, refers to that day length which is just sufficiently long to induce bulbing. At this critical day-length changes in such factors as temperature, nutrition and plant size have their most decisive effect on bulbing. Studies on onion bulbing in Sudan by Abdalla (1967), showed that under tropical conditions, temperature was a more important factor since it is more variable than day length. Obviously, these other factors also play a role.

The principal factor initiating bulbing is photoperiod (Brewster, 1990). Cultivars selection for a particular region is done on the basis of photoperiod. However, other factors such as spectral light, temperature and nutrition are also important and all factors interact in the process of bulb formation. The onset of bulbing as explained by Brewster, (1990), is when no more leaves are produced but bladeless scales and the ratio of the bulb to the stem collar is 2.0. Bulbing is therefore an outcome of a combination of factors of which day length, temperature and red: far-red light ratio of light are most important. Besides these, the rate at which the bulbs develop depend on other factors too, like nutrition and moisture as well as the available light during the growing season.

2.5. Effect of nitrogen rates on yield and quality of onions

Nitrogen influences growth and development of many plant species including onions. A general increase in total yield has beenreported with increasing nitrogen rates (Nasreen *et al.,*2007); Abdissa *et al.,* 2011; Fatideh and Asil, 2012).Plant height, leaf number, marketable yield, individual bulb weight and diameter were also reported to increase with increasing N rates. However, marked differences were noticed when nitrogen was applied before sowing and as a top dressing later. High sowing applications (>300kg N/ha) resulted in severe damping off (Sypien *et al.*, 1973). When applied as top dressing, the biggest bulb sizes were obtained with high nitrogen levels. The smallest sizes were produced by those plants that received no nitrogen.

Studies have also demonstrated that optimum N supply is necessary for maximum onion production and performance (Jilan *et al.,* 2004; Mansouri *et al*., 2014). However, excessive N especially if applied late can limit yields (Riekels, 1972; Sypien *et al*.1973) and increase storage losses (Dankhar and Singh, 1991). Excessive N applications have also increased leaf blade growth late in the season (Brewster, 1994), which delays bulb maturity (Schwartz and Bartolo, 1995). In addition, excessive N rates to the levels of 250 kg N/ha are uneconomical and hazardous to the environment as they lead to higher loses through denitrification, volatilization, runoff, leaching and inefficient utilization by the crop(Mansouri *et al.*,2014). Inadequate N on the other hand, can hasten maturity and limit yields (Henerisken, 1987; Brown *et al*., 1988; Brewster, 1994))

Riekels, (1977) observed that the response of onion to N application was apparently related to the amount of moisture available to the crop. With high rainfall, yields were found to increase with each increase in nitrogen. The crop also matured properly with normal growth. However, with low rainfall, maturity was influenced and yields declined as N ratesincreased. Thus topdressing N in dry conditions may not be effective in increasing yields and could even be detrimental to plant growth through the production of toxic compounds e.g. ammonia or by the development of high concentrations in the soil.

Nitrogen has also been found to affect quality of onion bulbs. Abdissa *et al.,* (2011), found that the biggest neck, bottlenecked onions are obtained with the application of high levels of Nitrogen. Excessive rates delay maturity of the crop due to the thick necks.Brewster *et al.,* (1987) found that where bulbs failed to reach maturity, leaves continued to be produced and the plants had big pseudo stems that failed to collapse a situation called “thick necking” or “bull necking”. The occurrence of thick necked plants that failed to collapse made drying and storage of bulbs difficult, since the thick pseudo stems could not be satisfactorily dried. Topdressingwith high rates of N affects negatively the shelf life of bulbs which correlates strongly with thickness of the necks. Wright and Grant, (1997) reported that the thick necks provided a high risk of contamination in storage.

Abdissa *et al.,* (2011); Valenzuella *et al.,* (1999) also found that doubling or splitting of bulbs increased with increased nitrogen fertilizer rate. Splitted bulbs which arise from multiple growing points that are normally suppressed by apical dominance are stimulated by high nitrogen levels leading to growth of lateral shoots. The shoots result to the malformation of the bulbs which are unmarketable and have poor keeping quality.

The percentage bolted plants which arise from premature seed stalk production were reported to increase with increasing N rates by Hassan, (1984). In contrast, a decrease was also reported to occur with increased N rates (Hassan and Ayoub, 1978; Abdissa *et al*., 2011). The onion bulb is penetrated by the seed stalk and becomes hard but prematurely decays in storage causing loss of the entire bulb.

Sprouting in storage reduces the keeping quality of onion bulbs. It has been reported to occur earlier with high N levels especially if applied late and latest with no N application (Sorensenand Grevsen, 2001, 2002; Fatideh and Asil, 2012). A higher average number of non-cracked dry scales per bulb and a better adherence of the skin to the bulb are good qualities for onion bulbs and are obtained with low levels or none.

To be used efficiently and affect quality positively, N requires other nutrients. Sulphur is an essential component of proteins without which the crop is unable to utilize nitrogen efficiently. It has also a marked effect on purgency of the bulbs (Thangasamy *et al*., 2013). Sufficient phosphorus improves yield and balances potential storage losses resulting from high N application (Yara, 2019). Potassium together with nitrogen are important nutrients influencing dry matter content of bulbs hence bulb weight and firmness (Milanez de Resende and Costa, 2014). Nitrogen together with calcium and copper influence skin integrity and colour (Yara 2019). Besides nutrition, plant density and variety will also influence bulb sizes and therefore the market quality (Demisie and Tolessa (2018). Moisture content influences positively bulb sizes (Zayton, 2009) but may also increase splitted bulbs which are not good for the market (Valenzuela *et al*., 1999). The period of curing or drying is also important for neck collapse and cealing tightly inorder to discourage sproutimg and prevent invasion of microrganisms causing rotting (Getenesh *et al*., 2015).

2.6. Storability of onion bulbs and factors affecting shelf life

After maturation, bulbs become dormant and enter a resting period (Brewster, 1994). This enables storage of the crop which can last as long as 7 months depending on the storage conditions. The reason for bulbs storage is to spread availability, keeping them during the glut period and making them available during scarcity. Conditions during storage must be optimized to maintain quality (Adamicki, 2005).

Bulbs are stored at room temperature or under refrigerated conditions. Those stored at room temperature can store for three months if properly dried (Ko *et al.,* 2002). Care must however be taken not to expose the bulbs to moisture. The store room must be kept dry and well ventilated (Joubet, 1997). Bulbs stored under refrigerated conditions (0.5^0C and 75% RH) can store for a longer period (6 - 7 months) but care must be taken to avoid freezing damage. Bulbs can also be stored under high temperatures close to 30^oC (Brewster, 2008). In Kenya, farmers store onions at room temperature due to economic and technological constraints where refrigeration is expensive and electrical power unreliable (Currah and Proctor, 1990).

Several factors affect the shelf life of onions in storage. Sprouting is one such factor which is regulated by a growth hormone (Grevsen and Sorensen, 2004). An example of such is Alyl disulphide which is produced in the leaves and translocated to the bulbs ascrop matures (Hygrotech, 2010). Hence sprouting is influenced by physiological maturity at harvest which is described by Brewster, (1994) as the extent at which plants fall over. A 50 - 90% physiological maturity (plants fallen) is regarded best (Gubb and MacTavish, 2002). Lifting of bulbs before 50% of the plants have fallen leads to sprouting of bulbs dueto insufficient hormone production. Higher levels of Alyl disulphide increases the storage potential of onion bulbs by inhibiting sprouting.

Sprouting is also influenced by temperatures. Low temperatures (10 – 20^{o}C) encourage sprouting (Benkablia *et al.*, 2002) while temperatures between 25^{o}C and 30^{o}C discourage sprouting (Miedman, 1994). Other factors influencing sprouting include genetic composition (Miedman, 1994) and topdressing with N fertilizers near maturity (Sorensen and Grevsen, 2001; 2002). Cultivars exhibit different storage potential due to their genetic composition with short day varieties storing for the shortest period (Hygrotech, 2010).

The size of bulb necks is another factor that influences shelf life of onions in storage. Thick collar is difficult to close while drying allowing contamination during storage with micro-organisms such as (*Pseudomonas gladioli*) (Wright and Grant, 1997). Curing is a post-harvest practice which is done to dry the bulb necks. It can be done in the field by exposing the bulbs to the sun or mechanically by forcingthrough heated air. It is considered well done when the necks are tightly closed and only then is the shelf life of the bulbs lengthened.

During refrigeration storage, the fluctuation of relative humidity also causes diseases. Ventilation can ease this problem and help to maintain the bulbs dry and dormant (Gubb and Mac Tavish, 2002). In ordinary room temperature storage, moisture loss due to dehydration, sprouting of bulbs or rotting limits storage life of onion bulbs and increases post-harvest losses. This gets worse as the duration of storage increases because sprouting and rotting also increases (Abate, 2012; Nabi *et al.*, 2013) hence compromising quality. Moisture loss can be controlled by keeping the relative humidity of the storage room within 65 – 75% (Ramin, 1999). Any rotted bulbs must also be removed and thrown away to avoid contaminating healthy ones (Getahun *et al.*, 2003)

In summary, physiological maturity, Cultivar, degree of curing, storage duration and storage conditions such as temperature and humidity are factors that affect shelf life and quality of bulbs. Because these factors result in loss of considerable amount of onion bulbs in quality and quantity, producers are compelled to sell their produce soon after harvest during the glut period at low prices (Abate, 2012).

2.7. Effect of time of fertilizer application

Timing of fertilizer application refers to the time fertilizer is applied in relation to stage of growth of the crop. It has been reported that during peak demand improves nutrient use efficiency reducing losses to the environment and increases yield of the crop (Sela, 2019). Hence timing of application has significant effect on crop yield and the environment. Application of fertilizer at the wrong time could lead to low fertilizer use efficiency and could even result to crop damage minimizing profitability.

Nitrogen is among the major nutrients applied in large amounts for crop production. Low plant N uptake is widely known to occur which is a consequence of processes of transformation and losses of N in the soil such as immobilization, denitrification, surface volatilization, leaching or erosion if heavy rains are experienced (Nielson, 2006). Besides using suitable technology such as slow and controlled release, urease inhibitors and nitrification inhibitors, management practices such as timing of application in relation to stage of growth of the crop is crucial in enhancing uptake.

According to Nielson, 2006, the potential of nitrogen loss is influenced by prevailing weather conditions at the time of application and soil type. Losses can happen more readily in sandy soils than in fine textured soils. Nitrate which is the most common available form of plant N is water soluble and easily lost through leaching with the movement of water. Ammonium on the other hand attaches to the soil particles and is not easily lost (Zhou et al., 2006). Clay soils with smaller particles have larger surface area where the NH_3^- ions adhere. These soils carry more water than courser ones, holding back nitrates which are easily leached. Timing of application in relation to precipitation and irrigation is fundamentally important to avoid leaching and surface runoff.

Surface applied nitrogen is also easily lost into the atmosphere through the process of volatilization. This is the process where NH_4^+ is converted to ammonia gas (NH_3) and lost from the plant soil-system. It is influenced by high ambient temperatures, rainfall, sunshine and soil pH greater than 7.0 (Tremblay *et al*., 2001). Time of application should consider these factors as they are critical in determining N loss through ammonia gas.

Denitrification is greatest in poor drained soils where anaerobic conditions prevail. Some microorganisms extract nitrogen from NO_2^- or NO_3^- instead of atmospheric O_2. Studies have revealed that thisprocess is greatest in N fertilized, irrigated soils (Tremblay *et al*., 2001). These studies showed a 10 – 30% loss of N through this process. Heavy soils that are poorly drained present the greatest risk to losses due to denitrification. The longer the fertilizer is in the soil the higher the risk of loss to these factors.

Therefore to achieve economic gains and environment conservation, efficient N use should be taken into account and matching the supply with crop demand is an effective way to achieve this (Cui *et al*., 2010). Ideally, nitrogen fertilizer should be applied just before the crops peak demand for N (Jones *et al.,* (2011). Most of the nitrogen and phosphorus used for grain/bulb/seed fill comes from the stem, leaves and head rather than directly from the soil. These nutrients should therefore be applied early enough to allow for more vegetative growth which can then provide nutrients during grain/bulb/seed fill. Low nutrient uptake early in a plants growth lowers nutrient quantity for the grain/bulb/seed fill, affecting both yield and quality.

The best time for nutrient application is dictated by the crops uptake pattern. Each nutrient has an individual uptake pattern in each crop. However, in all crops, maximum N uptake occurs in periods of maximum vegetative growth (Scharf and Lory, 2006). Nitrogen fertilizers should therefore be applied at the beginning of rapid growth. During this time there is maximum uptake and minimal losses to the environment and this becomes increasingly important to yield maximization, profitability and environmental conservation.

A study by Thangasamy, 2016, showed that the rate of uptake of N and K by an onion crop increased rapidly 15 - 45 days after transplanting reaching maximum at 45. Application after 60 days after transplanting delayed bulb development, increased collar thickness, number of twin and multiple bulbs and reduced storage quality. Hence too early application can lead to losses when the crop has not yet developed to put into use the nutrients. If not applied at the right time, 50 – 60% losses of N can be realized (Sela, 2018). Good timing is important for quick uptake to minimize the time nitrogen is in the soil as well as for its optimal use. Proper management of time of application gives enough nutrients to maximize yields and profits while minimizinglosses to the environment.

In Kenya, farmers apply a blanket recommendation of 78 kg N/ha two weeks after transplanting. However, farmers are observed to fertilize the crop again at the late stages of bulb development perhaps to compensate for losses incurred through leaching or merely from the anxiety that the yields will be less than needed to maintain profitability (MOA, 2013). This prompts the question as to whether the 78 kg N/ha is adequate and what implication the late application of fertilizer during bulb development has on yield and quality of onion.

CHAPTER THREE

THE INFLUENCE OF N FERTILIZER RATES AND TIME OF APPLICATION ON GROWTH AND YIELD OF ONION

3.1. Abstract

The productivity of onion is low in Kenya averaging 15 – 20 tons/ha due to use of low yielding varieties, low soil nutrients and poor agronomic practices among them improper use of fertilizers. An experiment was conducted at Food Crops Research Centre (KALRO-Kabete) in 2014 – 2015 to evaluate different nitrogenratestopdressed at different times on growth and yield of the onion crop. The treatments comprised of five N rates (0, 26, 52, 78 and 104 kg N/ha) and four times of application (3, 6, 9 and 12 weeks after transplanting). Two commonly grown varieties of onion, Red Creole and Red Tropicana F1 Hybrid were used. The experiment was laid in a randomised complete block design with a split-split plot arrangement and replicated three times. The varieties were the main plots, the fertilizer rates the sub plots and the time of application the sub-sub plots. Significant differences among nitrogen rates and time of its application were obtained in all the parameters studied. Nitrogen at 104 kg/ha applied at 6 weeks after transplanting gave significantly higher results with regard to plant height, number of leaves, bulb ratios, bulb diameter, bulb sizes, average bulb weight, yield and marketable yield. Six weeks after transplanting was the best application time with regard to most parameters and maturity of the crop. Yields increased linearly with increased N rates but declined by over 23% with late application at 12 weeks. Red Tropicana F1 hybrid performed better than Red Creole variety with regard to most parameters especially total and marketable yield. Nitrogen applied at the right time improved growth and increased yields. Since the yield response was linear, higher rates should be evaluated to get the optimal rate.

Keywords: Plant Height, Leaf number, Crop maturity, bulb weight, Marketable sizes, Bulb ratios and diameters

3.2. Introduction.

Onion is an important commercial vegetable crop in Kenya with an enormous potential. The crop is produced year round for domestic use with a little exported to specialized markets. It is an important source of income for many farmers and an important crop for cross border trade (Kimani et al, 1993). However, the productivity is low, mainly due to use of low yielding varieties and application of poor agronomic practices among them improper use of fertilizers.

Onions have a shallow root system and when environmental conditions are good, nutrients become the limiting factor to production. Hence onions often require fertilization to which they respond well (Rizk *et al.,* 2012). Applying sufficient plant nutrients and use of suitable varieties are critical to sustain increased production under declining soil fertility conditions and reducing land for cultivation.Among all nutrients, nitrogen is the most important and also the most limiting to onion production. It has been reported by several workers to cause significant improvement in growth and bulb yield. Henerisken, 1987 found significant increase in marketable yield of onion bulbs up to 120 kg /ha of N application. Experimenting with higher levels of up to 150 kg N/ha, Kumar *et al.*,1998 reported good growth performance with significant increase in plant height, leaf diameter, leaf number/plantand length of leaves. He also reported improved bulb maturity time and significantly increased bulb diameters and total yield. Abdissa *et al*., 2011 reported a significant reduction in the number of bolters at 92 kg N/ha but reported an extended physiological maturity and a significant increase in splitted bulbs. In Kenya, Nguthi, 1993 reported a linear yield response up to 39 kg N/ha but no significant effect on splitting of bulbs, bulb weight or neck-thickness.

The current blanket recommendation of 300 kg/ha CAN(78 kg N/ha) for onion production in Kenya (Oseka and Dienya, 2015) is inadequate since yields are still very low. Growers are reported to fertilize the crop at the late stages of bulb growth perhaps to compensate for losses incurred through leaching or merely from the anxiety that yields will be less than needed to maintain profitability. Therefore to optimize onion productivity a new recommendation for N and time of topdressing is required. This study sought to address this very pertinent requirement.

3.3. Materials and Methods

3.3.1. Experimental site

Two experiments were carried out at Food Crops Research Centre (KALRO- Kabete), for two seasons in 2014 and 2015 with supplemental drip irrigation. The site is situated at longitude 36^{o} 46'E and latitude 01^{o} 15'S, eight km North West of Nairobi city. It stands at an altitude of 1,787m above sea level in the upper Sub-humid agro-ecological zone UM3, with a bimodal rainfall distribution, the first season occurring from mid-March to May and the second seasonfrom mid-October to December. The mean annual temperatures range from 18 to 21^{o}C (Jaetzold *et al.*, 2006).

The soils are classified as Humic Nitisols (UNESCO, 1974) or Ustic Tropohumult (USDA, 1975). The top soil extends up to 15 cm depth and is dark reddish brown in colour and well drained. The experimental site had been fallow for two years. Soil testing was carried out prior to planting for major nutrients such as N, P, K, Calcium, Magnesium, Cation Exchange Capacity (CEC) and pH. Weather data for the period the crop was growing was collected from Kabete meteorological station situated near the experimental plots (Appendix 6).

3.3.2. Planting material

Two popular red varieties of oniongrown in Kenya, Red Creole and Red Tropicana F1 hybrid were used for the study. Seedlings grown from certified seeds on raised beds in a nursery were used.

The two varieties comprise the bulk of onions found in the local market but the Red Creole is of greater economic importance. Most small scale farmers plant this variety because the planting seed is cheaper while the hybrids including the Red Tropicana F1 Hybrid are very expensive and out of reach for most farmers.

The Red Creole variety has a deeper red colour with a flat round /rounded squat shape. The rings are tight and bulbs are firm but only slightly pungent. The Red Tropicana F1 hybrid on the other hand is lighter in colour, red to purplish. The bulbs are larger (thick) and flat with firm fresh which is more pungent. In the field, the leaves of Red Creole are bluish green while those of Tropicana F1 hybrid are green. The Red Creole variety is reputed to have better storage qualities while the Red Tropicana F1 Hybrid is higher yielding and more resistant to pests (*Thrips tobacci*) and diseases. Both are short day varieties and mature after 165 days.

3.3.3. Land preparation and nursery planting

The experimental plots were ploughed to a depth of 15 – 20 cm. Harrowing was done using a tine harrow to obtain good soil tilth. Big soil clods were broken mannually and remnants of weeds removed using hoes. The plots were raked to obtain a reasonably uniform and level seedbed for planting.

Fine seedbed 1 x 10 m for each variety was prepared for raising the seedlings. The soil was well worked, freed from trash, smoothened and leveled for even distribution of water. The seedbed was also raised 10 cm high to enhance good drainage.

Certified seeds sourced from reputable seed merchant was planted in drills, made 30cm apart. At planting diammonium phosphate fertilizer was used at 200 kg/ha. The soil had prior been mixed with 5 kg/m^2 of chicken manure and a nematicide.

After planting, watering was done once or twice dairy depending on weather conditions. Beds were mulched to avoid excess moisture loss. Weeds were mechanically controlled while diseases and pests were prevented by use of pesticides. Seedlings were hardened before transplanting for 7 – 10 days by withholding water.

3.3.4. Experimental layout and treatment allocation

The main treatments of the experiment comprised nitrogen rates, different times of application and two onion varieties. Five Nitrogen rates 0, 26, 52, 78 and 104 kg N/ha applied as 0, 100, 200, 300 and 400 kg Calcium Ammonium Nitrate (CAN)/ha were used. The recommended rate is 300 kg CAN/ha so the rates included at least one rate above the recommended. These rates were applied at 3, 6, 9 and 12 weeks after transplanting. The design of the experiment was a randomized complete block design (RCBD) with a split-split plot arrangement and replicated three times. The two varieties were the main plots, the five nitrogen levels the sub-plots and the four times of application the sub-sub-plots. Allocation of treatments and experimental material on the plots and blocks was through randomization according to principals and procedures of Steel and Torrie, (1990).

