

**EFFECTS OF NITROGEN LEVELS AND SPACING ON GROWTH, YIELDS
AND QUALITY OF TOMATOES (*LYCOPERSICON ESCULENTUM* MILL.)
GROWN IN A GREENHOUSE AT HIGH ALTITUDE IN KENYA**

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By

James Kiriimi Kiramana

**A THESIS SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD
OF THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE
OF EGERTON UNIVERSITY**



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2004

DECLARATION

This thesis is my original work and has not been submitted for the award of a degree examination in any other university.

James Kirimi Kiramana

Signature..........Date 13/9/04.....

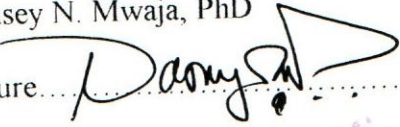
RECOMMENDATION

This thesis has been submitted with our approval as university supervisors.

Prof. F. M Itulya, Ph.D.

Signature..........Date September 13, 2004.....

Dr. Vasey N. Mwaja, PhD

Signature..........Date September 15, 2004.....

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DEDICATION

This thesis is dedicated to my parents Mr. Andrew K. Mburugu and Mrs. Veronica T. Kiramana with my appreciation.

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ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) is popular both in fresh market and processing industries. Production of tomatoes under greenhouse conditions is gaining popularity in Kenyan highlands. Its yields are limited by poor soil nutrition with nitrogen being the most limiting nutrient required in large quantities. Nitrogen fertilizer and spacing play a major role in yield and quality determination. This study investigated the effects of nitrogen levels and spacing on growth, yield and quality of tomatoes under greenhouse conditions at high altitude in Kenya. Plants were grown in a greenhouse on Tatton Farm of Egerton University, Njoro, Kenya. The study was conducted over a period of 10 months covering two seasons. The first season commenced in October 2002, and ended in February 2003, while the second one started in February 2003, and ended in July 2003. The nitrogen rates 0, 40, 80 and 120 kg N ha⁻¹ were each applied in two equal splits. Spacing was 40x30, 40x40, 50x30 and 50x40. The experimental design was a Split-Plot, arranged in a Randomized Complete Block Design, with three replications. Data on plant height were collected on a weekly basis throughout the entire growth period, beginning two weeks after transplanting. Fruit yield and quality data were taken after each harvesting.

Nitrogen levels did not significantly ($p \leq 0.05$) affect plant height, but the effect of spacing was significant ($p \leq 0.05$) with spacing of 40 x 30 cm having the highest height in season 1 and 50 x 30 cm in season 2. Wide spacing of 50 x 40 cm had the highest fruit size, with lack of additional nitrogen having the lowest fruit size in both seasons.

Total soluble solids were significantly ($p \leq 0.05$) lowered by lack of nitrogen application in both seasons. High nitrogen levels reduced fruit firmness in both

seasons. Total soluble solids and fruit firmness in season 1 were not significantly ($p \leq 0.05$) influenced by spacing of 40 x 40 cm and 50 x 40 cm. Number of trusses were highest with close spacing of 40 x 30 cm in both seasons. Spacing influenced days to flowering only in season 2. Fruit numbers and number of marketable fruits were significantly ($p \leq 0.05$) affected by spacing at 50 x 30 cm in season 1 and at 40 x 30 cm in season 2.

Nitrogen level of 80 kg ha⁻¹ had the highest fruit numbers in season 2. Nitrogen levels and spacing significantly ($p \leq 0.05$) affected fruit yields in season 1 with 80 kg N ha⁻¹ and spacing of 50 x 30 cm having the highest fruit yield. In season 1, spacing at 50 x 40 cm had the highest ($p \leq 0.05$) unit fruit weight and marketable unit fruit weight. Nitrogen level of 120 kg ha⁻¹ had the highest ($p \leq 0.05$) total leaf nitrogen content in both seasons. Less than 80 kg N ha⁻¹ and wide spacing 50x30 can be applied without adversely affecting the yields and total soluble solids and firmness of tomato fruits.

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CHAPTER ONE

INTRODUCTION

1.1. Background Information

The commercial tomato belongs to the Genus *Lycopersicon* and species, *esculentum* Mill. It is a relatively small genus within the extremely large and diverse family Solanaceae (Atherton and Rudich, 1986). Tomato is native to South America in the Andes Mountains of Peru and Bolivia, where it was used before Columbus (Splittstoesser, 1982).

Within the past century the cultivated tomato has become one of the most popular and widely consumed crop with an annual world production approaching 80 million metric tonnes (FAO, 2001). Its versatility in fresh or processed form has played a major role in its rapid and widespread adoption as an important food commodity (FAO, 2001). Tomato is an important source of vitamins A (900 IU), C (23 mg) and B2 (0.04 mg), and minerals such as K (244 mg), Fe (0.5 mg) and P (27 mg) per 100 g sample (Nonnecke, 1989).

The production of tomato in Kenya is approximately 18,163 ha, yielding 318,639 metric tones, and earning cash value of Kshs 5,102,573,579 (Anonymous, 2003). Tomato is third to kales and cabbages in terms of hectarage and production, but first overall in terms of cash value in horticultural vegetable crops (Anonymous, 2003).

The improvement of tomato yield and quality pose a major challenge to tomato growers in Kenya. Tomato production in Kenya is mainly under field conditions, where changes in climatic conditions do not allow realization of economic yield. There are fluctuations in the supply of tomatoes in the market, which lead to market glut during in season and shortage during off-season. The use of greenhouses

ensures constant supply of fresh market tomatoes by modifying crop environment to meet plant growth requirement at any time of the year. The off-season tomato production enables improved market prices. Production of tomatoes in high altitudes of Kenya is limited by low temperatures.

Growth of individual tomato shoots terminates with development of inflorescences. Tomato cultivars are classified as either 'determinate' or 'indeterminate', depending on the capacity of the shoot system to continue sympodial development. Indeterminate tomato cultivars produce branching systems that grow indefinitely and have a growth habit that is prostrate or scandent, while determinate cultivars produce branching systems of limited growth and develop into a form of a bush (Atherton and Rudich, 1986).

Determinate cultivars may grow up to 2 m in height and are erect with restricted flowering and fruiting, and are suitable for field conditions. The stem of an indeterminate cultivars grows indefinitely, reaching to more than 10 m within one year, making it ideal for long season continuous cropping in greenhouses as they flower and fruit regularly and evenly (Rick and Butler, 1956).

Staked tomato production is an important industry in the South Eastern United States and the cultural system is being tested in many other parts of the world (Davis and Estes, 1993). Yield and quality of tomatoes are influenced by many factors, including plant spacing and pruning (Davis and Estes, 1993). In indeterminate tomatoes, vegetative growth and reproductive development proceed concomitantly during the greater part of the plant life. A strong competition between developing leaves and apical meristem influences both the earliness of harvest and total yields. High assimilate availability under high light intensity conditions stimulates both meristem activity and leaf growth (Hussey, 1963a), but when plants are source-

limited (under high temperature and low light), young leaf growth is favoured at the expense of apical development. Continuous removal of young leaves counteracts this effect (Hussey, 1963b, Kinet, 1977).

Both spacing and soil fertility influence yields. With increasing plant populations, intra-plant competition becomes more important and eventually only flowers on the earliest clusters set fruits. These early yields increase as plant population increases, because there are more early clusters per unit area. Pruning is a labour intensive practice recommended and used on almost all staked tomatoes (Konsler and Gardner, 1990). Pruning of staked tomatoes increase fruit yields, but total marketable yields may decrease as pruning severity is increased. Non-pruned plants produce fruits of low weight and fewer large tomatoes as plants continue to partition carbohydrates to vegetative growth instead of reproductive growth (Davis and Estes, 1993). Pruning decreases flower clusters, but does not affect fruits per cluster (El-forgany and Morelook, 1982).

Nitrogen is the most limiting nutrient to crop production (Pionke et al., 1990). Like many vegetables, tomato is often heavily fertilized. Large amounts of nitrogen are often lost to leaching below the root-zone of vegetable crops (Pionke et al., 1990). Also, nitrogen fertilization, along with early season weed control, allows rapid crop establishment and growth, which is critical for the crop to suppress late-emergence weeds (Itulya et al., 1997). Nitrogen deficiency can seriously decrease yield and crop quality. The nitrogen composition of plant tissue has important nutritional consequences, since plants are a major source of proteins in human diet (Mohammed, 1995). Nitrogen is also a constituent of a large number of important compounds found in living cells, such as (enzymes) amino acids and nucleic acids (RNA and DNA)

(Lea and Leegold, 1993). Hence, nitrogen is critical in improving growth, yield and quality of vegetable crops.

The greenhouse production of tomatoes not only ensures faster growth than open field production because of enhanced control of temperature and carbon dioxide, but also gives the ability for high yields and quality (Geisenberg and Stewart, 1986). The effect of pre-harvest CO₂ enrichment, that is only achieved in protected cultivation (greenhouse), on post harvest quality has been shown to influence soluble sugars, ripening and mineral composition. Fruits produced under high CO₂ fruits have higher concentration of sucrose, glucose, fructose and total soluble solids than ambient CO₂ fruits (Behboudian and Tod, 1995).

1.2. Statement of the Problem

Tomato is an important crop in Kenya but little is known of its specific nitrogen fertilizer requirement when grown under greenhouse conditions in the Kenyan highlands. Due to soil and climate differences, results from other areas do not apply to Kenya directly. Spacing affects growth, yield and quality of tomatoes as well as pest and disease prevalence. However, there are no established tomato spacing recommendations under greenhouse conditions in the Kenyan highlands.

1.3. Objectives

The general objective of the study was to determine if tomato growth, yield and quality could be increased by manipulation of nitrogen fertility levels and plant spacing under greenhouse conditions in the high altitude areas in Kenya.

The specific objectives were to determine:

- (1) The effects of nitrogen levels on growth, yields and quality of tomatoes.
- (2) The effects of spacing on growth, yield and quality of tomatoes.
- (3) If interactions exist between nitrogen levels and plant spacing.

1.4. Hypothesis

The following hypothesis have been established for this study:

- (1) High levels of nitrogen result in increased yields and quality.
- (2) Intra-plant spacing of tomato influences tomato yield and quality more than inter-plant spacing
- (3) There are interactions between nitrogen levels and spacing on growth, yield and quality of tomatoes under greenhouse conditions in the Kenyan highlands

1.5. Justification of the Study

Tomato has always been a popular vegetable since its introduction to Kenya, both in fresh market and processing industry. It is also an important source of vitamins and minerals, such as K (244 mg/100 g), Fe (0.5 mg/100 g) and P (27 mg/100 g) (Nonnecke, 1989). Tomato is the highest vegetable income earner (Kshs. 5,102,573,579) and third from kales and cabbages in metric tonnes (318,639 MT) produced annually (Anonymous, 2003). Most commercial tomato cultivars are selected on the basis of their yield potential over a wide range of growing conditions. Weather patterns influence tomato production in the field due to seasonality. Production of tomatoes in Kenyan highlands under field conditions has been difficult due to low temperatures (16 to 19°C) while the optimal temperature for tomatoes is 21 to 24°C. Greenhouse production offers warmer conditions that promote faster growth of tomatoes for year-round supply. Knowledge of optimum spacing and nitrogen fertilizer will enhance production by increasing yields and possibly improving quality of tomatoes under protected structures.

