THE EFFECT OF NITROGEN FERTILIZATION AND PLANT DENSITY ON GROWTH, YIELD, QUALITY AND SHELF-LIFE OF BULB ONIONS (*Allium cepa* L).

BY

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A Thesis submitted in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE IN HORTICULTURE.

DEPARTMENT OF CROP SCIENCE

FACULTY OF AGRICULTURE

COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES

UNIVERSITY OF NAIROBI, KENYA.

1993

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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DECLARATION BY THE UNIVERSITY SUPERVISORS

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To my Husband Stephen Nguthi,

our son Nellex Nderitu and

our daughter Fiona Muthoni.

ACKNOWLEDEMENTS

I am grateful to Kenya Agiricultural Research Institute (K.A.R.I.) for providing the scholarship and the University of Nairobi for providing the facilities which enabled me to carry out this study.

I express my gratitude and appreciation to my supervisors, Dr. J.A. Chweya and Dr. P. M. Kimani for their guidance, advice and constructive criticism throughout the study and in writing up of this thesis.

I also acknowledge the assistance I received from the Field Station Technicians throughout the period I conducted the experiments.

Special thanks to my dear husband, Stephen, and son, Nellex for their encouragement, prayer and patience during long hours of my absence during the study. Thanks to Miss M.M. Keige who tirelessly typed this thesis.

Last but not least, I am grateful to God for enabling me carry out this study.

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ABSTRACT

Two experiments were conducted at the field station of the University of Nairobi, Kabete and at the National Horticultural Research Centre, Thika during the Short rains and Long rains, 1990 and 1991 respectively.

In the first experiment, the response of four (three recently introduced and one local onion cultivars) to application of four levels of nitrogen fertilizer (0, 13, 26 and 39 N Kg/ha) applied as CAN (26%) was studied. The 4 x 4 factorial experiment was laid out in a split-plot design with three replicates. Nitrogen was applied in the mainplots and the cultivars in the sub-plots. Data on days to maturity, total and marketable yield, bulb weight and size, neck-thickness, splitting and doubling, total soluble solids (TSS) and shelf-life was collected.

The results showed that total and marketable yield significantly increased with increasing nitrogen levels. However, the magnitude of this increase differed with locations, cultivars, and seasons. The highest bulb yield of 70.4 tons/ha was recorded at the highest level (39 Kg N/ha) of nitrogen. Increasing nitrogen upto 26 Kg/ha significantly reduced duration to maturity by about 4 days. Application of upto 13 Kg N/ha significantly reduced the number of bulbs in Grade 3 but had no significant effect on the number of bulbs in Grade 1 and 2. Nitrogen application had no significant effect on percentage splitting and doubling, bulb weight, neck-thickness and shelf-life.

Significant differences were observed between the cultivars in terms of maturity period, total and marketable yield, bulb weight and shelf-life. The newly introduced cultivars (KON5,KON6 and KON7) were all superior to the local cultivar (Tropicana F_1

hybrid) in all these aspects. Significant location differences were also detected where total and marketable yield, bulb weight and size and splitting/doubling were all significantly higher at Kabete than at Thika. Significant interactions between nitrogen and cultivars on total yield were and also between locations and nitrogen on splitting /doubling and TSS. The interaction between locations and cultivars on number of days to maturity, total yield, bulb weight and marketable yield was significant. A significant interaction between locations, nitrogen and cultivars was observed in total yield.

In the second experiment, the four onion cultivars were grown at three plant densities (38, 56 and 111 plants/m^2 to study the effect of plant density on bulb yield and quality. The experiment was laid out in a split-plot design with three replicates. Cultivars were planted in the mainplots and the density in the sub-plot.

Results showed that increasing plant density significantly increased total and Marketable yield. The percentage of splits and doubles significantly increased with plant density while the number of bulbs in Grade 1 was significantly reduced with increased plant density. Increasing plant density had no significant effect on maturity period , neck-thickness and bulb weight. The newly introduced cultivars (KON5, KON6 and KON7) were again significantly superior to the locally grown Red creole in terms of bulb yield, maturity period (they matured earlier) and had larger bulbs. Red creole showed a strong tendency to split especially at high plant density. Significant locational differences were observed in splitting/doubling, bulb weight and maturity period. The interaction between locations, plant density and cultivars on splitting and doubling was significant.

CHAPTER ONE

1.0 INTRODUCTION

The common onion (Allium cepa var. cepa) is the most important vegetable species of the tropics after the tomato (Grubben, 1977). Onions are valued for their distinctive pungent and mild flavors and even though they are not consumed in large quantities, their demand is fairly constant. This is because they are consumed in many homes almost daily as an essential seasoning for a wide variety of dishes.

The onion bulb consists of fleshy concentric scales which are enclosed in paper like wrapping leaves connected at the base by a flattened stem disc. It is these scales which are used as a vegetable. Total world production of bulb onions in 1987 was 25.3 million tonnes and the greater proportion of these (14.7 million tonnes) was grown in tropical countries (Currah and Proctor, 1990). However, many tropical countries import bulb onions as they are not able to meet their local demands. It is therefore important to increase production in these countries. In Kenya, the crop is commercially produced in the medium high altitude zones (1500m and above). These include Central, Rift Valley, Western and Eastern provinces (Kimani et.al, 1991). In the cool high altitude zones such as North and South Kinangop and Molo divisions the crop is grown under rainfed conditions. In semi-arid and arid areas such as Perkerra in Marigat, the crop is grown under irrigation. Bulb onions are grown by both large and small scale farmers.

Although the production in Kenya fluctuates from year to year, there has generally been an increase over the years. For example in 1974/75, 770 hectares were reported to have been under onion crop. In 1987, 3,749 ha were under onions (Ministry of Agriculture, Annual. Reports, 1975, 1978 and 1987).

Local demand for bulb onions has increased with the increase in population, improved living standards and diversification of eating habits. Although the hectarage under the crop has more than doubled over the years, the yields have remained quite low thus failing to meet this local demand. The yield varies between 5-20 tonnes/ha, the average being 9 tonnes/ha (N.I.B, Perkerra, 1986). Higher yields have been reported in other parts of the world for example 45.5 tonnes/ha in Japan, 39.1 tonnes/ha in Spain and 14.9 tonnes/ha in China (Pike, 1986). The low yields attained in Kenya are attributed to various factors such as low yielding cultivars, poor agro-techniques, pests and diseases.

The main onion cultivars grown in Kenya include:-

i) Bombay Red, which is susceptible to *Alternaria porri* (Purple blotch) and has a tendency to bolt. These two characteristics greatly reduce its yield.

ii) Red Creole, a popular cultivar which is resistant to *A. porri* but has a tendency to split and double. This also reduces quality and marketability of the bulbs.

iii) Tropicana Hybrid, which is an F_1 hybrid requiring a high level of management in the field. It also has a high splitting percentage.

iv) Texas Grano, a white cultivar whose keeping quality is low and not favored by majority of the people.

Due to these limitations of the existing cultivars, efforts have been made to introduce new cultivars into the country. These include short-day cultivars from Israel, U.K, India and Brazil. They are being introduced in the country through the Plant Breeding section of the Department of Crop Science of the University of Nairobi.

The cultivars are reported to be high yielding with long shelf life. Very little research has been carried out in Kenya to improve the growing practices of onions. In order to realise the yield potential of these new cultivars and even the existing ones, proper agro-techniques such as plant density and fertilization have to be established.

In Kenya, due to limitations of irrigation facilities, production of bulb onions often coincides with the rainy seasons (October-December and April- June). As such there are two peak seasons (January-February) and (August-September) during which the prices are reasonably low. At other times of the year, especially April, the prices are very high as the supply is low (H.C.D.A. Annual Report 1991). The existing cultivars, with the exception of Red Creole, have a short storage period (2-3 months). Since cold storage facilities are often expensive for developing countries, bulbs are stored in naturally ventilated sheds at ambient temperatures. It is therefore necessary to introduce cultivars that can store for long periods under the local conditions. Apart from cultivar differences, other factors also influence storage length of bulbs. These include storage temperature, relative humidity, stage of maturity at harvest and cultural practices. No research work has been carried out in Kenya to determine the effect of these factors on the storage life of onions.

The objectives of this study were therefore:-

1) To determine the effects of nitrogen fertility on growth, yield, quality and shelf life of three newly introduced cultivars and one local cultivar.

2) To determine the effects of plant density on growth, yield and quality of the cultivars.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Bulb Onion

The bulb onion (Alllium cepa var. cepa) is a member of the Alliaceae family which is intermediate between the Liliaceae and Amrylldaceae families (Purseglove, 1985). This family contains 30 genera and about 600 species. The genus Allium is large containing about 500 species. Nearly all of these species have the characteristic onion smell when injured. Most of the species are cultivated for food, but Allium cepa is the most widely grown species (Jones and Mann, 1965; T.D.R.I, 1986).

The crop and its relatives are thought to have originated from Central Asia possibly in the Iran West Pakistan region. Onions have been used by man for a long time and early cultivation is reported from Egypt where they were found depicted in tombs as early as 3,200-2,780 B.C. They were also recorded to have been eaten by pyramid builders and are referred to in the Bible (Numbers X 1, 5) and also in the Koran, (Part 1:61) (Jones and Mann, 1963; Purseglove, 1985).

Today the crop is grown in most parts of the world and its demand is worldwide. Over the years onions have become adapted to grow at different latitudes. Thus onions are grown in Tropical Asia (India, Burma, Malaysia, China Indonesia and the Philippines); North Africa (Egypt); West Africa (Senegal, Nigeria, Ghana, Ivory Coast); East Africa (Kenya, Tanzania); Tropical South and Central America (Mexico, Brazil) (Tindall, 1983).

The bulb onion is a biennial but grown as an annual in the tropics (Tindall, 1983). Normally, it forms a storage bulb in the first year and produces flowers and seeds in the second. However, in the tropics the bulbs are harvested as a vegetable crop.

The crop has shallow adventitious roots arising from a short stem. Most of the roots are found in the top 30cm of the soil and within a radius of 30cm from the bulb (Tindall, 1983; Pursglove, 1985). The onion has been reported to have one of the most limited root systems among the vegetable crops (Jones and Mann, 1963). The stem, which is very short is produced at the base of the plants and increases in diameter as the crop grows. New leaves are produced at the center of the broad short stem where the apex is. Each leaf arises from the stem tip (apex) as a ring which grows upwards to form a tube or the sheathing leaf-base. New leaves are produced inside the encycling leaf sheaths of older ones and grow up through them forming a firm structure commonly called the pseudostem. Bulbing is induced by photoperiod, temperature and plant size (Tindall, 1983). When these conditions are favorable a bulb is formed by the thickening of the leaf bases a short distance above the stem. As bulbing progresses, leaves near the bulb center abort their blades and become storage sheaths. Later as the bulb matures, the leaf sheaths weaken above the bulb and fall over. At this stage, the bulb is said to be mature and can be harvested (Jones and Mann, 1963; Tindall, 1983; Pursglove, 1985; T.D.R.I., 1986).

Photoperiod and temperature are important in the growth of bulb onions especially in bulbing (Jones and Mann, 1963). Physiologically, the onion is classified as a long-day plant. This means that a critical day-length must be attained before the onset of bulbing. This varies from 11-16 hours depending on the cultivar. Onions adapted to latitudes far away from the Equator initiate bulbing when day-lengths of 14-16 hours are reached. These long-day cultivars often fail to form bulbs in the tropical conditions. Short-day cultivars have been developed in the temperate zone and though they are physiologically still long-day plants, they respond to days which are short. They can initiate and form bulbs under photoperiods of 13 hours or less which are typical of many tropical areas (Jones and Mann, 1963; Tindall, 1983; and Currah and Proctor, 1990).

Temperature also plays an important role in bulbing which takes place more quickly at warm than at cool temperatures. Abdallah (1967), studied onion bulbing in Sudan and reported that temperature was the more important controlling factor as it was more variable than day-length in those conditions. Onions can be grown on a wide range of soils provided the pH is not less than 5.8. Alluvial or sandy loams are generally suitable. Clay soils are unsuitable unless lightened with organic matter as they tend to form a hard crust after rain or irrigation. Sandy soils dry too rapidly in hot weather and thus reduce yields. The soils should be adequately supplied with the major elements especially nitrogen and potash.

2.2 Effect of Nitrogen Fertilization on Crop Growth and Yield

Of the three major nutrients required by plants, nitrogen, phosphorus and potassium, nitrogen has the major controlling influence on growth. Nitrogen is a major constituent of amino acids, proteins and nucleic acids and plays a major role in the physiology of the plant (Harper, 1983). Much of the nitrogen present in soils and available for plant growth is in the form of organic nitrogen, i.e nitrogen tied up in protein, amino acids and other nitrogenous compounds. Some nitrate is frequently present but which is lost by leaching while the ammonium is usually bound as a cation (NH_4^+) to clay soils. The available form of nitrogen (NH_4^+ and NO_3^-) in soils is rarely over 1-2% of the total nitrogen in the soils (Ting, 1982). Nitrogen deficiency is frequently encountered in vegetable crops and symptoms of its deficiency were probably the first signs of malnutrition in plant identified by man (Purvis and Carolus, 1964). Since nitrogen is readily translocated in plants, deficiency symptoms first show on older leaves which exhibit a pale green or yellow colouration as the nitrogen in these older leaves is translocated to the young leaves (Ting, 1982).

Most plants can absorb both the cationic ion (NH_4^+) and the anion (NO_3^-) (Epstein, 1972). In most well aerated soils, nitrate is the principle form of available nitrogen and most plant do well with nitrates as the sole source of nitrogen. However, in acid soils, there are plants which absorb ammonium cation (Ting, 1982).

Nitrogen affects the vegetative part of most plant more than any other element. The size of the leaves and their duration are both increased by increasing the amounts of nitrogen applied. Low levels of nitrogen lead to leaves which are pale green as mentioned earlier. Growth of shoots and roots is restricted and the tops are short and thin (Purvis and Carolus, 1964). Due to the reduced leaf canopy, photosynthesis is reduced and consequently yields are also reduced. However, excessive application of nitrogen encourages excessive vegetative growth which leads to production of soft tissues that are easily damaged by bruising and diseases (Fordham and Biggs, 1985).

In bulb onions, nitrogen deficiency gives rise to plants that have an erect growth of leaves which are pale yellow or greenish yellow in colour (Jones and Mann, 1963).

These plants are slow in development and become distinctly stunted (Purvis and Carolus, 1965). They become stiff and upright in habit, the leaves are short and narrow and later, the tips of older leaves die and become bleached (Jones and Mann, 1963). Brewster and Butler (1989) found that application of high levels of nitrogen during the early part of the growing season promoted rapid bulbing while lower levels delayed bulbing. Brewster (1977) observed that low nitrogen resulted in lower growth rate and lower rate of leaf initiation. Zink (1962) working on growth and nutrient uptake of green bunching onions, showed that the quantity of N taken up by the crop increased throughout the growing season upto the time of harvest. He observed that maximum rate of mineral uptake coincided with the maximum rate of growth period which was the bulbing period. From these studies it is apparent that an adequate supply of N is vital throughout the growth period and especially during bulbing.

2.3 The Effect of Nitrogen Fertilization on Yield of Bulb Onions

Various reports on fertilizer trials have shown marked responses to the application of N fertilizers in bulb onions. Das et al. (1972) in India working on the effect of spacing and fertilization on the growth and yield of onions found that application of N significantly increased the yield of bulb onions compared to the control. Highest yields were obtained from the application of 120 or 160 kg N/ha. However, they found no significant differences between these two nitrogen levels. Sypien et al. (1973) investigating on the effects of using different doses of N either in split or full application on bulb yields reported that 75 kg N/ha gave the highest total yield. They observed that high doses of N (300 kg N/ha) decreased the total yields significantly. Lack of nitrogen also reduced yields as the plant's growth was retarded and produced small sized bulbs.

In India, Bhuiya, et al.(1974) observed that application of N significantly increased the onion yield. Application of 56.05 kg N/ha gave a 1.8% increase in yields over the control. The control (0 kg N/ha)gave a mean yield of 19.5 tons/ha while 56.05 kg N/ha gave 21.2 tons/ha. Rhandhawa and Singh (1974) studying the effect of N, P, K and planting distance on the maturity and yields of onions found that application of 150 kg N/ha gave a higher number of bulbs and a higher total yield/ha than applying 75 kg N/ha. The highest yield of 12.8 tons/ha was obtained with the application of 150kg N/ha while the lowest yield of 5.9 tons/ha was obtained from where no nitrogen was applied. Hedge (1986) comparing N and irrigation requirements in field trials found that the optimum level of N for bulbing was 150 kg N/ha. He found that adequate supply of N resulted in increased water use efficiency. Hassan and Ayoub (1978) working in Sudan found that 90 kg N/ha gave significantly higher yields than the control. They found that a higher rate of 180 kg N/ha slightly lowered the mean yields. Bolting, an undesirable character in bulb onions as it reduces yields and quality, is reportedly induced by cool temperatures (Jones and Mann, 1963). However, Bhamburkart et al. (1986) investigating the influence of N, planting dates and cultivars found that increasing N levels from 0-150 kg/ha decreased bolting by 50% thus increasing yields significantly. These studies indicate that application of N upto a certain level significantly increases total yields in onions. The optimum level varies with different locations and different soil conditions. Due to continuous cultivation of arable soils, they have been exposed to impoverishment in nitrogenous compounds as well as other essential elements. It is therefore important to establish the optimum level of nitrogen that should be applied to produce optimum yields of onions under our local conditions.

2.4 The Effect of Nitrogen Fertilization on the Number of Days to Maturity of Bulb Onions

As onions reach maturity they cease to produce new leaves and roots. The assimilates still present in the leaves are translocated to the bulbs; the tops, while yet green weaken just above the bulb and fall to the ground (Jones and Mann, 1963). At this stage, the crop is ready for harvesting. For a particular crop, the date of a defined percentage of tops fallen can be used as a measure of crop maturity. Various researchers have used different percentages such as 80% (Jones and Mann, 1963) as indications of maturity in onions. However, bulbs may continue to gain weight even after a 100% of tops have fallen. This is because the assimilates in the leaves continue to be translocated into the bulbs (Currah and Proctor, 1990). The stage of maturity is often important in commercial production and the date of harvesting will depend on various factors such as price, weather and immediacy of consumption of the crop. Early harvested onions often fetch high prices as the supply is usually low. On the other hand, bulbs that are harvested when they are too immature (i.e when most of the tops have not fallen) fail to cure properly and may start rotting or sprouting immediately in storage (Jones and Mann, 1963). If harvesting is delayed until most of the tops have fallen over, the bulbs may sunburn and lose their outer scales thus losing their quality even though the total yields may be higher.

Various factors influence the number of days it takes the crop to mature. These include; application of nitrogen fertilizers, cultivar differences, plant population, irrigation, and climatic conditions.

2.4.1 Application of nitrogen fertilizers

Adequate nitrogen nutrition of onions in their early growth cycle allows rapid growth during the juvenile phases. When other factors are not limiting, the crop develops rapidly, initiates bulbing and matures early (Currah and Proctor, 1990). Brewster and Butler, (1989) found that application of high levels of nitrogen during the early part of the growing season promotes rapid bulbing while low levels delay it. They found that low nitrogen treatments delayed bulb development resulting to delay in foliage collapse. Although the bulbing ratio was higher in low nitrogen plants in the early stages of growth, this was not accompanied by the transition from leaf blade to bulb scale production typical of normal bulbing. Earlier, Brewster (1977) had observed that low nitrogen resulted in lower growth rate and lower rates of leaf initiation. He observed that bulb scale initiation and therefore bulb maturity was also delayed. However, Randhawa and Singh (1974) working in India on a locally selected variety found that the application of nitrogen delayed maturity of onions. They found that plants took a maximum of 131.6 days to mature under the influence of 150 kg N/ha compared to 127.64 days and 128.19 days under 0kg and 75kg N/ha respectively. Brewster and Butler (1989) explained that high levels of nitrogen prevent or delay onion bulb initiation and thus maturity only under marginal photoperiods.

