UNIVERSITY OF
KWAZULU-NATAL

ASPECTS OF IMPROVING COLD HARDINESS OF TOMATO (*LYCOPERSICON ESCULENTUM*) VAR. ROSSOL

by

AMANUEL GHEBREHIWET GHEBRETINSAE

(BSC AGRIC., ASMARA, ERITREA)

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE
(HORTICULTURE)

in the

School of Agricultural Sciences and Agribusiness

Faculty of Science and Agriculture

University of KwaZulu-Natal

Pietermaritzburg

KwaZulu-Natal

JUNE 2004

DECLARATION

I hereby certify that the research work reported in this dissertation is the result of my own investigation, except where acknowledged.

Signed: ________________________

Amanuel G. Ghebretinsae

I certify that the above statement is correct.

Signed: ________________________

Dr. I. Bertling (Supervisor)

Signed: J Bower.

Prof. J. Bower (Cosupervisor)

ACKNOWLEDGEMENTS

There are many people who deserve formal recognition for the help and support I have received throughout my studentship at the University of Natal/KwaZulu Natal.

Firstly, I extend a special thank you to my supervisor, Dr. Isa Bertling, who mentored me throughout the project time. During my studies, the door to Isa's office was always open, and she readily stopped what she was working on to answer my sometimes inane questions, and gave me invaluable help and direction whenever I felt I needed it. For this I am very grateful.

A great deal of thanks must also go to Renate Oberholster, for help with the spectrophotometry work, Teri Dennison, for help in the laboratory, Julius Ochuodho, for help with statistical part of the work, Prof. John Bower and Prof. P. Greenfield, for their advises during earlier stages of my studies, Bob Maloji Kalala, Biniam Ghebreslassie and Dawit Teferi for assistance with laboratory techniques. I also thank the technical staff of the horticultural department for assistance during the fieldwork part of the study.

Eden Tesfu, who knows my dark self-doubts and my pitiful hunger for encouragement, and also knows when things go wrong, never let her love dampen her aspirations for a bit more elegance; I thank her very much.

To the people who have made significant investments and immeasurable contributions to my life: My mum Maasho W. Gebriel, my dad Ghebrehiwet Ghebretinsae and my brothers and sisters, I here give a special thank you.

Finally, I thank the Lord for giving me the desire, the dream and the faith to keep my hope for the thesis alive until the day of its appearance.

ABSTRACT

Tomatoes, particularly those of the determinate type, are one of the most popular vegetables in the East African country Eritrea. The crop is a source of income to small farm operators as well as commercial growers, and plays an important role in the nutritional supply of the population. Nonetheless, tomato production is limited during the cool season resulting - on the one hand - in a reduced nutritional supply during this period and - on the other hand - in an increased economic potential of the crop. Although performance of tomato plants under low temperature conditions is genetically influenced, prevailing temperatures as well as management practices also affect growth and development. In order to understand the long-term effects of a cold spell on tomato plants, experiments were carried out to determine the effect of a cold spell on plant vegetative and reproductive characteristics of determinate type "Rossol" tomatoes. Plants were moved for two to five subsequent nights from a tunnel to a cold room (4°C). The fruit set stage of "Rossol" tomatoes was found to be most sensitive to cold temperature, followed by the flowering stage. The juvenile stage was, of all the developmental stages examined, the least sensitive to cold. Furthermore, subjecting tomato plants for five subsequent nights (cumulative 60hrs) to 4°C resulted in a significant retardation of growth and development and in yield reduction. However, tomatoes exposed to a two-night cold spell during either the vegetative or the flowering stage recovered quickly and, ultimately, performed well.

Furthermore, trials were carried out under tunnel and field conditions to investigate the impact of potassium application as well as mulching on cold tolerance of "Rossol" tomatoes. Under low temperature conditions, increasing the level of potassium to up to 150% of the recommended level ($157.5\text{kg}*\text{ha}^{-1}$) resulted in quicker ontogenetic development and increased yields significantly.