The experimental area was 17.6 x 33 m(580.8 m^2) with the blocks separated by three metres and the main plots in each block separated by 2 metres while the sub-plots and sub- sub plots were separated by 1 metre from each other. Each block occupied an area of 9 x 17.6 m (158.4 m^2) including paths with 40 sub-sub plots. The main experimental area had 120 sub-sub plots. Main plots were 9 x 7.8 m (70.2 m^2), sub plots 1 x 7.8 m (7.8 m^2) and sub-sub plots 1 x 1.2 m (1.2 m^2).

In a sub-sub plot, each variety was planted in 5 rows of 10 plants each spaced at 30 x 10 cm giving apopulation of 50 plants. Within a sub-sub plot, the outer two rows were regarded as guard plants. Outside the main experimental area, more guard plants were planted in 6 lines/rows on each side.

3.3.5. Transplanting and treatment application

Transplanting was done 7-8 weeks after nursery planting when seedlings had attained pencil thickness in diameter. During transplanting,TSP fertilizer applied at 200 kg/ha. The fertilizer was placed on well prepared furrows and mixed intimately with the soil to avoid damaging the seedlings. Watering to field capacity was done soon after transplanting to facilitate establishment. Gaping was done after two weeks

The time of treatment application was structured in such a way that the onions received N after transplanting, before, during and after bulbing. This is the active growth period of the crop. To avoid damaging the seedlings, the fertilizer was side dressed. To minimize on N losses to water, fixation and air, a furrow was made next to the plant rows and the fertilizer was placed near the plant roots along the furrows and later covered with soil. The fertilizer was applied once for the whole amount

Routine cultural practices on weeds, pests and disease control was done as recommended. The crop was watered regularly using drip irrigation in absence of rain fall as was deemed necessary.

3.3.6. Data collection and harvesting

Harvesting was done when 50 – 70% of the plants had showed weakened pseudostems (fallen over). Sampling was done from the inner 3 rows with 5 inner plants taken from each row giving a sample of 15 onions from each sub-sub plot.Parameters measured during the study included leaf number, plant height, number of leaves, bulb ratios, % fallen at maturity, total and marketable yield, bulb sizes, bulb weight and bulb diameter, neck thickness, number of splitted bulbs and % bolters. Procedures taken for each parameter were as follows.

3.3.6.1. Growth parameters measurements

3.3.6.1.1. Plant height

Plant height was taken from the base of the plant to the tip of the longest leaf using a tape. This was done just before leaf fall.

3.3.6.1.2. Number of leaves

Data on leaf number commenced 3 weeks after transplanting and continued to be monitored every 3 weeks until time of harvest. The number of fully developed leaves capable of photosynthesis (> 5cm) were visually counted from the 15 plants within the sampling area.

3.3.6.1.3. Bulb ratios

The diameter of the neck and bulb of six labelled onions in each plot was measured every 4 weeks using a vernier caliper. The soil was removed carefully not to damage the roots in order to take the diameter from the widest region of the bulb as the plant was growing. Bulb ratio was calculated

by using the formula – Bulb ratios = $\frac{\text{Bulb diameter}}{\text{Neck diameter}}$

3.3.6.1.4. Crop maturity (% Fallen tops)

Physiological maturity at harvest is exhibited by tops falling over often called ‘leaf or neck fall’ (Brewster, 1994). Tops fallen over were visually counted at every plot when 50 - 75% of tops in the main experimental area were fallen. Percentage fallen tops were calculated in reference to the total number of plants in a plot.

3.3.6.2. Yield parameters measurements

3.3.6.2.1. Total weight

The fresh weight of the whole sample was taken soon after harvesting using an electronic weighing scale. The weight was converted to t /ha before undertaking data analysis.

3.3.6.2.2. Marketable yield

The marketable yield was determined by removing from the sample split bulbs, bolters, rotted and sprouted bulbs and reweighing the remaining sample. Bulbs with a diameter less than 20 cm were also considered as unmarketable. The weight was converted to t/ha to indicate the marketable yield.

3.3.6.2.3. Average bulb weight

It was determined from the average of the sample weight in each treatment by using the formula: - Total weight of bulbs/number of bulbs in the sample.

3.3.6.2.4. Bulb diameter

The diameter of the bulbs was taken at right angles to the longitudinal axis at the widest circumference of the bulb using a vernier caliper.

3.3.6.2.5. Bulb grades

After taking the diameter of the bulbs, the onions were grouped according to the following sizes:

- Size A: Less than 40 mm diameter – small (rejects)
- Size B: 40 – 80 mm diameter – medium size (most marketable)
- Size C: Greater than 80 mm diameter – large (for processing)

3.3.7. Soil analysis

A zig-zag pattern was adopted for collection of the soil using a soil auger. Twelve samples from 12 points were collected from the plot at 20 cm depth after which they were mixed thoroughly to obtain a composite sample. A sub sample of 500 g was scooped from this and taken to the lab for analysis. The analysis was performed at Food Crops Research Centre, KALRO - Kabete.

Before analysis the soil was dried, crushed and sieved. A working sample of 50 g was set aside. The soil was analysed for physical and fertility characteristics as shown in Table 2.

Table 2. Physical and fertility analysis conducted on soil from plots of experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Test	**Method**	**Reference**
Physical Analysis % Sand, Clay and Silt	Hydrometer method	Klute A. (eds), 1986
Chemical analysis Available nutrients, P, K, Na, Ca, Na, Mg, Mn	Melhlich double acid	Melhlich, *et al.*, 1962
Total Organic Carbon	Colorimetric method	Anderson, J. M., 1993
Total Nitrogen	Kjeldahl method	Bremner *et al.*, 1982
CEC	Ammonium acetate method	Rhodes, *et al.*, 1982
pH	pH meter	Melhlich, *et al.*, 1962
Available trace elements	HCL extraction method	Hinga, *et al.*, 1980

3.3.8. Data analysis

All measured parameters were subjected to analysis of variance (ANOVA), using Genstat statistical program, 15th edition (VSN International, 2012). Significance of differences between means of treatments were evaluated using Fishers protected LSD at 5% probability level ($p<0.05$). Correlation analysis was also carried out to determine correlations between parameters. A multiple linear regression analysis was carried out to model the relationship between the yield and the treatments.

3.4. Results

3.4.1. Physico-chemical properties of the experimental site

The analysis showed that the soil of the site was sandy clay loam in texture with an acidic (pH 4.35) reaction. Onions can grow in soils with up to pH 4.0, but the optimum ranges between 6.0 and 8.0 (Nikus and Mulugeta, 2010). The soil organic carbon and total nitrogen were rated as low. This means that the soil was poor in supplying organic carbon and also as a source of mineralized nitrogen for uptake by the crop hence external sourcing would be appropriate. The results showed that P, K, Mg, Na, Ca, the micronutrients Mn, Cu, Zn and total Cation Exchangeable Capacity (CEC) were adequate for onion production (Table 3).

Table 3.Physico-chemical properties of soil from the plots of the field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Particulars	**Top0-20cm**	**Rating**
Sand (%)	58	
Silt (%)	8	
Clay (%)	34	
Soil textural class		Sandy Clay Loam
Total N, (%)	0.05	Low
Organic carbon (%)	0.46	Low
pH (1:1: Soil: Water)	4.35	Acidic
CEC (me %)	0.5	Adequate
$P_{\text{Melhlich 1}}$ (ppm)	55	Adequate
Magnesium (me %)	1.22	Adequate
Sodium (me %)	0.049	Adequate
Calcium (me %)	2.9	Adequate
Potassium (me %)	0.80	Adequate
Manganese (me %)	0.64	Adequate
Zinc (ppm)	5.00	Adequate
Copper (ppm)	89.9	Adequate

3.4.2. Effect of nitrogen fertilizer and time of application on growth parameters

3.4.2.1. Plant Height

The rate of nitrogen and time of application significantly ($P<0.001$) influenced the plant height of the onion crop. There were significant interactions among fertilizer rate and time of application in both seasons. There were significant ($P\leq0.05$) differences among the varieties only in season two (Table 4,Table 5 and appendix 2.1.1. and 2.1.2.).

Plant height increased significantly ($P<0.001$) with increasing levels of fertilizer in both seasons with level 104 kg N/ha registering the highest mean height of 43.49 cm in season one and 43.06 cm in season two. The control plots recorded the lowest mean height of 33.48 cm in both seasons (Table 4). Results also show that early application of fertilizer affects plant height positively with early application at 6 weeks after transplanting recording the highest mean height of 40.63 cm in season one and 40.37 cm in season two. Late topdressing at 12 weeks after transplanting gave the lowest mean height of 37.50 cm in season one and 37.19 cm in season two. However, application of fertilizer very early at 3 weeks after transplanting was not as good as application at 6 weeks but results showed significantly higher mean heights compared to application at 9 or 12 weeks after transplanting. The performance of the two varieties was only significantly ($P\leq0.05$) different in season two. The Red Tropicana F1 hybrid recorded the highest mean height of 40.842 cm in season one and 40.073 cm in season two compared to Red Creole variety which recorded 37.549 cm in season one and 37.838 cm in season two.

Table 4. Effect of nitrogen rate, time of application and variety on plant height in experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	**Plant height (cm)** **Season 1**	**Plant height (cm)** **Season 2**
Nitrogen (kg N/ha)		
0	33.48 e	33.48 e
26	37.54 d	37.44 d
52	39.91 c	39.57 c
78	41.56 b	41.22 b
104	43.49 a	43.06 a
LSD (0.05)	0.4660	0.5427
Time (weeks)		
3	39.63 b	39.50 b
6	40.63 a	40.37 a
9	39.15 b	38.77 c
12	37.50 c	37.19 d
LSD (0.05)	0.4958	0.3483
Variety		
Red Creole	37.55	37.84 b
Red Tropicana F1 hybrid	40.84	40.07 a
LSD (0.05)	ns	1.1215
CV%	2.4%	1.7%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefiecient of Variation for plant height
ns = Not significant

Table 5. Effect of interaction of nitrogen rate, time of application and variety on plant height in experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

		Plant height (cm)			
		Season 1		Season 2	
Nitrogen Rate (Kg/ha)	Time in (Weeks)	Red Creole	Tropicana	Red Creole	Tropicana
0		31.4	35.6	32.3	34.7
	3	36.5	39.6	36.8	38.9
26	6	36.8	40.2	37.8	39.6
	9	36.4	38.4	36.0	38.6
	12	35.3	37.2	35.0	36.9
52	3	38.6	42.3	39.0	41.4
	6	40.2	43.2	40.3	42.6
	9	38.6	40.9	38.2	40.1
	12	36.2	39.3	36.6	38.4
78	3	40.5	44.3	40.5	43.3
	6	40.4	45.0	42.0	44.5
	9	40.4	43.0	39.8	42.1
	12	37.9	40.9	38.1	39.4
104	3	42.1	45.9	42.6	45.2
	6	43.6	47.2	43.6	46.0
	9	42.2	45.0	41.8	44.4
	12	39.6	42.4	39.6	41.3
LSD F		0.47		0.54	
LSD T		0.50		0.35	
LSD V		Ns		1.12	
LSD FxT		1.05		0.85	
LSD FxV		5.06		Ns	

LSD = Fishers Least Significant Difference at 5% probability level; Ns = Not significant
F = Fertilizer nitrogen
T = Time of application
V = Variety

3.4.2.2.Number of leaves

The rate of nitrogen fertilizer and time of application had significant ($P<0.001$) effect on the number of leaves per plantin both seasons butthe interaction was not significant . The two varieties did not show significant differences in both seasons (Table 6 and Appendix. 2.2.1 and 2.2.2)

The effect of nitrogen fertilizer on the number of leaves per plant was very highly significant ($P<0.001$) in both seasons. Maximum leaf number of 8.472 in season one and 8.681 in season two was obtained with the highest application rate of 104 kg N/ha while the lowest number of 7.449 in season one and 7.406 in season two was recorded with the control (0 kg N/ha). However, increasing fertilizer from 52 kg N/ha did not cause a significant increase in the number of leaves in the two seasons (Table 6).

The time of application had a very highly significant ($P<0.001$) effect in season one. In season two the time of application was only significant at $P\leq0.05$. Early application of fertilizer favoured more leaf formation with the highest leaf number of 8.258 recorded at 6 weeks after transplanting in season one and 8.429 recorded at 3 weeks after transplanting in season two. The lowest number of leaves (7.869 in season one and 7.904 in season two) was recorded with late application at 12 weeks after transplanting. there was no significant difference in the number of leaves between application at 3 and 6 weeks after transplanting (Table 6).

Table 6. Effect of nitrogen rate, time of application and variety onnumber of leaves in field experiment conducted at NARL, Kenya in 2014 and 2015 saesons

Treatment	Leaf number Season 1	Leaf number Season 2
Nitrogen (kg N/ha)		
0	7.499 b	7.406 c
26	7.887 b	8.135 b
52	8.336 a	8.405 ab
78	8.415 a	8.471 a
104	8.472 a	8.681 a
LSD (0.05)	0.4100	0.3140
Time (weeks)		
3	8.240 a	8.429 a
6	8.258 a	8.309 ab
9	8.121 ab	8.231 b
12	7.869 b	7.908 c
LSD (0.05)	0.2784	0.1800
Variety		
Red Creole	8.397 a	8.10 a
Red Tropicana F1 hybrid	7.847 a	8.34 a
LSD (0.05)	2.9196	1.2314
CV%	6.6%	4.2%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Time = weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for number of leaves

3.4.2.3. Bulbing ratios

Nitrogen and time of application had a very highly significant ($P<0.001$) effect on the bulbing ratios of the onions in both seasons. Howeve, there was a significant interaction betwenn the two factors on the bulbing ratios in season two. The two varieties were only significantly ($P \leq 0.05$)

different in season two(Table 7, Fig. 1 and Appendix 2.3.1 and 2.3.2).

Bulbing ratios increased significantly as the applied rates of nitrogen increased so that the highest mean ratios of 2.47 and 3.29 in season one and two respectively were obtained with the highest rate of 104 kg N/ha. However, in season two the effect of fertilizer depended on the time of application. The lowest mean ratios of 2.08 in season one and 2.91 in season two were obtained with 0 kg N/ha (Table 7).

The effect of time of application showed an inverse relationship with the bulbing ratios declining significantly with delayed time of application from 3 weeks to 12 weeks after transplanting (Fig 1). The highest mean ratios of 2.34 in season one and 3.23 in season two were obtained when fertilizer was applied at 3 weeks after transplanting while the lowest mean ratios of 2.19 in season one and 3.04 in season two were obtained when fertilizer was applied at 12 weeks (Table 7).

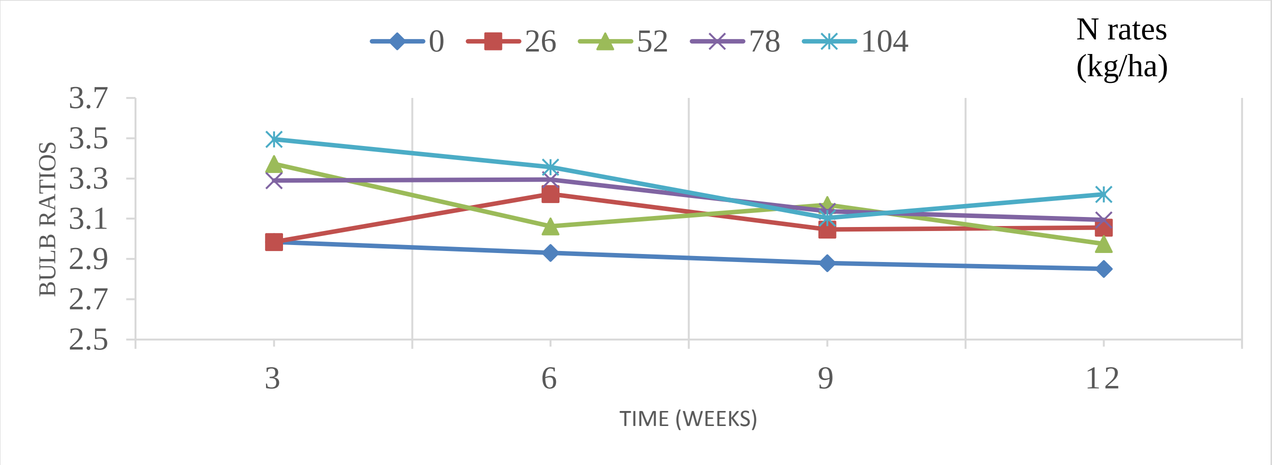


Fig 1. Interaction effect of fertilizer and time of application on bulb ratios in experiment conducted at NARL, Kenya in short rains of 2015.

Red Tropicana F1 hybrid had higher mean bulbing ratios in both seasons, 2.39 in season one and 3.51 in season two compared to Red Creole variety which had 2.18 in season one and 2.74 in season two. There were significant difference (P≤0.05) in season two (Table 7)

Table 7. Effect of nitrogen rate, time of application and variety on bulbing ratios in field experiment conducted at NARL, Kenya in 2014 and 2015 saesons.

Treatment	**Bulb ratios Season 1**	**Bulb ratios Season 2**
Nitrogen (kg N/ha)		
0	2.08 d	2.91 d
26	2.22 c	3.08 c
52	2.31 bc	3.15 bc
78	2.33 b	3.20 ab
104	2.47 a	3.29 a
LSD (0.05)	0.1119	0.1227
Time (weeks)		
3	2.34 a	3.23 a
6	2.33 ab	3.17 a
9	2.27 b	3.07 b
12	2.19 c	3.04 b
LSD (0.05)	0.0727	0.1000
Variety		
Red Creole	2.18	2.74 b
Red Tropicana F1 Hybrid	2.39	3.51 a
LSD (0.05)	ns	0.4332
CV%	6.2%	5.9%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Time = weeks after transplanting when the fertlizer was applied
CV = Coefficient of variation for bulbing ratios
ns = Not significant

3.4.2.4. % Fallen tops (Crop maturity)

There was a very highly significant ($P<0.001$) effect of nitrogen fertilizer application on maturity of the onion crop in the first season but not in the second season. The time of nitrogen application on the maturity of the onion crop was also very highly significant ($P<0.001$) in both seasons. There were significant differences among the varieties only in season two. The interaction effects were not significant in the two seasons(Fig. 2 and Appendix 2.4.1 and 2.4.2).

Generally there was a progressive increase in tops fallen over with increasing nitrogen rates. The control plots registered the lowest percentage of plants fallen over in both seasons (15.63 and 31.00 in season one and two respectively). Plants top-dressed with nitrogen recorded a higher percentage mean of fallen tops at harvest with level 104 kg N/ha recording the highest mean of 38.17 in season one and level 78 kg N/ha recording 40.67 in season two (Fig. 2).

Late nitrogen application delayed maturity with the lowest means recorded at 12 weeks after transplanting (11.67 in season one and 37.27 in season two). The highest means of crop fallen were recorded when application was done at 6 weeks after transplanting in both seasons (46.7 in season one and 49.27 in season two)

There was no significant difference among the two varieties in season one but in season two, Red Tropicana had a significantly ($P \leq 0.05$) higher % of fallen tops(Fig. 2).