2.4.2 Cultivar differences

Due to the tendency of bulb onions to bolt under low temperatures, cultivars have been selected in the temperate regions which mature early and escape the low temperatures in winter. The Texas Early Grano developed in Texas USA is one such variety (Currah and Proctor, 1990). This cultivar is high yielding and widely grown in the tropics although the bulbs have a short shelf-life and are mild in flavor.

2.4.3 Plant population

Since crop plants are not grown in isolation but rather in closely-spaced populations, there is always competition for light, water and nutrients. This competition influences the yield, quality and time of maturity of onion bulbs. Research work carried out on the effect of varying plant densities and time of maturity in onions has indicated that bulbs grown at higher densities mature earlier than at low densities (Brewster et. al., 1983 and Brewster and Butler, 1989).

2.4.4 Irrigation

Water is essential for plant growth and is a major factor which can limit growth. Water availability to plants is determined by the balance between transpiration and uptake from the soil through the roots. If the transpiration rate exceeds the rate of uptake then a deficit develops within the plants. Plants respond to water stress by closing their stomata thus reducing their water loss. However this reduces gaseous exchange in the leaves consequently slowing down photosynthesis and growth. Jones and Mann, (1963) reporting on work carried out on the effect of irrigation on the yield of onions indicated that supplemental irrigation increase both yield and bulb size. However, water stress was found to cause earlier maturity. Brewster et al. (1983) also found that irrigated plants matured later and had a longer bulbing period than non-irrigated plants.

2.4.5 Climatic conditions

The physical environment in which crops are grown can have pronounced effects on the type and rate of growth and development (Harper, 1983). Temperature and photoperiod play an important role in the growth and development of bulb onions. Consequently, long and short day cultivars have been developed which initiate bulbing and mature within certain photoperiods. Onions bulb and mature more quickly at warm than at cool temperatures (Jones and Mann, 1963). Currah and Proctor (1990) reporting on studies carried out in Zimbabwe on response of different cultivars to varying sowing dates in the cooler months of the year indicate that low temperatures of 17-23^{0}C allowed a long vegetative growing season thus delaying the time of maturity. Under conditions of extremely high temperatures, bulbs mature early and yields are often reduced (Jones and Mann, 1963 and Abdallah, 1967).

In Kenya no research work has been carried out on the effect of nitrogen on the time of maturity in onion bulbs. From the foregoing discussion, it can be seen that maturity is influenced by various factors. It is therefore important to establish whether nitrogen fertilization under Kenyan local environmental conditions has any influence on the maturity period of exotic as well as local cultivars.

2.5 Effect of Nitrogen Fertilization on the Quality of Bulb Onions

2.5.1 Neck thickness

This has been defined as a low ratio of bulb to pseudostem (neck) diameter, i.e.

low bulbing index, accompanied by continued leaf blade growth and failure to produce the softening in the pseudostem characteristic of normally ripening bulbs (Thomas and Rankin, 1982). Thomas and Rankin (1982) classified any bulbs with a ratio of bulb to pseudostem (neck) diameter below 3:1 as thick necked bulbs. Neck thickness is an undesirable characteristic in storage of onions. This is because when thick necked bulbs are harvested and the tops removed, the wounded necks are highly susceptible to disease pathogens. The bulbs may also continue to produce new leaves (sprouting) and are therefore not good for storage.

Several causes of neck-thickness have been identified. Premature death of leaves due to severe pest or disease attacks leads to production of new leaves which hold the top erect preventing it from collapsing at maturity (Jones and Mann,1963). Long-day cultivars when grown under short-day conditions produce bulbs with thick-necks (Jones and Mann, 1963). Adequate nitrogen nutrition in the early stages of growth promotes rapid and complete bulb maturing as mentioned earlier. However, excessive application has been reported to produce thick-necked bulbs. Thomas and Rankin (1982) studying the effect of ethephon on bulbing, bull-necking (i.e neck-thickness), yield and sprouting during storage of two onion cultivars applied high levels of N in order to induce high bull-necking. They found that excessive application of N (250kg/ha) when planting and a top - dressing of 125 kg/ha) gave a high level of neck-thickness in plots which were not treated with ethephon. Sypien et al. (1973) studying the effect of N fertilization on onion quality and storage observed that application of 0-150 kg N/ha before sowing seeds resulted in smaller percentage of bulbs with thick-necks. They observed higher percentages when high quantities of N were applied (300 kg N/ha) as a top-dressing.

2.5.2 Bulb weight

Bulb weight is one of the important yield parameters that contributes to the total yield of the crop. Application of N has been reported to influence the average bulb weight. Haggag et.al., (1986) studying the effect of N,P and K on the yield and the quality of onions found that addition of these nutrients significantly affected bulb weight, bulb diameter, bulb length, dry weight contents and total soluble solids. The highest percentage number of large bulbs (i.e bulbs with more than 150g) were obtained with the addition of 120 or 150 kg/ha nitrogen. El Tabbakah et al. (1979) reported that addition of 60 kg N/ha gave the highest percentage number of large bulbs (i.e bulbs with more than 150gms). Hassan and Ayoub (1978) working in Sudan on the effects of N, P and K on yield of onion found that application of 90kg N/ha significantly increased average bulb weight. It is apparent from these studies that different levels of N have varying effects on bulb weights in different areas. Therefore, it is difficult to use a specific rate of N for any of these investigations as the standard for high bulb weights. There is therefore need to investigate the optimum N level under our local conditions.

2.5.3 Bulb size

Onions are generally marketed according to grades that have been established in a particular country. Grading is important as it establishes a common basis between the buyer and the seller for judging the quality of the product in relation to its sales price. Onions are usually graded according to the size of the bulb. In Kenya, three grades have been established;

Grade 1 which includes bulbs which are 5cm or more in diameter

Grade 2 Bulbs that are less than 5cm but more than 3cm, and

Grade 3 Bulbs that are less than 3cm in diameter

Various factors influence the size of the bulbs. These include, cultivar differences and cultural practises. Some cultivars, such as the Early Texas Grano, genetically produce large sized bulbs while others, such as the Red Creole produce medium and small sized bulbs. Cultural practises such as plant density, irrigation and nutrition, may also influence bulb size. Fertilization with Nitrogen has been reported to increase bulb size (Sypien, et.al, 1973; Hassan and Ayoub, 1978 and Haggag, et. al., 1986). Sypien, et.al.(1973) observed that onions supplied with 300 kg N/ha produced the biggest bulb size of 4.5-7cm. They found the smallest bulbs in variant 0 kg N/ha most of which were 3.5-4.5cm.

2.5.4 Splitting and doubling

Splitting and to some extent doubling of onions occurs following the formation of more than one growing point from a bulb in a single season, which grows to form a bulb. Such bulbs have been found to be of low quality and they do not store well (Currah and Proctor, 1990). Fertilization with N increases percentage splitting and doubling in onions. Thus even though the total yields may be increased by N application higher rates may lower the marketable yield. Hassan and Ayoub (1978) reported that the large bulbs attained by N and P applications had more doubles than smaller bulbs produced by the control plots. They observed that application of 0, 90 kg, 180 kg N/ha increased doubling and splitting by 11.5, 14.2, and 13.6% respectively. In field trials in Nigeria, Amans et. al. (1990) made similar observations. Using 4 levels of nitrogen (0, 40, 80, and 120 kg N/ha) and 4 levels of phosphorus (0, 40, 80, and 120 kg P_2O_5/ha), they found that percentage splitting increased as the level of both nutrients increased.

2.5.5 Total soluble solids (TSS)

Bulb onions with high total soluble solids have been reported to store for longer periods than those with low contents (Foskett and Peterson, 1950; Bajaj, et. al, 1970 and Brewster, 1977). Total soluble solids are determined by extracting juice from the bulbs, which is placed on a refractometer and refractive indices obtained. Foskett and Peterson, (1950) investigating the relation of dry matter contents to storage quality in onions found that refractive indices can be used as a method of estimating the approximate dry matter percentage in bulb onions. Since then refractive indices (RI), which indicate the total soluble solids as percent sucrose, have been used as a good estimate of dry matter content in bulbs.

Application of N has been found to influence the total soluble solids of bulb onions. El Tabbakh et.al (1979) studying the effect of soil moisture regime on total soluble solids, hardness and storage of onion bulbs (cultivar Behairy) under different levels of N found that increasing the level of N from 0 to 150 kg N/ha decreased the total soluble solids (TSS) from 12.89 to 12.59% for 0 and 60kg N/ha respectively. They found that the highest TSS and hardness were achieved with irrigation every 5 weeks without fertilizer. However, Haggag et al. (1986) working on a different variety (Giza 6) found that increasing the level of N increased the total soluble solids. Therefore, other factors like irrigation and cultivar differences may influence the amounts of TSS in onions. Jones and

Mann (1963) have reported that onions vary in their TSS from as low as 4% in mild types to about 25% in those that are highly pungent. They reported that even within a cultivar, individual bulbs may vary considerably in their solids contents.

2.6 Effects of Plant Density on Crop Growth

The demand for vegetable crops has continued to rise in the recent years. However, due to economic, political and social pressures producers find it difficult to retain and maintain the existing production sites. They have therefore become increasingly concerned with maximizing yield per unit areas (Fordham and Biggs, 1985). The spacing of individual plant of a crop determines more than any other single factor the resources available to each plant and whether or not the total resources are fully utilised (Bleasdale, 1984). In the early seedling phases of growth, individual plants hardly interfere with one another as they are sufficiently widely spaced. However, as they grow, they start to interfere with one another and competition for resources begins. Harper (1983) has defined competition as the struggle between plants within a population for available resources, when the level of resources is below the combined needs of the members of the population. The resources that crops compete for are primarily light, water and nutrients.

The study of competition in crop plants involves the study of plant populations and their effects on crop growth and yield. Competition among individual crops occurs early at high plant densities. This results in an earlier reduction in the relative growth rates. At low plant densities, the plant grow on longer before competition causes a decline in growth. At very low densities, with most crops, competition may not occur at all and resources are not sufficiently utilised (Harper, 1983). Therefore the plant population used in any particular crop must avoid the inefficient use of resources at very low densities and the excessive competition at high densities.

Plant density is usually quantified in terms of the number of plants per unit area of land. The arrangement of the plants within a given population is also important. A square arrangement of plant results in higher yields (Hartridge-Esh and Bennet 1980). Harper (1983) has recommended that comparisons of the effects of plant populations should be made at standard row widths to remove any effects of plant arrangements. Bleasdale (1966) observed that both plant arrangement and plant density affect the growth and yield of onion bulbs. They found that at a given plant density, the yield tended to increase as the row spacing decreased. Hartridge-Esh and Bennet, (1980) also observed a similar trend. They observed that as density and rectangularity increased, the number of green leaves, scales and bulb size decreased. The number of scale leaves were 41% of the total rings at 80 plants/m^2 as compared to 14% at 7 plants/m^2.

Various problems are encountered with high plant densities. Awad, et. al. (1978) reported that purple blotch disease of onion caused by Alternaria porri was more severe in high-density plants than in low density. They found that the number of spots/plant (indicating severity of infection) was lowest in plants spaced at 20cm compared to 10cm and 5cm. Bleasdale (1966) observed that at high sowing rates, some plants died as a result of competition.

2.6.1. Effect of Plant Density on Onion Bulb Yield

Plant population studies in vegetables have given rise to two basic population-yield relationship. One is where yield per unit area increases with increase in population until a certain point beyond which further increase causes yield reductions. The other relationship is where there is very little decrease in yield once the maximum level is reached. Many vegetable crops such as carrots, parsnips, runner beans, cabbages and bulb onions exhibit this second relationship (Fordham and Biggs, 1985). Various workers have investigated the effects of plant density on the yield of bulb onions and have determined those plantings that produce the greatest weights of marketable bulbs. Although there seems to be conflicting results in regard to the yields-density relationship most of the workers observed an increase in the total yield of bulb onions with an increasing number of plants per hectare.

Bleasdale (1966) observed that the total yield of bulbs increased with an increasing number of plants/ha until an optimum, after which the yields declined. He found that decreasing the distance between rows at a given plant density increased the total yields. He concluded that at 70 plants/m^2, reducing the row spacing from 45cm to 22.5-30cm increased yields by 10-30%. Hartrdge-Esh and Bennet (1980) reported that increasing plant density from 40-80 plants/m^2 at a low rectangularity (1.8), increased the fresh weight by 25 to 30%. They noted that high plant densities produced higher percentage of medium-sized bulbs. Brewster and Salter (1980) investigating the effect of plant spacing on the yield and bolting of two cultivars found that the total and ware bulb yields of both cultivars increased linearly with increasing plant densities between 43 and 129 plants/m^2. They observed that a square arrangement of plants gave a 20% higher yield than a rectangular arrangement. Frappel (1973) reported that onions exhibited asymptotic relations i.e the yield did not decline after reaching the maximum.

2.6.2. Effect of Plant Density on Days To Maturity of Bulb Onions

Plant density influences the maturity period of various vegetable crops. Studies have shown that cauliflowers grown at very close spacings mature earlier than conventional crops and have a significantly synchronised maturity for an economical mechanical harvesting. Peas and French beans planted at high densities produce their first flush of pods at the same time and inter-plant competition reduces further flowering and pod production. This ensures early maturation and harvesting (Fordham and Biggs, 1985). Bulb onions have been reported to mature earlier at high densities than at lower ones. Hartridge-Esh and Bennet (1980) observed that plants grown at low density (7 plants/m^2) matured 12.5 days later than those in the highest density (100 plants/m^2. Brewster, et al. (1983) investigating the reasons for differences in maturity date and duration of bulbing caused by plant density tested two hypothesis:

1) That maturity is hastened and bulb growth duration shortened by a reduced assimilate supply resulting from more self-shading at higher densities;
2) That more intense competition for water and nutrients results in earlier maturity and shorter duration of bulb growth at high density.

They grew the crops at 25 and 400m^{-2} and applied shades to some low density plots at the start of bulbing to reduce irradiation of the plants by about 40%. They observed that plants grown at 400m^{-2} had an earlier onset of bulbing, a shorter duration of bulbing and earlier maturity. Shading had little effect on maturity date on plants grown at low density. These results failed to support hypothesis 1. To test the second hypothesis plants were grown at densities 50 and 400m^{-2} with or without irrigation using complete nutrient solution. They found that irradiated plants matured later and had longer bulbing period than non-irradiated plants lending support to hypothesis 2. This observation was also made by Brewster and Butler (1989) who suggested that increased water stress as a result of greater competition at higher plant densities could be the main factor that leads to rapid bulbs scale initiation and bulb maturity.

Randhawa and Singh (1974) working in India on a locally selected cultivar, found conflicting results. They planted onions at 3 spacing levels; 15 X 10cm, 15 X 15cm, and 15 X 20cm and found no significant difference between the levels in respect to number of days to maturity.

2.6.3. Effect of Plant Density on the Quality of Bulb Onions

2.6.3.1 Bulb weight and size

Plant density is known to influence the weight and size of different crops. Harper (1983) has reported that close spacing of carrots results in a higher proportion of the roots in the canning size. Thus even though the total yield increases with increasing density, the size decreases. In potatoes, Harper (1983) has reported that increasing the seedling rate increases the total tuber yield but decreases the marketable yield. This is because of the increased numbers of small tubers resulting from greater competition. Cauliflowers grown at very close spacing (40 plants/m^2) produce mini-curds which are ideal for processing (Fordham and Biggs, 1985).

In onions, high plant densities reduce both the weight and size of the bulbs (Bleasdale, 1966; Frappel, 1973; Hassan, 1978; Ricard and Wickens, 1979; Brewster and

Salter, 1980 and Hartridge-Esh and Bennet, 1980). Hassan (1978) investigating the effect of three between ridge spacings of 50, 60 and 70cm and 1, 2 and 3 rows/ridge and in-row spacing of 5, 10 and 15cm; found that increasing the number of rows/ridge decreased average bulb weights and the percentage of large bulbs. The percentage number of large bulbs for 3, 2 and 1 rows were 56, 63 and 78% and for 5, 10 and 15cm they were 54, 66 and 79% respectively.

Frappel (1973) observed that as density increased from 65-445 plants/m^2, there was a progressive shift of size from large to smaller grades. He found that in order to produce a high proportion of bulbs larger than 50mm in diameter (the grade requirements in Tasmania), plant density would have to be lowered to 70 plant/m^2. At this density, the total yield was only 80% of the potential yield. Brewster and Salter (1980) reported an increase in mean bulb weight from decreasing between-row spacing from 30cm to 15cm. Bleasdale (1966) working with different varieties at different plant densities reported that at the optimum plant densities for total yields, the bulbs were too small for normal market purposes. He concluded that in order to produce a crop within the required market sizes, plant densities below that giving optimum yield would have to be used. He also observed that some of the varieties would not produce large bulbs even when grown at low plant densities implying that bulb size also differs with cultivars.

2.6.3.2 Neck-thickness

Little research work has been reported on the effect of plant density on neck-thickness which is an important quality aspect in terms of storage. Currah and Proctor (1990) cited low plant density as one of the causes of neck-thickness in bulb onions. This could be due to the fact that without any competition, for nutrients, and light and water, the plant continues to produce new leaves even when bulbing has quite progressed. Excessive application of N, especially in the later stages of growth, coupled with late irrigation gives rise to thick-necked bulbs (Currah and Proctor, 1990). Therefore, since there is little competition for N and water in widely spaced plants, they are expected to form thick-necked bulbs.

2.6.3.3 Splitting and doubling

As mentioned earlier, competition between plants affects not only the total yields but also the size of plants. Widely spaced onion plants produce large plants which yield large sized-bulbs. Hassan (1978) observed that wide spacing resulted in large bulbs which were more vulnerable to splitting than small bulbs produced by narrower spacings. He reported that bulbs from 1, 2 and 3 rows per ridge had 38, 21 and 16% doubles and from 5, 10 and 15cm in-row spacing, there were 16, 25 and 34% doubles respectively. Hassan and Ayoub (1978) also noted the association of large bulb size with splitting and doubling. They reported that large bulbs attained by application of N and P had a higher percentage of split bulbs than smaller bulbs from the control.

2.7. Storage of Bulb Onions

As mentioned in chapter 1, consumption of onions is spread throughout the year and there is a steady demand all year round. In many tropical countries, production throughout the year is not usually possible and markets must be supplied from the store upto six months of the year. The aim in onion storage is to extend the dormant period and maintain quality. Bulb onions are known to have a natural dormant period if they are harvested when fully mature (Jones and Mann, 1963). However, this period of rest which is thought to be controlled by an interaction between promoters and inhibitors (Isenberg et. al., 1974 and Brewster 1977) disappears with time and the bulbs start sprouting and rooting. The major cause of loss in storage arise from rotting, sprouting and rooting (Pike, 1986).

Various factors influence the storage period of bulb onions and Currah and Proctor (1990) have categorised them into;

a) Genetically controlled factors,

b) Preharvest cultural factors

The first category involves cultivar differences. Cultivars differ considerably in their keeping quality. Jones and Mann (1963), reporting on work carried out in the United States on the keeping quality of various varieties stated that regardless of how the onions were grown and stored, the various varieties tended to assume the same relative position as to storage quality. Thus it has been possible to classify cultivars into storage groups such as poor, good and very good. Examples of cultivars which are poor in storage quality are the various Early Grano types. The Creole types and the Australian Brown are some of the cultivars with a good storage capacity (Thompson, 1982).

Various characteristics of the different cultivars influence their keeping quality. These include dry matter content, skin colour, skin number and quality and pungency.

2.7.1 Dry matter content

Dry matter contents in bulb onions varies from as low as 4% in some mild types to about 25% in those that are highly pungent (Jones and Mann, 1963). Foskett and

Peterson (1950) compared the storage ability of various varieties grown in the US, and their dry matter contents. They found that there was a tendency for varieties with a low dry matter content to sprout more during storage than those with high dry matter contents. Onions with high dry matter contents are firm and therefore more resistant to damage during harvesting and transport. However, they tend to yield less than onions with low dry matter and maybe less attractive to growers (Currah and Proctor, 1990).

2.7.2 Onion pungency

Pungency in onions is due to the presence of a number of sulphur containing organic compounds which release the volatile flavour when the onion tissue is damaged (Currah and Proctor, 1990). Bulb onions with high dry matter contents are also highly pungent (Jones and Mann, 1963) and although this is often associated with good storage quality, little research has been carried out to show the direct effect of pungency on storage performance.