CHAPTER TWO

LITERATURE REVIEW

2.1. Botany of Tomato

Tomato is a tender, semi-hardy plant which grows as an annual, but which is perennial in habit in its native South America (Atherton and Rudich, 1986). It belongs to the Solanaceae family (D'Arcy, 1979). The plant is classified as either determinate or indeterminate.

The main stem of indeterminate cultivars such as 'Money Maker' grows indefinitely, reaching a height of up to 10 m within a year in the greenhouse. Such cultivars are ideal for long season, continuous cropping in greenhouses as they flower and form fruits evenly. Determinate cultivars, which grow to 2 m in height, are erect and bushy, have restricted flowering and fruiting period, and are suitable for field conditions. They flower and set all their fruits within a short period of time. The harvest period for determinate tomatoes is generally short, unlike indeterminate tomatoes, which continue flowering and fruiting until they reach senescence (Picken et al., 1986). Tomato flowers are perfect and regular. The lower parts of the corolla are fused together with stamens within the column to form a staminal cone. The fruit is a true berry with a pericarp, fleshy septa between locules, a placenta and central axis (Picken et al., 1986).

The plant has a taproot with lateral roots. The taproot, if not damaged may be 1.5 m deep, while the lateral zone diameter reaches about 30 to 70 cm (Sanders et al., 1989). Tomato roots can be classified on the basis of their origin: a) radicle or primary roots; b) lateral roots (branch roots arising from the root pericycle; and c) adventitious roots (those arising within the lower 1 cm of the hypocotyl and upper 1 cm of the radicle (Zobel, 1975).

As indeterminate tomato seedlings develop, initiation of the floral axis terminates the primary vegetative axis (Sawhney and Greyson, 1972) and strong vegetative growth resumes from the axils of the last two initiated leaves on the primary sympodium directly below the inflorescence (Aung, 1976). The shoot originating from the axis of the initiated leaf displaces the inflorescence into a lateral position as it develops, the last initiated leaf is also displaced by the development of the lateral shoot so that at anthesis, the inflorescence appears in the internode between the last two initiated leaves on the primary sympodium (Calvert, 1965, Pickens et al., 1985).

2.2. Greenhouse Production of Tomatoes

Vegetable crop production is negatively affected by the unfavourable weather conditions that prevail during the year. Majority of smallholder growers have been growing them under rain fed and irrigated conditions under unprotected environment. This has resulted to high incidence of pest and diseases, which has lead to high use of farm inputs and labour thus reducing the economic gains (Anonymous, 2003).

The main difference of greenhouse compared with field production is the control of growth by manipulating the growing environment. Energy and carbon dioxide can be supplied and by growing in aeroponics, hydroponics or substrates like peat, rock wool, control of the root environment with regard to temperature, mineral and water supply is possible (Van de Vooren et al., 1986).

Tomatoes are grown in the field whenever climatic conditions permit economic yields to be attained. In the field, rainfall during crop development can disrupt planting. This is by providing favourable conditions for spread of certain fungal and bacterial diseases on any part of the plant. This usually happens during fruit development, particularly during fruit ripening. Fruit rots, such as alternaria,

phytophthora, fusarium and others, reduce yields by 50% (Geisenberg and Stewart, 1986). Plastic tunnels in combination with soil mulch provide good plant and fruit protection and improve temperature conditions. Tomatoes grown in plastic tunnels or greenhouses ripen earlier than those grown in open fields. Both greenhouse and plastic tunnels accelerate growth and ripening due to high temperatures. High temperatures usually enhance vegetative growth, particularly development of leaf area and stem length (Geisenberg and Stewart, 1986).

Greenhouses have many purposes apart from plant production. They are used as seedling production factories; protectors of plants from environmental factors favouring disease and pest development; enhancers of quality of the produce; laboratories for research work such as pollination control through isolation and extenders of production to be year-round (Liu and Nyanjage, 2002).

Under field conditions, direct seeded tomatoes are usually drilled in the field with 5 to 15 times as many seeds as the desired final plant number. Thirty to sixty seeds are drilled per metre length of row. After emergence and the appearance of three to four true leaves, plants are thinned to their final stand population. The population density is determined by eventual canopy size. Canopy size varies with soil type, fertility, irrigation and growing season (Geisenberg and Stewart, 1986). In the greenhouse, the optimum plant population is influenced by many factors, including the desired yield, labour, variety, growing method, planting date, length of crop, planting cost and price pattern (Van Dijk and Kintsch, 1983).

Temperatures play an important role in the production of tomatoes. High temperatures limit or prevent production of tomatoes during the summer in many regions of the world and can depress yields in principal production areas. The most serious effect of high temperatures is reduction or prevention of fruit set. Depending

on genotype and environmental conditions such as humidity and soil moisture, temperatures greater than 34/20°C day/night or a period of four hours at 40°C will cause blossom drop in most cultivars (Rick and Stevens, 1986). Tomatoes suffer chilling injury when exposed to low temperatures of about 10°C or less. Extended exposure to temperatures below 6°C can result in death of the plant and with less extreme exposure, growth is retarded. At temperatures below 13°C fruit set is inhibited (Picken, 1985).

Use of a greenhouse enhances temperature control to prevent any disorders like gray wall and blossom end rot. The covering material for tunnels used for tomatoes is polyethylene film with ultra-violet radiation stabilizer added (Dauple, 1979), because higher temperatures accumulated in some growing areas under these materials might be detrimental to good fruit set. These materials are used as walk-in-tunnels and greenhouses where temperatures can be controlled by suitable ventilation facilities. In tunnels, the side curtains are opened when temperatures are high and when the temperatures start decreasing they are closed (Geiserberg and Stewart, 1986). The curtains are held firmly by wire loops driven in the soil with an inclination towards the centre beds. This provides for better resistance against destruction by winds. The plastic film is stretched very tightly in each direction and tied to poles at both ends of the row. The plastic film is stretched out during the warm hours of the day to prevent slackness or damage to the tunnel. Ventilation is practiced to keep temperature and relative humidity at an optimum level for crop development and disease prevention (Dauple, 1979).

If there is a high rise of temperature in the tunnel while it is closed, sudden strong ventilation could cause dehydration of the plants because of the difference in relative humidity. If extreme temperature and humidity differences occur between

inside and outside the tunnel, ventilation is performed gradually beginning with small openings, 4 to 5 m apart (Atherton and Rudich, 1986).

In temperate countries the use of glasshouse is very common and mostly computers are used to control temperatures in glasshouses, although not widely. Other methods used are thermal screens in winter months to reduce energy loss and to ensure that minimum night temperatures can be maintained (Van de Vooren et al., 1986).

2.3. Effect of Spacing on Plant Growth

Tomato is an important vegetable with a ready local and exports market. Proper synchronizing of marketing and production coupled with good husbandry practices ensures economic gains to the tomato farmer. Proper plant spacing can greatly boost growth and production of tomatoes (Anonymous, 2003).

The number of plants per unit area and their arrangement has an influence on plant competition and yield (Bleasdale, 1965). However, tomato cultivars with dissimilar growth habits respond differently to spacing treatments (Frost and Kretchman, 1988). For a plant with vigorous growth habit, pruning and limiting nitrogen fertilizer applications control vigor (Konsler and Gardner, 1990), but close spacing reduces overall vigor (Fery and Janick, 1970). Gosselin and Trundel (1984) indicated that growing plants in higher root temperatures increases leaf area unless light was low due to close spacing. Plants grown with roots at 15°C had smaller, thicker and darker-green leaves than at 25°C, also the stomata close at a root temperature of 12°C than at a root temperature of 22°C. This condition reduces photosynthesis by limiting CO₂ assimilation. Floral development is promoted by the removal of young auxiliary shoots (Atherton and Harris, 1986). Kinet (1977) reported that flower abortion could be prevented by the removal of young leaves developing

immediately below the inflorescence. The removal helps in diverting assimilates to the apex, thereby influencing the initiation of the inflorescence, and not to the developing leaves.

In studies on a variety of staked and ground cultured tomatoes, plant size increased as in-row spacing increased. This showed that competition between plants limit plant size (Stoffella et al., 1988). The increased yields obtained with higher plant populations are primarily a function of the increased number of fruits produced per unit area. The increased yields result from the increased number of first flower clusters per unit area and not to any hastening of fruit maturity (Schmidt, 1952). The decrease in number of fruits per plant as population increases is due to development of fewer clusters, fewer flowers per cluster and lower percent fruit set (Reeve et al., 1962). Differences in growth of tomato plants diminish as the population increases (Fery and Janick, 1970).

2.4. Effect of Plant Spacing on Tomato Yield

Population density of the crop is decided according to various considerations. Factors determining plant spacing and arrangement are eventual canopy size, climatic conditions (Temperatures, light, nutrients, soil gases and water), and convenience of plant management and fruit harvest (Geisenberg and Stewart, 1986). Density of the plants can be increased or lowered depending on the soil fertility where under lower soil-fertility conditions; lower plant population would be advisable. Similarly, if available soil water is limited, a lower plant population should be chosen and hence plant spacing influence yields depending on various plant growth factors (Atherton and Rudich, 1986).

Earlier studies by Vittum and Tapley (1953) showed that decreasing plant population densities reduces early yields and total yields (Mohamed and Ali, 1988),

but fruit size is increased and number of fruits per plant are also increased (Frost and Kretchman, 1988). West and Pierce (1988) indicated that total yields increased as plant population increased to an optimum level. In their study, they reported that increases in density generally increases both early and total yields per hectare even though interplant competition for nutrients, moisture and light may decrease plant performance. In close spaced environments, disease and insect pressure may increase as density increases.

Donald (1951) showed that flower abortion could occur within overheated row covers or increased competition due to early stimulation of vegetative growth, which accounts for this inconsistency. Competition affects individual plant yield mostly when it occurs early in the growing season. Competition occurs in high plant densities earlier than the normal spacing. Bleasdale (1965) found that maximum yields were obtained when plants were arranged in square design or equidistant from each other.

Yield per plant decreases and there is a trend toward smaller fruits with a decrease in the number of flower clusters, fewer flowers per cluster and lower percent fruit set when plant density is high (Zahara and Herman, 1973). Currence (1941) found that early and total yields were highest for close spacing and standard determinate and dwarf tomato cultivars produced higher yield per plant at closer spacing compared to wider spacing. Bleasdale (1966) stated that a constant yield is produced in a range of plant densities when the plants are in competition for finite factors in space. Fruit size is reduced by water stress mainly as a result of a shorter fruit growth period (Ho and Hewitt, 1986). Atherton and Harris (1986) indicated that flower development is retarded in plants subjected to low water supply. Cell growth and elongation require water that creates turgor pressure, which brings about

irreversible growth by means of a hydrostatic pressure applied to the primary wall (Rudich and Luchinsky, 1986).