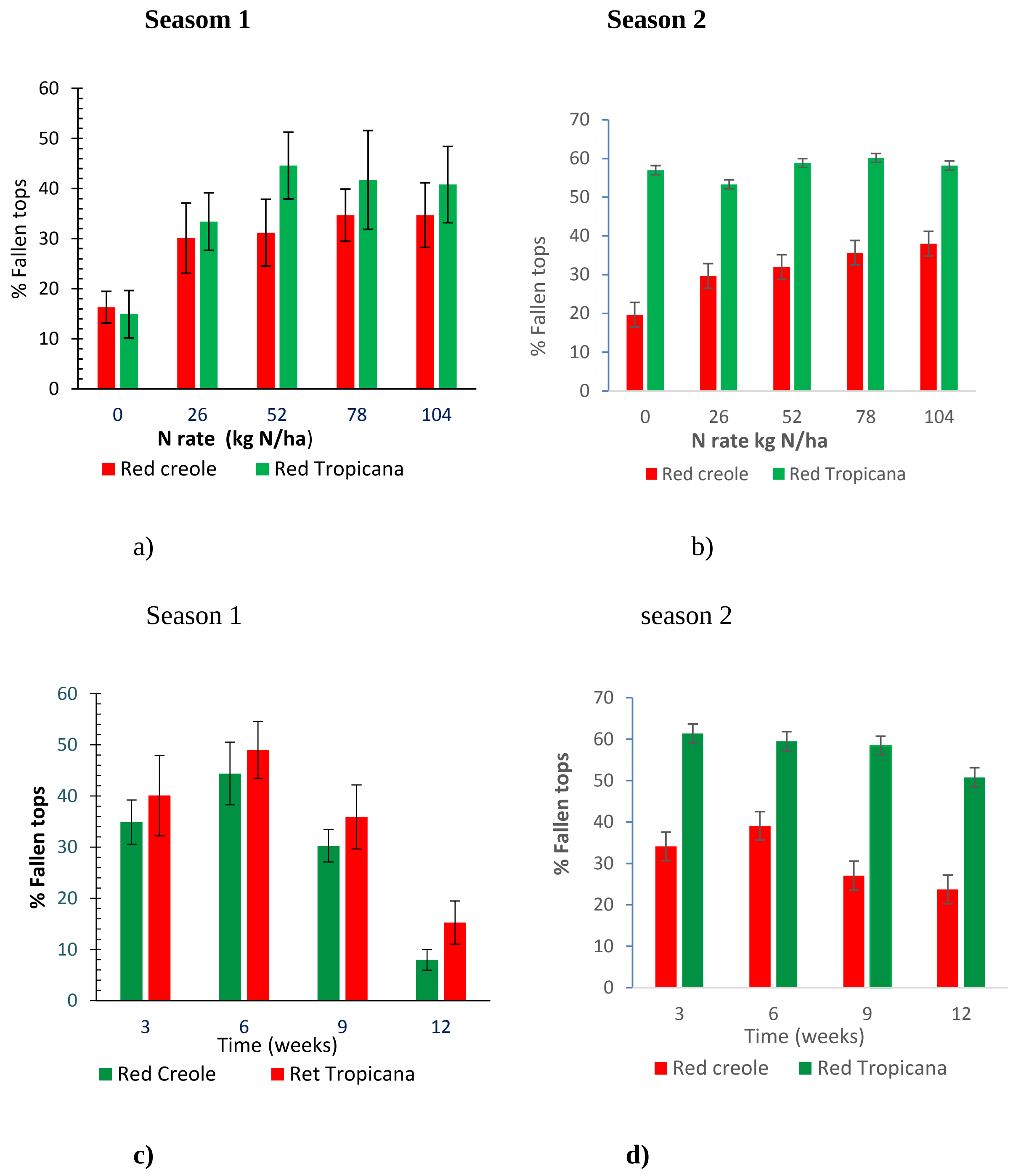


Fig. 2. Effect of N rates (a and b) and time of application(c and d) on % fallen bulbs taken in field experiment conducted at NARL, Kenya during 2014 and 2015 seasons

3.4.3. Effect of nitrogen fertilizer and time of application on yield and yield components

3.4.3.1. Total bulb yield

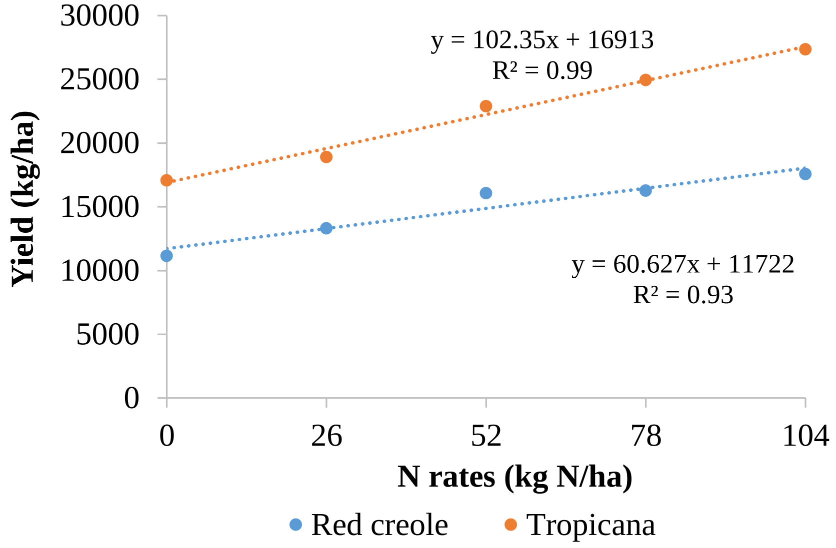
Both nitrogen and time of application significantly ($P<0.001$) influenced the total bulb yield of the onion crop, the result in both seasons. However, there was no significant interactionof the two factors. The main effect of variety was significant ($P\leq0.05$) only in season two (Table 8 and Appendix 2.5.1 and 2.5.2)

Total bulb yield increased significantly in response to the increasing rate of nitrogen (Table 8). The highest total bulb yield was attained at the rate of 104 kg N/ha in both seasons (22,459 and 23,652 kg/ha in season one and two respectively).

The lowest total bulb yield was obtained by control plots (14,123 kg/ha in season one and 12,864 kg/ha in season two). On average N fertilizer application resulted in a yield increase of 59% in season one and 84% in season two over the control.The yield response curves (Fig. 3) showed a linear relationship in both seasons where total bulb yield increased linearly with increased nitrogen rates .

Results of time of application show decreasing mean yields with late application of N fertilizer (Table 8) with the lowest being recorded at 12 weeks after transplanting (15,660 and 15,044 kg/ha in season one and two respectively). The highest yields were recorded with early transplanting at six weeks, with 20,476 kg/ha recorded in season one and 21,079 kg/ha in season two. This translates to a yield decrease of 30.75% in season one and 40.12% in season two due to late application at 12 weeks after transplanting.

a)Season 1



b) Season 2

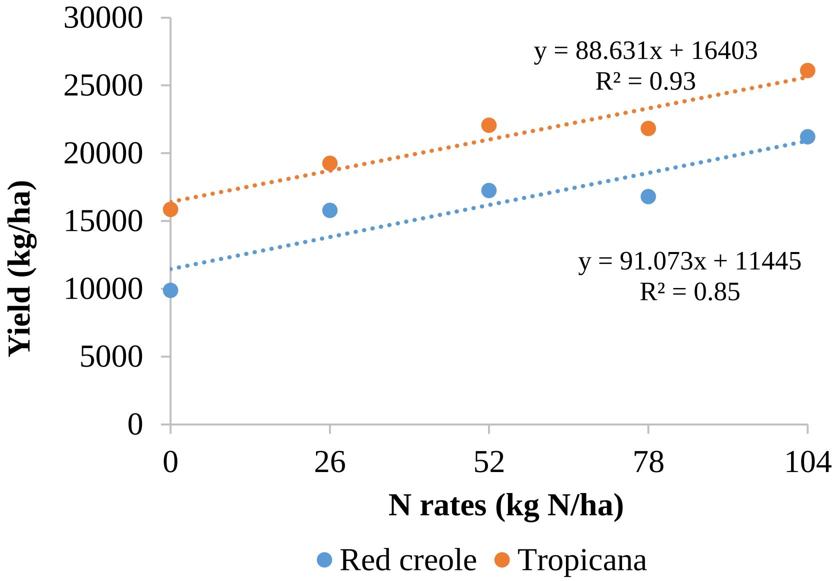


Fig. 3. Yield response curves of Red Creole and Red Tropicana F1 hybridto N rates in field experiment conducted at NARL, Kenya in 2014 (a) and 2015 (b) seasons.

In both seasons, Tropicana F1 hybrid recorded higher yields than Red Creole variety and the difference was significant (P≤0.05) in season two. The mean total bulb yield for Tropicana F1 hybrid was 22,236 kg/ha in season one and 21,012 kg/ha in season two while the respective total bulb yield of Red Creole was 14,874 and 16,181 kg/ha (Table 8).

Table 8. Effect of nitrogen rate, time of application and variety on total bulb yield in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons

Treatment	**Total bulb yield (kg/ha)** **Season 1**	**Total bulb yield (kg/ha)** **Season 2**
Nitrogen (kg N/ha)		
0	14,123 c	12,864 d
26	16,098 c	17,516 c
52	19,481 b	19,300 bc
78	20,612 ab	19,651 b
104	22,459 a	23,652 a
LSD (0.05)	2,099.4	2,119.1
Time (weeks)		
3	19,429 ab	19,881 a
6	20,476 a	21,079 a
9	18,655 b	18,383 b
12	15,660 c	15,044 c
LSD (0.05)	1,728.1	1,257.6
Variety		
Red Creole	14,874	16,181 b
Red Tropicana F1 hybrid	22,236	21,012 a
LSD (0.05)	ns	2,799.9
CV%	18%	13.1%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different atP≤0.05
Time = weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for total bulb yield
ns = Not significant

3.4.3.2. Marketable yield

Nitrogen rates and time of application significantly ($P<0.001$) influenced marketable yield in both seasons. Effect of variety was only significant ($P\leq0.05$) in season two. The interaction of fertilizer and that of variety influencedmarketable yield significantly ($P<0.01$) in season one(Table 9, Table 10 and appendix 2.6.1 and 2.6.2).

Although marketable yield increased significantly with increasing fertilizer rates in both seasons, there was no significant difference between level 26 kg N/ha and the control (0 kg N/ha) in season one. However, the lowest marketable yield of 12,916 kg/ha in season one and 12,804 kg/ha in season two were recorded from plots that received no N application while the highest marketable yield of 19,770 and 23,175 kg/ha in season one and two respectively were recorded from plots with the highest rate applied of 104 kg N/ha. This translated to 53 and 81% increase in season one and two respectively, in marketable yield over the control (Table 9).

The time of application also influenced the marketable yield in both seasons, the yield decreasing significantly ($P<0.001$) with late application of fertilizer. However, there was no significant difference between topdressing at 3 and 6 weeks after transplanting. Thus the lowest marketable yield of 13,467 kg/ha in season one and 14,904 kg/ha in season two were recorded when the crop was top dressed at 12 weeks after transplanting. The highest marketable yield of 18,070 and 19,816 kg/ha in the first and second season respectively were obtained when the crop was top dressed at 6 weeks after transplanting. The corresponding marketable yield decrease experienced due to late application was 34.18% in the first season and 32.96% in the second season (Table 9).

Varieties differed significantly ($P\leq0.05$) only in season two but in both seasons, Red Tropicana F1 hybrid recorded higher marketable yield of 21,785 kg/ha in season one and 20,973 kg/ha in season two. The Red creole variety recorded lower marketable yield of 10,789 and 15,154 kg/ha in season one andtwo respectively. Over all, marketable yield recorded in the second season was higher than that recorded in the first season.

Table 9. Effect of nitrogen rate, time of application and variety on marketable yield of bulbs in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	**Marketable yield (kg/ha)** **Season 1**	**Marketable yield (kg/ha)** **Season 2**
Nitrogen (kg N/ha)		
0	12,916 c	12,804 c
26	14,264 c	17,321 b
52	17,396 b	18,160 b
78	17,087 b	18,856 b
104	19,770 a	23,175 a
LSD (0.05)	1,629.8	2,288.6
Time (weeks)		
3	17,471 ab	19,804 a
6	18,070 a	19,816 a
9	16,139 b	17,728 b
12	13,467 c	14,904 c
LSD (0.05)	1,609.4	1,491.8
Variety		
Red Creole	10,789	15,154 b
Red Tropicana F1 hybrid	21,785	20,973 a
LSD (0.05)	ns	2,477.2
CV%	19.1%	16.0%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at$P \leq 0.05$
Time = Weeks after transplanting when the fertilizer was applied
CV = Coeficient of variation of marketable yield
ns = not significant

Table 10. Effect of interaction of fertilizer (F) and variety(V) on marketable yieldin field experiment conducted at NARL, Kenya in 2014 season.

	Marketable yield (kg/ha)	
	Season 1	
Nitrogen Rate (Kg/ha)	Variety	
	Red Creole	Red Tropicana
0	9,198	16,633
26	9,633	18,894
52	11,330	23,463
78	11,263	22,911
10	12,519	27,022
LSD FxV	12,836.3	

LSD FxV = Least significant difference for the interaction of fertilizer and variety

3.4.3.3. Average bulb weight

The main effects of nitrogen fertilizer and time of application both significantly ($P<0.001$) influenced the average bulb weight in both seasons. However there was no significant interaction among the two factors. The two varieties only significantly ($P\leq0.05$) differed in season two. (Table 11. and Appendix 2.7.1 and 2.7.2)

Increasing the rate of nitrogen application significantly ($P<0.001$) increased the average bulb weight (Table 11). However the weight decreased with late application of fertilizer with application at 12 weeks after transplanting registering the lowest (46.96 g in season one and 45.13 g in season two). The highest average bulb weight of 61.43 g in season one and 63.85 g in season two were obtained when the fertilizer was applied early at 6 weeks after transplanting (Table 11).

Varietal differences were only significant ($P\leq0.05$) in season two with Red Tropicana F1 hybrid recording higher average bulb weight.

Table 11. Effect of nitrogen rate, time of application and variety on average bulb weight in field

experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	Average bulb weight (g) Season 1	Average bulb weight (g) Season 2
Nitrogen (kg N/ha)		
0	42.37 c	38.93 d
26	48.30 c	52.56 c
52	58.44 b	57.90 bc
78	61.84 ab	59.70 b
104	67.38 a	70.96 a
LSD (0.05)	6.298	6.885
Time (weeks)		
3	58.29 ab	59.95 a
6	61.43 a	63.85 a
9	55.96 b	55.15 b
12	46.96 c	45.13 c
LSD (0.05)	5.184	3.963
Variety		
Red Creole	44.62	48.70 b
Red Tropicana F1 hybrid	66.71	63.34 a
LSD (0.05)	ns	9.58
CV%	18%	13.1%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at$P \leq 0.05$
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation of average bulb weight
ns = Not significant

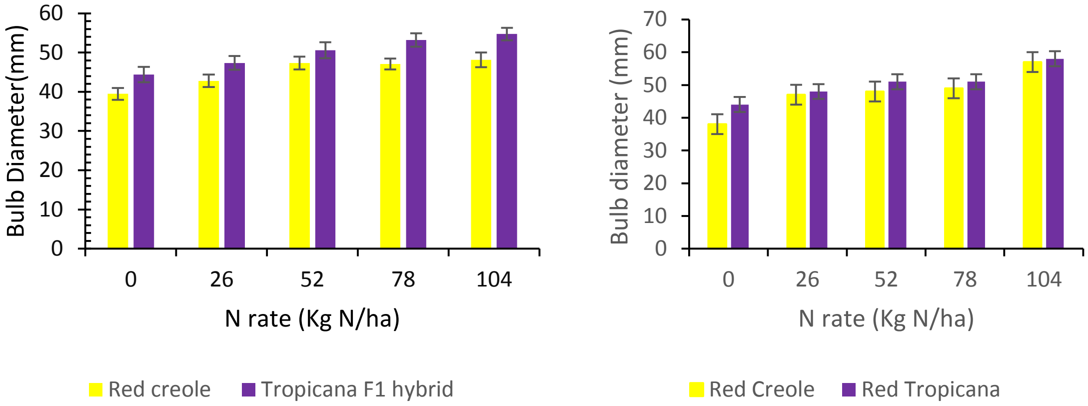
3.4.3.4. Bulb diameter

Nitrogen rates and time of application significantly ($P<0.001$) influenced the bulb diameters in both seasons. There were no significant differences among the varieties in both seasons. No interaction of factors was observed(Fig. 4 and Appendix 2.8.1 and 2.8.2).

Increasing the rate of nitrogen application consistently increased the mean bulb diameters of the onion crop. The widest average mean diameters of 51.44 and 57.21 mm in season one and two respectively were recorded from plots with the highest rate applied (104 kg N/ha). The Narrowest average mean diameters of 41.90 mm in the first season and 40.86 mm in the second season were recorded from plots that had no N applied. Application of higher rates above 52 kg N/ha had no significant difference in season one while in season two, significant differences did not occur between level 52 and 78 kg N/ha (Fig. 4).

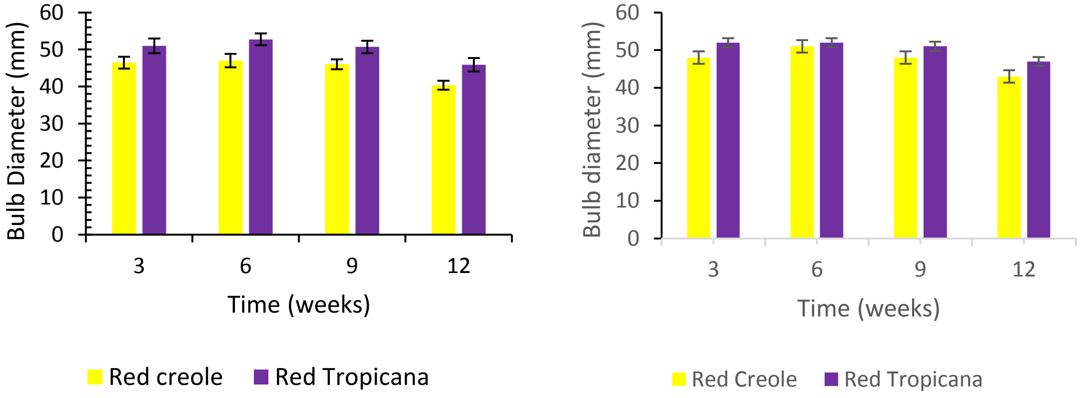
Mean bulb diameters declined with late application of fertilizer. Applying fertilizer at 12 weeks after transplanting resulted to bulbs with the narrowest average diameter of 43.11 mm in season one and 45.30 mm in season two. Plots top dressed early at 6 weeks after transplanting had the widest average bulb diameters of 49.88 and 51.56 mm in the first and second seasons respectively. There was no significant difference in top dressing late up to 9 weeks after transplanting in season one while in season two there was no significant difference in topdressing between 3 and 6 weeks after transplanting (Fig. 4).

Seasom 1 **Seasom 2**



a)b)

Season 1 **Season 2**



c) **d)**

Fig. 4. Effect of nitrogen rates(a and b) and time of application (c and d) on bulb diameterin field experiment conducted in NARL, Kenya in 2014 and 2015 seasons.

3.4.3.5. Bulb grades

3.4.3.5.1. Size A

Nitrogen rates and time of application significantly (P<0.001) influenced Size A bulbs in both seasons. The combined effect of variety and fertilizer exerted a significant (P<0.01) influence on Size A bulbsin season two. The two varieties were significantly (P≤0.05) different only in season two.(Tables 12, 14. and Appendix 2.9.1 and2.9.2).

Application of N significantly decreased the number of bulbs in Size A (bulbs less than 40 mm in diameter). However, there was no significant difference between the control and level 26 kg N/ha in season one. Highest mean number of bulbs in Size A were harvested from control plots (6.5 in season one and 5.708 inseason two). Application of 104 kg N/ha gave the lowest mean number of Size A bulbs (1.708 in season one and 0.292 in season two).

Late application of fertilizer significantly increased the number of bulbs in Size A. The highest mean number of bulbs in Size A (5.667 in season one and 4.333 in season two) were harvested when the crop was top dressed late at 12 weeks after transplanting while the lowest mean number of 2.633 and 1.067 in season one and two respectively were harvested when the crop was top dressed 6 weeks after transplanting.

Results also show that the Red Creole variety recorded highest mean of bulbs in Size A in both seasons the effect which was significant in season two. It recorded a mean of 4.58 in season one and 3.05 in season two while Red Tropicana F1 hybrid recorded 2.67 and 0.90 in season one and two respectively (Table 12).

Table 12. Effect of nitrogen rate, time of application and variety on size A bulbs in field

experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	Size A Season 1	Size A Season 2
Nitrogen (kg N/ha)		
0	6.500 a	5.708 a
26	5.042 a	1.583 b
52	2.792 b	1.208 b
78	2.083 b	1.083 b
104	1.708 b	0.292 b
LSD (0.05)	2.066	1.589
Time (weeks)		
3	2.800 b	1.367 b
6	2.633 b	1.067 b
9	3.400 b	1.133 b
12	5.667 a	4.333 a
LSD (0.05)	1.252	0.898
Variety		
Red Creole	4.58	3.05 a
Red Tropicana F1 hybrid	2.67	0.90 b
LSD (0.05)	ns	1.083
CV%	66.9%	88.1%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at P≤0.05
Size A bulbs = Bulbs less than 40 mm in diameter
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for size A bulbs
ns = Not significant

3.4.3.5.2. Size B

Nitrogen rates and time of application significantly ($P<0.001$) influenced Size B bulbs in both seasons. The interaction of fertilizer and variety significantly influenced size B bulbs in season two. The two varieties were significantly different only in season two (Tables 13, 14 and Appendix 2.10.1 and 2.10.2).

Application of N significantly increased the number of bulbs in Size B (bulbs whose diameter was .40 – 80 mm in diameter). Application of 104 kg N/ha had the highest mean number of bulbs in Size B which was 13.12 in season one and 14.50 in season two. Control plots had the least mean number of bulbs in Size B. However there was no significant difference between the control and 26 kg N/ha in season one. Although an increase in the mean number of bulbs in Size B was evident, addition of fertilizer from 52 kg N/ha in season 1 and 26 kg N/ha in season two had no significant effect (Table 13).

Late application of fertilizer decreased the mean number of bulbs in Size B with topdressing at 12 weeks after transplanting giving the lowest mean number of 9.33 in season one and 10.63 in season two. Top dressing the crop at 6 weeks after transplanting gave higher mean number of size B bulbs of 12.30 in season one and 13.83 in season two.

The effect of variety was significant only in the second season, but Red Tropicana F1 Hybrid had the highest mean number of bulbs in Size B . This variety recorded a mean of 12.25 in season one and 14.05 in season two while the Red Creole variety recorded 10.40 and 11.90 in the first and second season respectively(Table 13).