2.7.3 Onion skin quality

Varieties which have several layers of dry outer skin have a good storage performance as they are able to retain some of the skins during storage. Retention of onion skins during storage is important as they protect the scales from physical damage, infection and rapid water loss (Currah and Proctor, 1990). These workers have also reported that skin retention is strongly influenced by the relative humidity of the storage environment, decreasing rapidly when R.H. is less than 60%.

The second category of factors that influence the storage performance of bulb onions include factors such as, stage of harvest, irrigation, application of nitrogen and treatment with sprout inhibitors.

2.7.4 Stage of harvest

The stage of harvest is crucial because the substances that maintain dormancy are produced in the leaves and translocated to the bulbs during the later part of the growing season (Stow, 1976). This worker found that if bulbs are harvested too early, little of the sprouting inhibitor will have been translocated to the growing point and the bulbs continue to produce leaf initials which are seen as sprouting in storage. This phenomenon was also observed by Tucker et al. (1979) who 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. Although leaving the bulbs in the fields until all the leaves have dried does ensures maximum translocation of growth inhibitors to the growing point and gives high yields, extended field drying results in more diseases in storage and increased skin loss (Currah and Proctor, 1990).

2.7.5 Treatment with sprout inhibitors

Treatment with sprout inhibitors before harvest has been found to influence storage life. Many inhibitors or supressors have been studied but maleic hydrazide (MH) has been found to be the most effective. Rutherford and Whittle, (1982) reported that pre-harvest spraying with MH retarded sprouting by inhibiting nucleic acid metabolism and cell division thus prolonging the storage life of onions. Other workers who have reported on the use of MH as a sprout inhibitor include, Isenberg and Ang (1964); Kale et.al. (1991) and Dutta Ray et. al (1991). These latter workers compared the effects of ethryl, NAA, 2.4 S-T and MH on storage behaviour of bulb onions. They found that spraying with MH at 3,000mg/L resulted in significantly lower percentages of rotting bulbs after 4 months (0.9%) compared with the control treatments (17%). Application of 2,000mg/L of MH reduced sprouting to 5.4% after 4 months compared to 13% in the untreated onions.

2.7.6 Frequency of Irrigation

Late irrigation of bulbs leads to production of thick-necks which do not cure well and cannot store for long. This is because when topped, the necks do not dry easily and are susceptible to infection by pathogens. Kale et al. (1991) reported that high levels of irrigation {50 CPE (Cumulative Pan Evaporation)} resulted in significant increases in the numbers of sprouted and rotted onion bulbs in storage. They found that the extent of losses with high irrigation were 1.5-2 times more than those from the lower levels (100 CPE).

2.7.7 Temperature and relative humidity

Apart from these genetic and pre-harvest controlled factors bulb storage is also influenced by the storage conditions. Temperature and relative humidity are the two major storage conditions. As early as (1941), Karmarkar and Joshi observed that sprouting of onions in storage increased with storage temperatures reaching a maximum at 15^{0}C. Stow (1975a) also observed that temperatures above 25^{0}C kept onion bulbs dormant and losses from sprouting were relatively low. Chang et.al. (1987) working in Taiwan with three cultivars, Early Grano 502, Granex and a local cultivar stored at 10^{0}C and 30^{0}C room temperature, observed that little sprouting occurred at 30^{0}C. They found the highest percentage of sprouting in lots stored at 10^{0}C. Differences between the cultivars were also observed with the local cultivar having the lowest sprouting percentage while Granex had the highest. Stow (1975b) investigated the resistance of 20 cultivars of onions to rotting and sprouting at high temperature storage. He found that although high temperatures (30^{0}C) and low relative humidity (50%) reduced sprouting in most of the varieties, no variety showed any appreciable resistance to rotting. He concluded that cultivars do not show resistance to rotting at high temperatures but suppression of sprouting is a common character. Relative humidity has several distinct effects on stored bulb onions. High humidity in storage encourages rapid spread of diseases thus promoting rotting. It also encourages root development of the bulbs. Low humidity on the other hand leads to water loss and desiccation of bulbs. Stow (1975a) stored onions at a range of humidities, 35, 50, 60 and 70% at 30^{0}C. He found that losses from desiccation were greater at the lowest humidity than at the higher humidities. Rotting was greatest at the highest humidity during the latter months in storage. Sprouting also tended to be greatest at the highest humidity. He found that the total loss in weight due to discarding rotted and sprouted bulbs as well as dessication was consistently highest at the highest humidity after the first three months of storage.

From the above review, it is evident that various factors have to be considered in storage of bulb onions. Little work has been carried out in Kenya on onion storage. In this study, the effect of nitrogen on storage was studied.

2.8 Effect of Nitrogen Fertilization on Storage Life of Bulb Onions

Various studies have been carried out on the effects of fertilization on storage quality of various vegetable crops. Fritz and Habben (1973) reported that application of high levels of nitrogen prolonged the storage period of tomatoes but not that of carrots and snap beans. They reported that potassium increases storage of most vegetable crops by lowering the activity of enzymes breaking down caborhydrates. Potassium also raises the water content and lowers evaporation in spinach thus prolonging turgidity and shelf life. Application of nitrogen in bulb onions has been reported to influence their storage life. Isenberg and Thomas (1970) reported that nitrogen fertilizer treatment in the field did not greatly affect storage life of bulb onions. They observed that bulbs harvested from high-N plots showed only a slight increase in percentage sprouting compared to those from low-or no-N plots. However, they observed that the bulbs from the high-N plots entered a state of dormancy later than bulbs from the other two treatments. They concluded that the natural growth inhibitor, responsible for dormancy in bulbs was accumulated later in bulbs from the high-N plots and that some auxin, presumed to be synthesized during active growth was detected early in the storage period.

Diatchenko (1974) working on the influence of different ratios of N:P:K on the keeping quality of bulb onions and carrots found that there was an optimum ratio at which the keeping quality and resistance to disease were best. This ratio for onions was given as 46:17:37 ($N:P_2O_5:K_2O$). He noted that breaking this ratio by decreasing or increasing one of the elements lowered the keeping quality of the bulbs.

Currah and Proctor (1990) reviewing work carried out on some Indian varieties reported that a high nitrogen rate had little effect on their storage life. They reported that losses from plots given 150 Kg N/ha were only 3% more than those from 75 Kg N/ha. Storage differences between cultivars were much higher than the effects of N fertilizer. However, as discussed in section 2.4.1, excessive application of nitrogen especially in the later stages of growth was found to promote foliage growth leading to production of thick-necked bulbs. These bulbs when topped and stored are highly susceptible to pathogen infection leading to rots in storage.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Experimental Sites

Two experiments were carried out for two seasons: October-January, 1990 and April-August, 1991 locally referred to as Short rains and Long rains respectively. The experiments were conducted at the University of Nairobi farm, Upper Kabete Campus and the National Horticultural Research Centre, Samuru farm, Thika.

Kabete is located at latitude 1^0 15' South and longitude 36^0 44' East. It is 1829m above sea level with mean maximum and minimum temperatures of 23^0C and 13^0C respectively. The coolest months are June, July and August while the hottest months are Mid-December, January and February. However, this may vary from year to year. The area has a bimodal rainfall regime with an annual average of 1046mm The long rains start from mid-March upto mid-June. More than 50% of the annual average falls during these long rains season. The short rains which start from mid-October to December contribute about 30% of the annual average. Appendix 1 shows the rainfall and temperature figures for part of the years 1990 and 1991 during which the experiments were carried out.

The National Horticultural Research Centre, Thika, is located at latitude 1^0 09' South and longitude 37^0 04' East. It is approximately 1549m above sea level with mean minimum and maximum temperatures of 13.7^0C and 24.1^0C respectively. The coolest months are June, July and August while the hottest months are December, January, February and Early March. The area has a bimodal rainfall regime with an annual average of 992mm. The long rains start in mid-March to May while the short rains start from mid-October to November. Appendix I shows the rainfall and temperature figures recorded during the experimental period.

3.2 Soils

The soils in Kabete have been described as humic nitosols. They are well drained, extremely deep, dusky to red to dark reddish brown friable clay (Jaetzold and Schmidt, 1983).

The soils in Thika have been described as well drained extremely deep (120cm), dusky red to dark reddish brown friable clays with 69-84% clay content (Nyandat and D'costa, 1968). In order to determine the nutrient content of the soils, random samples were taken from both experimental sites at a depth of 0 to 30cm. The soils were analysed for the pH, exchangeable bases (Na, K, Ca, Mg and Mn), phosphorus, Total carbon and total nitrogen. The results of this analysis are presented in appendix 2.

3.3 The Onion Varieties Studied

In both experiments, three exotic and local cultivars were used. The three exotic cultivars are improved varieties from Israel introduced in the country through the Plant Breeding section of the Department of Crop Science of the University of Nairobi.

These cultivars were:

1) KON6-Early Red. This is a high yielding variety developed in Hazera for the early market. The bulbs are almost globe and the flesh is mild and soft. They mature relatively early and the bulbs are medium sized. They have a storage period of 3-4 months.

2) KON5-H508. This is an early high yielding hybrid with mild firm flesh. The bulbs are yellow skinned, rounded at the top and are medium to large sized. They store well under ambient conditions for 4-5 months.

3) KON7-3690177(4) (Grano No. 4). It is a medium early maturing variety with large straw yellow bulbs. It is high yielding with a shelf life of 4-5 months.

4) The two local cultivars were the popular Red Creole and the Tropicana F_1 hybrid. Red Creole which was used in experiment 2, has hard small to medium bulbs which have a flattened globe shape. The skin is reddish buff while the flesh is purple red. The bulbs mature in 190 days from seeding and store for 2-3 months if kept dry and well ventilated.

5) Tropicana F_1 hybrid (Tropicana). This cultivar was used in experiment 1 and is high yielding requiring a high level of management. The bulbs are red-skinned with a light pink firm flesh. They are medium-sized and can store for 1-2 months if kept dry and well ventilated.

3.4 Experimental Design

Two experiments were carried out; Experiment 1 was designed to investigate the effect of nitrogen fertilization on the yield, quality and storage life of four onion cultivars. Experiment 2 was to investigate the effect of plant density on the yield and quality of four onion cultivars.

3.4.1 Experiment 1. Effect of nitrogen fertilization on yield and quality of bulb onions

The treatments consisted of top - dressing with four levels of nitrogen; 0, 13, 26 and 39 Kg N/ha, (as 0, 50, 100 and 150 kg of CAN/ha) and four varieties of onions, (Tropicana F_1 hybrid, KON5-H508, KON7(3690177(4)) (Grano No.4), and KON6-Early Red). Thus there were 4 X 4 treatment combinations giving a total of 16 treatments. These were laid out in a split-plot design whereby the N levels were the main plots and the varieties were the sub-plots. The treatments were replicated 3 times giving a total of 48 sub-plots which were 2m X 0.9m each in size.

Seeds were sown in a nursery bed at Kabete on 25/8/90 and 14/3/91 for both experiments in the first and second seasons, respectively. Three weeks after emergence, the seedlings were top - dressed with 4.5 kg N/ha. They were regularly watered and sprayed with Dithane M-45 at the rate of 2 kg/ha to prevent infection with Alternaria porri (Purple blotch) and Peronospora destructor (Downy mildew).

The seedlings were transplanted after 8 weeks from seeding when they were pencil thick into small furrows that were 30cm apart. The plants were spaced 8cm from each other. Triple Superphosphate (TSP, 45% P_2O_5) was applied in the furrows at a rate of 100 kg/ha and thoroughly mixed with the soil during transplanting. The plants were well watered after transplanting. Four weeks after transplanting, the plants were top-dressed with the various levels of nitrogen.

3.4.2 Experiment 2. Effect of plant density on yield and quality of bulb onions

The experiment consisted of three levels of spacing; 30 X 12cm, 30 X 8cm and 30 X 4cm (which gave rise to 38, 56 and 111 plants/m^2 respectively), and four varieties; KON5, KON6, KON7 and Red Creole. Thus there were 3 X 4 treatment combinations giving a total of 12 treatment combinations. These were laid out in a split plot design, the varieties being the main plots and the spacing levels the sub-plots. The treatments were replicated three times giving a total of 36 sub-plots which were 2 X 0.9m in size.

The seedlings were transplanted into small furrows according to their respective densities. Diammonium phosphate (DAP, 18% N and 20% P_2O_5) was applied 34 at a rate of 200 kg/ha during transplanting. Immediately after transplanting, the plants were well watered.

3.5 Crop Husbandry

The plants were supplemented with irrigation water using overhead sprinklers during the two seasons in both sites. In the dry periods, the plants were irrigated twice a week and once or none during the wet periods. In both seasons and at the two sites the plants were attacked by both downy mildew and purple blotch. These were controlled by spraying Dithane M-45 at a rate of 2.5kg/ha and Ridomil at a rate of 2kg/ha. At Thika, incidences of onion thrips (*Thrips tabaci*) were observed in the later stages of the crop when the weather was becoming dry. These were controlled by spraying dimethoate (Rogor L40) at the rate of 2L/ha. The fields were kept free of weeds by hand weeding. Due to the prevailing wet weather in the early stages of the crop weeding was done severally.

3.6 Field Data Collection

Data on the following parameters were collected during each season for both experiments.

a) Number of days to maturity from transplanting time.

b) Total yield per hectare (tons/ha).

c) Percentage No. of split and double bulbs.

d) Bulb weight (grammes)

e) Bulb size (cm)

f) Neck-thickness (cm)

g) Total soluble solids (as an estimator of dry matter content). This was done for experiment 1 only.

h) Marketable yields (tons/ha)

i) Storage life (experiment 1 only)

3.6.1 Determination of number of days to maturity

At maturity, the tops drop, fall over and begin to dry up. Since the plants do not all mature at the same time, for a particular crop, maturity is determined by the date of a defined percentage of tops fallen. In this study the date at which more than 50% of the tops had fallen over, from the transplanting date, was used.

3.6.2 Determination of total yield (tonnes)

The outer rows in each subplot were not harvested as they acted as the guard rows for both experiments. Therefore, two rows in each plot were harvested, the tops were cut off and the bulbs weighed. The weight was expressed as the total yield in tons/ha.

3.6.3 Determination of number of split and double bulbs

All the harvested bulbs, from each crop were counted. The number of split and double bulbs was counted and expressed as a percentage of each plot total.

3.6.4 Determination of marketable bulb weight

The split and double bulbs were removed from each plot harvested. From the remaining bulbs, 15 were randomly selected and weighed. The mean weight of these 15 bulbs was used to determine the bulb weight in each treatment.

3.6.5 Determination of neck-thickness

Neck-thickness refers to the ratio between width of the bulb and width of the neck. A bulb is considered to be thick-necked when this ratio is less than 3:1 (Thomas and Rankin, 1982). The 15 bulbs randomly selected from **3.6.4** above, were used to determine neck-thickness. For each bulb, the maximum bulb diameter and the maximum pseudostem (neck) diameter were measured using a vernier caliper and expressed as bulb:neck ratio. The mean ratio of the 15 bulbs was used to indicate neck-thickness in each treatment.

3.6.6 Determination of bulb size

All the bulbs from each plot (excluding the splits and doubles) were counted and graded into three grades viz;

Grade 1	Bulbs with a diameter more than 5cm.
Grade 2	Bulbs with a diameter less than 5cm but more than 3cm.
Grade 3	Bulbs with diameter less than 3cm.

The diameter was measured with a vernier caliper. The number of bulbs in each grade was counted and expressed as a percentage of the total.

3.6.7 Determination of total soluble solids (TSS)

Ten bulbs were randomly picked from plot harvests. Juice was extracted using a mechanical squeezer and placed on a hand refractometer. The readings were taken as refractive indices which were converted into percentage total soluble solids using conversion tables from the Association of Official
Analytical Chemists (A.O.A.C.) (Hortwitz, et al. 1975).

3.6.8 Determination of marketable yield

All the bulbs from each plot were left to cure in a well ventilated store on racks for 4 weeks. This curing period is essential if bulbs are to be stored. However, if the bulbs are to be sold for immediate consumption, it may not be necessary. At the end of the curing period, all the sprouted and rotten bulbs were removed and the rest weighed. The total weight of each plot was expressed as marketable yield/ha (tons/ha).

3.6.9 Determination of storage life

The split and double bulbs were removed from each treatment. A 30 bulb sample from each treatment was placed in storage racks at room temperature. The number of bulbs that had sprouted or rotted after every 4 weeks were recorded for a duration of 3 months. The rotten and sprouted bulbs were expressed as percentage loss in storage.

3.7 Statistical Analysis

The data on percentage splitting and doubling, sprouting, rotting and grading were transformed using the angular transformation before analysis. After analysis, the means were transformed back to the original percentages for presentation. All the data was analysed using the Analysis of Variance Methods (ANOVA) as illustrated by Steel and Torrie (1980). Separation of means was done using Duncan's Multiple Range Test (DMRT) at the probability level of p= 0.05.

CHAPTER FOUR

4.0 RESULTS

4.1 Experiment 1: Effect of nitrogen and cultivar on:

4.1.1 Days to maturity of bulb onions

Application of N significantly influenced the number of days it took the bulbs to reach maturity during the first season (Short Rains, 1990) but not during the second season (Long Rains, 1991). Table 1 shows that application of N significantly reduced the number of days to maturity in the short rains. Plants supplied with 39 kg N/ha matured within 113 days compared to 116 days when no N was applied. During the long rains, there was also a tendency to decrease the maturity period with application of N although this was not significant.

In both seasons, significant differences were observed between the cultivars in their maturity period (Table 2). During the short rains, 1990 there were significant differences between all the cultivars. Cultivar KON5 matured earliest (98 days) followed by KON6 (106 days) KON7, (114 days) while Tropicana F_1 hybrid matured latest (131 days). During the long rains, 1991, Tropicana F_1 hybrid still matured latest while KON7 matured earliest. However, there was no significant difference between KON5, KON6 and KON7.

Significant locational differences were observed in both seasons (Table 3). During the short rains, bulbs matured significantly earlier at Thika (107 days) than at Kabete (117 days). In the long rains, bulbs matured earlier at Kabete (125 days) than at Thika (156 days).

Table 1: Effect of nitrogen on days to maturity , bulb yield, splitting and doubling, bulb weight, total soluble solids (TSS) and marketable yield of bulb onions grown at Thika and Kabete in 1990 and 1991.

Nitrogen level	Days to maturity 1990	Days to maturity 1991	Bulb Yield 1990	Bulb Yield 1991	Splitting/doubles 1990	Splitting/doubles 1991	Bulb Weight 1990	Bulb Weight 1991	TSS 1990	TSS 1991	Mkt. Yield 1990	Mkt. Yield 1991
kg/ha	no.		t/ha		%		g		%		t/ha	
0	116a**	144a	28.4a	45.0c	12.7a	16.2a	68.3a	114.8a	7.0a	7.9b	22.6bc	35.7a
13	111b	142a	30.3a	60.4b	14.6a	20.8a	65.0a	141.6a	7.1a	9.5a	21.9c	49.7a
26	111b	141a	33.9a	62.6ab	11.9a	20.5a	70.8a	142.8a	7.2a	9.2a	27.7a	45.3a
39	113b	136a	33.0a	70.4a	14.2a	19.3a	73.9a	157.0a	7.3a	10.1a	26.6ab	51.4a
CV%	3.7	11.1	24.5	22.3	19.3	33.7	8.2	42.0	13.9	19.7	26.4	40.6
S.E	0.8	3.8	1.9	2.7	1.0	1.3	5.4	11.9	0.3	0.4	1.6	3.8

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level.

Figures followed by the same letter down the column are not significantly different.

Table 2: Differences between four onion cultivars grown at Thika and Kabete in duration to maturity, bulb yield splitting and doubling, bulb weight, total soluble solids (TSS) and marketable yield In 1990 and 1991.