Weed control may be more effective when crops are planted at narrower spacing than when planted at standard row spacing. Narrow spacing enhances effectiveness of herbicides that do not give complete weed control (Williams et al., 1973). When narrow spacing is used, less cultivation is required for good weed control and satisfactory yields are achieved (Williams et al., 1973).

2.5. Effect of Nitrogen on Yield of Tomato Plants

Tomatoes grow moderately well over a range of levels of each nutrient. Manipulation of the nutrient supply is, however, essential in achieving the high yields of good quality fruit needed for profitable production. Nutrient levels must never become in excess or less than fully adequate for growth and yield. Plant growth and development are limited by insufficient nitrogen and yields are depressed at high levels of nitrogen (Adams, 1986). Factors affecting responses to nutrients determine the amount of each nutrient to apply. These factors include pH of the soil, nutrient source, soil moisture content, salinity of the soil, mode of irrigation, temperature, light and humidity among others (Atherton and Rudich, 1986).

Growth of tomato depends on an adequate supply of plant nutrients when all other requirements have been met. Meeting the nutrient requirements of the tomato is an important factor if large quantities of high quality fruits are to be produced effectively and efficiently annually. Takahashi et al., (1973) showed that flower initiation was delayed when nitrogen, phosphorous and potassium were in short supply. Delays in flower initiation due to nutrient deficiencies may reflect retardation of growth and development of the whole plant.

Of the nutrient elements applied, nitrogen is often added in the largest amounts and most often during the growing season (Gomez-lepe and Ulrich, 1974). Heavy applications of nitrogen depress the yield with maximum yields obtained at intermediate levels of nitrogen (Adams et al., 1978). Reduction in nitrogen supply results in the formation of one more leaf before the first inflorescence was initiated (Wittwer and Teubner, 1957).

Nitrogen fertilization along with early weed control, allows rapid crop establishment and growth, which is critical for the crop to suppress late emerging weeds (Itulya et al., 1997). Wilcox (1964) observed that there was no response to nitrogen applied before planting. Both pre-planting and supplementary dressing of nitrogen reduced fruit size and delayed ripening of tomatoes grown for 'once-over' harvesting (Nicklow and Downes, 1971).

Nitrogen is an integral component of many compounds including chlorophyll and enzymes essential for plant growth processes. It is an essential component of amino acids and related proteins, which are critical as building blocks for plant tissue (Brandy, 1990). Locasio and Dangler (1990) reported high yield of tomato under trickle irrigation with slow-release N sources, which enhances maturation of tomatoes. The form of nitrogen applied to the tomatoes affects growth and subsequent yields. The tomato in particular is prone to "ammonium toxicity". Plants exposed to ammonium nutrition as the only source of nitrogen develop typical symptoms such as reduced growth rate, yellowing of leaves, dark pitted lesions develop on the stem, foliar damage and blossom end rot of the fruit through which yields are drastically reduced (Wilcox et al., 1974).

Mason and Wilcox (1982) observed that the total nitrogen content in younger tomato leaves was high, while nitrate-nitrogen content was highest in the older leaves.

In their study, they observed that petioles had lower total nitrogen content than the total leaf on all sampling dates. Through fruit accumulation and early fruit expansion the 168 Kg N ha⁻¹ resulted in significant increases of the total nitrogen in whole leaves and petioles with little further increase from the 336 Kg N ha⁻¹. The leaf nitrate-nitrogen content of tomato leaf petioles increased with increasing nitrogen application rates. Leaf total nitrogen increased with increased nitrogen level. Fischer (1969) observed no effect of different nitrogen levels on flower initiation in plants grown at low irradiances and at a minimum air temperature of 15.5°C. Increases in nitrogen supply can produce increases in the number of flowers in the first inflorescence. The total nitrogen content of the leaf blades increased as the season progressed.

Deficiency in soil nitrogen causes depletion of nitrogen in plants, while excess soil nitrogen or potassium retards proteolysis thus reducing sap as opposed to leaf nitrogen (Pirson, 1955) as cited by Saidi (2000). The general purpose of nitrogen is promotion of growth of leaves. Plants under-supplied with nitrogen have small leaves, and reduced leaf area, resulting in reduced carbon assimilation and subsequent yields. Nitrogen status also affects leaf area expansion through the amount of assimilates flowing to the leaves (Van Kerlen et al., 1989). The response of applied nitrogen depends not only on the initial nitrogen content of the soil but also on immobilization or mineralization of nitrogen or denitrification during cropping (Adams, 1986).

High levels of nitrogen that are not in excess ensure very rapid growth of tomato seedlings in transplant containers, such that field survival is adversely affected (Liptey and Nicholls, 1993). A study carried out by Melton and Dufault (1991) on nitrogen, phosphorus and potassium fertility regimes on tomato transplant growth

found that increasing the level of phosphorus or potassium in the transplants leads to less marked increases in plant growth than does nitrogen.

High quality transplants are essential for successful tomato production because plant conditions at field setting affects stand, early and total yields and fruit size. Nitrogen and phosphorous are important elements in production of tomato plants. Fertilization regime during plant production in the greenhouse affects plant size and subsequent yielding ability (Weston and Zandastra, 1989). A decrease in the number of flowers in the first inflorescence due to the application of nitrogenous fertilizers is due to an increase in the incidence of flower abortion rather than a decrease in the number of flowers initiated (Atherton and Harris, 1986). Besford and Maw (1975) observed an increase in flower number as a result of increases in the supply of potassium, and retarded flowering and abortion of flowers due to low levels of potassium in sand culture.

Low level of nitrogen in solution culture results in delayed flower opening on plants pruned to carry a single truss of fruits (Fisher, 1969). Under some conditions like high temperatures, shortage of nitrogen can result in an increase in the incidence of flower abortion. Plants subjected to water stress and high temperatures, nitrogen deficiency produce an increase in the incidence of flower abscission and in some conditions a high level of nitrogen can promote style exertion (Atherton and Harris, 1986).

Depriving plants grown in solution culture phosphorous for 10 days, delayed anthesis by seven days and the number of flowers that open in the first inflorescence, reduced number of flower buds formed and the size of the floral organs (Menary and Van Staden, 1976).

Dobbs (1995) reported that all the three elements N.P.K. are essential for plant growth and crop production as they act synergistically to help in increasing yields. Nitrogen is needed for the development of dark-green color in plants, which is essential for rapid and continuous vegetative growth. Phosphorus aids plants in getting off to a rapid vigorous start, promoting early root formation, stimulating blooming, seed production and hastening maturity, whereas potassium is needed for plant health, disease resistance, ripening of fruits and development of full plump size fruits. Potassium and nitrogen are the main nutrients used for growing tomatoes. If K supply is low, either flower development or fruit set is reduced, and hence insufficient K supply results in reduction of the number of fruits and thereby fruit yield (Ho and Hewitt, 1986).

Plant vigor is increased with supply of nitrogen. Also plant height, leaf area and the number of flowers produced all increase in response to added nitrogen. Yield increases with moderate dressing of nitrogen both under glasshouse and in the field (Adams, 1986). Under protected structures like greenhouses regular checks of the nutrient status of the soil are necessary. Maintaining the correct fertilizer dosage is important in achievement of high fruit yields and quality (Van de Vooren et al., 1986).

Fusarium and bacterial wilts are serious problems in tomato production and may result in 100% yield loss. Liming certain soils to a pH of between 7 and 8 reduces severity of both fusarium and bacterial wilts of tomato. Use of nitrate-nitrogen and low pH increase fusarium wilt resistance (Woltz and Jones, 1973).

Nitrogen application results in increased ripe fruits and total yields with increasing nitrogen application rate (Mason and Wilcox, 1982). A study by Doss et al., (1981) showed that tomato yields averaged about 1.9 MT ha⁻¹ greater on high

nitrogen plots than on low rate plots. The effect of nitrogen application rate on marketable tomato yields tended to be higher on low nitrogen plots than on high nitrogen plots in the first two years. In the third year the yields were similar in about one half of the treatment and better in the higher nitrogen in the other treatment. The study showed that the lowest nitrogen rate used was adequate, especially when moisture was inadequate.

The average fruit weight of tomatoes increases with an increase in the nitrogen content of the liquid feed given to the plants. Higher nitrogen contents in the peat media, however, results in reduced fruit weight. The proportion of small fruits also increases with the amount of nitrogen in the base fertilizer and in the liquid feed (Adams et al., 1978). Low initial nitrogen reduces branching and early flower number in tomatoes, and significantly decreases early marketable yields. Early yields were however decreased at high initial nitrogen levels during the first trial (Wien and Minotti, 1988). This was attributed to a more rapid vegetative growth resulting in shading of the earliest clusters under the leaf canopy. Nitrogen fertilizer levels up to 84 kg ha^{-1} increase total marketable yields with no further increase beyond 84 kg ha^{-1} (Wien and Minotti, 1988).

2.6. Effect of Nitrogen Levels and Plant Spacing on Quality of Tomatoes

Quality is established by the characteristics and attributes that are involved in satisfying the demands, needs and expectations of the tomato consumer. Producers are concerned that their tomatoes have good appearance and few visual defects (Atherton and Rudich, 1986). Tomato cultivars must score highly on yield, disease resistance, ease of harvest, and shipping quality. Quality of appearance, firmness, ripening behaviour, and shelf life are the factors most important to receivers and market

distributors. Consumers on the other hand, consider good quality tomatoes as those that look good, are firm, and offer good flavour and nutritive value (Grierson and Kader, 1986). Many preharvest, harvest, and post-harvest factors influence the composition and quality of tomatoes. These include inherent genetic and environmental factors such as climatic conditions (temperature, light, pollutants) and cultural practices (soil type, nutrient and water supply, use of agricultural chemicals and harvesting method). Maturity stage at harvest and post-harvest handling procedures also affect tomato quality and its maintenance (Atherton and Rudich, 1986).

Spacing affects average fruit weight and size. Fruit weight generally increases as plant population density decreases (Ferry and Janick, 1970; Frost and Kretchman, 1988). Closely spaced plants without pruning produce small fruits (Stoffella et al., 1988). In addition, close spacing in the row tends to decrease both fruit size and soluble solids content (Emery and Munger, 1970). Soluble solids are the carbohydrates accumulated during maturation in the form of starch and as the fruit ripens starch is broken down to sugars (Thompson, 1996). Some of the variations in fruit size and soluble solids content among plants of different growth habits can be attributed to quantitative genetic differences.