Table 13. Effect of nitrogen rate, time of application and variety on size B bulbs in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	Size B Season 1	Size B Season 2
Nitrogen (kg N/ha)		
0	8.50 b	9.29 b
26	9.92 b	13.42 a
52	12.21 a	13.88 a
78	12.88 a	13.79 a
104	13.12 a	14.50 a
LSD (0.05)	2.071	1.572
Time (weeks)		
3	12.10 a	13.60 a
6	12.30 a	13.83 a
9	11.57 a	13.83 a
12	9.33 b	10.63 b
LSD (0.05)	1.255	0.901
Variety		
Red Creole	10.40	11.90 b
Red Tropicana F1 hybrid	12.25	14.05 a
LSD (0.05)	ns	1.185
CV%	21.4%	13.4%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Size B = Bulbs whose diameter was 40 – 80 mm in diameter
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for size B bulbs
ns = Not significant

3.4.3.5.3. Size C bulbs

Nitrogen rates significantly ($P<0.001$) influenced size C bulbs in season two while time of application had no significant influence in both seaseons. However, interaction of fertilizer and time of application influenced Size C bulbs in season one. The two varieties were not significantly different in both seasons (Tables 15, 16 and appendix 2.11.1.and 2.11.2).

There was significat difference among the nitrogen rates for C bulbs (bulbs whose diameter was > 80mm) only in season two where application of 104 kg N/ha had a significantly higher mean compared to other levels used in the trial. Size C was mostly confined to this level being totally absent from 0 in both seasons. Time of application had no significant influence on Size C bulbs but in season one, no Size C bulbs were recorded with late application at 12 weeks after transplanting. The significant interaction between fertilizer and time in season one showed that the two factors acted to influence the occurrence of Size C bulbs(Table 16).

Size B carried most of the harvested bulbs in the two seasons with Size C carrying very few. The harvest from season two produced more marketable bulbs in Size B and C and fewer in Size A.

Table 14: Effect of interaction of variety and N rates on size A and B bulbs in field experiment conducted at NARL, Kenya in 2015 season.

	Bulb grades			
	Season 2		season 2	
	Size A		Size B	
N rate (kg/ha)	Red creole	Red Tropicana	Red creole	Red Tropicana
0	8.83	2.58	6.17	12.42
26	1.83	1.33	13.17	13.67
52	1.83	0.33	13.17	14.58
78	2.17	0.25	12.83	14.75
104	0.58	0.00	14.17	14.75
LSD VxF	2.06		2.056	

V = Variety
F = Fertilizer (N rates kg/ha)
LSD VxF = Least significant differnce of interaction between variety and fertilizer

Table 15: Effect of nitrogen rates on Size C bulbs in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

Treatment	**Size C**	**Size C**
N rate (kg/ha)	Season 1	Season 2
00.000 0.000 b		
260.042	0.000 b	
52	0.000	0.042 b
78	0.042	0.000 b
1040.167	0.208 a	
LSD(0.05)	ns0.0739	

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at P≤0.05
Size C = Bulbs whose diameter is greater than 80 mm
ns = Not significant

Table 16. Effect of interaction of fertilizer and time on size C bulbs in field experiment conducted at NARL, Kenya in 2014 season.

	Size C			
	Season 1			
Nitrogen Rate (Kg/ha)	Time (weeks)			
	3	6	9	12
0	0	0	0	0
26	0	0.167	0	0
52	0	0	0	0
78	0	0	0.167	0
104	0.223	0.167	0	0
LSD FxT	0.2319			

F = Fertilizer (N rates in kg/ha)
T = Time (Weeks after transplanting when the fertilizer was applied)
LSD FxT = Least significant difference for the interaction of fertilizer and variety

3.4.4. Correlation analysis

In season one, yield had a significant (P<0.001) positive correlation with bulb diameter (r =

0.919**), number of leaves (r = 0.455**) and average bulb weight (r = 1.000**). Yield had also a significant ($P<0.01$) positive correlation with plant height (r = .249**)

In season two, a similar trend was observed. The yield had a significant ($P<0.001$) with bulb diameter (r = 0.627**), number of leaves (r = 0.483**) and average bulb weight (r = 0.993**). It also had a significant ($P<0.05$) positive correlation with bulb ratios (r = 0.181*) (Table 17 and appendix 3)

Table 17. Correlation between yield and growth parametersin field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

	Season			
	1		**2**	
Parameter	**PearsonCorrelation (r)**	**P-value**	**Pearson Correlation (r)**	**P-value**
Bulb Diameter (cm)	.919**	<0.001	0.627**	<0.001
No. of leaves	.455**	<0.001	0.483**	<0.001
Plant Height (cm)	.249**	0.006	0.115	0.214
Average B. wt. (g)	1.000**	0.000	0.993**	<0.001
Bulb Ratios	.046	0.618	0.181*	0.048
Neck Thickness (cm)	.041	0.655	0.170	0.063

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

3.5. Discusion

3.5.1. Effect of N fertilizer and time of application on growth parameters

Application of nitrogen fertilizer improved growth (plant height, leaf number, bulb ratios and percentage fallen at harvest) increasing with increasing rate of N. These findings are in agreement with those of Birhanu, (2016) who reported a significant increase in plant height and number of leaves at only 50 kg N/ha. Similarly Gessesew *et al.*, (2015) and Nasreen *et al*., (2007) reported significant increases in plant height and leaf number with increasing nitrogen levels. Ceesay, (1980) found the leaf numbers to increase in the early stages of growth reaching a peak and declining as maturity approached which he attributed to the inhibitory effect of bulbing on new leaf initiation and emergence and the drying of older leaves as maturity approached. Ceesay, (1980) also found the leaf numbers to increase with increasing fertilizer rates.

In the early part of the season, bulb growth was very slow and only a slight swelling of the false stem was observed hence bulb ratios were also very low. On the third month of data collection, most of bulb ratios were > 2.0 indicating that proper bulbing was taking place (Brewster, 1990). Most of the increase in bulb diameter took place late in the season when the leaves were drying and bulbs were maturing which was well exhibited in season two. Low N levels seemed to stimulate earlier bulb formation than high levels. However as growth progressed, lack of N limited bulb growth resulting to very low bulb ratios at the end of the season. Scully *et al*., (1945) reported that high N fertilizer reduced relative bulb formation and a low level promoted bulbing near the critical day length for bulb formation. The bulb ratios generally increased significantly with increased fertilizer rates applied.

The improved growth observed as a result of nitrogen application is because the element promotes cell division and elongation, hence growth. Nitrogen also plays a vital role in chlorophyll, enzyme and protein synthesis responsible for growth and development. Abundant proteins tend to increase the size of the plant, particularly the leaves (number, length and width) and accordingly these bring about an increase in photosynthates which are translocated to the bulbs to bring the changes in bulb ratios.

The best growth performance was achieved when the crop was top-dressed at 6 weeks after transplanting. At 3 weeks after transplanting the crop demand was not high enough to utilize the fertilizer more efficiently and effectively. At 6 weeks after transplanting, the crop was well established and almost at peak demand for nutrients so when top-dressed it grew vigorously to attain maximum growth utilizing most of the fertilizer hence the superior performance.

Although the crop was well established at 9 and 12 weeks after transplanting, top-dressing this late did not give the crop enough time to grow and bulbing sets in before substantial growth is achieved. With the onset of bulbing, the young developing leaves cease to form blades but develop into swollen bladeless 'bulb scales' (Brewster, 1994). The photosynthates are now channeled to these scale leaves to form the bulbs. If the crop has not achieved maximum height and a good number of leaves, it is unlikely there would be reasonable growth after onset of bulbing. With further bulb development, the older leaves begin to senesce from tip downwards (Brewster, 1977). The height of plant and number of leaves achieved at the onset of bulbing determine the size of the bulbs hence the poor bulb ratios achieved when the crop was top-dressed 9 and 12 weeks after transplanting. According to Jones *et al*., (2011), it is crucial to apply nitrogen early before peak crop demand to allow for more vegetative growth which can then provide nutrients during grain/bulb/seed fill.

Thus plants top-dressed early had increased growth but plants receiving nitrogen at the later part of crop growth were found to grow in a similar manner to untreated plants with reduced growth. Similar results were obtained by Hassanpour, (1983) who observed heights of onion plants generally decreasing with increase in the time of nitrogen application.

Although a significant difference in maturity of the crop was only obtained in the first season, a general increase in percentage fallen was observed across the increasing fertilizer rates in both seasons with the control recording the lowest. Similar results were obtained by Riekels (1977) with 34 kg N/ha, Ceesay (1980) with 300 kg N/ha and Henerisken (1987) with 120 kg N/ha, who found that N fertilizer hastened maturity. In contrast, Sorensen and Grevesen (2001) and Abdisa *et al.* (2011) with 138 kg N/ha, reported a delayed maturity as a result of nitrogen promoting excessive vegetative growth. Perhaps in this study the nitrogen applied was not high to cause excessive vegetative growth. The earlier maturity with increased N levels can be attributed to the greater growth associated with N. The higher leaf canopy produced absorbs a higher proportion of incident light decreasing the red: far red spectral ratio (R: FR) in going from the top to the bottom of the leaf canopy (Brewster, 1990). Bulb scale initiation is accelerated by decrease in R: FR (Mondal *et al*., 1986b), hence the hastened maturity.

The time of application was crucial for maturity of the crop such that even at high levels, maturity was delayed with late application. Early application of fertilizer quickens growth leading to a greater canopy and the crop matures faster while late application could cause a reduced canopy delaying maturity. Brewster, (1990) found a significant delay in maturity by delaying nitrogen fertilizer application 3 months later compared to applying before sowing.

Although significant differences in growth between the two varieties were only obtained in season two, Red Tropicana F1 hybrid showed better growth performance in all parameters tested in both seasons except leaf number in season one. A better performance is expected from a hybrid whose ability to withstand adverse conditions such as low nutrient availability or water shortage has been enhanced. Red Tropicana F1 hybrid was observed to grow faster, attaining a higher plant height and maturing earlier (plants of Red Tropicana were observed to lodge first).

3.5.2. Effect of N fertilizer and time of application on yield and yield attributing factors

The effect of nitrogen application on yield of the onion crop was consistent in both seasons. The yield increased linearly and significantly ($P \leq 0.001$) with increasing levels of applied N in the two seasons. A better response was experienced in the second season perhaps due to the increased availability of water as a result of heavy rains that prevailed. During this season, the yields of Red Tropicana F1 hybrid almost doubled at the highest rate of 104 kg N/ha, registering 83.86% yield increase over the control. These results are in conformity with results of previous studies. Nguthi, (1993) found significant yield increases up to 39 kg N/ha in the sandy clay loams of Kabete and also reported a linear yield response to nitrogen application. Abdisa *et al.,* (2011) reported significant yield increases up to 69 kg N/ha above which there was no significant difference. Similarly Dhital *et al*., (2017) reported significant yield increases up to 120 kg N/ha above which there was no significant difference. Pandy *et al*., (1994) reported significantly higher yields with application of 80 and 120 kg N/ha while Nasreen *et al*., **(**2007) reported similar results but with a yield decline above 120 kg N/ha. Since the yield response in this study was linear to application of nitrogen, further increase of fertilizer rate would result to optimum production but too much may result in a yield decline as reported by some workers mentioned above

The marketable yield followed a similar trend, increasing significantly with increasing N rates. However, marketable yield was lower than the total yield in both seasons with losses primarily due to splitted bulbs and bolters. Other losses which were minimal included rotted , sprouted and undersized bulbs of less than 20 mm in diameter. Similar results were reported by Henerisken, (1987), that the yield of marketable onion bulbs increased with N application up to 120kg N/ha. Birhanu, (2016) reported a 60.4% increase in marketable yield over the control by application of only 50 kg N/ha. However, late application of fertilizer at 12 weeks after transplanting reduced the total and marketable yield of the onion crop. Best results were obtained when the application was done at 6 weeks after transplanting. Perhaps this was the optimal time, the peak demand period for the onion crop which resulted to peak growth and production.

Average bulb weight, bulb diameter and bulb sizes also increased progressively and significantly with increasing N rates up to 104 kg N/ha. The average bulb weight, bulb diameter and bulb sizes followed a similar trend. Control plots had significantly lower bulb sizes, lower average bulb weight and lower bulb diameters than those with high N levels. The present results support previous work by Abdissa, *etal.,* (2011) who reported increased average bulb weight and bulb diameters by N application up to 69 kg N/ha. Nasreen, *et al*., (2007) also reported a significant increase in the diameter of bulbs due to application of N up to 120 kg N/ha. Nguthi, (1993) reported a general increase in Grade 1 and Grade 2 bulbs with increasing N levels up to 39 kg N/ha with a highest percentage of 36.7% of bulbs in grade 3 at the control (0 kg N/ha). Also Sypien, (1973) reported the largest bulbs of 4.5 – 7.0 cm with application of 300 kg N/ha and the smallest with no N application. However, application of fertilizer late in season at 12 weeks after transplanting had negativeeffect on these parameters perhaps due to delayed growth.

The bulb is a storage organ depending on other plants organs particularly the leaves and roots for supply. It is a sink for the accumulation of photosynthates and nutrients from the soil. When growth

is limited by lack of N especially in the early stages, the ultimate bulb yield will also be limited as observed with the 0 N plots or late application at 12 weeks after transplanting. Therefore the increased bulb weight, bulb diameters, bulb sizes and the ultimate total and marketable yield observed in this study could be attributed to an increased photosynthetic area including a greater number of leaves and increased plant height and also growth of roots in response to N application.

A greater vegetative growth leads to enhanced assimilates production and partitioning to the bulbs hence the improved results

This study show that, the final onion yield depends on the amount of vegetative growth before bulb formation. A greater vegetative growth leads to more assimilates being channeled to the growing bulbs hence affects bulb weight and the final yields. Nitrogen nutrition is a major factor affecting vegetative growth and therefore has a direct effect on the final yield. The higher the rate, the higher the yields obtained in this study. However, although the primary objective of any grower is to attain high yields for a good profit margin, too much nitrogen may also compromise quality and reduce the marketable yield. A balance has therefore to be made.

In general, variety Red Tropicana F1 hybrid had a good performance. It recorded higher total and marketable yield in both seasons which was significant in season two. It also recorded a significantly higher mean of size B bulbs which are preferred by consumers in the market while Red Creole recorded a higher mean of size A bulbs not so much preferred. Size C bulbs which are good for processing were also dominated by Red Tropicana. The highest number of curl bulbs was with Red Creole which had a very high number of splitted bulbs and some with < 20mm diameter from variant ‘0’ kg N/ha.

Differences among varieties has been reported by several workers. Islam *et al*., (2008), reported significant differences among six genotypes which were equally treated with fertilizers. Similarly, Gebisa, (2014) in Ethiopia found significant yield increases in variety Bombay Red compared to Adama Red and Nasik Red. Working with different varieties, Kimani *et al*., (1991) also found the Red Tropicana F1 hybrid to yield best among the locally grown varieties which included Red Creole. The difference between the two varieties could be attributed to their genetic potential. Red Tropicana is a hybrid with higher potential to yield better.

3.4.3. Correlation analysis on yield, yield attributing parameters and growth parameters

Correlation analysis showed that bulb total yield was positively correlated to the number of leaves, plant height, bulb diameter and average bulb weight. Similarly bulb diameter and average bulb weight were positively correlated to number of leaves and plant height. This correlation suggests that application of N fertilizer at the right time could improve certain plant parts particularly the leaves which could improve the capacity of the plant to produce more photosynthates that are mobilized to the organ of economic value increasing bulb weight and bulb diameter that ultimately led to enhanced yield per unit area. Similar results were reported by Abdisa *et al*., (2011); Nasreen *et al*, (2007) and Gessesew *et al*., (2015).

Bulb diameter was positively correlated to bulb neck thickness in season two suggesting that the application of N fertilizer at the proper time could lead to production of big sized bulbs with thick necks, which if not well cured could be a problem during storage.

CHAPTER FOUR

THE INFLUENCE OF RATE AND TIME OF NITROGEN APPLICATION ON THE QUALITY AND STORABILITY OF ONIONS

4.1. Abstract

Onion (*Allium cepa* L.) is one of the most important commercial vegetable crops grown by small-holder farmers in Kenya, for both local and export markets. Losses in storage mainly due to rotting and sprouting average 40%. Nitrogen (N) is one of the most important crop nutrients affecting growth and quality but with an impact on shelf-life of onion. Thisstudy was therefore conducted with an objective to determine N rates and time of application on onion storage life. The experiment was carried out in 2014 and 2015 at the National Agricultural Research Laboratories and the bulbs stored at room temperature for 3 months at the University of Nairobi (UON) botany laboratory. Nitrogen was applied as Calcium Ammonium Nitrate at five levels including 0, 26, 52, 78 and 104kg N ha^{-1} at 3, 6, 9 and 12 weeks after transplanting. Two commonly grown varieties, Red creole and Red Tropicana F1 hybrid were used. The treatments were laid in a randomized complete block design, with a split-split plot arrangement and replicated three times. N application at 78 and 104 kg/ha had significant effect on bulb splitting and neck thickness at harvest and adversely affected storage life through increased physiological weight loss (PWL) and rotting and sprouting of bulbs. Early application at 3 weeks led to increased PWL and rotting while late application at 9 and 12 weeks increased splitting and sprouting of bulbs. The Red creole variety exhibited a better shelf-life compared to the Red Tropicana F1 hybrid. Nitrogen application is important for increased yields but excessive application beyond 52 kg N ha^{-1} affects negatively bulbs intended for storage. Application at 6 weeks after transplanting enhanced quality of onion before and after storage.

Keywords:*Allium cepa,* PWL, accelerated sprouting, increased splitting, increased rotting.

4.2. Introduction

Onioncrop has a comparatively poor storability and significant post harvest losses ranging between 40 – 60% are incured(Maini *et al*., 1984). Due to seasonal glut, farmers are forced to sell onions at low prices to avoid storage and related losses (Abate, 2012). Storage of onion bulbs has therefore become a serious problem in Kenya. The post harvest losses contributing to this include poor quality, physiological loss in weight, sprouting and rotting of bulbs.

Storage losses of onions have been reported to reduce considerably by treatment of Maleic hydrazide (Pandey *et al*.,1994), ultra violet radiation (Lu *et al*.,1987), controlled atmosphere storage (Poldma *et al*., 2012), low temperature storage (Proctor *et al*., 1981) and high temperature storage (Ramin, 1999). Although these techniques work well to control post harvest losses, most of them involve costly investiment with specialized eguipment and storage structures not feasible for the small-scale farmer. Low cost farm level technology is required to extend the shelf-life of the crop. The main aim is to preserve quality and to make the bulbs available during lean periods.

At farm level, crop maturation at the time of harvesting, care at harvest, premature defoliation, skin integrity, curing and storage conditions are the main factors contributing to quality of bulbs in storage (Brewster, 1994). Quality of bulbs can also be affected by mineral nutrition, irrigation scheduling or rainfall (Chung, 1989), cultivar differences and use of growth factors (Hussein, 1996). Manipulation of these factors can be done to extend shelf-life and increase marketability of the commodity.

Nitrogen (N) is the most influential macronutrient which has been reported to affect marketable quality, taste and shelf life of onions in storage. Brewster 1994, reported that application of N caused significant improvement in growth and bulb yield but high level application shortens the storage life of the crop. Singh *et al.*, 1994 concluded that storage quality of CV. Pusa Red held at room temperature decreased with increasing rates of N up to 200 kg/ha. Sorensen and Grevisen, 2001 also concluded that too much nitrogen can result in increased susceptibility to diseases, increased double center in onions, reduced dry matter contents and storability and thus result in reduced marketable quality. Improved N fertilizer management for onion may help storability and ensure supply of bulbs during lean periods thus offering farmers premium prices. Therefore the objective of this study was to determine the influence of N fertilizer and time of its application on quality and storability of onion bulbs.

4.3. Materials and Methods

4.3.1. Description of the experimental site

The experiment was conducted at the Food Crops Research Centre (KALRO-Kabete) for two seasons from 2014 to 2015 as described in chapter 3.

4.3.2. Experimental material

The experimental materials were obtained from experiment 1 comprising of two popular varieties grown in Kenya, the Red Creole and Red Tropicana F1 Hybrid.

4.3.3. Treatments and experimental design

The treatments were five N rates applied as CAN and four different times of application as described in chapter 3. The experimental design was a randomized complete block design with a split-split plot arrangement and replicated three times.

4.3.4. Harvesting, post-harvest storage and data collection

At harvest, sampling was done from the 3 inner rows of a sub-sub plot excluding the guard plants. Samples were taken from the inner 5 plants and 3 rows giving a sample of 15 onions from which data was taken. Harvesting was done when 50 - 70% of the plants had fallen over.

After harvesting, quality data including the number of split bulbs, neck size and % bolters was recorded. For storability study, onion bulbs from each treatment were stored at ambient conditions on clean wooden benches in the laboratory. The bulbs were put in labelled khaki paper bags and left open for good aeration. Storability parameters included physiological loss in weight (PLW), bulbs sprouted, number of sprouts, length of sprouts, rotted bulbs and severity of rotting were taken at 1 month interval for a period of 3 months.

4.3.4.1. Quality parameters

The diameter of the neck at harvest influences the rate of curing (drying) and hence the keeping quality of bulbs in storage. The neck diameters for all the sampled onions were taken at harvest using a Vernier caliper. The measurement were taken 5 mm above the top of each bulb.Bolted plants were visually counted from the plots, recorded and later expressed in percentage (%) in relation to the number of plants in the plot.The number of split bulbs in the sample was determined by simply counting the number of bulbs splitted in the sample.

4.3.4.2. Storage parameters

4.3.4.2.1. Physiological loss in weight.

Weight of bulbs was recorded using an electronic weighing scale after every four weeks interval. The physiological loss in weight (PLW) was calculated using the formula

PLW = initial weight – weight at 4th week interval.