Cultivars	Days to maturity 1990	Days to maturity 1991	Bulb Yield 1990	Bulb Yield 1991	Splitting/doubles 1990	Splitting/doubles 1991	Bulb Weight 1990	Bulb Weight 1991	TSS 1990	TSS 1991	Mkt. Yield+ 1990	Mkt. Yield+ 1991
	no.		t/ha		%		g		%		t/ha	
Tropicana	131a**	154a	27.1a	42.8c	16.1a	16.9a	60.8b	101.1c	9.2a	11.5a	22.7a	29.5c
KON6	106c	141b	25.5a	61.2b	14.5a	18.3a	61.9b	153.6ab	6.7b	7.9c	20.0a	48.5b
KON5	98d	136b	28.6a	58.3b	17.4a	22.9a	69.5b	136.9b	6.5b	9.3b	20.8a	45.7b
KON7	114b	133b	44.3b	76.0a	7.6b	18.7a	85.8a	164.4a	6.2b	8.0c	35.3b	58.4a
C.V(%)	5.1	10.8	19.7	13.7	48.4	42.5	25.1	21.6	13.5	21.8	23.9	25.3
S.E.	1.2	3.1	1.3	1.7	2.1	1.7	3.6	0.4	0.3	0.4	1.2	2.3

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) at 5 % level

Figures followed by the same letter down the column are not significantly different.

+ Mkt. Yield = Marketable yield.

Table 3: **Interaction between locations and cultivars on days to Maturity in bulb onions grown at Thika and Kabete in 1990 and 1991.**

Cultivar	Short rains, 1990				Long rains, 1991			
	Days to maturity				Days to maturity			
	Locations				Locations			
	Thika	Kabete	Mean	S.E.	Thika	Kabete	Mean	S.E.
Tropicana	130a**	132a	131	1.2	171a	136a	154	3.1
KON6	99e	113bc	106		160a	121a	141	
KON5	90f	106d	98		151a	121a	136	
KON7	111cd	118b	114		142a	124a	133	
Mean	107	117	112		156	125	141	
C.V (%)	5.1				10.8			
S.E.	0.6				4.4			

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT), 5%.

Figures followed by the same letter are not significantly different.

4.1.2 Total onion bulb yield

Application of N had significant effect on total yield only during the long rains. Increasing the level of nitrogen progressively increased the total yield (Figure 1). The highest mean yield of 70.4 Tons/ha was obtained with application of 39 kg N /ha while the lowest (45 Tons/ha) was from the control. During the short rains, the total yield also tended to increase with increase in N although this was not significant.

In both seasons significant differences were observed between the cultivars in their total yield (Table 2). KON7 outyielded all the other cultivars significantly in both seasons. During the short rains it gave a mean yield of 44.3 Tons/ha compared to 25.5, 27.1 and 28.7 Tons/ha for KON6 Tropicana F_1 hybrid and KON5 respectively. The yield of the last three cultivars were not significantly different. During the long rains, KON7 still outyielded all the other cultivars. It yielded 76.0 Tons/ha compared to 61.2, 58.3 and 42.8 Tons/ha for KON6, KON5 and Tropicana F_1 hybrid, respectively. There was no significant difference between KON6 and KON5.

The interaction between nitrogen levels and cultivars was highly significant during the long rains (Table 4). At 0 level of N, no significant difference was observed between KON6, KON5 and KON7. However, Tropicana F_1 had significantly low yield compared to these latter three cultivars. Increasing N from 0 to 13 kg/ha significantly increased yield in all cultivars except in KON5. At 13 kg N/ha, There was no significant difference between Tropicana F_1 hybrid and KON5 and also between KON6 and KON7. Further increase of N significantly increased yield only in KON5 and KON7.

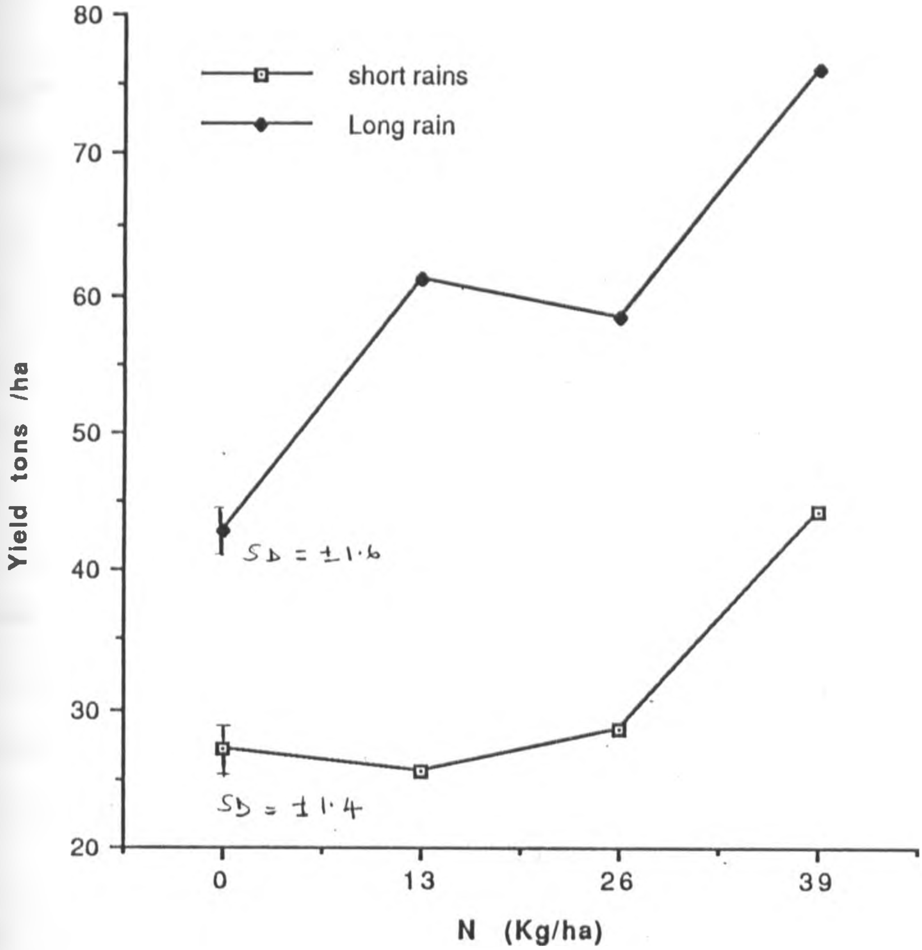


Fig. 1 Effect of Nitrogen on the yield of bulb onions grown at Thika and Kabete in 1990 /91

Table 4: Interaction between nitrogen levels and cultivars on total yield of bulb onions grown at Thika and Kabete in long rains, 1991.

Nitrogen (Kg/ha)	Total yield (tons/ha) Cultivars Tropicana	KON6	KON5	KON7	Mean
0	27.6g**	46.3ef	50.4def	55.7de	45.0
13	46.0ef	69.6bc	51.3def	74.4b	60.4
26	41.7f	60.0cd	59.8cd	88.7a	62.6
39	56.0de	69.0bc	71.9b	84.8a	70.4
Mean	42.8	61.2	58.4	75.9	59.6
C.V (%)	13.7				
S.E.(cultivars)	1.7				
S.E.(nitrogen)	2.7				

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% Level. Figures followed by the same letter are not significantly different.

The interaction between location and cultivar was significant as shown in Table 5 for both seasons. In both locations, KON7 outyielded all the other cultivars although the yields at Kabete were higher than at Thika. During the short rains at Kabete the ranking for the cultivars was 53.3, 33.7, 31.2 and 30.8 Tons/ha. for KON7 Tropicana F_1 hybrid, KON6 and KON5 respectively. There was no significant difference between KON6 and KON5. In Thika, the ranking was 35.3, 26.5, 20.5 and 19.9 Tons/ha for KON7, KON5, Tropicana F_1 hybrid and KON6 respectively with no significant difference between KON6 and Tropicana F_1 hybrid. During the long rains at Thika the ranking was as follows from the highest to the lowest:- KON7 (70 Tons/ha), KON6 (56.3 Tons/ha), KON5 (50.3 Tons/ha) and Tropicana F_1 hybrid (37.3 Tons/ha). At Kabete, the ranking was similar but the yields were higher than at Thika. At both sites there was no significant difference between KON6 and KON5.

Locational effects were also significant during the two seasons. Yields were higher at Kabete than at Thika, being 37.2 Tons/ha at Kabete and 25.5 Tons/ha at Thika for the short rains and 65.7 Tons/ha at Kabete and 53.5 Tons/ha at Thika during the long rains (Table 5).

The interaction between location x nitrogen x cultivar was also significant during the long rains (Table 6). Figure 2 show the response of the four cultivars to different levels of N in the two locations. At Kabete, increasing the level of N progressively increased the yield of Tropicana F_1 hybrid while the trend for KON7 and KON6 was different in that the yield increased upto 13kg N /ha then decreased with application of 26 kg N /ha and eventually increased at 39 kg N /ha. The yield for KON5 slightly decreased with application of 13 kg /ha and then progressively increased with further increase in N. At Thika increasing N level from 0-13 kg/ha increased the yield of Tropicana F_1 hybrid. Further increase (26 kg /ha) decreased the yield but increase to 39 kg/ha increased the yield. KON6 showed a similar trend while the yield of KON7 increased upto 26 kg/ha and decreased with further addition of N. Increasing N level progressively increased yield in KON5.

Table 5: **Interaction between locations and cultivars on total yield of bulb onions grown at Thika and Kabete in 1990 and 1991.**

Cultivars	Short rains, 1990 Tons/ha Locations			Long rains, 1991 Tons/ha Locations		
	Thika	Kabete	Mean	Thika	Kabete	Mean
Tropicana	20.5d**	33.7b	27.1	37.3c	48.3c	42.0
KON6	19.9d	31.2bc	25.5	56.3b	66.2b	61.2
KON5	26.5c	30.8bc	28.7	50.3b	66.4b	58.3
KON7	35.3b	53.3a	44.3	70.0a	81.9a	76.0
Mean	25.5	37.2	31.4	53.5	65.7	59.4
C.V (%)	19.7			13.7		
S.E.(locations)	1.1			2.4		
S.E.(cultivars)	1.3			1.7		

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT), 5% level.

Figures followed by the same letter are not significantly different.

Table 6: **Interaction between locations, nitrogen levels and cultivars on total yield of bulb onions grown at Thika and Kabete in 1991.**

Tons/ha

Nitrogen Levels kg/ha	Cultivars	Locations Thika	Kabete	Mean	S.E.
0	Tropicana	14.1p**	41.1mno	27.6	2.4
	KON6	36.0o	56.7hijklm	46.3	
	KON5	36.7o	64.1fghi	50.4	
	KON7	40.7no	70.7cdefgh	55.7	
13	Tropicana	47.2klmno	44.8lmno	46.0	
	KON6	71.5cdefgh	67.8defghi	69.6	
	KON5	41.1no	61.5fghijk	51.3	
	KON7	63.3fghij	85.6abc	74.4	
26	Tropicana	35.2o	48.2jklmno	41.7	
	KON6	56.7hijklm	63.33fghij	60.0	
	KON5	53.0ijklmn	66.7efghi	59.8	
	KON7	94.4a	83.0abcd	88.7	
39	Tropicana	52.6ijklmn	59.3ghijkl	56.0	
	KON6	61.1fghijk	76.9bcdef	69.0	
	KON5	70.4cdefgh	73.3bcdefg	72.0	
	KON7	81.5abcde	82.2ab	84.8	
Mean		53.5	65.6	59.6	
C.V (%)		13.7			
S.E.		1.9			

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) 5% level.

Figures followed by the same letter are not significantly different.

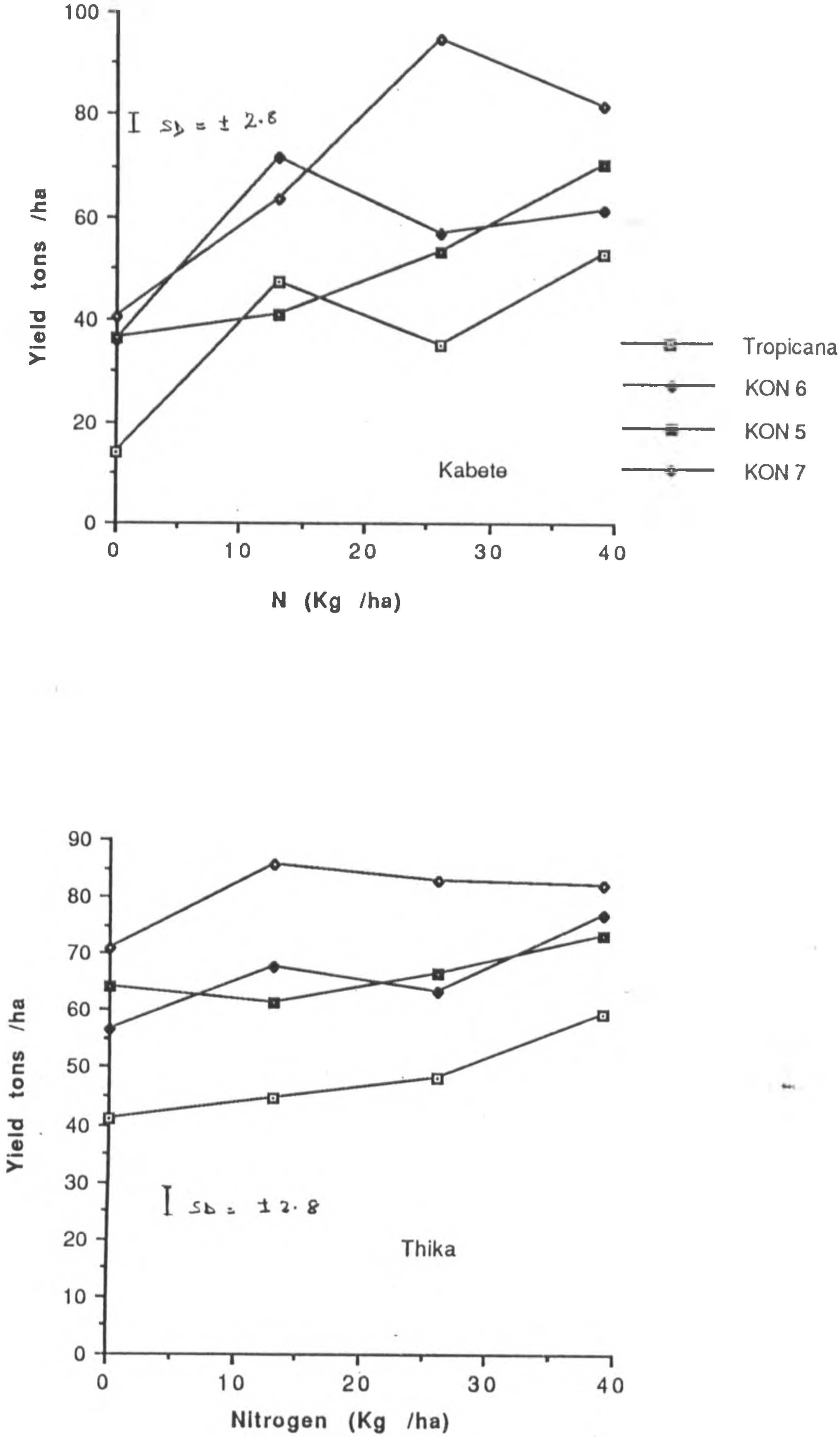


Fig 2. Interaction between locations, nitrogen and cultivars on yield of bulb onions grown at Thika and Kabete in 1991.

4.1.3 Splitting and doubling of onion bulbs

Application of N had no significant effect on percentage splitting and doubling of bulbs in both seasons. However, significant differences were observed between the cultivars during the short rains (Table 2). KON5 had the highest number of split and double bulbs (17.4%) while KON7 had the lowest (7.6%). There was no significant difference between KON6, KON5 and Tropicana F_1 hybrid.

The locational effects were significant in both seasons. Kabete had higher percentages of split and double bulbs than Thika. Kabete had 22.2 and 13.1% while Thika had 6.6 and 9.1% during the short and long rains respectively (Table 7).

A significant interaction between locations and nitrogen levels was observed in the short rains (Table 7). At Kabete application of different levels of N had no significant effect on splitting and doubling. At Thika, Application of 39 kg N/ha significantly increased the percentage splitting compared to the control. However, there was no significant difference between levels 13, 26 and 39 kg N/ha and between 0, 13 and 26 kg N/ha.

Table 7: **Interaction between locations and nitrogen levels on percentage splitting and doubling in bulb onions grown at Thika and Kabete in 1990 and 1991.**

	Short Rains, 1990			Long rains, 1991		
	% Splitting /doubling			% Splitting/doubling		
N	Locations			Locations		
kg/ha	Thika	Kabete	Mean	Thika	Kabete	Mean
0	4.6c**	23.9a	14.3	4.2a	12.3a	8.3
13	6.6bc	25.1a	15.9	10.1a	15.4a	12.8
26	5.9bc	19.6a	12.6	9.6a	15.1a	12.4
39	9.1b	20.2a	14.7	12.4a	9.6a	11.0
Mean	6.6	22.2	14.4	9.1	13.1	11.3
C.v(%)		48.4				
S.E. (locations)		0.59				
S.E. (nitrogen)		0.85				

Key: ** = Mean Separation by Duncan's Multiple Range Test DMRT) at 5% level. Figures followed by the same letter are not significantly different.

4.1.4 Bulb weight

Nitrogen application had no significant effect on bulb weight in both seasons. However, significant differences were observed between the cultivars (Table 2). During the short rains, KON7 had the highest bulb weight of 85.8gms while Tropicana F_1 hybrid had the lowest weight of 60.8gms although this was not significantly different from KON6 and KON5. During the second season, KON7 still had the highest bulb weight (164.4gms) but this was not significantly different from KON6. Tropicana F_1 hybrid had the lowest weight (101.1gms).

Locational effects were significant during the short rains. Bulbs at Kabete were significantly larger than at Thika (Table 8). The interaction between locations and cultivars was significant in both seasons (Table 8). During the short rains at both sites, KON7 had the highest bulb weight although this was not significantly different from Tropicana F_1 hybrid at Kabete and KON5 at Thika. At Thika Tropicana F_1 hybrid had the lowest bulb weight (40gms) while KON5 had the lowest (69.4gms) at kabete. At Thika there was no significant difference between Tropicana F_1 hybrid and KON6 and between KON5 and KON7 while at Kabete there was no significant difference between Tropicana F_1 hybrid, KON6 and KON5. All the cultivars with the exception of KON5 performed differently in both locations.

The Interaction between Location, nitrogen and cultivar was significant during the short rains (Table 9). The response of the different cultivars to varying levels of N in the two locations is shown in Figure 3. At both sites, KON7 and KON6 showed a similar trend. At Thika, increasing N level from 0-26 kg/ha progressively increased the bulb weight of both KON6 and KON7 but further increase to 39 kg/ha lowered the weight. At Kabete, when N level was increased 0-13 kg/ha the bulb weight increased. At Kabete increasing N level slightly increased the bulb weight of Tropicana F_1 hybrid while at Thika this effect was not significantly exhibited. At Thika, increasing the level of N progressively increased yield in KON5 while at Kabete increasing N increased yield.

Table 8: Interaction between locations and cultivar on bulb weight of onions Grown at Thika and Kabete in 1990 and 1991.

S.R. 1990

g/bulb

Cultivar	Locations Thika	Kabete	Mean	S.E.
Tropicana	40.00c**	81.7ab	60.8	3.56
KON6	52.20c	71.7b	61.9	
KON5	69.50b	69.4b	69.4	
KON7	78.9ab	92.8a	85.8	
Mean	60.1	78.9	69.5	
S.E.	6.60			
C.V. (%)	25.1%			

L.R., 1991

Cultivar	Locations Thika	Kabete	Mean	S.e
Tropicana	112.2b	90.0b	101.1	6.1
KON6	140.0b	167.2a	153.6	
KON5	128.8b	145.0b	136.9	
KON7	164.3a	164.5a	164.4	
Location mean	136.3	141.7	139.0	
C.V. (%)	21.6			
S.E.	8.7			

Key: Mean Separation by Duncan's Multiple Range Test (D.M.R.T.) at 5 % level.
Figures followed by the same letter are not significantly different.

Table 9: Interaction between locations, nitrogen and cultivars on bulb weight of onions grown at Thika and Kabete in 1990.