Nevertheless, the largest single factor contributing to fruit size and soluble solids differences among the growth habit appears to be their varying fruit number per inflorescence (Emery and Munger, 1970). Shade produced by dense vegetative growth and subsequently lower temperature cause the beneficial effect of close spacing on colour development (Moore et al., 1957).

Tomato has many physiological disorders, such as blossom end rot (BER), which has been associated with low fruit Ca concentration, high K and Mg stylar to

calyx concentration ratios and low transpiration rate. High level of N fertilization and $\text{NH}_4\text{-N}$ increase BER incidence (Pill and Lambeth, 1980). Gray wall, a disorder of tomato fruits, occurs during maturation and ripening. It results in brown discolorations on outer fruit wall, and may appear on immature green fruit as well as ripe fruit. Internally, severe browning usually appears in the outer pericarp in regions associated with vascular bundles. Low N and high K reduce internal browning (Picha and Hall, 1981). Blotchy ripening which is an irregular or defective ripening of tomato is a serious problem. External blotchy ripening is of economic importance to the tomato industry, because of difficulty in marketing blemished fruit. The presence of blotchy areas, especially on fruit shoulder, reduces the value of tomato primarily because of difficulty in removing the peel from affected portions of the fruit. As K: N ratios increase there is a decrease of exterior blotchy ripening of tomatoes (Locascio and Dangler, 1990).

Heavy application of nitrogen reduces fruit size and delays ripening of tomatoes. Proportion of unevenly ripened fruit tends to be highest at intermediate levels of nitrogen, decreasing when the plant growth is limited by insufficient nitrogen and also high levels lead to hollow (boxy or puffy) fruit (Adams et al., 1978). Nitrogen application decreases colour, firmness and edible quality of most vegetables and fruits (Shewfelt and Prussia, 1993). Mary et al. (1994) reported that the highest N rate resulted in the highest peelable fruit percentage. Lowest nitrogen and potassium combinations produce softest fruits, while highest nitrogen and potassium combinations produce firmest tomato fruits (Huett, 1998). Soft fruits have short shelf-life and usually cause severe harvest losses.

Stevens and Peterson (1973) reported that phosphorus concentration is an important factor in quality of tomato fruits, because of its effect on the relationship

between pH and titratable acidity. Both pH and titratable acidity are crucial to tomato quality because of their effect on flavour and processing. In cultivated cultivars with low sugar concentration, a lower acid concentration is sometimes desired to give a more favourable sugar/acid ratio. Low phosphorus level in low acid cultivars results in more acceptable pH. At high K supply, acidity increases as colour and shape of fruits improve, whereas at low potassium supply, growth period of a tomato fruit is shortened (Besford and Maw, 1975).

Tomato products processed in plain tin cans are occasionally subject to chemical, non-microbial spoilage due to accelerated de-tinning. Quality of tomatoes greatly reduces and very high levels of N, high temperature, low light intensity and poor water supply favour this spoilage (Wilcox and Hoff, 1973).

Van Emden (1992) showed that many insects might benefit as good nutrition is applied. Insects such as aphids, leaf hoppers, mites, thrips and leaf miners have all been found to breed or develop more rapidly on plants given good nitrogen fertilization. Presence of such insect pests lowers the quality of fruits due to pest damage. Stoll (1995) as cited by Saidi (2000) reported that unbalanced fertilization could provoke a more virulent attack of diseases and pests as a result of either plant undernourishment or an oversupply of nutrients. Furthermore, excessive nitrogen application increases aphid ingestion and results in weak plants, which show less resistance to plant diseases.

Adams et al., (1978) showed that as N content of liquid feed increases, total solids content of expressed fruit juices declines from 3.55 to 3.33 g 100 ml⁻¹. Sugar content similarly declines from 2.45 to 2.25 g 100 ml⁻¹. Nitrogen content of tomato leaves also increases when fertilizer is applied, the greatest increase occurring with the 56N–56P–56K and 50N–112P–50K treatments, compared to the 50N–50P–0K and control treatments (Danchak and Smith, 1990).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Research Site

The study was conducted in a greenhouse at the Horticulture Department research field on Tatton Farm of Egerton University, Njoro, Kenya. Tatton farm lies at a mean latitude of $0^{\circ} 23'$ South, longitude of $35^{\circ} 35'$ East, and altitude of 2200 m above sea level. The study was carried out in two seasons, the first one beginning in October 2002 and ending in February 2003. The second season commenced in February 2003 and ended in June 2003. The site had previously been used as an orchard, but currently it is under greenhouse vegetable production. The soil type of the site is a vitric mollic andosol's well-drained sandy loam.

3.2. Treatments

The experimental design was a split-plot, arranged in a randomized complete block, with three replications (Figure 1). The main plots were nitrogen fertilizer levels because of nitrogen's mobility in soil when in solution, while spacing formed the sub-plots.

The nitrogen rates were: 0, 40, 80 and 120 kg N ha^{-1} , each rate applied in two splits in the form of urea (46% N). The first 50% (20, 40 and 60 kg N ha^{-1}) was applied two weeks after transplanting, followed by another application of 20, 40 and 60 kg nitrogen, two weeks later. The initial fertility of the greenhouse land was 4 kg N ha^{-1} , 1.3 kg K ha^{-1} and 8.3 kg P ha^{-1} .

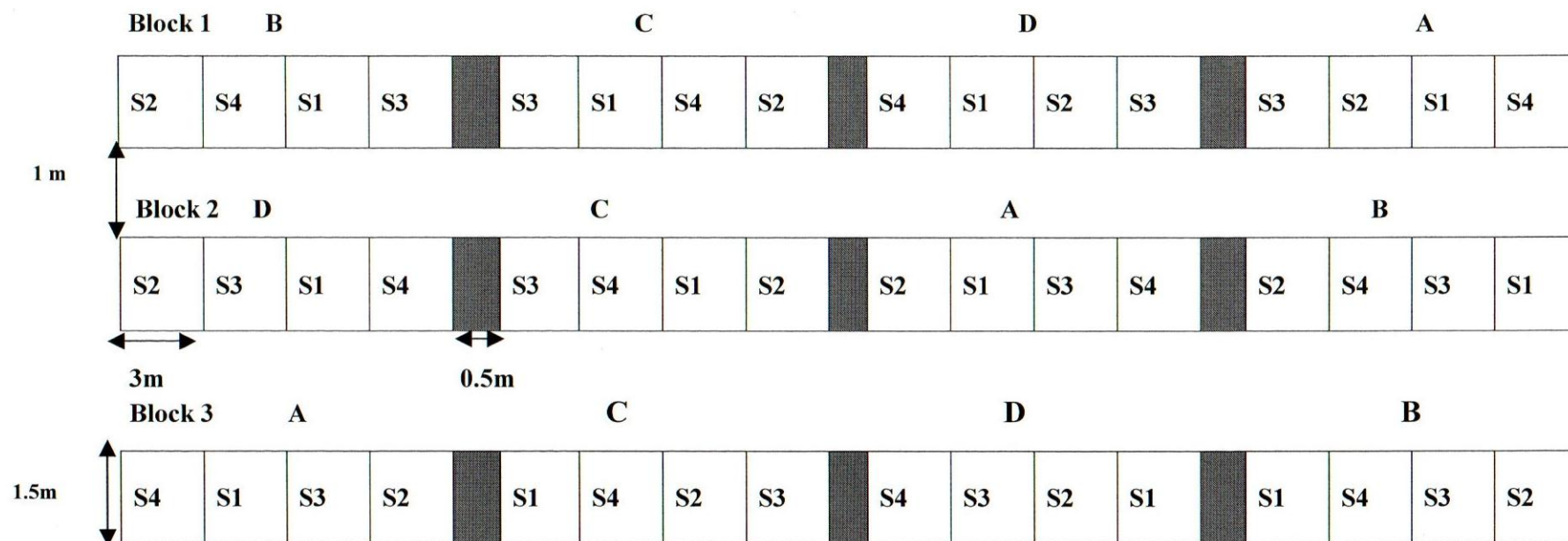


Fig. 1. Experimental layout

Fertilizer levels

A = 0 kg N ha⁻¹

B = 40 kg N ha⁻¹

C = 80 kg N ha⁻¹

D = 120 kg N ha⁻¹

Spacing levels

S1 = 40 cm x 30 cm

S2 = 40 cm x 40 cm

S3 = 50 cm x 30 cm

S4 = 50 cm x 40 cm



- Trenches lined with white polythene

The inter-row and intra-row spacing (in cm) were: 40x30, 40x40, 50x30 and 50x40, which formed the subplots. The sub-plots measured 3 m by 1.5 m. The occupied area remained constant for all the plots.

All data were subjected to the Analysis of Variance using MSTAT-C computer programme and where the F-test was significant, either Least Significant Difference or the Duncan's Multiple Range Test depending on the number of means did separations.

3.3. Nursery Establishment and Operations

The seeds of 'Money Maker' were planted in plastic pots (measuring 8 cm top diameter, 4.5 cm bottom diameter and 8.7 cm length). Seeds of 'Money Maker' variety have high germination percentage and mature early. Pots were filled with a mixture of manure and soil in the ratio of 1:1. The pots were watered thoroughly before planting and slightly after planting using a watering can. The seedlings were grown in the greenhouse and transplanted on attaining a height of 15–20 cm after 4 weeks. Watering was carried out regularly with a watering can so that the availability of water was not a limiting factor.

3.4. Land Preparation

Soil sample was taken using a soil auger to 15 cm depth before planting and after planting to determine the soil nutrient status. The greenhouse soil was dug using a folk hoe, prepared to fine tilth and leveled to ensure uniform water distribution and infiltration. Soil was treated with a nematicide (Carbofuran) 2 g per planting hole to control nematodes and other soil microorganisms harmful to tomato plants.

At planting, fertilizer in the form of triple super phosphate (TSP) was applied at a rate of 23 kg P ha⁻¹. After 2 weeks, nitrogen fertilizer in the form of urea was split-applied twice in liquid form, starting at two weeks after transplanting. Potassium

also was applied uniformly in all the plots in the form of Muriate of Potash after two weeks at the rate of 305 kg K ha⁻¹ in all the plots (Macharia, personal communication).

Trenches measuring 0.5 m wide and 0.8 m deep were dug and white polythene sheet placed underneath. Soil was returned to the trench to ensure the plots are level. Trenches lined with Polythene were used to separate the main plots to avoid interference of fertilizer, especially nitrogen, which is mobile and can confound the effects by moving from high concentration to lower ones once in solution.

3.5. Transplanting

Transplanting was done six weeks after seeding, when seedlings had attained 15 to 20 cm height. Seedlings were planted at different spacings and different nitrogen rates as shown in Figure 1.