An average was calculated at the end of thestorageperiod.

4.3.4.2.2. Sprouted bulbs

The cumulative number of sprouted bulbs was taken in each sample every 4th week interval by visually counting the number sprouted in the sample. An average was calcurated at the end of the storage period.

4.3.4.2.3. Number of sprouts

The number of sprouts in each sprouted bulb in a sample was visually counted and recorded every 4th week interval. An average was calculated at the end of the storage period

4.3.4.2.4. Length of sprouts

The length of each sprout in each sprouted bulb in a sample was taken every 4th week using a ruler. An average was calculated at the end of the storage period.

4.3.4.2.5. Rotted bulbs

The incidence of rotting was determined by visually counting the bulbs rotted in each sample every 4th week. The total number of onion bulbs which were rotted was calculated by taking the average at the end of the storage period.

4.3.4.2.6. Extent of rotting (%)

The extent of rotting was determined by visually examining the rotted bulb and deciding what percent of bulb had rotted. An average was calculated at the end of the storage period.

4.3.5 Data analysis

All data were subjected to Analysis of Variance (ANOVA), using GENSTAT statistical program, 15th (SP1) edition (VSN International, 2012). Significance of differences between means of treatments were evaluated using Fishers Protected Least Significance Difference (LSD) test at 5% probability level ($P<0.05$).

4.4. Results

4.4.1. Effect of nitrogen levels and time of application on quality parameters

4.4.1.1. Bulb neck thickness.

The influence of nitrogen fertilizer on bulb neck thickness was highly significant ($P<0.001$) in both seasons. The time of application had no significant influence in season one but was highly significant (P<0.001) in season two. There was an interaction effect fertilizer and variety on bulb neck diameterin season 2 (Tables 18, 19 and Appendix2.12.1 and 2.12.2).

Increasing the rate of nitrogen application consistently and significantly increased the bulb neck diameters in both seasons (Table 19). However there was no significant difference between level 52 kg N/ha and 78 kg N/ha in both seasons. The widest bulb neck diameters of 14.87 mm in season one and 10.48 mm in season two was recorded with the highest rate of fertilizer (104 kg N/ha) while the narrowest diameter of 12.59 mm in season one and 7.94 mm in season two was recorded with the control (0 kg N/ha). Application at 6 weeks gave widest neck size of 9.64 mm which was significant.There was no significant difference in bulb neck diameters between the two varieties.

Table 18. Effect of interaction of fertilizer and variety on neck thickness of bulbs in field experiment conducted at NARL, Kenya in 2015 season.

	Neck thickness (mm)	
	Season 2	
Nitrogen Rate (Kg/ha)	Variety	
	Red Creole	Red Tropicana
0	8	8
26	10	8
52	10	9
78	11	9
104LSD FxV	11	10
	1.4	

F = Fertilizer (N rates in kg/ha)
T = Time (weeks after transplanting when fertilizer was applied)
LSD FxV = Least sigmificant difference of interaction between fertilizer and variety

Table 19. Effect of nitrogen rate, time of application and variety on neck thickness of bulbsin field

experiment conducted at NARL, Kenya in 2014 and 2015 seasons

Treatment	**Neck thickness (mm)** **Season 1**	**Neck thickness (mm)** **Season 2**
Nitrogen (kg N/ha)		
0	12.59 d	7.94 d
26	13.54 c	9.01 c
52	14.46 b	9.69 b
78	14.58 b	9.96 b
104	14.87 a	10.48 a
LSD (0.05)	0.2688	0.3000
Time (weeks)		
3	14.06	9.52 ab
6	13.89	9.64 a
9	14.00	9.35 b
12	14.09	9.14 c
LSD (0.05)	ns	0.2000
Variety		
Red Creole	13.93	10.05
Red Tropicana F1 hybrid	14.08	8.78
LSD (0.05)	ns	ns
CV%	3.8%	4.2%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at P≤0.05
ns = Not significant
Time = Weeks after transplanting when the fertilizer was applied
CV = Coeficient of variation for neck thickness of bulbs

4.4.1.2. Bolting

Therewas no significant of N rates and time of application on bolting of the onion crop. No bolting incident occurred in the first season. However, during the second season, bolting was significantly (P≤0.05) evident for the Red Tropicana F1 Hybrid variety, with very minimal bolting for the Red Creole Variety (Table 20, Fig. 5 and Appendix 2.13.1).

The percentage number of bolters decreased at first with increasing fertilizer rates from 0 kg N/ha to 52 kg N/ha and then started to increase with further addition of fertilizer (Fig.5). Level 104 kg N/ha had the highest percentage number of bolters (4.00%) while level 52 kg N/ha had the least (2.83%). Application of fertilizer at 6 weeks after transplanting had the highest percentage of bolted bulbs (3.87%) while early application at 3 weeks after transplanting had the least (2.60). The percentage bolters generally increased with late application but more so between 6 and 9 weeks after transplanting. The Red Tropicana F1 hybrid recorded the highest percent mean of bolters of 6.5 while Red Creole recorded the least of 0.07% (Table 20).Plate 1 shows bolted bulbs with a hard centre not good for the market and which can allow entry of microoganisms

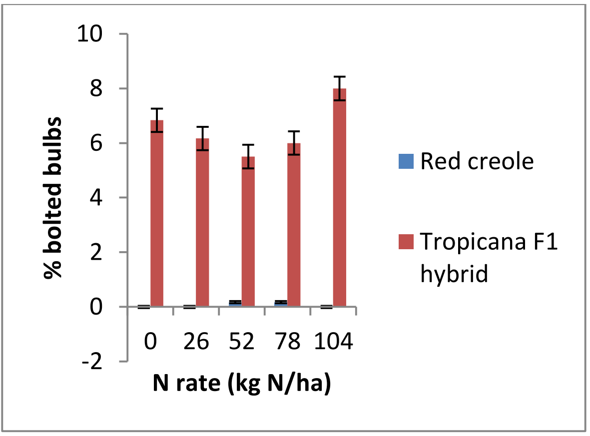


Plate 1. Bolted bulbs of Red TropicanaFig.5. Effect of N rates on % bolted bulbs
F1 hybrid in field experimentin field experiment conducted at
Conducted at NARL, Kenya in 2015 seasonNARL, Kenya in 2015 season.

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Table 20. Effect of nitrogen rate, time of application and variety on % bolted bulbs in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons

Treatment	**% bolted**	**% bolted**

	Season 1	**Season 2**
Nitrogen (Kg N ha^{-})		
0	0	3.42
26	0	3.08
52	0	2.83
78	0	3.08
104	0	4.00
LSD (0.05)	0	ns
Time (weeks)		
3	0	2.60
6	0	3.87
9	0	3.60
12	0	3.07
LSD (0.05)	0	ns
Variety		
Red Creole	0	0.07 b
Red Tropicana F1 hybrid	0	6.50 a
LSD (0.05)	0	6.071
CV%	0	86%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at $P \leq 0.05$
ns =Not significant
Time = Weeks after transplanting when fertilizer was applied
CV = Coefficient of variation for % bolted bulbs

4.1.3. Bulb splitting

The effect of nitrogen application was highly significant ($P<0.01$) on the number of splitted bulbs in both seasons. Time of application also had a highly significant ($P<0.01$)effect on bulb spliting in season one, but a very highly significant ($P<0.001$) effect in season two. The main effect of variety had a significant ($P \leq 0.05$) influence on bulb splitting in both seasons. There wereno significant interaction effectson the parameter in both seasons (Table 21 and Appendix 2.14.2 and 2.14.2).

Bulb splitting increased with the increase in fertilizer applied with 104 kg N/ha recording the highest mean of 4.29 in season one and 2.04 in season two. Level 0 kg N/ha recorded the lowest mean of split bulbs of 2.88 in season one and 0.75 in season two. Differences were observed between the two seasons with the higher bulb splittingrecorded in season one.

Plate 2. Split bulbs of Red Creole in field experiment conducted at NARL, Kenya in 2015 season

Late application of fertilizer after transplanting also accelerated splitting with the highest mean of 4.40 recorded at 12 weeks after transplanting in season one. In season two, the highest mean of 1.87 was recorded at 9 weeks after transplanting, the difference which was significant at ($P \leq 0.05$) form the rest (Table 21).

There was also significant ($P \leq 0.05$) difference between the two varieties in both seasons with the Red Creole having higher bulb splitting with a mean of 5.88 (32.6 %) in season one and 2.33 in season two (Table 21, Plate 2).

Table 21. Effect of nitrogen rate, time of application and variety on number of splitted bulbs in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons

Treatment	**No. splitted Season 1**	**No. splitted Season 2**
Nitrogen (kg N/ha)		

0	2.88 c	0.75 c
26	3.33 bc	1.08 bc
52	3.58 b	1.54 ab
78	4.29 a	1.67 a
104	4.29 a	2.04 a
LSD (0.05)	0.693	0.5697
Time (weeks)		
3	3.10 c	1.03 b
6	3.26 bc	1.37 b
9	3.93 ab	1.87 a
12	4.40 a	1.40 b
LSD (0.05)	0.704	0.4587
Variety		
Red Creole	5.88 a	2.33 a
Red Tropicana F1 hybrid	1.47 b	0.50 b
LSD (0.05)	3.2040	1.4342
CV%	62.7%	37.1%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at P≤0.05
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for number of splitted bulbs

4.4.2. Effect of nitrogen and time of application on storage parameters

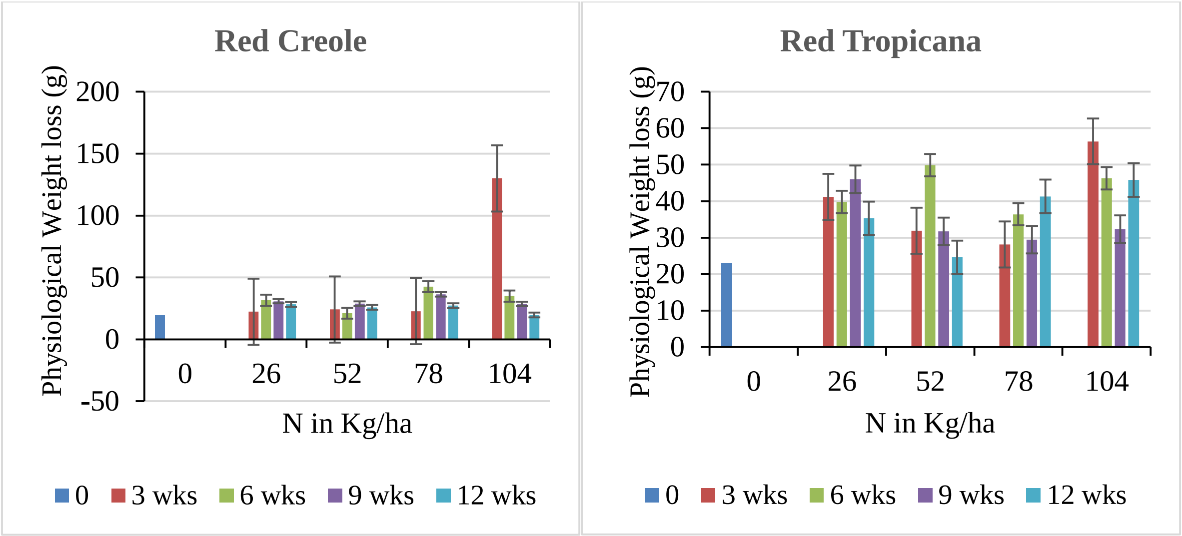
4.4.2.1. Physiological weight loss (PWL)

The main effect of nitrogen fertilizer significantly (P<0.001) influenced PWL of the onion bulbs in both seasons. Time of application significantly (P<0.001) influenced PWL only in season two. The interaction effect of fertilizer and time of application significantly (P<0.001) influenced PWL in season one only. Also the main effect of variety significantly (P≤0.05) influenced PWL only in season two. The combined effect of variety, nitrogen fertilizer and time of application was only significant (P<0.01) in season one (Table 22, Fig. 6 and Appendix 2.15.1 and 2.15.2).

Physiological weight loss of the bulbs increased significantly with increase in N rates increased in both seasons. The control plots recorded the lowest PWL of bulbs (21.32 g in season one and 31.92 g in season two). The highest mean of PWL of bulbs was 49.32 g in season one recorded from 104 kg N/ha and 72.01 g in season two recorded from 78 kg N/ha (Table 22).

Time of application significantly affected PWL only in season two. Late application reduced PWL of bulbs. The highest loss of weight of 39.5 g in season one and 67.37 g in season two was recorded when the crop was top dressed early at 3 weeks after transplanting. The lowest loss of weight of 29.33 g in season one and 14.11 g in season two was obtained when the crop was top dressed late at 12 weeks after transplanting (Table 22).

In season two the Red Tropicana F1 hybrid had a significantly higher PWL of bulbs of 87.7 g compared to Red Creole variety which had a PWL of 28.8 g (Table 22).



a) **b)**

Fig. 6. Interaction effect of N rates and time of application on PWL of bulbs (a, b) in storage experiment conducted at University of Nairobi, Kenya in 2014 season.

Table 22. Effect of nitrogen rates, time of application and variety on PWL of bulbs taken in storage experiment conducted at University of Nairobi, Kenya in 2014 and 2015 seasons.

Treatment	PWL (g) Season 1	PWL (g) Season 2
Nitrogen (kg N/ha)		
0	21.32 c	31.92 c
26	34.43 b	56.90 b
52	29.76 bc	61.92 ab
78	33.03 b	72.01 a
104	49.32 a	68.32 a
LSD (0.05)	10.28	14.51
Time (weeks)		
3	39.50	67.37 a
6	34.90	66.46 a
9	30.60	54.92 b
12	29.30	44.11 c
LSD (0.05)	ns	10.65
Variety		
Red Creole	31.7	28.8 b
Red Tropicana F1 hybrid	35.5	87.7 a
LSD (0.05)	ns	42.84
CV%	47.1%	35.4%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for PWL of bulbs
ns = Not significant

4.4.2.2. Number of bulbs sprouted

Application of N fertilizer significantly reduced the number of bulbs sprouted in season one. Plots that had not received N in season one had the highest mean number of sprouted bulbs of 6.82 while plots that had received the highest level of 104 kg N/ha had the least mean number of 4.33. In season two, application of N fertilizer had no significant influence on the mean number of sprouted bulbs (Table 23 and appendix 2.16.1 and 2.16.2).

Late application of fertilizer significantly increased mean number of sprouted bulbs in season one. Plants top dressed at 12 weeks after transplanting had the highest mean number of 6.04 while plants top dressed at 6 weeks after transplanting had the least number of 4.64 (Table 23). The time of application had no significant effect in season two.

Varietal effect was only significant in season two where Red Tropicana F1 hybrid had a significantly higher mean number of sprouted bulbs of 7.96 than the Red Creole variety which had a mean number of 0.71. Plate 3 shows sprouted bulbs of Red Tropicana F1 hybridsampled from the experiment (Table 23).No significant imteractions were observed in both seasons.

Plate 3. Sprouted bulbs of Red Tropicana F1 hybridin storage experiment conducted at University of Nairobi, Kenya in 2014 and 2015 seasons.

Table 23. Effect of N rates, time of application and variety on the number of bulbs sprouted in storage experiment conducted at Uiversity of Nairobi, Kenya in 2014 and 2015 seasons

Treatment	Number sprouted Season 1	Number sprouted Season 2
Nitrogen (kg N/ha)		
0	6.82 a	4.14
26	5.01 b	3.87
52	4.68 b	4.51
78	4.39 b	4.40
104	4.33 b	4.70
LSD (0.05)	1.041	ns
Time (weeks)		
3	4.83 b	4.52
6	4.64 b	4.32
9	4.67 b	4.10
12	6.04 a	4.39
LSD (0.05)	0.928	ns
Variety		
Red Creole	5.11	0.71 b
Red Tropicana F1 hybrid	4.99	7.96 a
LSD (0.05)	ns	4.198
CV%	35.6%	40.4%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at $P \leq 0.05$
Time = Weeks after transplanting when fertilizer was applied
ns = Not significant
CV = Coefficient of variation for number of bulbs sprouted

4.4.2.3. Number of sprouts

An interaction effect of variety and time significantly ($P \leq 0.05$) influenced number of sprouts in season two (Table 24 and Appendix 2.17.1 and 2.17.2).

Application of nitrogen fertilizer significantly reduced the number of sprouts in season one but had no significant effect in season two. The highest mean number of sprouts (8.31) was recorded from plots that received no N while the lowest mean number of sprouts (6.01) was recorded with the highest level of fertilizer applied (104 kg N/ha). Time of application of fertilizer had no significant effect in bothseasons (Table 25).Plate 4 shows a bulb with multiple sprouts.

Plate 4. A bulb (Red Tropicana F1 hybrid) with multiple sprouts in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Table 24. Interaction effect of time and variety on the number of sprouts in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

	No. of sprouts	
	Season 2	
Time (T) (in weeks)	Variety (V)	
	Red Creole	Red Tropicana
3	0.58	25.82
6	1.44	22.11
9	0.67	21.71
12	1.53	19.87
LSD TxV	14.991	

Time = Weeks after transplanting when the fertilizer was applied
LSD TxV = Least significant difference for the interaction of time and variety

Table 25. Effect of N rates, time of application and variety on the number of sprouts in the storage experiment conducted at University of Nairobi, Kenya in 2014 and 2015 seasoms.

Treatment	Number of sprouts Season 1	Number of sprouts Season 2
Nitrogen (kg N/ha)		
0	8.31 a	8.24
26	7.44 ab	11.04
52	6.28 bc	12.04
78	6.03 c	12.51
104	6.01 c	14.03
LSD (0.05)	1.312	ns
Time (weeks)		
3	6.36	13.20
6	6.63	11.78
9	6.83	11.19
12	7.43	10.70
LSD (0.05)	ns	ns
Variety		
Red Creole	7.47	1.06 b
Red Tropicana F1 hybrid	6.16	22.38 a
LSD (0.05)	ns	16.902
CV%	39.1%	34.7%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at $P \leq 0.05$
ns = Not significant
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation for number of sprouts

Variety Red Tropicana F1 hybrid had the highest mean number of sprouts in both seasons which was significant in season two. Variety Red Creole had a good performance in storage especially in season two where a mean number of 1.06 was obtained compared to that of Red Tropicana F1 hybrid of 22.38 (Table 25).

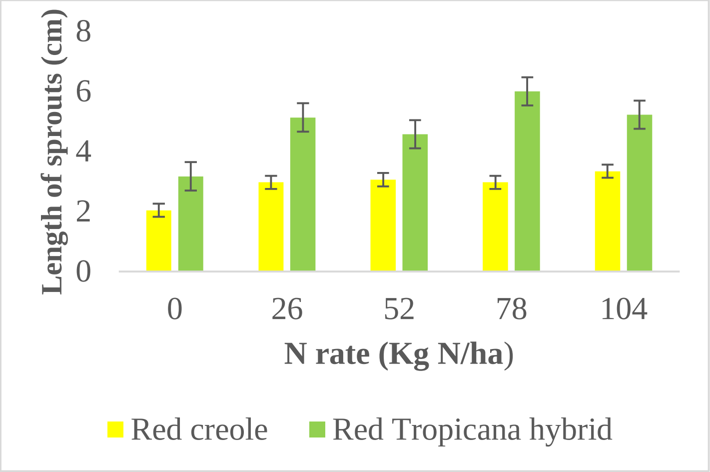
4.4.2.4. Sprouts length

Application of N significantly ($P<0.01$) increased the length of sprouts in both seasons . The length of sprouts increased with increase in fertilizer rates up to 78 kg N/ha after which a downward trend was observed in both seasons. However, no significant differences between fertilizer rates above 26 kg N/ha occured. The shortest mean length of sprouts was recorded with the control plots, 2.609 cm in season one and 5.561 cm in season two. The longest mean length was recorded with level 78 kg N/ha in both seasons, 4.483 and 10.471 cm in the first and second season respectively. The time of application had no significant influence on the length of sprouts in both seasons (Fig. 7 and Appendix 2.18.1 and 2.18.2).

Significant ($P\leq0.05$) differences in the length of sprouts were also observed between the two varieties in both seasons. After 3 months storage, Red Tropicana F1 hybrid had the longest sprouts in both seasons, 4.82 cm in season one and 14.13 in season two. The Red Creole variety had the shortest sprouts, 2.88 cm in season one and 3.33 cm in the second season. The length of sprouts were longest in the second season (Fig.7). Plate 5 shows long multiple sprouts of a shriveled bulb of Red Tropicana F1 hybrid.No interaction of factors was observed in both seasons

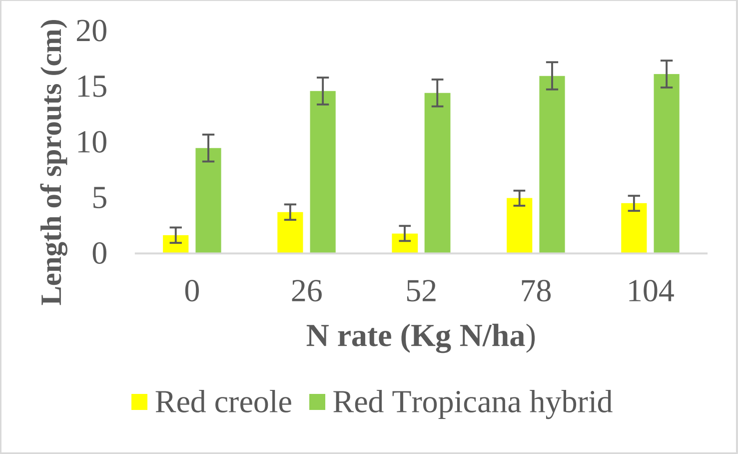
Plate 5. A shrivelled bulb with long multiple sprouts in the storage experiment conducted at the Uiversity of Nairobi, Kenya in 2015 season.