Short Rains,1990

g/bulb

Nitrogen (Kg/ha)	Cultivars	Locations Thika	Kabete	Mean
0	Tropicana	73.3i**	84.4hi	78.9
	KON6	89.0ghi	168.9abcd	129.0
	KON5	88.7ghi	155.6abcd	122.1
	KON7	113.3defghi	144.5bcdefg	128.9
13	Tropicana	155.3abcd	88.9ghi	122.1
	KON6	131.0bcdefghi	180.0abc	155.5
	KON5	115.3defghi	142.2bcdefgh	128.8
	KON7	142.0bcdefgh	177.8abc	160.0
26	Tropicana	91.0fghi	91.1fghi	91.1
	KON6	171.0abcd	153.3bcde	162.2
	KON5	126.7cdefghi	146.7bcdefg	136.7
	KON7	213.3a	148.9bcdef	181.1
39	Tropicana	129.0bcdefghi	95.6efghi	112.3
	KON6	169.0abcd	166.7abcd	167.8
	KON5	184.3abc	135.6bcdefgh	160.0
	KON7	188.7ab	186.7abc	187.7
Mean		136.3	141.7	139.0
S.E.(locations)		8.4		
S.E.(cultivars)		8.7		
C.V (%)		21.6		

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% Level. Figures followed by the same letter are not significantly different.

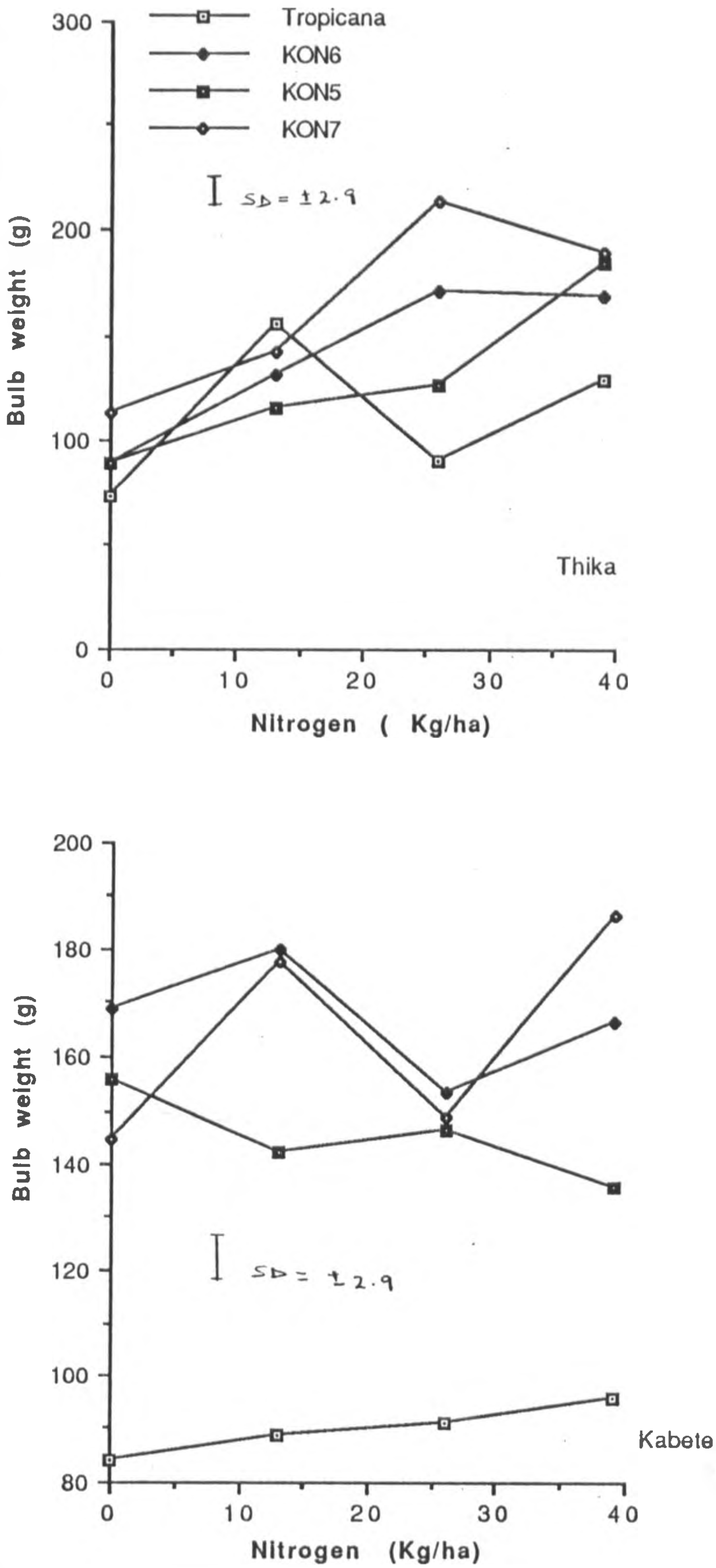


Fig 3. Interaction between locations, Nitrogen and cultivars on bulb weight of onions grown at Thika and Kabete in 1990

4.1.5 Bulb size

Application of N did not significantly influence the number of bulbs in Grade 1 and 2 but had a significant effect on the number of bulbs in Grade 3 during the short rains (Table 10). Application of N significantly decreased the number of bulbs in Grade 3 (i.e. bulbs that were less than 3cm in diameter). However, there was no significant difference between levels 13, 26, and 39 kg N/ha.

The mean number of bulbs in Grade 2 (i.e. bulbs with diameter more than 3cm but less than 5cm) was higher than either Grade 1 or 3 at all levels of N in the short rains. However, in the second season, Grade 1 (i.e. bulbs with diameter more than 5cm) had the highest number of bulbs (Table 11).

Significant locational differences were observed in both seasons. During the short rains at Thika, most of the bulbs were in Grade 2 and 3 while at Kabete most of the bulbs were in Grade 1 and 2. In the second season there were more bulbs in Grade 1 (63.8%) at Kabete than at Thika (51.2%) as shown in Table 11.

4.1.6 Total soluble solids

During the short rains, application of N had no significant effect on total soluble solids (TSS). In the long rains, application of N significantly increased TSS. Application of 39 kg N/ha increased the TSS from 8% (0 kg/ha) to 10.1%. There was no significant difference between levels 13, 26 and 39 kg N/ha (Table 1).

Significant differences between the cultivars were observed in both seasons (Table 2). Tropicana F_1 hybrid had the highest TSS (9.2%) and (11.5%) in the short rains and long rains respectively. KON7 had the lowest (6.2%) in the short rains although there was no significant difference between KON6 , KON5 and KON7. In the long rains, KON6 had the lowest TSS (7.9%) although this was not significantly different from KON6 and KON7.

Table 12 shows that there was a significant interaction between nitrogen levels and locations for TSS during the long rains . At Thika , increasing N level from 0 to 39 kg N/ha increased the TSS by 3.7%. There was no significant difference between 13, 26 and 39 kg N/ha. At Kabete, application of N also tended to increase TSS although there was no significant difference between the four levels. The highest (10.8%) and lowest (7.1%) TSS was obtained from Thika with the application of 39 and 0kg N/ha respectively.

Table 10: Effect of nitrogen on bulb size of onions grown at Thika and Kabete in 1990 (%).

	Short Rains,1990		
	% no. of bulbs		
Nitrogen (kg/ha)	Grade 1	Grade 2	Grade 3
0	27.0a**	45.4a	35.7a
13	31.4a	52.6a	11.8b
26	34.8a	50.7a	11.8b
39	31.7a	53.5a	12.7b
Mean	30.2	50.5	18.0
C.V. (%)	28.5	12.7	34.5

Table 11: Effect of location on bulb size of onions grown at Thika and Kabete in 1990 and 1991 (%).

	Short Rains, 1990	
Grades	Locations	
	Thika	Kabete
Grade 1	15.3b**	47.5a
Grade 2	55.3a	44.6a
Grade 3	26.8a	4.7b

	Long Rains, 1991	
Grades	Locations	
	Thika	Kabete
Grade 1	51.2b	63.8a
Grade 2	32.7a	25.6b
Grade 3	12.7a	4.9c

Key: For Tables 10 and 11.
** Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level.
Figures followed by the same letter down the column are not significantly different.
N.B. Grade 1- Bulbs with more than 5cm diameter
Grade 2- Bulbs with more than 3cm and less than 5cm
Grade 3- Bulbs with less than 3cm.

Table 12: Interaction between locations and nitrogen levels on total soluble solids (%) in bulb onions grown at Thika and Kabete in 1991.

Long Rains, 1991

% TSS

Nitrogen (kg/ha)	Locations Thika	Kabete	Mean
0	7.1c**	8.8b	8.0
13	9.7ab	9.2ab	9.5
26	9.7ab	8.7b	9.2
39	10.8a	9.3ab	10.1
Mean	9.3	9.0	9.2
C.V.(%)	21.8		
S.E.(locations)	0.3		
S.E.(nitrogen)	0.4		

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter are not significantly different.

4.1.7 Marketable yield of bulb onions

The effect of N on total marketable yield was significant during the short rains. The highest mean marketable yield was obtained by application of 26 kg N/ha while the lowest was from the application of 13 kg N/ha (Table 1). There was no significant difference between level 26 and 39 kg N/ha. In both seasons, there were significant differences between the cultivars in their marketable yield (Table 2). KON7 had the highest mean marketable yield (35.3 and 58.4 Tons/ha for the short and long rains respectively) while Tropicana F_1 hybrid had the lowest (20.0 and 29.5 Tons/ha for the short and long rains respectively.

The locational effect was also highly significant in both seasons. Marketable yield was higher at Kabete than at Thika. The interaction between locations and cultivars on marketable yield was significant during the short rains (Table 13). KON7 had the highest marketable yield at both locations. However, its yield at Thika 23.4 (Tons/ha) was not significantly different from that of Tropicana F_1 hybrid, KON6 and KON5 at Kabete. At both sites, no significant difference was observed between Tropicana F_1 hybrid, KON5 and KON6.

Table 13: Interaction between locations and cultivars on marketable yield of bulb onions grown at Thika and Kabete in 1990.

Short Rains, 1990

Tons/ha

Cultivars	Locations Thika	Kabete	Mean
Tropicana	17.1c**	28.3b	22.7
KON6	12.4c	27.6b	20.0
KON5	15.3c	26.3b	20.8
KON7	23.4b	47.2a	35.3
Mean	17.0	32.3	24.7
C.V. (%)	24.0		
S.E.(locations)	0.9		
S.E.(cultivars)	1.2		

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level

Figures followed by the same letter are not significantly different.

4.1.8 Bulb sprouting during storage

Application of different levels of N had no significant effect on sprouting in storage of bulbs from both locations. However, significant differences were observed between the cultivars. After three months of storage, Tropicana F_1 hybrid had the highest number of sprouted bulbs from both locations (43.5 and 51% from Kabete and Thika respectively). KON7 had the lowest (11.1%) number of spouted bulbs from Thika while KON6 had the lowest (32.8%) from Kabete (Table 14). Figure 4a and b show the cumulative sprouting percentages during the three months of storage for all the cultivars from the two locations. It will be noted that bulbs grown at Thika had high sprouting percentage from the first 60 days of storage with little increase in the last 30 days. On the other hand bulbs grown at Kabete showed progressive increase in sprouting with the third month having the highest number of sprouted bulbs.

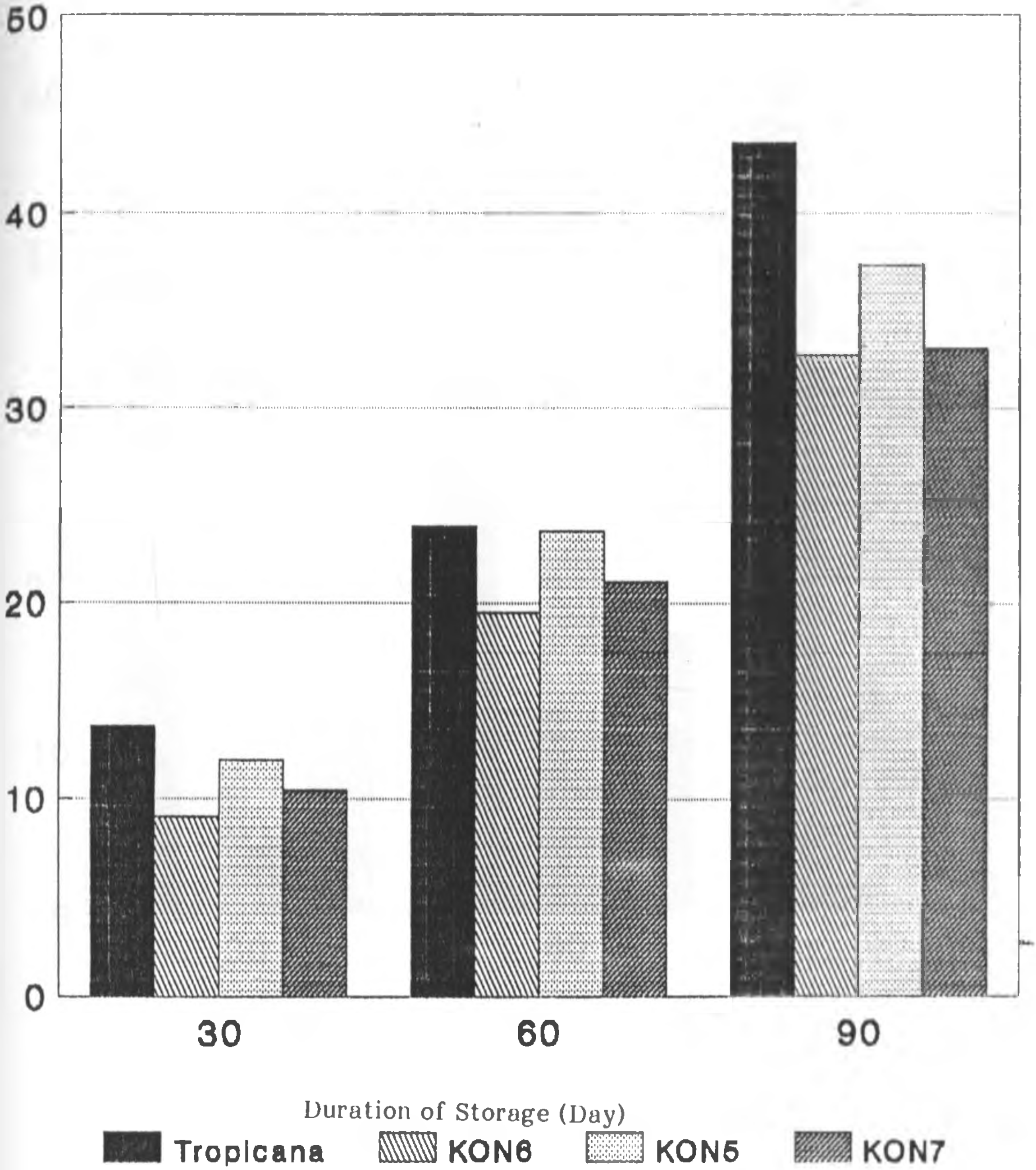


Figure 4a
Differences Between 4 Onion Cultivars
Grown at Kabete in % Sprouting in Storage

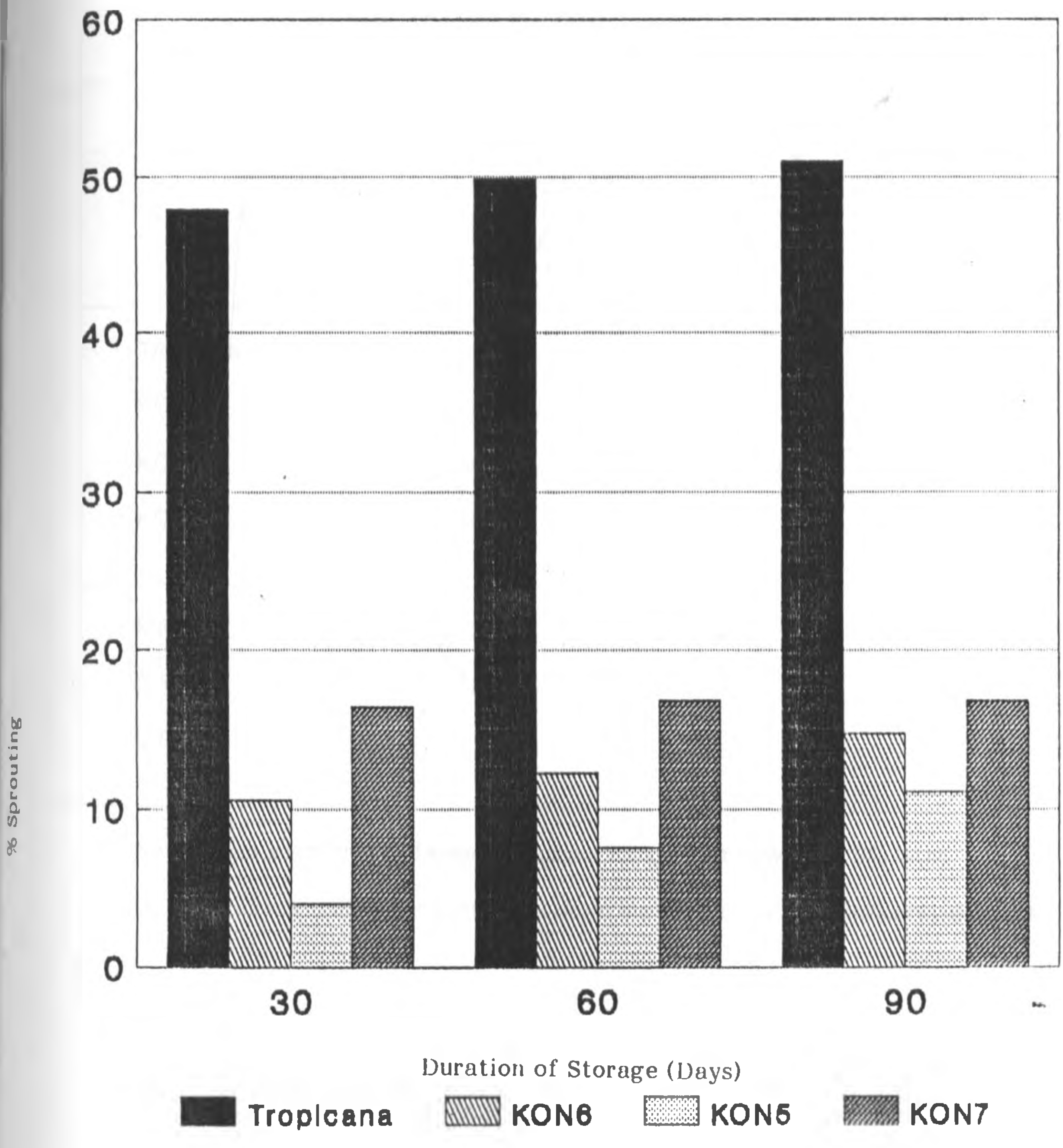


Figure 4b
Differences Between 4 Onion Cultivars
Grown at Thika in % Sprouting in Storage

Table 14: Cultivar differences in % sprouting during storage of bulb onions grown at Thika and Kabete in 1991.

Cultivars	Locations	
	% Sprouting	
	Thika	Kabete
Tropicana	51.0a	43.5a
KON6	14.8b	32.8a
KON5	11.1b	37.3a
KON7	16.8b	33.1a
Mean	23.4	36.7
C.V.(%)	30.1	24.1
S.E.	2.0	2.5

Key: Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level.

Figures followed by the same letter down the column are not significanlty different.

4.1.9 bulb rotting during storage

Application of nitrogen had no significant effect on rotting of bulbs in storage. However, cultivars showed significant differences. Table 15 shows that Tropicana F_1 hybrid had the lowest percentage number of rotted bulbs (21.8% from Thika and 7.9% from Kabete) while KON5 had the highest (39.6% from Thika and 27.3% from Kabete). Figure 5a and b show the cumulative rotting percentages for all the four cultivars from two locations.

Table 15: Differences between cultivars in % rotting in storage of bulb onions grown at Thika and Kabete in 1991.

Cultivars	Locations	
	% Rotting	
	Thika	Kabete
Tropicana	21.8a	7.9b
KON6	34.5a	20.8a
KON5	39.6a	27.3a
KON7	33.6a	25.2a
Mean	32.4	20.3
C.V.(%)	22.4	44.4
S.E.	2.1	2.6

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter down the column are not significantly different.