3.6. Plant Training and Pruning

The tomato plants were trained to a single stem twisted around a sisal twine suspended from wires stretched horizontally and parallel to the tomato beds. Poles (2.2 m high) spaced at 4 m supported the wires at 35 cm apart and 2 m high. At the bottom, each string was tied directly to another wire running horizontally at 30 cm from the ground. The plants were trained on attaining 35 cm height from the ground. Lateral shoots were removed as soon as they appeared using a pair of shears. Care was taken not to damage plants. Old and diseased leaves were defoliated as soon as they appeared

3.7. Irrigation

Irrigation was done using drip tubes as soon as the tensiometers reading reached 0.3 bars. Two tensiometers were installed in all the main plots and monitoring of soil moisture was done every morning daily during the whole cropping season. All

plots received equal amounts of water, which was applied on the same day to avoid variations. Before planting, the plots were watered uniformly using sprinkler irrigation until field capacity was reached and thereafter plots were installed with irrigation drip tubes on the soil surface. Discharge rate for the driplines was 3.9 litres per minute.

3.8. Temperature Control

Extreme temperatures during the day were controlled using ventilation-cooling systems. This was done by raising the side curtains and opening the doors. This helped in lowering high temperature during the day. Closing doors and dropping curtains at sunset controlled low night-temperatures. Temperature monitoring was done using thermometers. The nine locations selected included: both sides of the greenhouse, the middle, starting from the doorstep, centre and the rear end of the greenhouse. Monitoring of temperature was done three times per day, thus morning, noon and evening.

3.9. Pest and Disease Control

Pests and diseases like early and late blights (*Phytophthora infestans*), leaf spots and bacterial wilt were identified and judiciously controlled using appropriate methods, including chemical and cultural practices. Pests such as African bollworms, thrips, whiteflies, rats and moles were also controlled. The chemicals used were Karate, Diazinon, Bulldock and Ridomil. Bacterial wilt was prevented from spreading to healthy plants by roguing the affected plants and applying lime on the infected holes. Rats were controlled using chemical baits applied on maize seeds, while trapping killed moles.

Weeds were controlled using plastic mulch and uprooting when necessary. Mulching was done on the day of transplanting by placing the polythene film on each

plot and covering its sides with soil. Holes opened at planting time on the polyfilm depending on the spacing in each plot.

3.10. Harvesting

Harvesting began as soon as the first fruits reached breaker stage. Harvesting was done twice per week from all plants in the centre row; outer rows and plants at the end of each plot served as guard rows. Fruits were graded soon after harvesting, based on size using a vernier caliper. Fruits were categorized into small (<4 cm), medium (4–6 cm), large (6–8cm), extra large (>8 cm) in diameter (Thompson, 1996).

3.11. Parameters Studied

3.11.1. Growth

- a) Height of 5 randomly selected plants per plot was measured using a ruler every week for 7 weeks and the average height recorded.
- b) Days from transplanting to first flower initiation were recorded and early yields were also recorded in each treatment combination.
- c) The number of trusses produced per plant in every plot was counted and recorded.

3.11.2 Total Nitrogen Determination

The nitrogen content of old leaves was determined using the Kjeldahl method (Hind, 1995). The old leaves were stripped in every plot from randomly selected plants as soon as they started showing chlorosis (a sign of senescence) and their fresh weight was determined by weighing. The leaves were oven-dried at 70°C until completely dry. Dry leaves crushed easily on touching. They were ground into powder and then the dry weight was determined. The dried leaves were ground using a mortar and pestle and the powder was placed in paper bags.

3.11.3 Fruit Quality

a) Fruit Size

Size was determined by measuring the fruit at the widest part, starting from the attachment of the fruit to the plant to the blossom end and then at the diameter of the fruit. All measurements were made using a Vernier caliper. Five randomly selected fruits per plot were measured and graded into different sizes every other week. Fruits were categorized into small (<4 cm), medium (4–6 cm), large (6–8cm), extra large (>8 cm) in diameter (Thompson, 1996). Low quality fruits were those measuring less than 4 cm and high quality were those measuring above 6 cm as per the marketing quality (Nyanjage, personal communication).

b) Fruit Firmness

Thirty harvested fruits from each plot were randomly selected and their firmness determined using a penetrometer (Bishops Instrument, Italy). Thus, a penetrometer was used to punch the fruit at five locations. Readings were recorded in kilograms m⁻² and then the average reading was used in data analysis. Other fruits were measured every two days (2, 4, 6, 8, 10) to determine the storage life. The fruits were stored at 20°C. Fruit firmness was monitored throughout the ripening period. Quality of fruits was graded on the number of days taken to lose shelf life. Those that took 5 days and beyond were considered to be of high quality.

c) Total Soluble Solids

Total soluble solids content of the juice of 30 randomly selected, table ripe tomato fruits per plot was measured using a hand refractometer (0-30% brix). The fruit surface was cut using a knife, the juice squeezed into the refractometer opening and the refractometer cap replaced. The reading was recorded and the refractometer

cleaned with moist tissue for the next reading. Fruits with 4–9% brix were considered to have high quality (Atherton and Rudich, 1986).

3.11.4. Yields

a) Total Yields

All the fruits harvested per 3 x 1.5 m area were counted and weighed separately on each harvesting date. Fruit count was used to extrapolate the number of fruits per hectare and fresh fruit weight to calculate metric tones per hectare. The average fruit weight was calculated for each treatment by dividing the total weight over the number of fruits harvested per plot.

b) Marketable and Unmarketable Yields

Fruits were separated into two lots of marketable and unmarketable fruits. Marketable fruits were picked at breaker stage. Size was determined using a Vernier caliper and categorized into small, medium, large and extra large in diameter. Unmarketable fruits were those with physiological disorders such as cracks and blossom end rot or other types of blemish. Fruits from each category were counted and weighed separately. Marketable fruits were those with fruit size >4cm, without cracks, blemish, disease incidence, and other physiological disorders.

CHAPTER FOUR

RESULTS AND DISCUSSION

In this thesis, data are presented in four categories, covering growth, quality, yield and total leaf nitrogen content. Plant height, number of trusses and number of days to flowering represented the effect of nitrogen levels and spacing on growth. Fruit size, fruit firmness and total soluble solids represented fruit quality. Fruit numbers, number of marketable fruits, fruit yields, marketable fruit yields, and unit fruit weight and marketable unit fruit weight, represented yields.

4.1. Effect of Nitrogen Levels and Spacing on Plant Height

Nitrogen levels did not significantly ($p \leq 0.05$) affect the plant height in both seasons (Tables 1 and 2). Spacing significantly ($p \leq 0.05$) influenced plant height in season 1 (Tables 1), with no effect in season 2.

There was an interaction between nitrogen levels and spacing in both seasons (Tables 1 and 2). This coincided with application of nitrogen fertilizer and agreed with Adams (1986), who stated that plant vigour generally increases with the supply of nitrogen. He found that plant height; leaf area and the number of flowers produced increase in response to added nitrogen.

Planting height significantly ($p \leq 0.05$) increased with plant age both seasons (Tables 1 and 2). Lowest plant height at all ages was at spacing of 50 x 40 cm. Bleasdale (1965) indicated that the number of plants per unit area and their arrangement has an influence on plant competition and yield. Fery and Janick (1970) observed that closer planting influences the concentration of the harvest, because of plant habit and competition for light, nutrient, oxygen and water.

Table 1. Effect of nitrogen (N) levels and spacing (S) on tomato plant height (cm) at different plant age (W) during season 1 (October, 2002)

2 weeks (W) after planting					4 weeks (W) after planting				6 weeks (W) after planting				8 weeks (W) after planting					
Spacing (cm)																		
N Levels (kg ha ⁻¹)	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	N means	
0	57.3	56.2	54.7	57.6	92.5	93.5	84.3	96.1	137.4	131.2	128.3	133.4	163.5	165.3	162.4	163.0	111.1	
40	58.3	52.1	60.1	52.2	101.4	98.6	93.8	94.8	144.4	144.5	146.0	135.6	172.5	173.5	171.4	163.2	116.4	
80	58.5	58.2	60.6	55.5	99.0	95.3	103.6	92.2	138.9	135.0	145.2	128.8	166.3	163.9	169.5	160.2	114.4	
120	56.9	58.2	57.7	54.9	97.3	96.9	96.8	91.0	141.8	136.9	141.3	132.2	169.9	163.1	173.6	163.6	114.5	
S Means	57.8f	56.2f	58.3f	55.0f	97.6e	96.1e	95.7e	93.5e	140.6c	136.9c	140.2c	132.5d	168.1a	166.4ab	169.2a	162.5b		
WxN	56.5	55.7	58.2	56.9	91.6	97.2	97.5	95.5	132.6	142.7	137.0	138.1	163.5	170.2	165.0	167.5		
NxS	112.7ijk	11.5jkl	107.4l	112.5ijk	119.2g	117.2ghi	117.9gh	111.5jkl	115.7ghij	113.1hijk	119.7g	109.2kl	116.5ghij	113.8hijk	117.3ghi	110.4kl		
W Means	56.8s				95.5r				137.6q				166.6p					

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 2. Effect of nitrogen (N) levels and spacing (S) on tomato plant height (cm) at different plant age (W) during season 2 (March, 2003)

2 weeks (W) after planting					4 weeks (W) after planting				6 weeks (W) after planting				8 weeks (W) after planting					
Spacing (cm)																		
N Levels (kg ha ⁻¹)	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	40x30	40x40	50x30	50x40	N means	
0	44.0	41.6	43.6	44.8	74.9	69.6	70.6	74.0	109.9	104.4	107.9	113.7	146.3	144.2	153.9	147.1	93.1	
40	45.1	39.8	41.5	39.6	77.6	69.5	77.2	64.9	114.8	112.9	113.1	103.5	152.2	149.2	159.0	148.0	94.2	
80	44.5	45.5	44.5	41.1	72.9	74.0	78.5	72.1	105.1	107.3	117.7	104.4	150.8	147.0	160.0	147.7	94.6	
120	42.6	42.4	41.6	42.9	72.1	73.9	73.5	69.5	110.5	111.0	109.1	107.1	151.5	149.5	154.5	145.9	91.5	
S Means	44.1	42.3	42.8	42.1	74.6	71.8	74.9	70.1	110.1	108.9	112.0	107.2	150.2	147.5	156.8	147.2		
WxN	43.5	41.5	43.9	42.4	72.3	72.3	74.4	72.3	108.9	111.1	108.6	101.2	147.9	152.1	151.4	150.3		
NxS	93.8abcd	89.9bcd	94.0abcd	94.9abc	97.4ab	92.9abcd	97.7ab	88.9cd	93.3abcd	93.5abcd	100.2a	91.3bcd	94.2abcd	94.2abcd	86.4d	91.3bcd		
W	42.8h				74.9g				107.5f				150.4e					
Means																		

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

The highest height under close spacing was due to intense interplant competition that may have lead to decrease in light intensity resulting in increased internodal length. Shading of lower leaves may occur even to the point where they become parasitic to photosynthetic reserves (Rodriquez and Lambeth, 1975). Plant height was higher in plots treated with nitrogen, with high nitrogen levels and areas without application of nitrogen having lower plant heights. This is similar to findings of Atherton and Rudich (1986) who stated that plant vigour generally increases with supply of nitrogen. White (1938) as cited by Atherton and Rudich (1986) found that tomato plant height, leaf area and the number of flowers produced increased all in response to added nitrogen. In addition, Atherton and Rudich (1986) stated that high plant density due to closer spacing allows undesirable etiolation and also causes greater plant root disturbance

In the current study, there were no significant variations in plant height for season 1 but the weeks after transplanting showed great variations (Tables 1 and 2).