Season 1



a)

Seaon 2



b)

Fig. 7. Effect of N rates on the length of sproutsin storage experiment conducted at University of Nairobi, Kenya in 2014 (a) and 2015 (b) seasons.

4.4.2.5. Bulbs rot

Nitrogen fertilizer had a significant ($P \leq 0.05$) influence on the number of rotted bulbs in both seasons. Time of application had a very highly significant ($P<0.001$) influence in season two but none in season one. The combined effect of variety, fertilizer and time had a significant ($P \leq 0.05$) influence on the number of rotted bulbs in season one while only the combined effect of fertilizer and time had a significant ($P \leq 0.05$) influence in season two. The two varieties were not significantly different in both seasons (Table 26, Fig. 8 and Appendix 2.19.1 and 2.19.2).

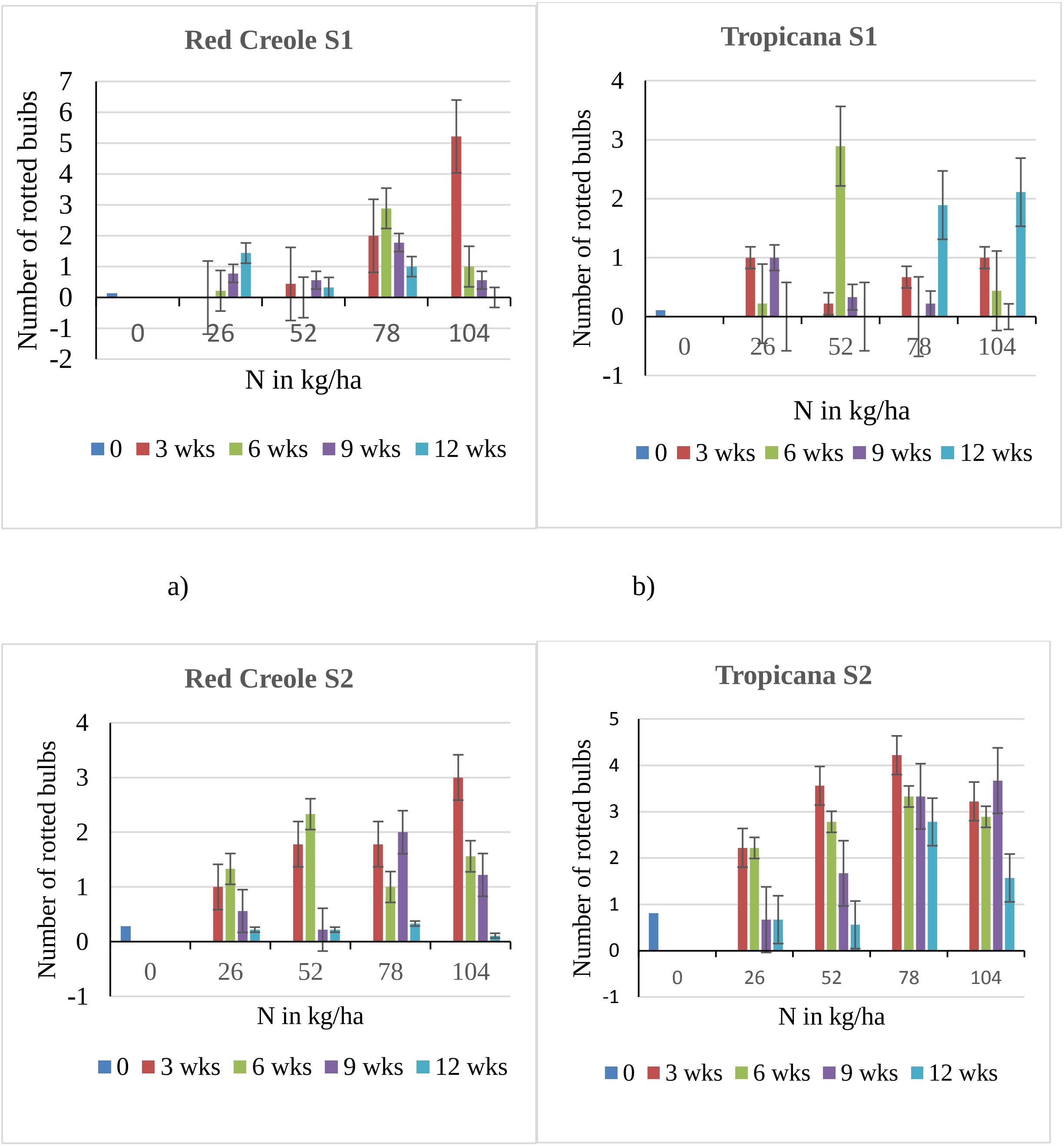
Application of nitrogen fertilizer increased significantly ($P \leq 0.05$) the number of rotted bulbs as rates increased with 78 kg N/ha registering the highest number of rotted bulbs in both seasons, 1.31 in season one and 2.35 in season two. The lowest number of rotted bulbs was recorded with 0 kg N/ha in both seasons, 0.13 in season one and 0.54 in season two. However, there was no significant difference with addition of fertilizer from 52 kg N/ha (Table 26).

Time of application decreased the number of rotted bulbs in both seasons, the difference between different times of application being very highly significant ($P<0.001$) in season two. The highest number of rotted bulbs was recorded when the crop was top-dressed three weeks after transplanting (1.09 in season one and 2.19 in season two) while the lowest number of rotted bulbs was recorded when the crop was top-dressed 12 weeks after transplanting in both seasons (0.72 in season one and 0.91 in season two). Plates 6 and 7 shows rotted bulbs sampled during the experiment.

The two varieties were not significantly different in both seasons but the Red Tropicana F1 hybrid recorded higher number of rotted bulbs. A higher number of rotted bulbs was recorded in season two than in season one (Table 26).

Plate 6. Bulbs infected with white rot (Sclerotium cepivorum Berk) in storage experiment conducted at University of Nairobi, Kenya in 2014 season

Plate 7. Bulbs infected with black rot (Aspergillus niger) in storage experiment conducted at University of Nairobi, Kenya in 2015 season.



a) b)

c)d)

Fig. 8. Interaction effect of N rates, time of application and variety on number of rotted bulbs in the storage experiment conducted at University of Nairobi, Kenya in 2014 (a,b) and 2015 (c,d)

Table 26. Effect of N rates and time of application on the number of rotted bulbs in storage experiment conducted at the University ofNairobi, Kenya in 2014 and 2015 seasons.

Treatment	**Number of rotted bulbs Season 1**	**Number of rotted bulbs Season 2**
Nitrogen (kg N/ha)		
0	0.13 b	0.54 c
26	0.58 ab	1.24 bc
52	0.60 ab	1.64 ab
78	1.31 a	2.35 a
104	1.30 a	2.15 a
LSD (0.05)	0.815	1.0087
Time (weeks)		
3	1.09	2.19 a
6	0.99	1.82 ab
9	0.54	1.41 bc
12	0.72	0.91 c
LSD (0.05)	ns	0.5461
Variety		
Red Creole	0.94	0.99
Red Tropicana F1 hybrid	0.62	2.18
LSD (0.05)	ns	ns
CV%	166.3%	66.8%

Fishers protected least significant difference (LSD) test among means at 5% probability level. Means followed by different letters in the same column are significantly different at P≤0.05
ns = Not significant
Time = Weeks after transplanting when fertilizer was applied
CV = Coefficient of variation for number of rotted bulbs

4.4.2.6. Severity of rotting (%)

Application of nitrogen increased the severity of bulb rotting in both seasons and the difference was significant in season two (Table 27 and Appendix 2.20.1 and 2.20.2). The lowest percentage of severity of bulb rotting of 5.7 and 15% in season one and two respectively was recorded with variant 0 kg N/ha. The highest percent severity of rotting of 30.4% in season one and 39.46% in season two were recorded with variant 104 kg N/ha and 78 kg N/ha respectively. However, the two levels were not significantly different.

The severity of rotting decreased with late application of fertilizer in both seasons, the lowest percent rotting of 15.6 and 21.70 in season one and two respectively being recorded when the crop was top-dressed late at 12 weeks after transplanting. The highest percent of rotting of 24.9 in season one and 37.69 in season two were recorded when the crop was top-dressed early at 3 weeks after transplanting. These results were significant ($P \leq 0.05$) in season two.

The two varieties were significantly different ($P \leq 0.05$) only in season two. The Red Tropicana F1 hybrid recorded a higher percentage of rotted bulbs of 35.4 compared to that of Red Creole of 21.1%. A higher percent of rotted bulbs was recorded in season two compared to season one. (Table 27).

The interaction effect of variety, fertilizer and time of application influencedsignificantly the severity of bulb rotting in season one (Table 28).

Table 27. Effect of N rates, time of application and variaty on severity of rotting (%) in storage experiment conducted at University of Nairobi, Kenya in 2014 and 2015 seasons.

Treatment	Severity of rotting (%) Season 1	Severity of rotting (%) Season 2
Nitrogen (kg N/ha)		
0	5.7	15.00 c
26	24.4	26.53 b
52	22.9	21.57 bc
78	30.2	39.46 a
104	30.4	38.82 a
LSD (0.05)	ns	10.22
Time (weeks)		
3	24.9	37.69 a
6	21.0	30.39 ab
9	19.5	23.92 b
12	15.6	21.70 b
LSD (0.05)	ns	11.19
Variety		
Red Creole	27.7	21.1 b
Red Tropicana F1 hybrid	17.7	35.4 a
LSD (0.05)	ns	13.42
CV%	128.1%	76%

Fishers protected least significant difference (LSD) test among means at 5% probability level.
Means followed by different letters in the same column are significantly different at $P \leq 0.05$
ns = Not significant
Time = Weeks after transplanting when the fertilizer was applied
CV = Coefficient of variation of severity of rotting

Table 28. Interaction effect of N rate, time of application and variety on severity of rotting in storage experiment conducted at University of Nairobi, Kenya in 2014 and 2015 seasons.

		Severity of rotting (%)			
		Season 1		Season 2	
Nitrogen Rate (Kg/ha)	Time of App (Weeks)	Red Creole	Tropicana	Red Creole	Tropicana
0	10.55	10.55	19.85	10.8	19.18
26	3	0.0	33.0	32.8	39.6
	6	16.7	16.7	24.2	46.0
	9	30.6	29.7	10.3	13.7
	12	68.9	0.0	2.2	43.4
52	3	30.0	6.7	19.4	46.3
	6	0.0	63.3	13.8	22.8
	9	22.2	27.8	14.4	24.1
	12	33.3	0.0	14.4	17.2
78	3	29.7	18.3	49.3	47.3
	6	56.0	0.0	34.2	45.3
	9	37.7	15.6	32.3	46.3
	12	58.0	26.7	22.8	38.0
104	3	91.2	33.3	43.4	51.4
	6	42.8	14.4	50..0	33.4
	9	16.7	0.0	14.4	53.3
	12	0.0	45.1	1.1	63.3
LSD F		ns		10.22	
LSD T		ns		11.19	
LSD V		ns		13.42	
LSD FxTxV		50.56		ns	

LSD FxTxV = Least signicance difference for the interaction of fertilizer, time and Variety
LSD F = least significant difference for fertilizer N
LSD T = Least significant difference for time
LSD V = Least significant difference for variety
ns = Not significant

4.5. Discusion

4.5.1. Effect of N fertilizer and time of application on quality parameters

Quality parameters are important for the purpose of marketability or storage of the crop. Application of nitrogen significantly increased the formation of thick necked bulbs in both seasons. Although other factors such as physiological maturity may have played a role, the thickness increased with increasing nitrogen rates. The wider neck diameters could be attributed to vigorous growth of the onion plants as a result of the higher doses of nitrogen. This result is consistent with Jilan, (2004) who reported that application of N at 200 kg/ha increased significantly the number of thick necked bulbs. In contrast, Abdisa *et al*., (2011) reported no significant effect of nitrogen fertilizer on the formation of thick necked bulbs.

Early application of fertilizer was also observed to increase bulb neck diameters significantly in season two. Adequate nitrogen nutrition early during the juvenile phases allows for rapid growth of the crop leading to thick necks as observed. However, Brewster, (1987) reported that neck thickness is a physiological disorder that is influenced by seasons, sites and cultural practices.

According to Gilan and Ghaffor, (2003), onion bulbs with thinner necks (6 – 9 mm) can be stored for a longer period as they can dry and close up quickly minimizing pathogen infection and moisture loss hence maintaining turgidity. Such bulbs are good both for the market and for storage. Although nitrogen improves yield, it lowers the quality of the bulbs by increasing the neck sizes. Other factors reported to affect bulb neck thickness are delayed maturity (Brewster, 1987) and cultivar (Naz and Amjad, 2004). The varieties in this study showed no significant differences with regard to bulb neck diameters.

Bolting only occurred in season two and varied greatly between the two cultivars with Red Tropicana F1 hybrid recording a significantly higher incidence regardless of N fertilizer level or time of application. This result is consistent with a report by Rabinowitch, (1990) that bolting varies from year to year and that genotype also influences. He also reported that the C/N ratio determines whether the onion crop remains vegetative or produces a flower stalk. Appropriate N fertilization at the time onion plants are susceptible to flower induction may reduce the incidence of bolting. Perhaps this is why a decline, though not significant occurred up to 52 kg N/ha.

In support to this claim are results of Diaz-Perez *et al.,* (2003) who found a steadily declining incidence of bolting with increasing N rates up to 192 kg/ha. Abdisa *et al*., (2011) also reported a decline of bolters up to 22% in response to only 92 kg N/ha.

According to Brewster, (1997); Roberts *et al*., (1997), untimely bolting in bulb crop is also triggered in response to such conditions as sufficient low temperatures when the plants are ready to form bulbs. The number of leaves has also been used to determine the critical plant size at which bolting can be induced under low temperature conditions. Khorkhar *et al*., (2007) reported that the sensitive plant size is when 7 – 10 leaves have been formed.

As no significant results were obtained with N fertilizer or time of application, bolting of the Red Tropicana F1 hybrid variety may have been influenced by low temperature. The cool weather which prevailed in the second season during the heavy short rains occurring from November to December 2015 coincided with bulbing of the onion crop in the experiment. The plants had already attained 7 – 10 leaves and minimum average temperatures during this period ranged from 12.5 to 14.9^{o}C (see appendix 6). The fact that there was minimal bolting for the Red Creole variety indicates its low sensitivity to low temperatures unlike the Red Tropicana F1 hybrid variety (Agic *et al*., 2007; Van den berg, 1997). Bolting renders the onions hard at the center reducing their marketability.

The formation of split bulbs or doubles was significantly influenced by nitrogen and time of its application with the highest mean number of split or doubled bulbs achieved at the highest rate of application and late topdressing of the crop. Steer, (1980) reported splitting or doubling of bulbs to occur as a result of multiple growing points which is genetically controlled with shallots at the extreme in this respect. Other factors influencing may be cultural or environmental and nitrogen application is one cultural factor that promotes multiple growing points to increase lateral shoot development. Similar results were obtained by Abdisa *et al*., (2011) who reported an increase in doubling or splitting with increased fertilizer application up to 92 kg N/ha. In contrast Nguthi, (1993) reported no significant effect on percentage of splitted or doubled bulbs with 39 kg N/ha in both seasons.

Late application promoted vigorous growth late in the season increasing lateral shoot development resulting to more splitting or doubling hence the highly significant results obtained with late application from 9 weeks to 12 weeks (Table 18).

Highly significant differences were observed between the two varieties in their tendency to split or double. In both seasons, Red Creole variety recorded the highest mean number of split and double bulbs reaching over 30% in season one. This result compares positively with that of Nguthi, (1993) who recorded a 34% of splits and doubles in Red Creole variety for two seasons.

Although split or doubled onions are perfectly edible, they have been found to be of low quality for the market often being discounted (Van den berg *et al*., 1997) and do not store well (Currah and Proctor,1990). For nitrogen to increase splitting of bulbs lowers the quality in this respect.

4.5.2. Effect of N fertilizer and time of application on storage parameters

Application of nitrogen fertilizer significantly ($P<0.001$) influenced physiological loss in weight of the onions in storage in both seasons. The bulbs cumulative weight loss increased with the advancement of storage period due to dry matter and water loss. Generally, the loss in weight increased with increase in N fertilizer rates. Similar results were obtained by Tekalign *et al*., (2012) who reported high onion bulb weight losses as N application rate increased. Also Tesfa *et al*., (2015) found increased bulb weight losses with increasing N fertilizer levels when working with different cultivars of shallots.

The higher bulb weight loss at higher N levels could be attributed to the larger bulbs produced at higher N rates which have larger surface area and hence higher rates of respiration. Jilani *et al*., (2004) reported that large size bulbs stored at 120 days at ambient conditions lost more weight compared to small and medium sized bulbs. The high Physiological Weight Loss (PWL) may be primarily due to rotting and sprouting of bulbs under high nutrient application to the crop.

Application of nitrogen fertilizer significantly reduced the number of sprouted bulbs in season one while it had no significant influence in season two. A significantly ($P<0.001$) higher number of sprouted bulbs were recorded from plots that had not received any nitrogen fertilizer in season one because the plants took longer to mature and were harvested while their leaves were still green. The stage of harvest is crucial because the substances that maintain dormancy are produced in the leaves and are translocated to the bulbs later during maturity (Komochi, 1990). When bulbs are harvested early as it was in this case, little of the sprouting inhibitor will have been translocated to the growing point hence the bulbs continue to produce leaf initials which are seen as sprouting in storage. Turker *et al*, (1979) reported that sprouting in storage of two cultivars Rijnsburger bola and Robusta occurred earlier in bulbs harvested a month early when the leaves were still erect.

This explains why the bulbs from plots that received no N sprouted very early in the first week of storage. Bulbs from plots that received nitrogen matured early and had accumulated substantial amount of the sprouting inhibitor at harvest. They began to sprout much later after a month in storage and the sprouting was minimal. Bulbs from plots that received N late in the season at twelve weeks after transplanting had a significantly higher number of sprouted bulbs in the same season. The plants from these plots were not yet mature as late application of N stimulated growth late in the season. In season two, bulbs were harvested when plants were mature (50 - 75% fallen) and nitrogen application had no significant effect. Contrary to these results were those of Tekalign *et al*, (2012) who found 63% increase in sprouting of stored onion bulbs by application of 69 kg N/ha. Danker and Singh, (1991) also reported that high dose of N produced thick necked bulbs that increased sprouting in storage due to greater access of oxygen and moisture to the central growing point.

Differences were observed between the two cultivars with regard to the number of sprouted bulbs with Red Tropicana F1 hybrid recording the highest number sprouted in both seasons which was significant ($P<0.05$) in season two. Nguthi, (1993) also reported a high number of sprouted bulbs for Red Tropicana F1 hybrid ranging from 43.5 – 52% after a three months storage. Currah and Proctor, (1990) reported that application of N had no significant effect on storage loses but cultivars showed significant differences. The high level of sprouting exhibited by Red Tropicana F1 hybrid may be attributed to genetic variation on dormancy characteristics.

With regard to the number of sprouts, application of N was significant ($P<0.01$) in the first season with the highest number of sprouts recorded with plots that received no N fertilizer. The reason for this as explained above was because these plots were harvested when the leaves were still green and erect and therefore had very little of the sprout inhibitor. In season two where harvesting was done when a higher percentage of plants had matured (50 - 75% top fall), the reverse happened. Though not significant, application of N progressively increased the number of sprouts so that the highest number was recorded at level 104 kg N/ha while the least was recorded with the control. Celestino, (1961) alluded that the role of N in increasing sprouting could be attributed to the increase in concentration of growth promoters than inhibitors with the high nutrition. The time of application had absolutely no significant effect on the number of sprouts though generally the sprouts appeared to increase with early application of fertilizer.

The Red Tropicana F1 hybrid recorded a very high mean number of sprouts in season two which was significantly ($P<0.05$) different from that of Red Creole. This showed how prolific this variety was and this too could be attributed to genetic variability in dormancy characteristics between the two cultivars.

Nitrogen application also had a significant ($P<0.01$) influence on the length of sprouts in both seasons. The length of sprouts increased progressively with increasing fertilizer rates and of course with increase in storage time. This too could be attributed to the role of N in increasing the concentration of growth promoters (auxins) with the high nutrition and hence vegetative growth. However, the time of N application had no significant effect on the length of sprouts.

Significant ($P<0.05$) differences on the length of sprouts were observed between the two varieties in both seasons. After 3 months of storage, the Red Tropicana F1 hybrid had the longest sprouts compared to the Red Creole variety. The sprouts became extremely long in season two hitting a mean of 14.13cm (Plate 3). This difference was again attributed to genetic variability in the ability to sprout. According to Currah and Proctor, (1990), cultivars that bulb rapidly (as Red Tropicana does) are soft textured and generally of low keeping quality sprouting easily in storage. Sprouting leads to the transfer of dry matter and water from the edible fleshy scales to the sprouts, resulting in increased shriveling and hence loss of market quality (Getenesh, 2015).