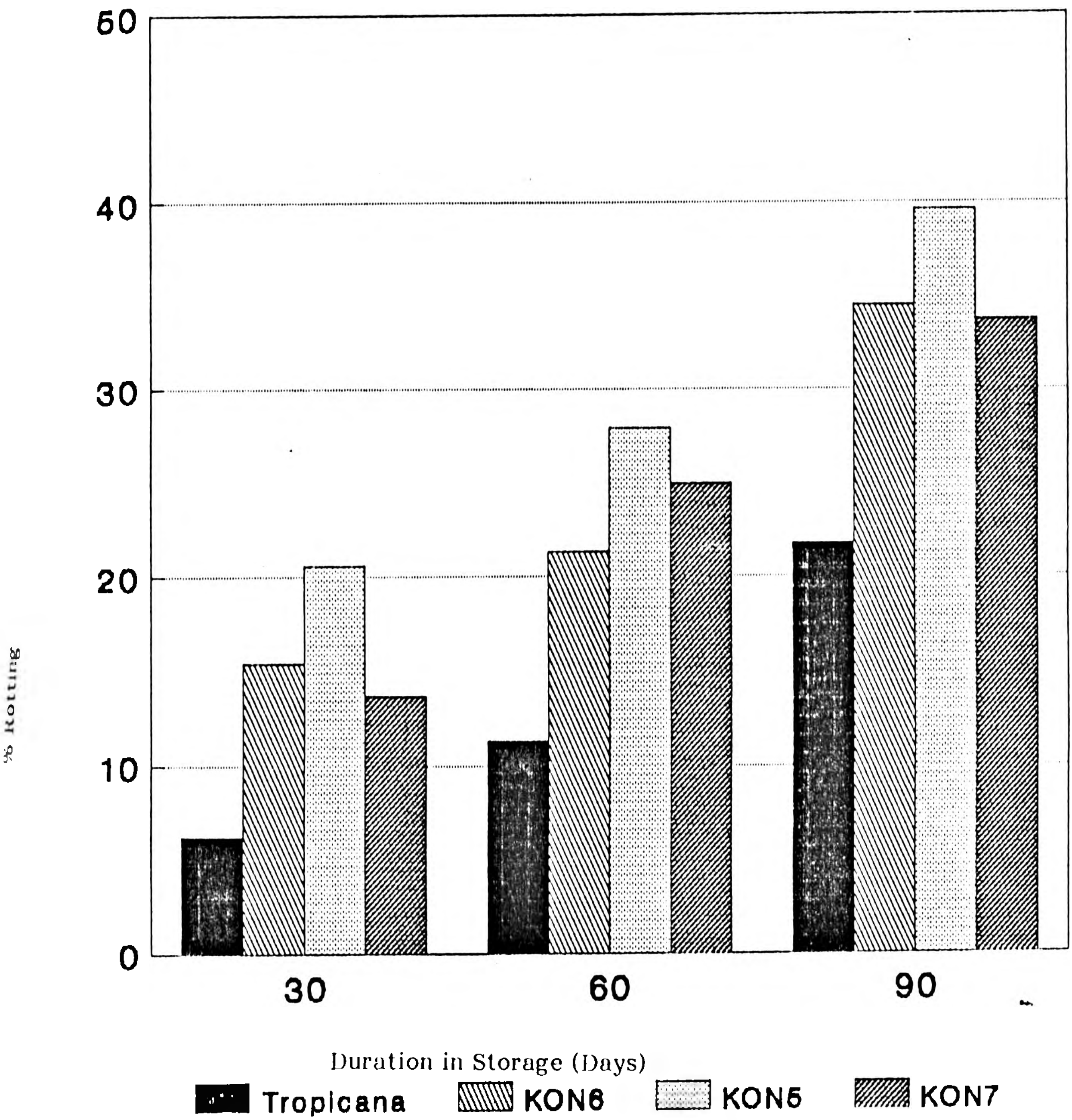


Figure 5a
Differences in 4 Cultivars Grown at
Thika in % Rotting During Storage

4.2 Experiment 2. Effect of plant density and cultivar on yield and quality of bulb onions

4.2.1 Number of days to maturity

Plant density had no significant effect on days to maturity in both seasons. However, cultivars differed significantly in their maturity period in both seasons. In the short rains, KON5 mature earliest (96 days) while Red Creole matured latest (116 days). During the long rains , KON6 matured earliest (124 days although there was no significant difference between KON6, KON7 and KON5. Red Creole was the latest to mature taking 147 days (Table 16).

During the short rains, the locational effect was highly significant. Bulbs matured within 97 days at Thika compared to 115 days at Kabete. The interaction between locations and plant density on maturity period was also significant during the short rains (Table 17). At Thika, increasing plant density had no significant effect on days to maturity. At Kabete, increasing plant density from 38 to 56 plants /m^2 significantly increased the number of days to maturity. Further increase to 111 plants /m_2 had no significant effect.

During the long rains, the effect of the interaction between location and cultivars on days to maturity was significant. Table 18 shows that at Thika Red Creole matured significantly later than all the other cultivars while at Kabete there was no significant difference between the cultivars.

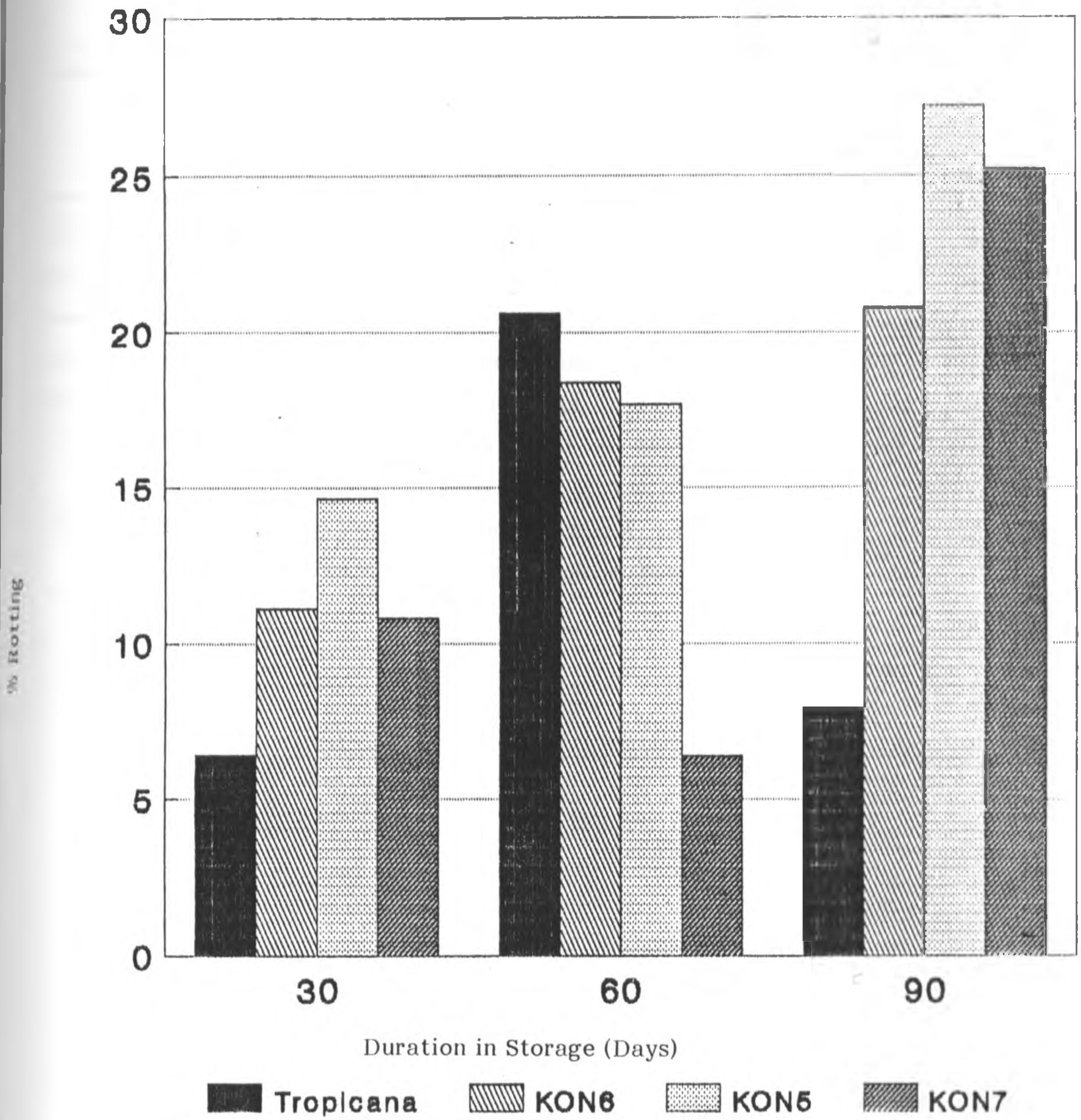


Figure 5b
Differences in 4 Cultivars Grown at
Kabete in % Rotting During Storage

Table 16: Differences between cultivars grown at Thika and Kabete in duration to maturity, bulb yield, splitting and doubling bulb weight, bulb size and marketable yield in 1990 and 1991.

	Days to maturity		Bulb Yield		Splitting/Doubling		Bulb Weight		Bulb size		Mkt. Yield +	
Cultivar	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
	no.		tons/ha		%			g		cm	tons/ha	
Red												
Creole	116a**	147a	33.2a	46.4bc	34.3a	34.4a	66.3a	114.8c	41.8a	50.4a	28.9a	37.8b
KON6	99bc	124b	21.1b	59.1ab	11.6c	14.8c	78.9a	203.3a	30.0b	50.6a	16.9b	50.5ab
KON5	96c	128b	22.8b	39.6c	13.6c	16.9bc	81.2a	131.7bc	23.7c	46.6a	17.6b	35.1b
KON7	111ab	132b	38.2a	70.0a	25.9b	20.8b	97.8a	188.1ab	40.0a	59.4a	30.7a	60.9a
CV(%)	16.6	9.5	40.5	38.1	19.1	30.0	46.4	49.4	22.0	46.4	35.7	21.5
S.E.	4.1	2.9	2.8	1.5	1.0	1.5	8.9	18.6	1.8	5.1	1.9	3.7

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level

Figures followed by the same letter down the column are not significantly different.

+ Marketable yield

Table 17: **Interaction between locations and plant density on days to maturity of bulb onions grown at Thika and Kabete during the short rains, 1990.**

<u>Days to maturity</u>

Plant Density plants/m^2	Locations Thika	Kabete	Mean
38	96c**	119a	105
56	97c	112b	106
111	96c	115ab	107
Mean	97	115	106
C.V (%)	4.8		
S.E.(locations)		2.9	
S.E.(plant density)		1.0	

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter are not significantly different.

Table 18: Interaction between locations and cultivars on number of days to maturity in bulb onions grown at Thika and Kabete during the long rains, 1991.

Cultivars	Days to maturity: Locations		Mean
	Thika	Kabete	
Red Creole	159a**	135b	147
KON6	125b	122b	124
KON5	122b	135b	128
KON7	135b	130b	132
Mean	135	131	133
C.V. (%)	2.3		
S.E.(locations)	2.1		
S.E.(cultivars)	3.6		

Key: ** Mean separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter are not significantly different.

4.2.2 Total bulb yield

In both seasons, increasing plant density progressively increased the total yield. During the short rains, the highest density (111 plants/m^2) gave the highest mean total yield (34.4 Tons/ha) while the lowest density, 38 plants/m^2 ,gave the lowest (24.9 Tons/ha). However, there was no significant difference between plant density 38 and 56 plants/m^2. In the long rains, the yield increased progressively as the density increased with differences between all the densities (Table 19). Plant density of 111 plants/m^2 gave the highest yield (62.7 Tons/ha) while that of 38 plants/m^2 gave the lowest 45.7 Tons/ha.

Significant differences were observed between the cultivars in their total yield in both seasons. KON7 had the highest mean total yield (38.2 Tons/ha) in the short rains although there was no significant difference between KON7 and Red Creole. There was also no significant difference between KON6 and KON5. During the long rains, KON7 had the highest yield (70 Tons/ha) it was not however significantly different from KON6. There was also no significant difference between Red Creole and KON6 and between Red Creole and KON5 (Table 16).

4.2.3 Bulb weight and size

Plant density had no significant effect on bulb weight in both seasons. However, significant differences were observed between the cultivars in the long rains (Table 16). KON7 had the highest mean bulb weight (203.3g) although this was not significantly different from KON7 (188.1g). Red Creole had the lowest bulb weight (114.8g) but this was not significantly different from KON5.

Table 19: Effect of plant density on days to maturity, bulb yield, splitting and doubling, bulb weight, bulb size and marketable bulb yield of onions grown at Thika and Kabete in 1990 and 1991.

Plant Density	Days to maturity		Bulb Yield		Splitting/doubling		Bulb weight		Bulb size		Marketable yield	
	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991	1990	1991
Plants/m²	no.		tons/ha		%		g		cm		tons/ha	
38	107a**	133a	24.9b	45.7c	20.5b	19.4b	84.2a	176.1a	34.1a	57.3a	19.6b	38.7c
56	105a	134a	27.1b	53.1b	18.5b	24.9a	83.7a	152.3a	32.5a	52.1ab	23.0b	44.8b
111	106a	133a	34.4a	62.7a	25.1a	20.9a	75.3a	150.1a	35.0a	45.9b	28.0a	54.8a
CV(%)	4.8	2.3	18.8	21.3	22.8	28.4	23.1	28.1	22.0	21.5	27.9	21.6
s.e.	1.0	0.6	1.1	2.3	1.0	1.3	3.8	9.2	1.8	2.3	1.3	2.0

Key:** Means separation by Duncan's Multiple Range Test (DMRT) at 5% level.

Figures followed by the same letter down the column are not significantly different.

Locational differences were also observed during the short rains. Bulbs at Thika were significantly heavier (93.3gms) than at Kabete (68.7g).

During the long rains , plant density had significant effects on bulb size (Table 19). The lowest plant density (38 plants/m^2) gave the highest percentage number of bulbs in Grade 1 (bulbs with diameter more than 5cm). There was no significant difference between plant densities 56 and 38 plants/m^2. No significant effect of plant density on bulb size was found during the short rains. However, the cultivars differed significantly. Red Creole had the highest number of bulbs in Grade 1 (41.8%) while KON5 had the lowest (23.7%). There was no significant difference between KON7 and Red Creole (Table 16).

The interaction between locations and cultivars on bulb size was significant during the short rains (Table 20). Red Creole had the highest percentage number of bulbs in Grade 1 at Kabete while at Thika KON7 had the highest. At both locations KON5 had the lowest percentage number of bulbs in Grade 1.

The interaction between plant density and cultivars on bulb size was also significant during the short rains (Table 21). For Red Creole, as the plant density was increased from 38 to 56 plants/m^2, the percentage number of large bulbs (i.e. bulbs with more than 5cm in diameter) increased. However, further increase in density resulted in fewer large bulbs although the change was not significant. For cultivars KON6 and KON5, increasing plant density had no significant effect on bulb size. Increasing plant density from 38 to 56 plants /m^2 for KON7 reduced the percentage number of large bulbs. Further increase to 111 plants /m^2 resulted in large bulbs although this was not significantly different from 38 plants /m^2

Table 20: Interaction between locations and cultivars on bulb size of onions grown at Thika and Kabete during the short rains, 1990.

Cultivars	% no. of bulbs in grade 1		
	Locations		Mean
	Thika	Kabete	
Red Creole	35.6b**	48.0a	41.8
KON6	35.2b	24.6c	30.0
KON5	24.4c	23.1c	23.7
KON7	44.8a	35.2b	40.0
Mean	35.0	32.7	33.8
C.V (%)	30.0		
S.E.(locations)	1.3		
S.E (cultivars)	2.2		

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter are not significantly different.

Table 21: Interaction between plant density and cultivars on bulb size of onions grown at Thika and Kabete during the short rains, 1990.

	% no. of bulbs in grade 1				
Plant Density	Cultivars				Mean
plants/m^2	Red Creole	KON6	KON5	KON7	
38	34.4bc**	34.1bc	27.9cd	40.1ab	34.1
56	46.3a	26.1cd	22.4d	35.1bc	32.5
111	44.6a	30.0cd	21.0d	44.8a	35.0
Mean	41.8	30.0	23.7	40.0	33.8
C.V (%)	22.0				
S.E.(cultivars)	1.5				
S.E.(plant density)	1.8				

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter are not significantly different.

4.2.4 Splitting and doubling

In both seasons, plant density effect on splitting and doubling was significant. During the short rains, increasing plant density from 38 to 111 plants /m^2 significantly increased percentage splitting and doubling by 4.6%. However, there was no significant difference between plant densities 38 and 56 plants/m^2. In the long rains increasing plant density from 38-56 plants/m^2 increased percentage splitting and doubling by 5.5%. However, further increase to 111 plants/m^2 decreased the number of split and double bulbs although there was no significant difference between 38 and 56 plants/m^2 (Table 19).

Highly significant differences were observed between cultivars in their tendency to split and double (Table 16). In both seasons, Red creole had the highest number of split and double bulbs (34.3% and 34.4% in the short and long rains respectively). .The interaction between cultivars and plant density was significant in both seasons (Table 22). During the short rains, increasing plant density from 38-111 plants/m^2 in Red creole significantly increased percentage number of split and double bulbs. In KON7, increasing plant density from 38-56 plants/m^2 significantly decreased splitting and doubling. Further increase to 111 plants/m^2 increased splitting and doubling although there was no significant difference between 38 and 111 plants/m^2. No significant differences were observed in KON6 and KON5 at all density levels. Red Creole had significantly higher splitting and doubling percentages in all three plant densities than KON6, KON5 and KON7. During the long rains, increasing plant density from 56-111 plants/m^2 significantly decreased splitting and doubling for KON6 and KON7. Increasing plant density had no significant effect on Red Creole and KON5. No significant differences were observed in the other cultivars. However, Red Creole had significantly higher splitting and doubling percentages in all three plant density levels than the other cultivars.

The interaction between locations, cultivars and plant density was significant during the two seasons (Table 23). Figure 6a show the response of the four cultivars to increasing plant density in the two locations during the short rains. At Thika, splitting and doubling increased with increasing plant density in Red Creole. In the other 3 cultivars, KON5, KON6 and KON7, increasing plant density from 38 to 56 plants/ m^2 decreased splitting and doubling while further increase to 111 plants/m^2 had the opposite effect. However, these differences were only significant in KON7. In Kabete, increasing the plant density from 38 to 56 plants/m^2 significantly lowered splitting and doubling in Red Creole. Further increase to 111 plants/m^2 resulted in increased splitting and doubling. There was no significant difference between 38 and 56 plants/m^2. There were no significant differences between KON6 and KON5 in all plant density levels. During the long rains, increasing plant density from 38 to 111 plants/m^2 significantly increased splitting and doubling in Red Creole. There was no significant difference between 56 and 111 plants/m^2. In all the other three cultivars no significant differences were observed. At Thika, increasing plant density from 38 to 56 plants/m^2 in KON6 significantly increased splitting and doubling. There was no significant difference between 38 and 111 plants/m^2. Increasing plant density from 38 to 111 plants/m^2 in KON7 significantly decreased splitting and doubling but there was no significant difference between 38 and 56 plants/m^2. Red Creole and KON5 showed no significant effects of plant density in this aspect (Figure 6b).

During the short rains, the location effect was highly significant. At Thika, there were more split and double bulbs (30.6%) than Kabete (12.2%). There was no significant difference in the long rains (Table 23).

Table 22: Interaction between cultivars and plant density on splitting and doubling (%) of bulb onions grown at Thika and Kabete in 1990 and 1991.

plant Density Plants/m^2	Red Creole	KON6	KON5	KON7	Mean
		% splitting/doubling 1990			
38	30.8b**	9.4d	15.4cd	26.5b	20.5
56	30.6b	11.2d	13.2cd	19.0c	18.5
111	41.6a	14.3cd	12.1d	32.3b	25.1
Mean	34.3	11.6	13.5	25.9	21.4
C.V (%)	22.8				
S.E.(cultivars)	2.0				
S.E.(density)	1.0				
		1991			
38	29.7ab**	13.4de	13.7de	20.8cd	19.4
56	36.3a	20.2cd	16.4de	26.6bc	24.9
111	37.1a	10.8e	20.5cd	15.1de	20.9
Mean	34.4	14.8	16.9	20.8	21.7
C.V (%)	30.0				
S.E.(cultivars)	2.5				
S.E.(density)	1.5				

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level. Figures followed by the same letter down the column are not significantly different.