4.2. Effect of Nitrogen Levels and Spacing on Number of Trusses

Nitrogen levels did not significantly affect the number of trusses produced per plant, but spacing significantly affected the number of trusses in both seasons. Close spacing of 40 x 30 cm had the highest number of trusses, with 40 x40 and 50 x 40 cm having the lowest number of trusses in season 1(Tables 3). In season 2 40 x 30 had the highest number of trusses though not significantly different to 50 x 30 cm (Tables 4). There was no significant difference between spacing of 40 x 40 and 50 x 40 cm in both seasons (Tables 3 and 4). These findings are in disagreement with those of Reeve et al. (1952) where the number of trusses per plant was the same for plants spaced at 60 cm and 120 cm in the row but trusses per acre were doubled by the close spacing due to many plants set per unit area.

Table 3. Effect of nitrogen (N) levels and spacing (S) on number of trusses per plant during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	10.0*	10.3	10.9	10.4	10.4a**
40x40	8.2	8.6	8.6	8.5	8.5c
50x30	9.5	9.8	10.0	9.6	9.4b
50x40	8.4	9.9	8.7	8.7	8.7c
N Means	9.1*	9.4	9.6	9.3	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 4. Effect of nitrogen (N) levels and spacing (S) on number of trusses per plant during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	9.3*	8.6	8.5	9.6	9.0a**
40x40	8.3	8.0	8.7	8.5	8.4b
50x30	8.5	8.6	8.5	10.0	8.9a
50x40	8.0	8.6	9.1	9.3	8.7b
N Means	8.5	8.4	8.7	9.5	

*Values not followed by a letter are not significantly different to the F-test at $P \leq 0.05$.

**Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

At close spacing number of trusses increase due to shading which leads to lowering of temperatures. Low temperatures and high irradiance reduces the number of leaves subtending the first inflorescence resulting to plant etiolation leading to production of many trusses under close spacing (Atherton and Harris, 1986). Zahara and Herman (1973) stated that as densities increase, there is a decrease in the number of flower clusters and fewer flowers per cluster. This contradicts findings in Tables 3 and 4. In this study, there was no significant interaction between nitrogen fertilizer and spacing on the number of trusses.

The number of trusses determines the total fruit yields in tomato. Many trusses are set but an average of five trusses produces high yields. The other trusses set fruits, which are very small and most of them abort or others just set flowers on which no fruit is produced. This could be caused by the apex, which appears to be a stronger sink than an initiating inflorescence and when the supply of assimilates is inadequate, the inflorescence only obtains assimilates after the demands of the apex have been met.

Under such conditions, where the apex is a stronger sink than an initiating inflorescence, the inflorescence may abort, while the growth of young leaves continues (Ho and Hewitt, 1986). In addition, Ho (1980) stated that fruits become very small due to competition between trusses. When assimilate supply is limiting, growth of a fruiting truss suppresses flowering of later trusses, resulting in poor growth of distal fruits due to vigorous growth of proximal fruits, which develop earlier. The final size of fruits is related to their positions on the truss and on the plant with the largest size being at the proximal position of the truss and lower parts of the plant. Therefore during rapid growth, both the rates of maximal growth and starch accumulation of proximal fruits are higher than those of distal fruits.

4.3. Effect of Nitrogen Levels and Spacing on the Number of Days to First Flowering and Early Yields

Nitrogen levels did not significantly affect the number of days to first flowering after transplanting and the early yields and spacing in season 1 (Tables 5 and 6). Spacing significantly affected flowering, with plants spaced at 40 x 30 and 50 x 40 cm taking longer to flower (13 days) in season 2 (Table 7).

Table 5. Effect of nitrogen (N) levels and spacing (S) on days to first flowering during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	12*	11	11	12	12
40x40	11	12	11	11	11
50x30	10	11	12	13	12
50x40	13	13	12	12	13
N Means	12	12	12	12	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

Table 6. Effect of nitrogen (N) levels and spacing (S) on early yields in kilograms per plot the first 2 weeks after production during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	18*	27	18	16	20
40x40	23	23	31	19	24
50x30	21	18	25	16	20
50x40	19	18	19	14	18
N Means	20	22	24	16	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

Table 7. Effect of nitrogen (N) levels and spacing (S) on days to first flowering during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	13*	13	14	14	14a**
40x40	11	11	13	12	12c
50x30	12	13	12	12	12c
50x40	13	13	13	13	13b
N Means	12	13	13	13	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 8. Effect of nitrogen (N) levels and spacing (S) on early yields in kilograms per plot the first 2 weeks after production during season 2 (March2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	13*	7	6	15	10
40x40	19	19	23	30	23
50x30	18	9	7	23	14
50x40	10	16	14	10	13
N Means	15	13	13	20	

* Values not followed by a letter are not significantly different according to F-Test at $P \leq 0.05$.

Kinet (1977) stated that increasing light intensity reduces the number of leaves below the inflorescence and stimulates the rate of flower initiation, resulting in early flowering. Also, Calvert (1965) observed that the higher the temperature, the earlier the opening of flowers, provided that premature failure does not occur since abortion is triggered by high temperature and limiting irradiance. In season 1, solar radiation was high unlike the second season that was rainy and humid throughout the season.

Early yields were not affected by nitrogen levels and spacing (Tables 6 and 8). However, plants with wide spacing and high nitrogen level, early yields were reduced during season 1. This could also be attributed to high level of nitrogen encouraging vegetative growth at the expense of the fruit development. These observations are in disagreement with Takahashi et al. (1973), who reported that flowering was delayed when N, P and K were in short supply. Also, Fisher (1969) observed no effect of nitrogen on flowering in plants grown at low irradiances and at a minimum air temperature of 15.5°C. In addition, Nicklow and Downes (1971) observed that both pre-planting and supplementary dressings of nitrogen reduced fruit size and delayed ripening of tomatoes grown for 'once over' harvesting. Austin and Dunton (1970) observed that nitrogen delayed timing of earliest maximum yields, and that in wide spacing, maximum yields of marketable fruits from plants spaced 90 cm apart in dual rows was 8 days earlier than from plants spaced at 45 cm in single rows.

4.4. Effect of Nitrogen Levels and Spacing on Yields

Tomato production is adversely affected by both fertility and spacing. Low and high nitrogen levels affect many attributes in tomato quality and yield. Austin and Dunton (1970) showed that close spacing and high fertility levels are required to increase total yields and number of fruits per plant. Kays and Nicklow (1974) stated that the common characteristic of changes in cultural techniques for many agronomic crops has been the use of higher plant densities. The impetus for this change has been largely economic as in the case of tomato.

4.4.1. Fruit Numbers

The yields were seriously affected by bacterial wilt and the prevailing weather conditions during season 2. This resulted in low yields in season 2, compared to season 1 (Tables 9 and 10).

Table 9. Effect of nitrogen (N) levels and spacing (S) on fruit number per hectare ('000') during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	687.0*	937.0	845.0	807.0	819.0ab**
40x40	602.0	870.0	819.0	727.0	754.0b
50x30	966.0	817.0	896.0	985.0	866.0a
50x40	612.0	659.0	619.0	711.0	650.0c
N Means	667.0	821.0	795.0	807.0	

*Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 10. Effect of nitrogen (N) levels and spacing (S) on fruit number per hectare ('000') during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	766	796	907	716	796
40x40	605	622	710	669	652
50x30	634	687	790	876	747
50x40	505	508	715	613	585
N Means	628b**	653b	780a	718ab	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

**Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiples Range Test.

There was no significant effect of nitrogen levels on the fruit numbers in season 1. However, there was a significant difference in tomato fruit numbers due to spacing (Table 9). In addition, there was significant effect of nitrogen levels on the tomato fruit numbers in season 2. In current study, 40 kg ha⁻¹ and spacing of 50 x 30 cm had more fruit numbers in season 1 (Table 9), while 80 kg ha⁻¹ and Spacing of 40 x 30 cm had more fruit numbers in season 2 (Table 10).

Wide spacing resulted in fewer fruits when compared to close spacing. Close spacing had the highest fruit numbers due to the large number of plants per unit area compared to wide spacing (Tables 9 and 10) in both seasons. This is consistent with the findings by Mohamed and Zeineb (1988), who observed that reduction in row spacing ranging from 60 to 40 cm resulted in a total yield increase of 24%. Further reduction in spacing from 60 to 20 cm resulted in a total yield increase of 43%. These results were contrary to observations reported by Vittum and Tapley (1953), who reported that as plant densities increased above 19000 plants per hectare, yield per plant, fruit size, and number of fruits per plant decreased. Also Fery and Janick (1970) reported that the increased yields obtained with higher plant populations were primarily a function of the increased number of fruits produced per unit area. There were no significant interactions between nitrogen levels and plant spacing in the current study.

4.4.2. Marketable Tomato Fruit Numbers

Results (Tables 11 and 12) indicate that nitrogen had no significant effect on marketable fruits in both seasons, whereas spacing significantly affected the number of marketable fruits in both seasons.

Table 11. Effect of nitrogen (N) levels and spacing (S) on number of marketable fruits ('000') per hectare during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	459.0*	610.0	554.0	465.0	522.0a**
40x40	418.0	649.0	617.0	480.0	541.0a
50x30	489.0	507.0	596.0	610.0	551.0a
50x40	419.0	430.0	427.0	418.0	437.0b
N Means	446.0	549.0	549.0	507.0	

* Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$.

** Values not followed by the same letter within a letter series are not significantly different at $P \leq 0.05$ according to the Duncan's Multiple Range Test.

Table 12. Effect of nitrogen (N) levels and spacing (S) on number of marketable fruits ('000') per hectare during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	588*	567	684	526	591.0a**
40x40	448	470	510	518	487.0ab
50x30	496	562	556	593	552.0ab
50x40	406	360	518	430	428.0b
N Means	484.	490	567	517	

* Values not followed by a letter are not significantly different according to f-test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan multiple Range test.

Spacing of 50 x 30 cm had the highest significant number of marketable fruits in season 1, while spacing of 40 x 30 cm had the highest number of marketable fruits in season 2 (Tables 11 and 12).