Application of nitrogen fertilizer significantly ($P<0.05$) influenced the number of rotted bulbs in both seasons, the number increased with the level of fertilizer applied. The highest number of rotted bulbs was observed at application of 78 kg N/ha while the lowest was with the control plots in both seasons. A 7.87% increase of rotted bulbs in season one and 12.03% in season two were realized with addition of fertilizer over the control. Similar results were obtained by Woldetsadik and Workneh, (2010) who reported the highest percentage of rotted bulbs at 150 kg N/ha and the least with 0 kg N/ha. Tekalign *et al*., (2012) reported the highest number of rotted bulbs with the highest rates of 115 and 138 kg N/ha compared to other treatments and the control. Also Gebisa, (2014) reported highly significant percentage of rotted bulbs at 300 kg N/ha with 70 – 90 days of storage.

The increase in the number of rotted bulbs with increased N rates could be attributed to the fact that higher rates of nitrogen cause plants to produce large bulbs with soft succulent tissues which makes them susceptible to attack by disease causing micro-organisms. Also high rates of nitrogen lead to production of bulbs with thick necks which are difficult to dry (close) during curing allowing entry of micro-organisms which cause rotting.

There were no significant differences with regard to the number of rotted bulbs between the two varieties used in the experiment in both seasons. However, Red Tropicana F1 hybrid recorded a 7.93% increase of rotted bulbs over the Red Creole variety in season two which was quite high. This difference could be attributed to genetic variability in rotting of the two cultivars. Also the high number of bolters that occurred with the Red Tropicana in season two could have contributed to the rotting difference. Varietal differences in rotting have been reported before by several workers. Gebisa, (2014) reported differences among varieties at 60 and 70 days of storage. Diaz-Perez *et al*., (2003) reported a higher percentage of rotted bulbs in Pegasus (63%) than Granex 33 (52%) after 8 months of storage.

Interaction of variety, fertilizer and time of application also significantly ($P<0.01$) influenced the number of rotted bulbs in season one and that of fertilizer and time ($P<0.05$) in season two. Extent of rotting advanced progressively with increased levels of nitrogen which was highly significant in season two though none significant in season one. This shows that the higher the rate of nitrogen, the softer the bulbs become and the more easily the rotting occurs after attack by spoilage micro-organisms. The extent of rotting was highest with early application (3 weeks), meaning the earlier the fertilizer is applied the softer the bulbs become and the more they rot after attack by the spoilage micro-organisms. The varieties recorded a significant difference in season two with Red Tropicana having a higher mean percentage extent of rotting. This could be attributed to varietal differences in succumbing to microbial attack and in the degree of softness after nitrogen application.

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CHAPTER FIVE

GENERAL DISCUSSION,CONCLUSION AND RECOMMENDATIONS

5.1. General discussion and conclusion

Increasing nitrogen rates from 0 – 104 kg N/ha increased vegetative growth, yield (total and marketable) and yield components (bulb weight, diameters and sizes) but reduced the quality by increasing the number of splitted bulbs, thick necks, rotting and sprouting in storage. Both N rates and time of application influenced plant height, number of leaves and bulb ratios. The interation of the two was observed to have a highly significant effect on plant height in both seasons.Generally increasing N rates increased the number of leaves in both seasons.

Although low N ratestended to stimulate earlier bulb development, this did not translate to higher yields or earlier bulb maturity. Bulb development as well as maturity was hastened by high N rates applied early in the season at 6 weeks after transplanting. Consequently, bulb weight and bulb diameter in the final harvest generally increased with increasing N fertilizer resulting to higher yields. Unfortunately, an optimum yield was not reached with the yield increasing linearly with the levels of N applied. The best rate predicted from this study was 104 kg N/ha which is also the economic rate.

High rates of N had negative effect on the quality of the bulbs. The thickness of pseudostems generally increased with increased N rates. Higher levels of N resulted to big sized bulbs with thick necks. Higher levels of N also resulted to greater splitting of bulbs, a characteristicwhich appeared to be inherent and therefore more pronouncedin the Red Creole variety. Increased N levels increased splitting of this variety with some plots registering up to 50% split bulbs. Since farmers in Kenya popularly grow this variety due to its cheap and available seed, bulb splitting could be minimized by cultural practices such as application of reduced N levels and use of integrated nutrient management. Breeding against this characteristic is also possible.

Bolting which only occurred in season two was neither affected by N nor its time of application. However some researchers (Gebretsadik and Dechassa, 2018) have reported reduced bolting with high levels up to 150 kg N/ha. Perhaps levels applied in this experiment were too low to cause a significant effect. High levels of N supposedly encourage vegetative growth hence discouraging premature seed stalk production. Rabinowitch, (1990) reported that the C/N ratio determines whether the onion plant remains vegetative or produces a flower stalk and that bolting decreased steadily as the C/N ratio decreased (increase in N content in the bulb).Bolting of the crop in this experiment was attributed to the low temperatures that prevailed in the season. The Red Tropicana F1 hybrid was more susceptible compared to Red Creole variety, suggesting an inherent genetical characteristic of the variety.

The best growth, yield and quality were obtained when N fertilizer was applied early at 3 - 6 weeks after transplanting. Late application (9 – 12 weeks) adversely affected plant height, number of leaves, bulb ratios and delayed crop maturity. Yield was also reduced as well as yield components (bulb weight and diameter) resulting to reduced marketable bulb sizes. Moreover, late application caused more splitting of bulbs and thicknecked bulbs. The predicted optimum time of N application from this study was 6 weeks after transplanting.

With regard to storage, it was observed that application of N beyond 52 kg/ha was disadvantageous because it reduced storability by enhancing PLW, sprouting and rotting of bulbs. Physilogical loss in weight and rotting were significantly influenced by N fertilization with the highest rotting and loss in weight experienced at the highest rate (104 kg N/ha) applied. Higher rates of N encouraged plants to produce large bulbs with soft succulent tissues which made them more susceptible to attack by disease causing microorganisms (Currah and Proctor, 1990). The Large bulbs also respire more due to the large surface area resulting to more water loss and hence more loss in weight. Due to its role in protein synthesis, higher N rates encouraged sprouting and growth of the sprouts further reducing the storability of the bulbs.

Application of N early in the season at 3 weeks after transplanting produced large bulbs with thick necks which resulted to the highest number of rotted bulbs and storage weight loss. Application of high levels late in the season at 12 weeks after transplanting significantly increased the length of sprouts in storage due to stimulated growth late in the season (high auxin levels) and failure to accumulate sustainable levels of the hormone maintaining dormancy.

The storage life of onions depends on many factors but probably the most important is cultivar. The performance of Red Tropicana F1 hybrid in terms of growth, yield and quality was impressive. It being a hybrid was able to overcome challenges of nutrition, pH and water availability to give a good yield compared to Red Creole variety. However, the variety easily sprouted and rotted in storage, succumbing to diseases such as bacterial rot, black and white mould. It also lost a lot of water and therefore was considered not suitable for keeping to cover in period of shortage. The Red Creole variety lost less water and had a lower number of sprouted and rotted bulbs displaying excellent quality and long storage life in both seasons. This variety is therefore recommended if farmers are producing to cover in the period of shortage.

The study has demonstrated that nitrogen fertilizer levels and time of application areamong the key agronomic practices that can increase onion production in Kenya.

5.2. Recommendations

1) Top dressing at 6 weeks after transplanting was recommended for high yields and quality.

2) Red Tropicana F1 Hybrid was recommended for commercial production due to high yields.

3) Application of 52 kg N/ha was recommended for bulbs intended for storage due to reduced rotting and sprouting.

5.3. Recommendations for further studies

1) The yield increased linearly with increased fertilizer application upto the highest level applied of 104 kg N/ha. Therefore an optimal rate was not achieved. Higher levels should be tried to reach optimal production and to allow calculation of an economic rate of application

2) Cost benefit analysis of higher N rates for optimum production should be carried out

3) Loses were high in storage due to sprouting and rotting especially for Red Tropicana F1 hybrid. Different time of harvesting to minimize sprouting and perhaps curing duration to avoid storage diseases could be investigated

4) Application of 52 kg N/ha gave good results for storage bulbs. However the yield at this level were still low. Higher fertilizer rates and curing studies should be tested. Higher rates with storage treatments should also be tried

5) Evaluation of modern or recently developed cultivers with different N rates should be done.

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APPENDICES

Appendix 1. Soil analysis results in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

1.1. Soil Texture Analysis (Hydrometer Method)

Sample description	Soil Depth	Sand %	Clay%	Silt %	Texture Grade
NARL Site	Top 0 – 20 cm	58	34	8	Sandy Clay Loam

1.2. Soil Chemical (Fertility) Analysis

Sample description	NARL Site	Lab No./2014 14053
Soil Depth	Top 0 - 20cm	
Fertility Results	**Value**	**Class**
Soil pH	4.35	Extremely acidic
Exch. Acidity me%	0.5	Adequate
Total Nitrogen %	0.05	Low
Total Org. Carbon %	0.46	Low
Phosphorous ppm	55	Adequate
Potassium me%	0.80	Adequate
Calcium me%	2.9	Adequate
Magnesium me%	1.22	Adequate
Manganese me%	0.64	Adequate
Copper ppm	2.88	Adequate
Iron ppm	89.9	Adequate
Zinc ppm	5.00	Adequate
Sodium me%	0.20	Adequate

Appendix 2.1.1. ANOVA forplant height in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	120.881	60.4405	1.29	
Variety	1	325.3813	325.3813	6.93	0.119
Residual	2	93.9509	46.9754	81.02	
Fertilizer	4	1439.101	359.7752	620.5	< 0.001
Variety x Fertilizer	4	8.9887	2.2472	3.88	0.022

Residual	16	9.277	0.5798	0.63	
Time	3	143.3295	47.7765	51.85	< 0.001
Variety x Time	3	6.3973	2.1324	2.31	0.085
Fertilizer x Time	12	29.7272	2.4773	2.69	0.006
Variety x Fertilizer x Time	12	2.6312	0.2193	0.24	0.995
Residual	60	55.2837	0.9214		
Total	119	2234.949			
CV%	2.4				

Appendix 2.1.2.ANOVA forplant height in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	55.5327	27.7664	13.62	
Variety	1	149.9313	149.9313	73.55	0.013
Residual	2	4.0767	2.0384	2.59	
Fertilizer	4	1311.349	327.8372	416.88	< 0.001
Variety x Fertilizer	4	0.3265	0.0816	0.1	0.98
Residual	16	12.5824	0.7864	1.73	
Time	3	163.9902	54.6634	120.21	< 0.001
Variety x Time	3	2.5324	0.8441	1.86	0.147
Fertilizer x Time	12	39.8861	3.3238	7.31	< 0.001
Variety x Fertilizer x Time	12	5.9964	0.4997	1.1	0.378
Residual	60	27.2837	0.4547		
Total	119	1773.487			
CV%	1.7				

Appendix 2.2.1. ANOVA fornumber of leaves in field experiment conducted at NARL, Kenya in 2014 season

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	5.9333	2.9667	0.21	
Variety	1	9.0603	9.0603	0.66	0.503
Residual	2	27.6262	13.8131	30.77	
Fertilizer	4	16.727	4.1817	9.32	< 0.001
Variety x Fertilizer	4	0.8243	0.2061	0.46	0.765

Residual	16	7.1816	0.4489	1.54	
Time	3	2.8879	0.9626	3.31	0.026
Variety x Time	3	0.2544	0.0848	0.29	0.831
Fertilizer x Time	12	4.8791	0.4066	1.4	0.192
Variety x Fertilizer x Time	12	2.9597	0.2466	0.85	0.601
Residual	60	17.4328	0.2905		
Total	119	95.7666			
CV%	6.6				

Appendix 2.2.2. ANOVA fornumber of leaves in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	5.7477	2.87	1.17	
Variety	1	1.7065	1.71	0.69	0.492
Residual	2	4.9145	2.87	9.33	
Fertilizer	4	23.4773	5.87	22.3	< 0.001
Variety x Fertilizer	4	0.7935	0.20	0.75	0.570
Residual	16	4.212	0.26	2.16	
Time	3	4.473	1.49	12.22	< 0.001
Variety x Time	3	0.2292	0.08	0.63	0.601
Fertilizer x Time	12	2.6882	0.22	1.84	0.061
Variety x Fertilizer x Time	12	2.1605	0.18	1.48	0.159
Residual	60	7.3182	0.12		
Total	119	57.7206			
CV%	4.2				

Appendix 2.3.1. ANOVA forbulb ratios in field experiment conducted at NARL, Kenya in 2014 season

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	0.59094	0.29547	3.47	
Variety	1	1.33036	1.33036	15.61	0.058
Residual	2	0.17044	0.08522	2.55	
Fertilizer	4	1.95937	0.48984	14.65	<0.001

Variety x Fertilizer	4	0.21553	0.5388	1.61	0.22
Residual	16	0.53501	0.63344	1.69	
Time	3	0.42338	0.14113	7.11	<0.001
Variety x Time	3	0.03431	0.01144	0.58	0.633
Fertilizer x Time	12	0.274	0.02283	1.15	0.339
Variety x Fertilizer x Time	12	0.25614	0.02134	1.08	0.396
Residual	60	119045	0.01984		
Total	119	6.97993			
CV%	6.2				

Appendix 2.3.2. ANOVA forbulb ratios in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	0.43955	0.22	0.72	
Variety	1	17.83901	17.8	58.66	0.017
Residual	2	0.60819	0.3	7.56	
Fertilizer	4	1.99137	0.5	12.38	<0.001
Variety x Fertilizer	4	0.14892	0.04	0.93	0.473
Residual	16	0.64338	0.04	1.18	
Time	3	0.69229	0.23	6.76	<0.001
Variety x Time	3	0.05891	0.02	0.58	0.633
Fertilizer x Time	12	0.79585	0.07	1.94	0.047
Variety x Fertilizer x Time	12	0.22536	0.02	1.55	0.872
Residual	60	2.0471	0.03		
Total	119	25.48993			
CV%	5.9				

Appendix 2.4.1. ANOVA for% fallen tops in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	2937.8	1468.9	0.39	
Variety	1	969.0	969.0	0.26	0.664
Residual	2	7592.9	3796.4	15.78	
Fertilizer	4	8953.9	2238.5	9.31	< 0.001

Variety x Fertilizer	4	705.8	176.4	0.73	0.582
Residual	16	3848.8	240.6	0.93	
Time	3	19810.6	6603.5	25.43	< 0.001
Variety x Time	3	31.0	10.3	0.04	0.989
Fertilizer x Time	12	3589.9	299.2	1.15	0.338
Variety x Fertilizer x Time	12	3153.4	262.8	1.01	0.45
Residual	60	15579.8	259.7		
Total	119	67172.9			
CV%	50				

Appendix 2.4.2. ANOVA for % fallen tops in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	414.2	207.1	0.57	
Variety	1	21067.5	21067.5	58.02	0.017
Residual	2	726.2	363.1	2.23	
Fertilizer	4	1729.67	432.42	2.66	0.071
Variety x Fertilizer	4	1017.67	254.42	1.56	0.232
Residual	16	2602.27	162.64	2.06	
Time	3	2651.03	883.68	11.2	< 0.001
Variety x Time	3	460.37	153.46	1.94	0.132
Fertilizer x Time	12	1073.8	89.48	1.31	0.351
Variety x Fertilizer x Time	12	687.13	57.26	0.73	0.721
Residual	60	4734.67	78.91		
Total	119	37164.5			
CV%	20.1				

Appendix 2.5.1. ANOVA for total bulb yield in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	1.78	0.889	0.46	
Variety	1	5.72	5.72	2.95	0.228
Residual	2	3.88	1.94	46.88	
Fertilizer	4	3.88	9.71	23.46	< 0.001

Variety x Fertilizer	4	2.78	6.95	1.68	0.204
Residual	16	6.62	4.14	1.05	
Time	3	1.36	4.52	11.47	< 0.001
Variety x Time	3	3.86	1.29	0.33	0.806
Fertilizer x Time	12	3.67	3.06	0.78	0.671
Variety x Fertilizer x Time	12	2.08	1.73	0.44	0.941
Residual	60	2.36	3.94		
Total	119	2.05			
CV%	18				

Appendix 2.5.2. ANOVA for total bulb yieldin field experiment conducted at NARL, Kenya in 2015 season

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	19.4	9.7	2.84	
Variety	1	585.208	585.208	55.13	0.018
Residual	2	33.267	16.633	1.0	
Fertilizer	4	36.617	9.154	28.23	< 0.001
Variety x Fertilizer	4	14.583	3.646	0.62	0.656
Residual	16	20.5	1.281	1.9	
Time	3	32.692	10.897	30.81	< 0.001
Variety x Time	3	4.692	1.564	0.14	0.934
Fertilizer x Time	12	30.183	2.515	1.07	0.398
Variety x Fertilizer x Time	12	9.683	0.807	0.85	0.601
Residual	60	111.5	1.858		
Total	119	898.325			
CV%					

Appendix 2.6.1.ANOVA formarketable yield of bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	1109804	554902	0.84	
Variety	1	7345801	7345801	11.1	0.079
Residual	2	1323387	661693	46.07	
Fertilizer	4	1431894	357973	24.92	< 0.001

Variety x Fertilizer	4	361001	90250	6.28	0.003
Residual	16	229813	14363	0.73	
Time	3	762777	254259	12.93	< 0.001
Variety x Time	3	61013	20338	1.03	0.384
Fertilizer x Time	12	835066	27922	1.42	0.182
Variety x Fertilizer x Time	12	258016	21501	0.09	0.382
Residual	60	1179852	19664		
Total	119	14398423			
CV%	20.1				

Appendix 2.6.2.ANOVA formarketable yield of bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	74304	37152	1.85	
Variety	1	2057225	2057225	102.16	0.01
Residual	2	40273	20137	0.71	
Fertilizer	4	2672121	668030	23.59	< 0.001
Variety x Fertilizer	4	82582	20645	0.73	0.585
Residual	16	453126	28320	1.68	
Time	3	983863	327954	19.41	< 0.001
Variety x Time	3	23236	7745	0.46	0.712
Fertilizer x Time	12	338053	28171	1.67	0.097
Variety x Fertilizer x Time	12	129527	10794	0.64	0.801
Residual	60	1013731	16896		
Total	119	7868041			
CV%	16				

Appendix 2.7.1. AONVA for average bulb weight in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	445.8	2275.8	0.46	
Variety	1	14632.2	14632.2	2.95	0.228
Residual	2	9930.5	4965.2	46.88	
Fertilizer	4	9938.4	2484.6	23.46	< 0.001

Variety x Fertilizer	4	711.5	177.8	1.68	0.204
Residual	16	1694.7	105.9	1.05	
Time	3	3467.8	1155.9	11.47	< 0.001
Variety x Time	3	98.7	32.9	0.33	0.805
Fertilizer x Time	12	940.2	78.4	0.78	0.671
Variety x Fertilizer x Time	12	531.3	44.3	0.44	0.941
Residual	60	6044.7	100.7		
Total	119	52541.8			
CV%	18				

Appendix 2.7.2. ANOVA foraverage bulb weight in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	554.45	277.23	1.86	
Variety	1	6436.18	6436.18	43.27	0.022
Residual	2	296.46	148.73	1.18	
Fertilizer	4	13066.6	3266.65	25.81	< 0.001
Variety x Fertilizer	4	155.09	38.77	0.31	0.869
Residual	16	2025.06	126.57	2.15	
Time	3	5884.0	1961.33	33.3	< 0.001
Variety x Time	3	5.13	1.71	0.03	0.993
Fertilizer x Time	12	966.67	80.56	1.37	0.207
Variety x Fertilizer x Time	12	648.86	54.07	0.92	0.535
Residual	60	3533.54	58.89		
Total	119	33573			
CV%	13.7				

Appendix 2.8.1. ANOVA fordiameter of bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	446.72	223.36	0.34	
Variety	1	778.6	778.6	1.19	0.39
Residual	2	1313.48	656.74	38.2	
Fertilizer	4	1479.29	369.82	21.51	< 0.001

Variety x Fertilizer	4	42.53	10.63	0.62	0.656
Residual	16	275.06	17.19	1.28	
Time	3	813.9	271.3	20.23	< 0.001
Variety x Time	3	8.33	2.78	0.21	0.891
Fertilizer x Time	12	141.02	11.75	0.88	0.575
Variety x Fertilizer x Time	12	68.31	5.69	0.42	0.948
Residual	60	804.71	13.41		
Total	119	6171.94			
CV%	7.7				

Appendix 2.8.2. ANOVA fordiameter of bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	28.736	14.368	0.8	
Variety	1	233.337	233.337	12.95	0.069
Residual	2	36.05	18.025	1.01	
Fertilizer	4	3294.854	823.714	46	< 0.001
Variety x Fertilizer	4	135.522	33.881	1.89	0.161
Residual	16	286.502	17.906	2.26	
Time	3	652.298	217.433	27.49	< 0.001
Variety x Time	3	33.797	11.266	1.42	0.244
Fertilizer x Time	12	124.165	10.347	1.31	0.238
Variety x Fertilizer x Time	12	99.528	8.3	1.05	0.418
Residual	60	474.528	7.909		
Total	119	5399.388			
CV%	5.7				