Table 23: Interaction between plant density, cultivars and locations on splitting and doubling (%) in bulb onions grown at Thika and Kabete in 1990 and 1991.

Cultivars	Plant Density Plants/m²	Locations Thika	Kabete	Mean	s.e
		Short Rains, 1990			
Red Creole	38	30.9bcd**	30.8bcd	30.8	2.0
	56	46.6a	14.6gh	30.6	
	111	49.5a	33.7bc	41.6	
KON6	38	17.0fgh	1.8j	9.4	
	56	16.7fgh	5.6ij	11.2	
	111	24.7cdef	3.9ij	14.3	
KON5	38	27.2cde	3.6ij	15.4	
	56	21.5efg	4.9ij	13.2	
	111	22.2cde	1.8j	12.1	
KON7	38	37.6b	15.3gh	26.5	
	56	26.6cde	11.5hi	19.0	
	111	46.0a	18.6efgh	32.3	
	Mean	30.6	12.2	21.4	
	C.V (%)	22.8			
	S.E.	0.7			
		Long Rains, 1991			
Red Creole	38	35.5abc	24.0cdefg	29.7	2.5
	56	32.0bcd	40.8ab	36.3	
	111	30.3bcde	44.0a	37.2	
KON6	38	12.2gh	14.5fgh	13.4	
	56	24.8cdef	15.6fgh	20.2	
	111	11.9gh	9.7h	10.8	
KON5	38	13.1fgh	14.3fgh	13.7	
	56	19.7efgh	13.1fgh	16.4	
	111	25.2cdef	15.7fgh	20.5	
KON7	38	27.6cde	14.0fgh	20.8	
	56	31.1bcde	22.1defg	26.6	
	111	14.6fgh	15.5fgh	15.1	
	Mean	23.2	20.3	21.7	
	C.V (%)	28.4			
	S.E.	1.1			

Key: ** Mean Separation by Duncan's Multiple Range Test (DMRT) at 5% level.
Figures followed by the same letter down the column are not significantly different.

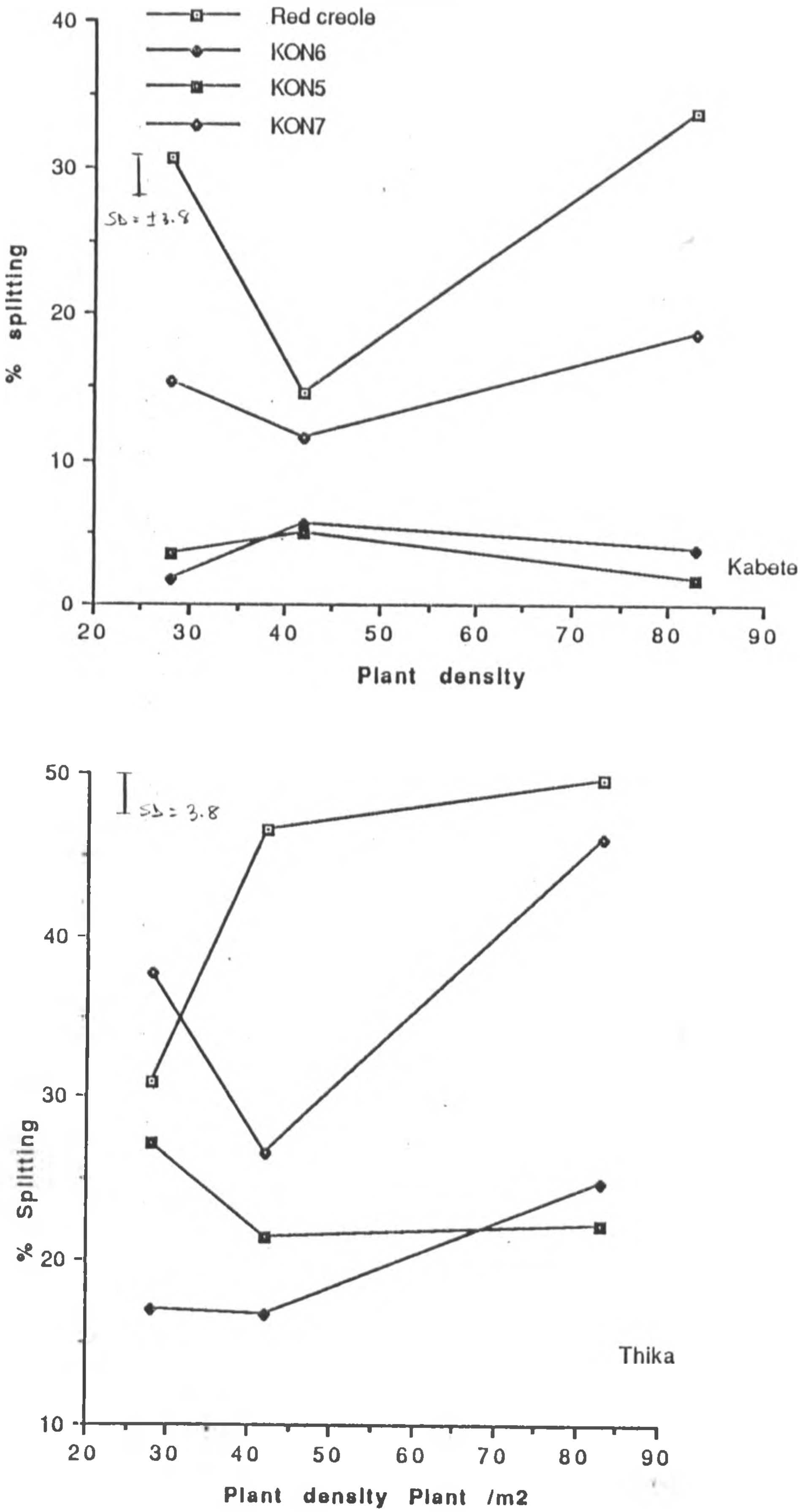
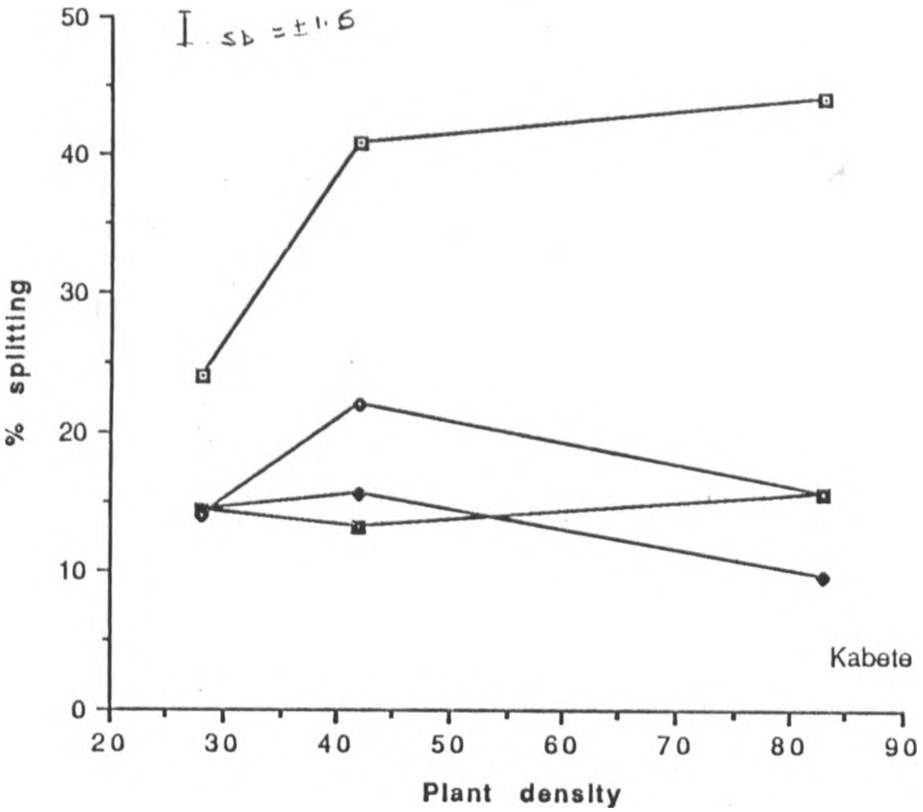


Fig 6a. Interaction between locations cultivars and plant densities on percentage splitting of onion bulbs grown at Thika and Kabete in 1990



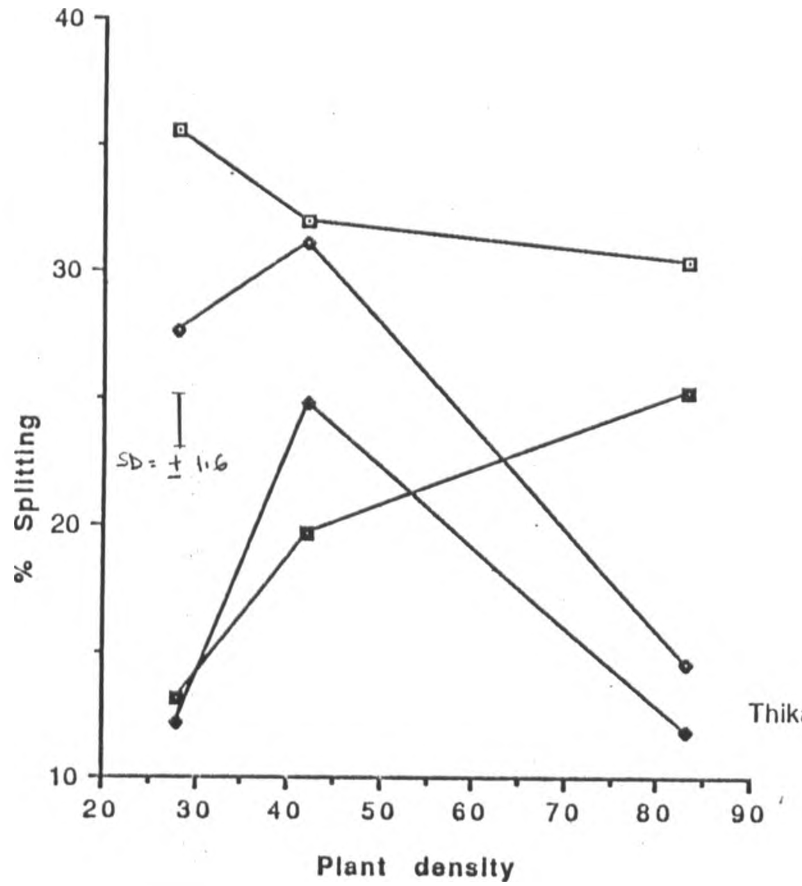


Fig 6b. Interaction between cultivars, locations and plant density on Percentage splitting of onion bulbs grown at Thika and Kabete in 1991.

4.2.6 Marketable yield

Marketable yield was significantly influenced by plant density in both seasons. The highest mean marketable yield was from 111 plants/m^2 (28 and 54.8 Tons/ha for the short and long rains respectively). While the lowest was from 38 plants /m^2 (19.6 and 38.8 Tons/ha for the short and long rains, respectively) (Table 19).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of nitrogen and cultivar on yield and quality of bulb onions

5.1.1 Days to maturity of bulb onions

Application of N hastened the maturity of the bulbs. 39 kg N/ha reduced the duration to maturity by 3 days compared to the control. This agrees with what other researchers have found. Currah and Proctor, (1990) reported that adequate application of N in bulb onions allows the crop to develop rapidly, initiate bulbing and mature early. Brewster and Butler, (1989) also found that low N levels delayed bulb development resulting to delay in foliage collapse and thus late maturity. They observed that even though the low N plants had a high bulbing ratio in the early stages of growth, this was not accompanied by the transition from leaf blade to bulb scale production which is typical of normal bulbing. The bulbs therefore matured later than the high N plants.

Brewster, (1977) also observed that low N resulted in lower growth rate and lower rates of leaf initiation and consequent delay in maturity.

5.1.2 Bulb yield

There was a significant increase in yield with the application of N compared to the control. During the long rains, application of 39 kg N/ha gave 70.4 tons/ha compared to 45 tons/ha when no N was applied. This agrees with what several other workers have found. Hassan and Ayoub, (1978) found highly significant responses to N applied at 90 kg/ha, with yield increases of 18-36% compared to untreated plants. Das at.al., (1972) found that application of 120 or 160 kg N/ha significantly increased total yield compared to the control. In the present study, a linear response curve was exhibited. Other workers for example Hassan (1984) reported a parabolic response curve. This author found that a high rate of N, 180 kg/ha gave slightly lower mean yields than 90 kg/ha. Sypien et.al. (1973) reported that application of 75 kg N/ha gave the highest total yield while 300 kg/ha significantly reduced yields. Therefore since the levels used in this study were lower than the above mentioned levels, further increase in N could either increase or decrease yield. During the short rains application of N significantly increased marketable yield. The highest yield (27.7 tons/ha) was obtained with the application of 26 kg N/ha. During the long rains this effect was not significant.

5.1.3 Bulb quality

5.1.3.1 Bulb size

Application of N significantly reduced the number of bulbs in grade 3 (i.e. bulbs with diameter less than 3cm). Plants supplied with 39 kgN/ha had 20.7% of the bulbs in grade 3 compared to 36.7% when no N was applied. A general increase of number of bulbs in Grade 1 and 2 was also observed with the application of N. Other researchers among them sypien et al. (1973) have reported an increases in bulb size with the application of N. Sypien et al.(1973) reported that onions supplied with 300kg N/ha produced the largest bulbs of 4.5-7.0cm while the smallest were obtained when no N was applied.

In this study, the bulbs tended to be large (over 5cm in diameter) at all levels of N especially during the long rains season. This could be due to the favourable climatic conditions during this season and could have resulted in the high total yields observed.

The rainfall was slightly higher in the Long rains (Appendix 1) and the temperatures were slightly lower which led to a longer growing period. Currah and Proctor (1990) reported that bulbs grown under low temperatures take longer to mature but produce higher yields which could probably due to larger and heavier bulbs.

5.1.3.2 Total soluble solid

Application of 39 kg N/ha increased TSS from 8% (0 kg) to 10.1%. This observation agrees with what Haggag et.al. (1986) found. Working with cultivar Giza, Haggag et. al. (1986) reported that increasing N from 0-150 kg/ha increased TSS. Onions with low TSS have a tendency to sprout more during storage than those with high dry matter content (Foskett and Peterson 1950). Therefore application of N would be expected to prolong shelf-life of bulb onionsas it increases TSS.

5.1.3.3 Sprouting during storage

Application of N had no significant effect on sprouting of bulb onions in storage. These results agree with what Isenberg and Thomas (1970) reported. These researchers found that bulbs harvested from high N plots showed only a slight increase in percentage sprouting compared to those from low or no N. Even though N increased dry matter content, this did not seem to influence their shelf-life. These results disagree with the report by Foskett and Peterson (1950) who observed that onion bulbs with low dry matter content have a tendency to sprout more in storage than those with high dry matter content.

5.1.4 Cultivar Differences

5.1.4.1 Number of days to maturity

The newly introduced cultivars matured earlier than the locally grown Tropicana F_1 hybrid. During the Short rains, Tropicana F_1 hybrid took 131 days to reach maturity compared to 98, 106 and 114 days for KON5, KON6 and KON7 respectively . During the long rains, Tropicana F_1 hybrid took 154 days compared to 136, 141 and 133 days for KON5, KON6 and KON7 respectively. Currah and Proctor (1990) reported that cultivars differ in their maturity period and some cultivars have been developed to mature earlier than others in order to escape some environmental conditions such as cold or hot weather which would prevent proper bulb development.

5.1.4.2 Bulb yield

The newly introduced cultivars gave higher yields than the locally grown Tropicana F_1 hybrid. During the short rains Tropicana F_1 hybrid produced 27.1 tons/ha compared to 25.5, 28.6 and 44.3 tons/ha for KON6, KON5 and KON7 respectively. During the long rains, Tropicana F_1 hybrid produced 42.8tons/ha compared to 61.2, 58.3 and 76.0 tons/ha for KON6, and KON5 and KON7 respectivley. Kimani, et al. (1991) also observed that these new cultivars gave higher bulb yield than three other local cultivars among them Tropicana F_1 hybrid. Although these cultivars were more susceptible to downy mildew and purple blotch than Tropicana F_1 hybrid this did not seem to greatly affect their yield and with proper disease control they could even give higher yields. Among the newly introduced cultivars KON7 had the highest bulb yield.

1.4.3 Splitting and doubling

Differences between the cultivars in splitting and doubling were observed during the short rains season. KON7 had the lowest percentage of split and double bulbs (7.6%) compared to 16.1, 14.5 and 17.4% for Tropicana F_1 hybrid. KON6 and KON5. Currah and Proctor, (1990) have also reported cultivar differences in splitting. In experiments made under controlled environmental conditions they reported that one cultivar out of the four in the trial reacted by producing numerous lateral bulbs which continued to grow rather than form bulbs. The other three cultivars did not react in this way. During the short rains, the mean temperatures were also higher than during the long rains (Appendix 1a and b). These could have resulted in higher percentage of split and double bulbs. Currah and Proctor, (1990) reported that bulbs grown at high temperatures tend to split and form double bulbs.

5.1.4.4 Bulb weight

Cultivars differed significantly in their bulb weight. During the short rains, KON7 had the highest bulb weight (85.5 gm) compared to 60.8, 61.9 and 69.5 gm for Tropicana F_1 hybrid, KON6 and KON5 respectively. During the long rains, KON7 still had the highest (164.4 gm) compared to 101.1, 153.6 and 136.9 gm for Tropicana F_1, KON6 and KON5 respectively. Kimani et. al. (1991) also made similar observations when comparing three locally grown cultivars, Red creole, Tropicana F_1 hybrid and Bombay Red with seven newly introduced cultivars among them KON5, KON6 and KON7. They found that the latter had larger bulbs than the local cultivars.

5.1.4.5 Total Soluble Solids (TSS)

The newly introduced cultivars had lower TSS than Tropicana F_1 hybrid which had 9.2 and 11.5 % compared to 6.7, 6.5 and 6.2 % and 7.9, 9.3 and 8.0 % for KON6, KON5 and KON7 respectively for the short and long rains. Jones and Mann, (1963) reported that onion cultivars differ in their TSS. Onions with high TSS tend to yield less than those with low TSS Currah and Proctor (1990). In the present study it was noted earlier that Tropicana F_1 hybrid had lower total yields than any of the introduced cultivars. It would therefore appear that there is a correlation between TSS and total yield. Cultivars with low TSS usually bulb rapidly, are soft textured and generally of low keeping quality (Currah and Proctor, 1990). From earlier observations it was noted that the newly introduced cultivars bulbed and matured earlier than Tropicana F_1 hybrid. Thus there also seems to be a correlation between TSS and maturity.

5.1.4.6 Marketable yield

Differences observed between the cultivars in their marketable yield was closely comparable to their total yield. If the total yield was high then the marketable yield was also high. KON7 which had the highest total yield (44.3 and 76.0 tons/ha for the short and long rains respectively) also had the highest marketalbe yield (35.3 and 58.4 tons/ha for the short and long rains respectively. However, losses during the four weeks when the bulbs were cured were higher in KON5 during the short rains (28.9%) and Tropicana F_1 hybrid (31%) during the long rains. The high loss in KON5 during the curing period was due to the fact that it was severely infected with downy mildew from the field which caused the bulbs to rot in storage. On the other hand during the long rains Tropicana F_1

hybrid was harvested while the leaves were still green because it took long to mature and the bulbs would have been destroyed by rain water if left longer in the field. This led to high sprouting during the curing period.