Spacing of 50 x 40 cm in both seasons had the lowest number of marketable fruits, which could be attributed to the few fruits produced due to few fruit bearing stems produced per unit area. As plant density increased, yields per unit area increased asymptotically. This is evidence in that the total yields were highest in close spacing but the numbers of marketable yields were not as high compared to wide spacing. This is in agreement with West and Pierce (1988) who showed that total season yields increased as plant population increased to an optimum level (20,000 plants). They pointed out that increases in density generally increase both early and total yields per hectare. In addition, Vittum and Tapley (1953) found that as densities increased, fruit size decreased and hence, the small fruit size due to close spacing was due to the reductions in the number of clusters per plant, flowers per cluster, and fruit set. Plant competition caused by population pressure resulting in rapid decrease in size at high densities, could have contributed to low marketable fruits per hectare (Frost and Kretchman, 1988). This is consistent with the observations made by Austin and Dunton (1970) who reported that the size of tomato was influenced by plant population, but not by fertilizer treatment.

The higher plant population led to competition for finite factors like oxygen, light, water and nutrients (Bleasdale, 1966). Fruit size decreases with successive harvesting, and hence decreased the marketable number of fruits. This could be probably due to the deterioration of the earlier-formed fruits and ripening of later-formed fruits, which are typically smaller. When plants are spaced closely, the number of unmarketable fruits increases, decreasing the number of marketable fruits in successive harvests. The number of fruits per plant and the fruit weight increased with increasing spacing while the total production per hectare decreased. There was no significant interaction between nitrogen fertilizer and spacing on the marketable fruits.

4.4.3. Fruit Weight

Yields are very important in determining the economic yield potential of a unit area. This is the objective way of determining productivity of a given area. Nitrogen levels and spacing significantly affected fruit weight with lack of nitrogen and spacing of 50 x 40 cm having low yields in season 1, but there was no significant effect of nitrogen levels and spacing during season 2 (Table 13 and 14).

Table 13. Effect of nitrogen (N) levels and spacing (S) on yields (MT ha⁻¹) per hectare during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	37.8*	54.3	49.5	44.1	46.4e**
40x40	33.3	52.0	51.8	44.9	45.5ef
50x30	35.4	47.2	56.6	57.7	49.2e
50x40	38.5	42.2	38.9	42.9	40.6f
N Means	36.2b**	48.9a	49.2a	47.4a	

* Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 14. Effect on nitrogen levels and spacing on yields (MT ha⁻¹) per hectare during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				Spacing means
	0	40	80	120	
40x30	48.2*	43.7	58.3	39.2	47.4
40x40	41.6	35.6	38.7	40.7	39.2
50x30	44.1	45.6	44.7	51.2	46.4
50x40	37.9	30.7	45.1	33.4	36.7
Means	43.0*	38.9	46.7	41.1	

* Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$

In both seasons, closely spaced plots had numerically higher total yields. These findings were similar to observations by Zahara and Herman (1973) who stated that an increase in plant density often results in an increase in marketable fruits per hectare, and hence, these could have increased the yields. Currence (1941) and Reeve et al., (1962) found that total yields were highest for close spacing compared to wide spacing. This probably resulted in an increase in fruit yields per hectare and not the unit fruit weight.

Lack of nitrogen resulted in low yield during season 1 (Table 13). The plants without nitrogen lacked vigor. Rajagopal and Rao (1974) reported that nitrogen deficient plants had lower levels of endogenous auxins and reduced gibberellin activity resulting in low weight.

The levels of growth inhibitors are higher in nitrogen-deficient plants. Usually, nitrogen deficiency results in high rates of flower drop, especially, at high temperatures (Abdalla and Verkerk, 1970). This probably contributed to the low yields in nitrogen deficient plants in the current study. Also Mohammed and Zeineb (1988) reported that nitrogen fertilizer on tomatoes in the Sudan increased yields, but the increase in yield was limited mainly to the lowest application rate. Austin and Dunton (1970) observed no difference in the total weight of fruit among the nitrogen levels and spacing treatments. In this study, there was no interaction between nitrogen levels and spacing on yields.

4.4.4. Yields of Marketable Fruits

Nitrogen levels had no significant influence on marketable fruit yields in both seasons. In season 1, spacing of 50 x 30 cm had the highest marketable fruit yields of 41.6 metric tones (MT) followed by 40 x 40 cm with 38.9 MT, (Tables 15 and 16).

Table 15. Effect of nitrogen (N) levels and spacing (S) on yields of marketable fruits (MT ha⁻¹) (season 1, October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	31.0*	43.7	40.8	33.9	37.4ab**
40x40	27.1	45.8	45.8	36.6	38.9ab
50x30	35.7	38.7	45.9	46.1	41.6a
50x40	33.1	35.0	32.7	36.0	34.2b
N Means	31.8	40.8	41.3	38.2	

*Values not followed by a letter are not significantly different according to the F- Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 16. Effect of nitrogen (N) levels and spacing (S) on yields of marketable fruits (MT ha⁻¹) during season 2 (March 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	43.2*	38.9	53.6	34.7	42.6
40x40	37.2	32.0	33.6	37.0	34.9
50x30	39.5	41.2	38.9	44.0	40.9
50x40	34.6	27.5	39.4	28.0	32.9
N Means	38.6*	34.9	41.4	35.9	

* Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$.

Widest intra-plant spacing of 50 x 40 cm had the lowest marketable yields but equal to 40 x 40 cm in both seasons. This result could be attributed to the few fruit bearing plants resulting in few fruits per area. This could be attributed to the plant arrangement. Spacing did not significantly affect marketable fruit yields during season 2. In season 2, wide-spaced plots produced low marketable yields, which worsened when plants were infected with bacterial wilt that further reduced both the total and marketable yields. This observation disagreed with Bleasdale (1965) who found that maximum yields result when plants are arranged equidistant from each other unlike in the current study, where rectangular arrangement yielded higher than the square arrangement in both seasons (Tables 15 and 16). Mack and Varseveld (1982) also reported that yields of plants in square arrangements are higher than in row plantings, and the yield is greater for high population than for low populations. Mohammed and Zeineb (1988) observed that in-row spacing had no effect on marketable yield presented as percentage weight of total yield.

4.5. Effect of Nitrogen levels and Spacing on Unit Fruit Weight

Nitrogen levels did not significantly affect the unit fruit weight in both seasons (Tables 17 and 18). However, spacing significantly affected the total unit fruit weight in season 1, with wide-spacing having the highest unit fruit weight of 62.8 g, although there was no significant differences between 40 x 40, 50 x 30 and 50 x 40 cm. Close spacing had the lowest unit fruit weight but there was no significant difference between 40 x 30, 40 x 40 and 50 x30 cm in season 1(Table 17). There was no significant effect of nitrogen levels and spacing on unit fruit weight in season 2 (Table 18). This observation can be attributed to the damage caused by the bacterial wilt in some of the plots leading to a reduction in both the fruit numbers and the total yields.

In season 2, bacterial wilt led to the death of the whole plant. Spacing of 50x40 had the highest mean unit fruit weight of 62.8g compared to the rest in both seasons.

The higher unit fruit weight associated with wide spacing was in agreement with Locascio and Williams (1994) who observed that weight of fruits produced per plant was 30% higher with a 31 cm compared to 23 cm. In row plant spacing and yields per plant were not influenced by the nitrogen rate.

Zahara (1970) also stated that close spacing of determinate cultivars resulted in a reduction in weight of individual fruits. Vittum and Tapley (1953) also observed that increasing fertility reduced the average weight per fruit.

Table 17. Effect of nitrogen (N) levels and spacing (S) on unit fruit weight in grams (g) during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	56.3*	58.6	59.8	54.2	57.2b**
40x40	56.0	59.9	64.8	61.1	60.5ab
50x30	56.2	58.5	63.0	58.8	59.1ab
50x40	62.2	65.0	62.6	61.3	62.8a
N Means	57.7	60.5	62.6	58.9	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 18. Effect of nitrogen (N) levels and spacing (S) on unit fruit weight in grams (g) during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	62.6*	58.7	65.0	53.5	59.9
40x40	67.8	55.6	54.8	60.5	59.7
50x30	68.4	60.8	56.6	59.6	61.4
50x40	75.5	59.1	63.1	53.5	62.8
N Means	68.6*	58.5	59.9	56.7	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

At higher nitrogen level, plants set many fruits per plant that the gross-drain of minerals and carbohydrates increased towards vegetative growth with low assimilates being directed towards fruits, resulting in smaller fruits with low unit weight.

4.6. Effect of Nitrogen levels and Spacing on Marketable Unit Fruit Weight

Nitrogen levels did not significantly affect the marketable unit fruit weight in both seasons (Tables 19 and 20).

Spacing did not significantly affect marketable fruit weight in season 2 (Table 20). However, wide spacing of 50 x 40 cm had the highest marketable unit fruit weight in both seasons, whereas marketable unit fruit weight of spacing 50 x 30, 40 x 40 and 40 x 30 cm decreased in that order as plant population increased due to inter plant competition in both seasons (Table 19 and 20).

Nitrogen levels and spacing had no significant effect on the marketable unit fruit weight in season 2, this could have been due to increased bacterial wilt infection, in some plots, which drastically reduced both the yield and the fruit numbers.

There was no interaction between nitrogen levels and spacing in both seasons, indicating that the treatment effect were additive and independent.

Table 19. Effect of nitrogen (N) levels and spacing (S) on marketable unit fruit weight in grams (g) during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	67.6*	71.9	73.9	72.0	71.4b**
40x40	66.0	70.4	76.9	75.6	72.2b
50x30	72.6	76.1	76.0	75.3	75.0ab
50x40	78.1	81.2	75.8	75.7	77.7a
N Means	71.1	74.9	75.6	74.7	

*Values not followed by a letter are not significantly different according to the F- Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 20. Effect of nitrogen (N) levels and spacing (S) on marketable unit fruit weight in grams (g) during season 2 (March 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	73.3*	73.7	69.3	63.1	69.8
40x40	79.5	65.4	71.0	70.4	71.6
50x30	79.1	65.1	71.5	73.4	72.5
50x40	85.1	68.6	79.3	64.2	74.3
N Means	79.3*	68.4	72.8	67.8	

*Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

4.7. Effect of Nitrogen Levels and Spacing on Fruit Quality

In this study, the quality parameters studied in relation to nitrogen levels and plant spacing included fruit size, fruit firmness and total soluble solids of tomatoes.

4.7.1. Effect of Nitrogen Levels and Spacing on Fruit Size

Among the factors affecting fruit appearance are colour, shape, defect and decay. While both nitrogen levels and plant spacing significantly influenced fruit size of tomatoes in season 1, spacing only had significant effect on fruit size in season 2 (Tables 21 and 22).