Appendix 2.9.1. ANOVA forsize Abulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	51.45	25.725	0.21	
Variety	1	110.208	110.208	0.91	0.441
Residual	2	242.717	121.358	10.65	
Fertilizer	4	408.417	102.104	8.96	< 0.001

Variety x Fertilizer	4	29.75	7.437	0.65	0.633
Residual	16	182.333	11.396	1.94	
Time	3	176.492	58.831	10	< 0.001
Variety x Time	3	5.558	1.853	0.32	0.814
Fertilizer x Time	12	19.05	1.587	0.27	0.992
Variety x Fertilizer x Time	12	65.317	5.443	0.93	0.528
Residual	60	352.833	5.881		
Total	119	1644.125			
CV%	66.9				

Appendix 2.9.2. ANOVA for size Abulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	24.2	12.1	6.37	
Variety	1	138.675	138.675	72.99	0.013
Residual	2	3.8	1.9	0.28	
Fertilizer	4	439.383	109.846	16.3	< 0.001
Variety x Fertilizer	4	134.783	33.696	5	0.008
Residual	16	107.833	6.74	2.23	
Time	3	223.958	74.653	24.68	< 0.001
Variety x Time	3	24.292	8.097	2.68	0.055
Fertilizer x Time	12	53.417	4.451	1.47	0.161
Variety x Fertilizer x Time	12	27.083	2.257	0.75	0.701
Residual	60	181.5	3.025		
Total	119	1358.925			
CV%	88				

Appendix 2.10.1. ANOVA for size B bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	46.35	23.175	0.2	
Variety	1	102.675	102.675	0.87	0.45
Residual	2	236.45	118.225	10.33	
Fertilizer	4	393.283	98.321	8.59	< 0.001

Variety x Fertilizer	4	30.617	7.654	0.67	0.623
Residual	16	183.2	11.45	1.94	
Time	3	167.292	55.764	9.45	< 0.001
Variety x Time	3	5.292	1.764	0.3	0.826
Fertilizer x Time	12	20.917	1.743	0.3	0.988
Variety x Fertilizer x Time	12	66.25	5.521	0.94	0.518
Residual	60	354	5.9		
Total	119	1606.325			
CV%	21.4				

Appendix 2.10.2. ANOVA forsize B bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	25.35	12.675	5.57	
Variety	1	138.675	138.675	60.96	0.016
Residual	2	4.55	2.275	0.34	
Fertilizer	4	421.55	105.388	15.97	< 0.001
Variety x Fertilizer	4	133.95	33.488	5.07	0.008
Residual	16	105.6	6.6	2.17	
Time	3	220.425	73.475	24.16	< 0.001
Variety x Time	3	24.225	8.075	2.65	0.057
Fertilizer x Time	12	58.45	4.871	1.6	0.116
Variety x Fertilizer x Time	12	25.65	2.137	0.7	0.743
Residual	60	182.5	3.042		
Total	119	1340.925			
CV%	13.4				

Appendix 2.11.1. ANOVA forsize C bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	0.15	0.075	1.29	
Variety	1	0.13333	0.13333	2.29	0.27
Residual	2	0.11667	0.05833	1.27	
Fertilizer	4	0.45	0.1125	2.45	0.088

Variety x Fertilizer	4	0.11667	0.02917	0.64	0.644
Residual	16	0.73333	0.04583	1.18	
Time	3	0.16667	0.05556	1.43	0.243
Variety x Time	3	0.06667	0.02222	0.57	0.636
Fertilizer x Time	12	1.08333	0.09028	2.32	0.016
Variety x Fertilizer x Time	12	0.35	0.02917	0.75	0.697
Residual	60	2.33333	0.03889		
Total	119	5.7			
CV%	394.4				

Appendix 2.11.2. ANOVA forsize C bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	0.05	0.025	1	
Variety	1	0	0	0	1
Residual	2	0.05	0.025	1.71	
Fertilizer	4	0.78333	0.19583	13.43	< 0.001
Variety x Fertilizer	4	0.08333	0.02083	1.43	0.270
Residual	16	0.23333	0.01458	0.29	
Time	3	0.1	0.03333	0.67	0.576
Variety x Time	3	0.13333	0.04444	0.89	0.452
Fertilizer x Time	12	0.81667	0.06806	1.36	0.210
Variety x Fertilizer x Time	12	0.45	0.0375	0.75	0.697
Residual	60	3	0.05		
Total	119	5.7			
CV%	447.2				

Appendix 2.12.1. ANOVA forneck thickness of bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	7.2056	3.6028	15.69	
Variety	1	0.6951	0.6951	3.03	0.224
Residual	2	0.4592	0.2296	1.19	
Fertilizer	4	84.3237	21.0809	109.23	< 0.001

Variety x Fertilizer	4	1.5036	0.3759	1.95	0.151
Residual	16	3.0879	0.193	0.69	
Time	3	0.673	0.2243	0.80	0.497
Variety x Time	3	0.1889	0.663	0.23	0.879
Fertilizer x Time	12	6.2816	0.5235	1.87	0.057
Variety x Fertilizer x Time	12	1.6458	0.1371	0.49	0.912
Residual	60	16.7763	0.2796		
Total	119	122.8406			
CV%	3.8				

Appendix 2.12.2. ANOVA for neck thickness of bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	12.5207	6.2603	1.41	
Variety	1	48.8113	48.8113	11.01	0.08
Residual	2	8.8672	4.4336	21.46	
Fertilizer	4	91.809	22.9523	111.1	< 0.001
Variety x Fertilizer	4	5.4939	1.3735	6.65	0.002
Residual	16	3.3055	0.2066	1.35	
Time	3	4.2012	1.4004	9.14	< 0.001
Variety x Time	3	1.2092	0.4031	2.63	0.058
Fertilizer x Time	12	1.3462	0.1122	0.73	0.715
Variety x Fertilizer x Time	12	2.1864	0.1822	1.19	0.312
Residual	60	9.197	0.1533		
Total	119	188.9476			
CV%	4.2				

Appendix 2.13.1 ANOVA for % bolted bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	109.067	54.533	0.91	
Variety	1	1241.633	1241.633	20.79	0.045
Residual	2	119.467	59.733	3.46	
Fertilizer	4	19.533	4.833	0.28	0.885

Variety x Fertilizer	4	25. 533	6.383	0.37	0.827
Residual	16	276.133	17.258	2.16	
Time	3	28.633	9.544	1.19	0.319
Variety x Time	3	26.233	8.744	1.09	0.358
Fertilizer x Time	12	109.533	9.128	1.14	0.345
Variety x Fertilizer x Time	12	123.267	10.272	1.29	0.251
Residual	60	479.333	7.989		
Total	119	2558.367			
CV%	86.1				

Appendix 2.14.1. ANOVA fornumber of split bulbs in field experiment conducted at NARL, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	19.4	9.7	0.58	
Variety	1	585.208	585.208	35.18	0.027
Residual	2	33.267	16.633	12.98	
Fertilizer	4	36.617	9.154	7.14	< 0.002
Variety x Fertilizer	4	14.583	3.646	2.85	0.059
Residual	16	20.5	1.281	0.69	
Time	3	32.692	10.897	5.86	< 0.001
Variety x Time	3	4.692	1.564	0.84	0.476
Fertilizer x Time	12	30.183	2.515	1.35	0.214
Variety x Fertilizer x Time	12	9.683	0.807	1.43	0.943
Residual	60	111.5	1.858		
Total	119	898.325			
CV%	37.1				

Appendix 2.14.2. ANOVA for number of split bulbs in field experiment conducted at NARL, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	11.4667	5.7333	1.72	
Variety	1	100.8333	100.8333	30.25	0.032
Residual	2	6.6667	3.3333	3.85	
Fertilizer	4	24.5833	6.1458	7.09	0.002

Variety x Fertilizer	4	7.25	1.8125	2.09	0.13
Residual	16	13.8667	0.8667	1.1	
Time	3	10.5667	3.5222	4.46	0.007
Variety x Time	3	5.1	1.7	2.15	0.103
Fertilizer x Time	12	7. 6833	0.6403	0.81	0.637
Variety x Fertilizer x Time	12	7.8167	0.6514	0.83	0.624
Residual	60	47. 3333	0.7889		
Total	119	243.1667			
CV%	62.7				

Appendix 2.15.1. ANOVA forphysiological weight loss of bulbs in storage experiment conducted at University of Nairobi, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	1947.6	973.8	1.43	
Variety	1	425.6	425.6	0.63	0.511
Residual	2	1357.9	678.9	2.4	
Fertilizer	4	9927.4	2481.9	8.79	< 0.001
Variety x Fertilizer	4	1519.2	379.8	1.34	0.297
Residual	16	4518.9	282.4	1.13	
Time	3	1915.7	638.6	2.56	0.064
Variety x Time	3	1524.6	508.2	2.03	0.119
Fertilizer x Time	12	15058.8	1254.9	5.02	< 0.001
Variety x Fertilizer x Time	12	8842.8	736.9	2.95	0.003
Residual	60	14994.7	249.9		
Total	119	62033.2			
CV%	47.1				

Appendix 2.15.2. ANOVA forphysiological weight loss of bulbs in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	10333.6	5166.9	1.74	
Variety	1	104017.4	104017.4	34.97	0.027
Residual	2	5948.6	2974.3	5.29	
Fertilizer	4	23988.9	5997.2	10.67	0.001

Variety x Fertilizer	4	5468.8	1367.2	2.43	0.09
Residual	16	8994	562.1	1.32	
Time	3	10842.7	3614.2	8.49	0.001
Variety x Time	3	3366.4	1122.1	2.64	0.058
Fertilizer x Time	12	3302.1	275.2	0.65	0.794
Variety x Fertilizer x Time	12	1982.1	165.2	0.39	0.963
Residual	60	25534.8	425.6		
Total	119	203779.3			
CV%	35.4				

Appendix 2.16.1. ANOVA for number of bulbs sprouted in storage experiment conducted at University of Nairobi, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	25.046	12.523	0.3	
Variety	1	0.408	0.408	0.01	0.93
Residual	2	83.672	41.836	14.45	
Fertilizer	4	101.265	25.316	8.74	< 0.001
Variety x Fertilizer	4	9.309	2.327	0.8	0.541
Residual	16	46.337	2.896	0.9	
Time	3	40.418	13.473	4.17	< 0.01
Variety x Time	3	5.981	1.994	0.62	0.607
Fertilizer x Time	12	61.069	5.089	1.57	0.124
Variety x Fertilizer x Time	12	19.32	1.61	0.5	0.908
Residual	60	193.907	3.232		
Total	119	586.732			
CV%	35.6				

Appendix 2.16.2.ANOVA fornumber of bulbs sprouted in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	38.539	19.269	0.67	
Variety	1	1579.293	1579.293	55.29	0.018
Residual	2	57.124	28.562	5.47	
Fertilizer	4	10.741	2.685	0.51	0.726

Variety x Fertilizer	4	6.059	1.515	0.29	0.88
Residual	16	83.522	5.22	1.7	
Time	3	2.8	0.933	0.3	0.822
Variety x Time	3	14.619	4.873	1.59	0.201
Fertilizer x Time	12	25.496	2.125	0.69	0.751
Variety x Fertilizer x Time	12	25.659	2.138	0.7	0.747
Residual	60	183.704	3.062		
Total	119	2027.556			
CV%	40.4				

Appendix 2.17.1. ANOVA for number of sprouts in storage experiment conducted at University of Nairobi, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	24.496	12.248	0.4	
Variety	1	52.008	52.008	1.71	0.321
Residual	2	60.8	30.4	6.61	
Fertilizer	4	100.033	25.008	5.44	0.006
Variety x Fertilizer	4	32.033	8.008	1.74	0.19
Residual	16	73.556	4.597	0.65	
Time	3	18.803	6.268	0.88	0.456
Variety x Time	3	11.395	3.798	0.53	0.661
Fertilizer x Time	12	64.026	5.335	0.75	0.698
Variety x Fertilizer x Time	12	106.767	8.897	1.25	0.272
Residual	60	426.926	7.115		
Total	119	970.844			
CV%	39.1				

Appendix 2.17.2. ANOVA for number of sprouts in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	766.07	383.04	0.83	
Variety	1	13639.11	13639.11	29.46	0.032
Residual	2	925.88	462.04	9.92	
Fertilizer	4	471.44	117.86	2.52	0.082

Variety x Fertilizer	4	365.44	91.36	1.96	0.15
Residual	16	747.03	46.69	2.83	
Time	3	105.49	35.16	2.13	0.106
Variety x Time	3	186.18	62.06	3.76	0.015
Fertilizer x Time	12	254.4	21.2	1.28	0.252
Variety x Fertilizer x Time	12	294.52	24.54	1.49	0.155
Residual	60	991.46	16.52		
Total	119	18747.03			
CV%	34.7				

Appendix 2.18.1. ANOVA for length of sprouts in storage experiment conducted at University of Nairobi, Kenya in 2014 season

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	7.583	3.791	2.17	
Variety	1	113.225	113.225	64.95	0.015
Residual	2	3.487	1.743	0.72	
Fertilizer	4	51.99	12.997	5.38	< 0.006
Variety x Fertilizer	4	12.569	3.142	1.3	0.312
Residual	16	38.654	2.416	0.94	
Time	3	8.144	2.715	1.06	0.374
Variety x Time	3	2.119	0.706	0.27	0.843
Fertilizer x Time	12	29.624	2.469	0.96	0.496
Variety x Fertilizer x Time	12	30.992	2.583	1	0.456
Residual	60	154.218	2.57		
Total	119	452.605			
CV%	20.2				

Appendix 2.18.2. ANOVA for length of sprouts in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	10.88	5.44	0.08	
Variety	1	3497	3497	54.35	0.018
Residual	2	128.67	64.34	2.96	
Fertilizer	4	388.15	97.04	4.46	< 0.013

Variety x Fertilizer	4	78.47	19.62	0.9	0.486
Residual	16	348.29	21.77	1.58	
Time	3	76.36	25.45	1.85	0.148
Variety x Time	3	18.84	6.28	0.46	0.714
Fertilizer x Time	12	123.04	10.25	0.74	0.703
Variety x Fertilizer x Time	12	235.17	19.6	1.42	0.181
Residual	60	826.36	13.77		
Total	119	5731.24			
CV%	42.5				

Appendix 2.19.1. ANOVA for number of rotted bulbs in storage experiment conducted at University of Nairobi, Keya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	20.069	10.034	21.37	
Variety	1	3.008	3.008	6.41	0.127
Residual	2	0.939	0.469	0.36	
Fertilizer	4	24.939	6.235	3.52	0.03
Variety x Fertilizer	4	11.543	2.886	1.63	0.216
Residual	16	28.363	1.773	1.05	
Time	3	4.632	1.544	0.92	0.438
Variety x Time	3	7.388	2.463	1.46	0.234
Fertilizer x Time	12	32.113	2.676	1.59	0.119
Variety x Fertilizer x Time	12	50.487	4.207	2.5	0.01
Residual	60	101.074	1.685		
Total	119	284.555			
CV%	166.3				

Appendix 2.19.2. ANOVA for number of rotted bulbs in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	38.339	19.169	2.91	
Variety	1	42.404	42.404	6.44	0.126
Residual	2	13.169	6.584	2.42	
Fertilizer	4	50.796	12.699	4.67	0.011

Variety x Fertilizer	4	8.874	2.219	0.82	0.533
Residual	16	43.474	2.717	2.43	
Time	3	27.159	9.053	8.1	0.001
Variety x Time	3	0.596	0.199	0.18	0.911
Fertilizer x Time	12	26.359	2.197	1.96	0.044
Variety x Fertilizer x Time	12	10.015	0.835	0.75	0.701
Residual	60	67. 093	1.118		
Total	119	328.278			
CV%	66.8				

Appendix 2.20.1. ANOVA for severity of rotting of bulbs in storage experiment conducted at University of Nairobi, Kenya in 2014 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	4125.7	2062.9	1.4	
Variety	1	2991.3	2991.3	2.04	0.29
Residual	2	2937.5	1468.8	1.16	
Fertilizer	4	9810.9	2452.7	1.93	0.154
Variety x Fertilizer	4	4293.2	1073.3	0.85	0.516
Residual	16	20291.5	1268.2	1.49	
Time	3	805.6	268.5	0.32	0.813
Variety x Time	3	390.4	130.1	0.15	0.927
Fertilizer x Time	12	12685.8	1057.1	1.25	0.275
Variety x Fertilizer x Time	12	27683.8	230.0	2.75	0.005
Residual	60	50910.4	848.5		
Total	119	136926.1			
CV%	128				

Appendix 2.20.2. ANOVA for severity of rotting of bulbs in storage experiment conducted at University of Nairobi, Kenya in 2015 season.

Source of variation	d.f.	s.s.	m.s.	v.r	P-value
Rep stratum	2	8357.9	4179	14.31	
Variety	1	6120.4	6120.4	20.96	0.045
Residual	2	584	292	1.05	

Fertilizer	4	11051.9	2763	9.91	0.001
Variety x Fertilizer	4	940.3	235.1	0.84	0.518
Residual	16	4461.7	278.9	0.59	
Time	3	4825.5	1608.5	3.43	0.023
Variety x Time	3	1984.2	661.4	1.41	0.249
Fertilizer x Time	12	1339	111.6	0.24	0.995
Variety x Fertilizer x Time	12	5692.7	474.4	1.01	0.45
Residual	60	28148.1	469.1		
Total	119	73505.7			
CV%	76.6				

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Appendix 3. Correlation Analysis in field experiment conducted at NARL, Kenya in 2014 and 2015 seasons.

3.1 Season 1

	Yield (g)	Bulb Diameter	No. of leaves	Plant Height (cm)	Average bulb wt.(g)	Bulb Ratios	Neck Thickness

Yield (g)	Pearson Correlation	1	.919**	.455**	.249**	1.000**	.046	.041
	Sig. (2-tailed)		.000	.000	.006	.000	.618	.655
	N	120	120	120	119	120	120	120
Bulb Diameter	Pearson Correlation	.919**	1	.482**	.211*	.918**	-.026	.093
	Sig. (2-tailed)	.000		.000	.021	.000	.780	.312
	N	120	120	120	119	120	120	120
No. of leaves	Pearson Correlation	.455**	.482**	1	.141	.453**	-.148	-.046
	Sig. (2-tailed)	.000	.000		.126	.000	.106	.616
	N	120	120	120	119	120	120	120
Plant Height (cm)	Pearson Correlation	.249**	.211*	.141	1	.248**	-.035	-.027
	Sig. (2-tailed)	.006	.021	.126		.006	.702	.773
	N	119	119	119	120	119	119	119
Average bulb wt.(g)	Pearson Correlation	1.000**	.918**	.453**	.248**	1	.047	.044
	Sig. (2-tailed)	.000	.000	.000	.006		.611	.634
	N	120	120	120	119	120	120	120
Bulb Ratios	Pearson Correlation	.046	-.026	-.148	-.035	.047	1	.033
	Sig. (2-tailed)	.618	.780	.106	.702	.611		.722
	N	120	120	120	119	120	120	120
Neck Thickness	Pearson Correlation	.041	.093	-.046	-.027	.044	.033	1
	Sig. (2-tailed)	.655	.312	.616	.773	.634	.722	
	N	120	120	120	119	120	120	120

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

3.2 Season 2

		Yield-g	Bulb Diameter	Number of leaves	plant Height (cm)	Average bulb wt.(g)	Bulb Ratios	Neck thickness
Yield-g	Pearson Correlation	1	.627**	.483**	.115	.993**	.181*	.170

	Sig. (2-tailed)		.000	.000	.214	.000	.048	.063
	N	120	120	120	119	120	120	120
Bulb Diameter	Pearson Correlation	.627**	1	.177	-.120	.622**	.062	.423**
	Sig. (2-tailed)	.000		.053	.194	.000	.499	.000
	N	120	120	120	119	120	120	120
Number of leaves	Pearson Correlation	.483**	.177	1	.076	.471**	.132	.063
	Sig. (2-tailed)	.000	.053		.414	.000	.152	.494
	N	120	120	120	119	120	120	120
plant Height (cm)	Pearson Correlation	.115	-.120	.076	1	.115	.144	-.064
	Sig. (2-tailed)	.214	.194	.414		.213	.117	.486
	N	119	119	119	120	119	119	119
Average bulb wt.(g)	Pearson Correlation	.993**	.622**	.471**	.115	1	.188*	.167
	Sig. (2-tailed)	.000	.000	.000	.213		.039	.068
	N	120	120	120	119	120	120	120
Bulb Ratios season	Pearson Correlation	.181*	.062	.132	.144	.188*	1	-.140
	Sig. (2-tailed)	.048	.499	.152	.117	.039		.128
	N	120	120	120	119	120	120	120
Neck thickness	Pearson Correlation	.170	.423**	.063	-.064	.167	-.140	1
	Sig. (2-tailed)	.063	.000	.494	.486	.068	.128	
	N	120	120	120	119	120	120	120

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Appendix 4: Minimum temperature data in field experiment conducted at NARL, Kenya in 2015 season.

Month	**Minimum Temperatures (°C)**
January	12.5
February	13.6
March	14.2
April	15.3

May	15.0
June	13.0
July	12.1
August	12.0
September	12.5
October	14.9
November	14.9
December	14.7