5.1.4.7 Storage

Differences were observed between the cultivars in their shelf-life. Tropicana F_1 hybrid had the highest number of sprouted bulbs in storage from both locations (43.5 and 52 % for Kabete and Thika respectively).KON6, KON5 and KON7 had 14.8, 11.1 and 16.8 % respectively from Thika and 32.3, 37.3 and 33.1 % respectively from Kabete. Differences between cultivars in their storage quality have also been reported by Currah and Proctor, (1990). They reported that application of N had no significant effect on losses in storage but cultivars showed significant differences. It has been noted elsewhere in this study that Tropicana F_1 hybrid had higher TSS than all the three newly introduced cultivars and that onions with high TSS have good storage quality. However, in this study, the newly introduced cultivars which had low TSS ranging from 6.2-9.3% had better storage ability than Tropicana F_1 hybrid which had 11.5% TSS. Currah and Proctor (1990) reported that the genetic linkage between storage quality and TSS is not absolute, as cultivars recently developed from Israel have both good storage ability and low TSS.

5.1.5 Seasonal Differences

The total and marketable yield, bulb weight and bulb size were all higher in the long rains than in short rains. These differences could have been due to the drier conditions prevailing in the short rains season compared to long rains season. During the short rains, the total rainfall received during the growing period of bulbs (October-January) at Kabete was 324.5mm compared to 426.5mm in the long rains. At Thika, even though the rainfall received during the long rains was lower (364.5mm) than the short rains (486.7mm), the crop was sufficiently supplemented with irrigation (Appendix 1A and B). Currah and Proctor (1990), reported that onions are sensitive to water stress and their growth can be inhibited even before the leaves wilt visibly. The differences in yield could also have been due to severe attack of the crop by downy mildew caused by Peronospora destructor and purple blotch caused by Alternaria porri in its early stages of growth during the short rains . During the long rains, these diseases were identified earlier and controlled effectively. In the long rains, the crop also had a long growing period due to the low temperatures (Appendix 1A and B) which could have led to the increase in yield. Jones and Mann (1963) reported that low temperatures delay bulbing, enabling the plants to develop considerable foliage which consequently form large bulbs and therefore increase in yield.

The bulbs also matured earlier during the short rains than the long rains. This difference was especially notable in the crop grown at Thika where duration to maturity was longer for all the cultivars during the long rains. However, the differences between the seasons were very small at Kabete. At Thika this could have been due to the slightly higher temperatures in the short rains. Jones and Mann (1963) reported that onions grown under high temperatures mature fast but give low yields.

5.1.6 Locational Differences

Total and marketable yield were higher at Kabete than at Thika. The bulbs were also larger and heavier, which could have led to the high yield. Even though splitting and doubling was higher at Kabete than Thika, this did not seem to significantly reduce the marketable yield. The probable reason for these differences could be due to the differences in the soil nutrients. From appendix 2, it will be noted that the soil at Kabete had generally higher nutrient contents than at Thika. Also at Thika, the soil was deficient in phosphorus and even though some phosphorus was applied at planting the amount was not probably sufficient for proper development of the plants. Phosphorus is essential for cell division and development and deficiency in bulb onions leads to slow growth and delayed maturity (Jones and Mann,1963).

The crop at Thika was also severely affected by downy mildew caused by Peronospora destructor and purple blotch caused by Alternaria porri especially during the short rains. These are the most important diseases of bulb onions in Kenya and they greatly reduce yields.

5.1.7 Interactions

5.1.7.1 Interaction between locations and cultivars on days to maturity, total and marketable yield and bulb weight

A significant interaction between location and cultivars on days to maturity was observed. All the newly introduced cultivars performed differently in the two locations. Brewster, et. al. (1979) investigating on the performance of a range of cultivars at a number of sites also found significant cultivar and location interactions for maturity period.

Similar observations were also reported by Kimani, et. al. (1991). These findings indicate that days to maturity for different cultivars vary in different locations.

5.1.7.2 Interaction between nitrogen levels and cultivars on total yield

The significant interaction between nitrogen and cultivars on total yield implies that the differences in yield between the four cultivars varied with the level of nitrogen. When no nitrogen was applied there was no significant difference between the three newly introduced cultivars. However, Tropicana F_1 hybrid had significantly low yields compared to the other three cultivars. As nitrogen level was increased total yield increased in all cultivars with significant differences between them. This implies that different cultivars respond differently to the application of nitrogen.

5.1.7.3 Interaction between locations and nitrogen on TSS and splitting and doubling.

Significant interactions between locations and nitrogen levels on splitting and doubling and TSS were observed. However, in both cases the differences were only significant at Thika. There was a clearly marked increase between the control (0kg N/ha) and 39kg N/ha in splitting and doubling at Thika. Therefore even though the combined analysis indicated that nitrogen had no significant effect on splitting and doubling, this interaction seems to indicate that this quality aspect of bulbs also depends on the environmental conditions under which they are grown. It should also be noted that this interaction was only significant during the short rains when temperatures were higher at Thika than at Kabete. It was noted elsewhere in this study that onions grown at high temperatures tend to split and form double bulbs (Currah and Proctor, 1990).

Application of N significantly increased TSS at Thika but again the differences were only significant between the control and the other three levels of nitrogen (13, 26 and 39kg/ha) but not between the three levels.

5.1.7.4 Interaction between nitrogen, location and cultivar on bulb yield and weight

Earlier it was found that the interaction between nitrogen x cultivar and that between location x cultivar on bulb yield was significant. This implies that all these three variables are interdependent and the interaction between location x nitrogen x cultivar confirms this. It was seen that the response of the cultivars to N varied considerably at Thika compared to Kabete. This implies that the response to nitrogen varied between the cultivars and also between the two locations.

5.2 Effect of plant density on yield and quality of bulb onions

5.2.1 Total and marketable bulb yield

A progressive increase in total and marketable yield was observed as the plant density was increased giving an asymptotic yield-density relationship, i.e, the yield did not decline after reaching the maximum. The highest total and marketable yield (62.7 and 54.8 tons/ha) was obtained with the highest plant density (111 plants/m^2). This indicates that yield may either increase or decrease with an increase in density beyond the highest (111 plants/m^2). Bleasdale (1966) reported that total yield of bulbs increased with an increased in plant density until and optimum was reached after which it declined. He found that 70 plants/m^2 increased yield by 10-30%. However, Frappel (1973) reported that onions exhibited an asymptotic relationship similar to what has been observed in this study.

5.2.2 Effect of plant density on bulb size

Increasing plant density decreased the bulb size. The highest percentage number of bulbs in Grade 1 (i.e., bulbs with a diameter more than 5cm) was obtained at 38 plants/m^2. However at this density the total yield was only 73% of the potential yield. Since yield did not seem to decrease with an increase in density, it would be possible to increase the density to get slightly smaller bulbs but higher total yield.

5.2.3 Splitting and doubling

Increasing plant density from 38 to 111 plants/m^2 significantly increased splitting and doubling form 20.5 to 25.1 % and 19.4 and 20.9 % for the short and long rains respectively. density was increased. This is contrally to what other workers have reported. Hassan (1978) and Hassan and Ayoub (1978) reported that widely spaced plants produced large bulbs which had a high tendency to split and form double bulbs. In this study, the large bulbs produced at low densities did not seem to display this tendency. Other genetic or environmental factors could have resulted in this kind of behaviour. Currah and Proctor (1990) have reported that the genetics of splitting and doubling and the influence of the environment are not well understood.

5.2.4 Interactions

5.2.4.1 Interaction between locations and plant density on number of days to maturity

Although a significant interaction between locations and plant density on days to maturity was observed, differences between the plant densities were only significant at

Kabete. However, significant differences were observed between the two locations. At all levels of plant density bulbs matured earlier at Thika than at Kabete. This implies that maturity period differs with different plant densities as wells as different environmental conditions.

5.2.4.2 Interaction between locations and cultivars on number of days to maturity and bulb size

The interaction between locations and cultivars on number of days to maturity was only significant at Thika. At kabete no significant differences were observed between the cultivars in their maturity period. At Thika, Red Creole matured significantly later than all the other three cultivars. No significant differences were observed in the maturity period of the newly introduced cultivars between the two locations.

Significant differences were also observed between some of the cultivars and the two locations in their bulb size. The ranking of the cultivars was different in the two locations. At Thika, KON7 had the highest number of bulbs in Grade 1 while at Kabete, Red Creole had the highest. The only cultivar whose performance did not change in the two locations was KON5.

5.2.4.3 Interaction between plant density and cultivars on onion bulb size and splitting and doubling.

The significant interaction between plant density and cultivars on bulb size showed that the cultivars responded differently to the various plant density levels. This implies that bulb size was influenced by both plant density as well as the cultivar differences. A significant interaction between plant density and cultivars on splitting and doubling was also observed. As plant density increased the change in percentage splitting and doubling was different depending on the cultivars.

5.2.4.4 Interaction between location, plant density and cultivar on splitting and doubling

The significant interaction between locations, plant density and cultivars implies that the interaction between plant density and cultivars differs in the two locations. It would therefore appear that splitting and doubling is influenced by these three variables and the differences observed between the two seasons confirms the influence of the environmental conditions.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

Effect of Nitrogen Fertilization on Yield Quality and Shelf-life of Bulb Onions

From this study, the following conclusions and recommendations have been made;

1. Application of nitrogen has appreciable effects on bulb yield and quality. Since application of N increased yields and decreased the maturity period, depending on factors such as price, immediacy of consumption and weather conditions, the lower level (26 Kg/ha) can be used in order to hasten maturity or the higher level (39 Kg/ha) to attain maximum yields. The level of N can also be varied to attain the size of bulbs that are required by the local markets.

2. All the newly introduced cultivars outyielded the locally grown cultivar Tropicana F_1, with KON7 growing also matured earlier, had lower TSS, higher bulb weight, and longer storage period. However, even though these new cultivars were superior to the local Tropicana, they were found to be highly susceptible to purple blotch caused by Alternaria porri and downy mildew caused by Peronospora destructor Berk. Casp. These are some of the most important diseases of onions in Kenya. It is therefore recommended that effective control measures for these diseases be studied if these cultivars are to be introduced to the Kenyan farmer.

3. Locational differences were observed in the growth and yield of the onions between the locations. This indicates that different environmental conditions influence the performance of onions. It is therefore recommended that similar

work be carried out in other onion growing ares in the country to ascertain the requirements in these areas.

4. The significant interactions observed between nitrogen , cultivars and locations indicate that all the three variables are interdependent. Therefore the yield and quality of onions depends on the environmental conditions in the location where grown, the level of nitrogen applied and the cultivar being grown.

6.2 Effect of Plant Density on Yield and Quality of Bulb Onions

The following conclusions and recommendations have been made from this study;

1. Increasing plant density from 38 to 111 plants/m^2 progressively increased total and marketable yield with the highest yield being attained from 111 plants/m^2. Increasing plant density also decreased the number of bulbs in grade 1 (bulbs with more than 5cm). Therefore, plant density can be varied to give different bulb sizes depending on the market requirements.

2. All the newly introduced cultivars, KON6, KON7,and KON5 matured significantly earlier than the locally grown Red creole. Cultivar KON7 outyielded all the other cultivars. The total yield for KON5 and Red creole was not significantly different. Despite the high yield attained in Red creole, the marketable yield was greatly reduced by its tendency to split and form double bulbs.

3. Locational differences were also observed in maturity period and other bulb qualities. Significant interactions between plant density, cultivar and location were observed. This indicates that the three variables were interdependent and that the differences in response of the cultivars to various plant densities are not of the

same order of magnitude in the two locations. It is therefore recommended that plant population studies be carried out in different growing areas and with various other cultivars

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APPENDICES

Appendix 1

Temperature and Rainfall Data for Kabete and Thika During the Experimental Period.

A: Kabete. (Source. Meteorological Department).

Month	Total Rainfall (mm)	Temperature °C)		
		Max.	Min.	Mean
July, 1990	13.6	21.5	10.4	15.8
Aug. 1990	21.0	20.3	11.5	15.9
Sept. 1990	31.8	23.6	11.3	17.5
Oct. 1990	90.0	23.8	13.3	18.5
Nov. "	126.0	22.0	12.8	17.8
Dec. "	74.6	22.3	13.2	19.0
Jan. 1991	33.9	24.4	12.7	18.5
Feb. 1991	0.4	25.2	13.1	19.6
Mar. "	84.8	26.1	13.7	19.9
Apr. "	158.3	23.9	14.4	19.3
May, "	281.4	22.4	14.8	18.4
June, "	12.5	21.9	12.6	17.3
July,"	15.4	20.3	9.9	14.95
Aug. "	19.4	22.0	10.1	16.1
Sept. "	23.6	23.9	10.1	17.0

B: Thika (Source. Meteorological Office. Thika)

Month	Total Rainfall (mm)	Temperature(^{0}C)		
		Max.	Min.	Mean
July, 1990	43.3	22.2	11.5	16.9
Aug. "	3.3	22.7	12.5	17.6
Sept. "	61.4	25.5	11.7	18.6
Oct. "	72.9	25.8	14.6	20.1
Nov. "	178.2	24.3	14.9	19.7
Dec. "	167,6	24.0	14.3	19.0
Jan. 1991	67.7	25.8	12.9	19.4
Feb. "	6.2	27.11	12.6	20.0
Mar. "	98.0	28.0	13.7	20.8
Apr. "	195.2	25.9	15.1	20.5
May, "	141.0	24.8	15.7	20.2
June,"	17.9	23.8	13.9	18.9
July, "	2.7	22.2	13.2	17.7
Aug. "	7.4	23.4	12.1	17.8
Sept. "	0.3	25.8	11.6	18.8
Oct. "	40.8	27.3	14.0	20.6

Appendix 2

Soil Analysis Results.

Depth (0-30cm)	Thika	Kabete
pH	6.0	6.2
Na m.e.%	1.28	1.75
K m.e %	0.83	1.58
Ca m.e %	5.1	13.05
Mg m.e %	4.03	4.9
Mn m.e %	0.11	0.5
P ppm	<u>11.0</u>	36.5
N %	0.15	0.32
C %	<u>1.35</u>	<u>1.93</u>

Deficiencies are underlined. Soils are moderately to slightly acid. Phosphorus is deficient in Thika. Carbon (and hence total Nitrogen) is low.

Appendix 3

Mean Squares and Significances of Locations,Nitrogen and Cultivar Effects on Yield, Days to Maturity and Quality of Onion Bulbs Grown at Two Locations in 1991.

Source of Variation	df	Bulb Yield	Days to Maturity	Splitting/ Doubling	Bulb weight	Marketable yield
Locations	1	3291.0**	2350.3**	4261.5**	8437.2**	5604.9**
Loc(reps)	4	517.4	52.7	1135.9**	1414.8	98.1
Nitrogen	3	153.5	68.4*	27.6	341.2	198.9*
Location x Nitrogen	3	68.7	17.3	68.8*	1027.6	41.1
Error	12	59.0	17.1	17.2	704.3	42.4
Cultivars	3	1815.1**	4692.1**	338.9**	3191.8**	1231.0**
Location x Cultivar	3	190.2	243.8**	60.5	1801.7**	213.9**
Nitrogen x Cultivar	9	16.5	24.9	32.1	496.6	17.9
Location x Nitrogen x Cultivar	9	26.2	46.0	16.4	360.6	22.3
Error	48	38.1	32.8	107.4	304.8	34.9

*,** Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 4

Mean squares and significancies of locations, nitrogen and cultivar effect on yield, days to maturity and quality of onion bulbs. 1991

Source of variation	df	Bulb yield	Days to Maturity	Splitting & doubling	Bulb weight	Total soluble solids	Mkt. Bulb Yield
locations	1	3583.8**	22353.5**	370.7**	687.9	1.9	6211.7**
Locs(Reps)	4	447.0	268.9	277.8	3537.0	12.5*	594.6
Loc.xNit.	3	542.4	173.8	130.4	5908.5	12.4*	121.4
Error	12	176.8	242.6	41.9	3412.8	3.3	342.3
Cultivars	3	4422.5**	1992.8**	163.2	18402.4**	66.7**	3448.6**
Loc.XCult.	3	44.0	501.3	73.4	2763.6**	2.3	71.5
Nit.XCult.	9	243.2**	245.1	31.0	824.6	3.4	127.5
Location X Nit.XCult.	9	176.0*	168.9	31.7	1889.3*	1.7	65.8
Error	48	66.8	230.6	66.6	900.4	4.0	132.1

*, ** Significant at the 0.05 and 0.01 probability level respectively.

Appendix 5

Mean Squares and Significancies of Locations, Cultivars and Plant Density Effects on Yield, Days to Maturity and Quality of Onion Bulbs.

Short Rains, 1990

Source of variation	df	Bulb yield	Days to Maturity	Splitting & doubling	Bulb weight	Mkt. Bulb Yield
Locations	1	55.7	6123.6**	6078.5**	767.0	240.7
Loc.(reps)	4	376.4	272.6	298.6	14118.5	159.7
Cultivars	3	1219.0**	1660.3**	2072.4**	33010.8**	959.8**
Loc.XCult.	3	207.5	142.7	39.5	6214.9	349.8*
Error	12	135.7	308.9	16.6	6213.5	70.3
Plant Density	2	602.7**	52.2	272.5**	4985.5	482.2**
Loc.XP.D.	2	18.3	96.2*	51.8	442.2	158.7*
Cult.XP.D.	6	58.8	40.3	95.2*	1021.4	5.8
Loc.XCult. X P.D.	6	39.0	38.1	147.2**	840.8	29.2
Error	32	29.3	25.4	23.7	2018.8	42.9

*, ** Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 6

Mean Squares and Significancies of Locations, Cultivar and Plant Density on Yield, Days to Maturity and Quality of Onion Bulbs. LR, 1991

Source of variation	df	Bulb yield	Days to Maturity	Splitting & doubling	Bulb weight	Mkt. Bulb Yield
Location	1	795.4	410.9	148.4	10894.5**	610.9
Loc(reps)	4	2093.1*	284.2	174.9	383.3	1865.8*
cultivar	3	3276.5**	1909.3	1397.4**	3012.9	2562.8*
Loc.XCult.	3	1061.3	1028.7	100.6	1498.4	1023.4
Error	12	419.6	156.9	42.5	1415.5	459.5
Plant Density	2	1739.9**	7.3	191.8*	597.7	1579.7**
Loc.XP.D.	2	201.9	22.3	61.9	9.2	48.7
Cult.XP.D.	6	197.9	9.4	105.4*	596.8	118.9
Loc.XCult. X P.D.	6	174.3	11.1	129.3*	508.7	182.2
Error	32	130.7	9.7	37.9	351.2	99.3

*, ** Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 7

Mean squares and significances of cultivars and nitrogen effects on sprouting during storage. L.R. Thika

Source of variation	d.f.	% Sprouting (days)		
		30	60	90
Replication	2	140.0	91.5	72.9
Nitrogen	3	25.1	65.7	59.0
Error	6	113.4	103.0	83.6
Cultivar	4	4546.4**	4417.9**	4129.7**
Cultivar x Nitrogen	9	40.1	31.2	42.5
Error	24	53.2	41.5	49.6

L.R.1991 Kabete

Source of variation	d.f.	% Sprouting (days)		
		30	60	90
Replication	2	28.3	131.7	156.3
Nitrogen	3	27.0	76.5	46.9
Error	6	38.0	109.0	112.5
Cultivar	3	46.6	56.5	298.5**
Cultivar x Nitrogen	9	68.7	74.3	62.9
Error	24	51.0	78.2	77.8

** Significant at 0.01 probability level

Appendix 8

Mean squares and significances of cultivars and nitrogen effects on rotting in storage L.R. 1991 Kabete

Source of Variation	d.f.	% Rotting (days) 30	60	90
Replication	2	284.3	254.7	164.1
Nitrogen	3	99.7	150.8	177.5
Error	6	84.9	80.1	78.3
Cultivar	3	135.8	485.4**	908.3**
Cultivar x nitrogen	9	41.0	51.6	92.4
Error	24	65.3	65.5	81.0

L.R. 1991 Thika

Source of Variation	d.f.	% Rotting (days) 30	60	90
Replication	2	151.3	71.5	170.0
Nitrogen	3	76.6	28.3	61.2
Error	6	105.6	69.0	36.0
Cultivar	3	426.4**	624.8**	686.4**
Cultivar x nitrogen	9	29.1	29.1	53.2
Error	24	81.3	53.8	52.4