Table 21. Effect of nitrogen (N) levels and spacing (S) on fruit size (cm) during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	5.0*	5.3	5.2	4.9	5.1h**
40x40	5.5	5.9	6.1	5.7	5.8f
50x30	5.0	5.5	5.5	5.4	5.3g
50x40	6.1	6.2	6.4	5.9	6.1e
N Means	5.4b**	5.8a	5.8a	5.5b	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 22. Effect of nitrogen (N) levels and spacing (S) on fruit size (cm) during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	5.1*	5.3	5.2	5.1	5.2b**
40x40	6.2	6.7	6.7	6.4	6.5a
50x30	5.4	5.3	5.5	5.5	5.5b
50x40	6.4	7.1	6.6	6.5	6.7a
N Means	5.8	6.1	6.0	5.9	

* Values not followed by a letter are not significantly different according to the F-test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Spacing significantly affected fruit size, with the closest spaced plants having the smallest fruits, while the widest spaced plants had the largest fruits in both seasons (Tables 21 and 22). Spacing of 40 x 30 and 50 x 30 cm were not significantly different, and so were the spacing of 40 x 40 and 50 x 40 cm in season 2 (Table 22). Tomato plants in Season 2 had larger fruits than season 1. This was probably due to changes in climatic conditions during the experimentation period. The decrease in size due to close spacing was in agreement with observations by Moore et al. (1957) who reported that close spacing was accompanied by a reduction in fruit size. Studies by Fery and Janick (1970) indicated that increasing plant population in the field or greenhouse increased the early and total yields per unit area, but decreased the number of fruit set per plant and fruit size. Also Vittum and Tapley (1953) found that as densities increased, yield per plant, fruit size, and number of fruits per plant decreased. The decreases were likely due to the reductions in the number of clusters per plant, flowers per cluster, and fruit set. Plant competition is also influenced by population pressure resulting in rapid decreases in size at high densities (Frost and Kretchman, 1988).

Plots without nitrogen and those with the highest nitrogen level had the smallest fruit size (Tables 21 and 22). This was in agreement with Vittum and Tapley (1953), who observed that increasing the fertility level considerably reduced the average size per fruit. They suggested that at the high fertility level plants were able to set so many fruits per plant that the gross drain of minerals and carbohydrates was larger and resulted in smaller fruits. The decrease in fruit size was greater at low fertility level than at higher levels. The results from this study contradicted the report by Austin and Dunton (1970), who showed that size of fruits was influenced by plant population and harvest date, but not by fertilizer treatment. The higher plant

population produced smaller fruits with fruit size decreasing with successive harvests. This may be attributed to the competition for nutrients, light, water and oxygen.

4.7.2. Effect of Nitrogen Levels and Spacing on Fruit Firmness

One of the important parameters in tomato fruit quality is firmness, which is associated with the stage of ripeness. Firm fruits are most suited for fresh market shipping, and show less damage during mechanical harvesting. Firmness affects susceptibility of tomatoes to physical damage and consequently their shipping ability (Grierson and Kader, 1986).

Nitrogen levels and spacing significantly influenced fruit firmness with high nitrogen levels reducing and close spacing of 40 x 30 cm and 50 x 30 cm, increasing fruit firmness in season 1 (Table 23). High nitrogen levels reduced fruit firmness in season 2 (Table 24). Spacing did not significantly influence firmness in season 2 due to humid conditions during the growth period. Wide-spaced plots were less firm compared to those from close-spaced plots. All the levels of nitrogen significantly influenced fruit firmness with increase in nitrogen application greatly reducing fruit firmness in both seasons (Tables 23 and 24).

Table 23. Effect of nitrogen (N) levels and spacing (S) on fruit firmness (kg m⁻²) during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	2.3*	2.1	1.8	1.1	1.8g**
40x40	2.0	1.5	1.2	1.0	1.4h
50x30	2.2	1.9	1.5	1.2	1.7g
50x40	2.1	1.7	1.4	0.9	1.5h
N Means	2.1a**	1.8b	1.5c	1.0d	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 24. Effect of nitrogen (N) levels and spacing (S) on fruit firmness (kg m⁻²) during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	2.3*	1.8	1.7	1.3	1.8
40x40	2.4	2.0	2.0	1.5	2.0
50x30	2.2	2.3	2.0	1.5	2.0
50x40	2.5	2.0	2.2	1.8	2.1
N Means	2.4a**	2.1b	2.0b	1.5c	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test

High nitrogen level greatly reduced fruit firmness. These results agreed with the studies on canning tomatoes by Moore et al. (1957) where firmness was reduced by fertilizer applications. High N, P, and K reduced firmness of canning tomatoes. In addition, Garrison et al. (1967) observed that adequate (73 kg ha^{-1}) nitrogen improved fruit quality by prolonging shelf life, increasing fruit size, colour and taste. Excess nitrogen (110 kg ha^{-1}) decreases fruit size, keeping quality, colour and taste. This was in agreement with the findings from the current study where less firm fruits were observed under high nitrogen level (120 kg ha^{-1}). Spacing did not significantly affect fruit firmness in season 2. However, fruits from wide-spaced plots were significantly less firm compared to those from close-spaced plots in season 1. There was no significant interaction between nitrogen fertilizer and spacing on fruit firmness.

4.7.3. Effects of Nitrogen Levels and Spacing on Total Soluble Solids

While nitrogen levels and plant spacing significantly influenced total soluble solids (TSS) in season 1 (Table 25), only nitrogen significantly influenced TSS in season 2 (Table 26). Spacing of 40×40 and 50×40 gave the highest total soluble solids in season 1, but there was no significant effect of spacing on the total soluble solids in season 2. This could be due to increased solar radiation during season 1, that increased the respiration rate of the tomato fruits, resulting in degradation of starch and production of glucose and fructose contributing to high sugar content of the fruits (Thompson, 1996). Where plants were closely spaced, fruit shading occurred, resulting in low respiration rates and slowed ripening reducing TSS. All Nitrogen levels resulted in significantly higher TSS in both seasons compared to control (Tables 25 and 26).

In addition, closer plant spacing influenced the TSS levels, with closer spacing decreasing the TSS in season 1. This is in agreement with observations of Emery and Munger (1970), where closer spacing in the row decreased both fruit size and total soluble solids content. When yields per plant are low genetic potential for high total solids can be realized. However, when yields are high it is difficult to realize this potential (Rick and Stevens, 1986).

Table 25. Effect of nitrogen (N) levels and spacing (S) on total soluble solids (TSS) during season 1 (October, 2002)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	3.7*	4.0	4.2	4.1	4.0f**
40x40	3.9	4.2	4.3	4.3	4.2e
50x30	3.7	4.0	4.1	4.0	4.0f
50x40	4.0	4.3	4.3	4.4	4.3e
N Means	3.8 b**	4.2a	4.2a	4.2 a	

* Means not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Means followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Table 26. Effect of nitrogen (N) levels and spacing (S) on fruit total soluble solids (TSS) during season 2 (March, 2003)

Spacing (Cm)	Nitrogen levels (kg ha ⁻¹)				S Means
	0	40	80	120	
40x30	4.0*	4.1	4.2	4.0	4.1
40x40	3.9	4.2	4.2	4.1	4.1
50x30	3.8	4.0	4.2	3.9	4.0
50x40	4.1	4.1	4.1	4.1	4.0
N Means	3.8b**	4.1a	4.2a	4.0a	

* Values not followed by a letter are not significantly different according to the F-Test at $P \leq 0.05$.

** Values followed by the same letter within a letter series are not significantly different at $P \leq 0.05$, according to the Duncan's Multiple Range Test.

Plant spacing in season 2 had no significant effect on total soluble solids. During season 2, the total soluble solids were lower than in season 1. This may be attributed to plant growth differences due to seasonal changes during the trial period. Solar radiation received during season 1 influenced the supply of leaf assimilates, because when solar radiation is high, both dry matter and sugar content of the fruit are at their highest (Ho and Hewitt, 1986).

Nonetheless, findings of Mohammed and Zeineb (1988) indicated that closer spacing had no effect on the soluble solids content of fresh tomato fruits. These findings were in agreement with the results reported by El-Hilo (1972) and Hassan (1978) but contrary to those reported by Fadl (1983) which indicated that closer spacing reduced soluble solids content of tomato fruits. In the current study, nitrogen levels applied had no significant influence on the total soluble solids. These findings were consistent with the results reported by Mohammed and Zeineb (1988) that soluble solids contents of fresh tomato fruits were not appreciably affected by nitrogen application. Garison et al., (1967) indicated that nitrogen tends to decrease the percent total soluble solids in the juice and increases titratable acidity. This study did not show any significant interaction between nitrogen levels and plant spacing on total soluble solids of fresh tomato fruits.

4.8. Effect of Nitrogen Levels and Spacing on Total Leaf Nitrogen Content of Leaves

In this study, total nitrogen content of old leaves showing signs of senescence were analyzed. Analysis of the older leaves reflects the overall nutritional history of the plant whereas the nutrient content of the younger leaves is for diagnostic test and relates to the nutrient supply that is currently available (Adams, 1986). The leaf nutrient contents are associated with growth. The content reduces as the number of

trusses increases. When a plant has 2 trusses the content is 4.8 and reduces to 3.1 as the plant reaches 12 trusses (Adams, 1986).

While nitrogen levels and spacing significantly influenced total nitrogen content of older leaves in season 1, there was no significant effect of spacing on total nitrogen content of leaves in season 2 (Table 27 and 28). There was no consistency with the spacing but the nitrogen levels showed a linear increment in total leaf nitrogen content as nitrogen level increased. The first season showed low total leaf nitrogen content when compared to season 2. This could be attributed to the differences in planting times and the prevailing weather conditions in both seasons. In season 1, there was no significant difference between nitrogen levels 40 and 80 kg ha⁻¹, but plots without nitrogen and those of 120 kg ha⁻¹ were significantly different (Table 27). In second season, 80 and 120 kg N ha⁻¹ were not significantly different (Table 28). In season 1, spacing of 40 x 30, 50 x 30 and 50 x 40 cm had a similar effect on the total leaf nitrogen but, 40 x 40 cm gave the highest total leaf nitrogen levels (Table 27).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, the following conclusions are made:

1. Heavy application of nitrogen beyond 80 kg ha⁻¹ does not necessarily increase yields of tomatoes under greenhouse conditions at high altitude in Kenya. Farmers could, therefore, save some nitrogen fertilizer by applying lower rates than 80 kg N ha⁻¹ without adversely affecting yields.
2. Close spacing produces high yields, but many fruits are small and the unit fruit weight decreases.
3. Wide spacing of 50 x 40 cm leads to low yields due to low plant population per unit area, but fruit quality is improved as size is bigger and unit fruit weight is higher.
4. Heavy application of nitrogen (120 kg ha⁻¹) reduces the number of total and marketable fruits per hectare.
5. Heavy application of nitrogen (120 kg ha⁻¹) reduces fruit size and the fruit firmness.
6. Low nitrogen levels reduce fruit total soluble solids.

The following recommendations can be made based on this study:

1. Nitrogen levels between 40 and 80 kg N ha⁻¹ should be applied under greenhouse tomato production.
2. Spacing of 50 x 30 cm should be adopted as it gives high yields and firm fruits.
3. Further, studies are needed to investigate a wide range of plant populations involving different cultivars of tomato.

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