On the other hand, supplying tomato plants with 50% and 200% of the recommended potassium level reduced growth, delayed development and decreased yield and yield attributes.

Using black plastic mulch also increased plant growth and speeded up plant development. Maize stover mulch, however, retarded plant growth and development so that certain stages of the phenological cycle were reached later than by non-mulched plants. However, yield and yield attributes increased significantly using stover mulch.

Therefore, the management practises potassium fertilization and mulching provide excellent tools to increase the tolerance of tomato plants to low temperature conditions. Furthermore, organic mulches can be used to delay crop development and time maturity to achieve high retail process of the commodity in the cool winter months.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF ABBREVIATIONS

DW	dry weight
FW	fresh weight
FERTREC	Cedara fertilization recommendation system
K	potassium
RKL	FERTREC recommended soil potassium level
K1	50% of the FERTREC recommended soil potassium level
K2	100% of the FERTREC recommended soil potassium level
K3	150% of the FERTREC recommended soil potassium level
K4	200% of the FERTREC recommended soil potassium level
S1	growing medium consisting of clay: sand (2:1) mixture
S2	growing medium consisting of sand: composted pine bark (4:1) mixture
B	black plastic mulch
M	maize stover mulch
U	control
MeOH	methanol

CHAPTER ONE

GENERAL INTRODUCTION

1.1 HISTORICAL BACKGROUND OF TOMATO PRODUCTION

The tomato (*Lycopersicon esculentum* Mill.), a member of the solanaceous crops, originated in the western coastal plains of South America, which extend from Ecuador to Chile (Kinet and Peet, 1997). From there the species spread, as a weed, throughout the continent and into Central America (Darby, 1973). Particularly in the arid deserts of South and Central America, which extend from near the equator to approximately 30° South, "wild" tomatoes and related species (Yamaguchi, 1983) are still widespread.

Although it is certain that the origin of *Lycopersicon esculentum* was South America, the tomato was probably first cultivated and plants selected, based on fruit size, in Mexico (Jones, 1996). The introduction of the crop into Europe appears to have occurred from Mexico. In Europe, the tomato first had a reputation of being "dangerous food" because of its relationship to other poisonous solanaceous species such as belladonna (*Atropa belladonna*) and mandrake (*Podophyllum peltatum*) (Rubatzky and Yamaguchi, 1997). Following its introduction to Europe and finally its acceptance, tomato cultivation spread quickly throughout the world.

Despite originating in an area with non-seasonal climate, the tomato grows well under a wide range of conditions throughout the world (Mills, 1990). Tomatoes can be grown from near the arctic circle (under protection) to the equator (Yamaguchi, 1983). Exceptions to this general distribution pattern occur where soils have poor drainage as well as under inadequate or excessive solar irradiance, extreme temperatures and where nutritional and water problems prevail (Rick, 1978).

1.2 WORLD TOMATO PRODUCTION

Tomato is, after potato, the most widely grown solanaceous vegetable crop. Fresh market and processing tomatoes are produced worldwide on approximately 3.7 million ha with a yearly worldwide production of about 107 million tons (FAO, 2002). Worldwide tomato production has been increasing from year to year due to the use of modern cultivars and improved cultural practices. In 2002, world tomato production exceeded that of bananas, oranges and grapes (FAO, 2002). The main production regions are located in temperate zones, close to the 40th parallels to the equator North and South (Fig. 1). However, most of this production is based in the Northern hemisphere, where 91% of the world's crop is produced between July and December (FAO, 2002). The remaining 9% are produced in the Southern hemisphere between January and June. Brazil is an exception, being the only country of the Southern hemisphere to process more than one million tons per year at the same time as the Northern hemisphere.

Despite the fact that many countries have a tomato growing and processing industry, the production is strongly concentrated in eight countries producing almost 80% of the world's crop.

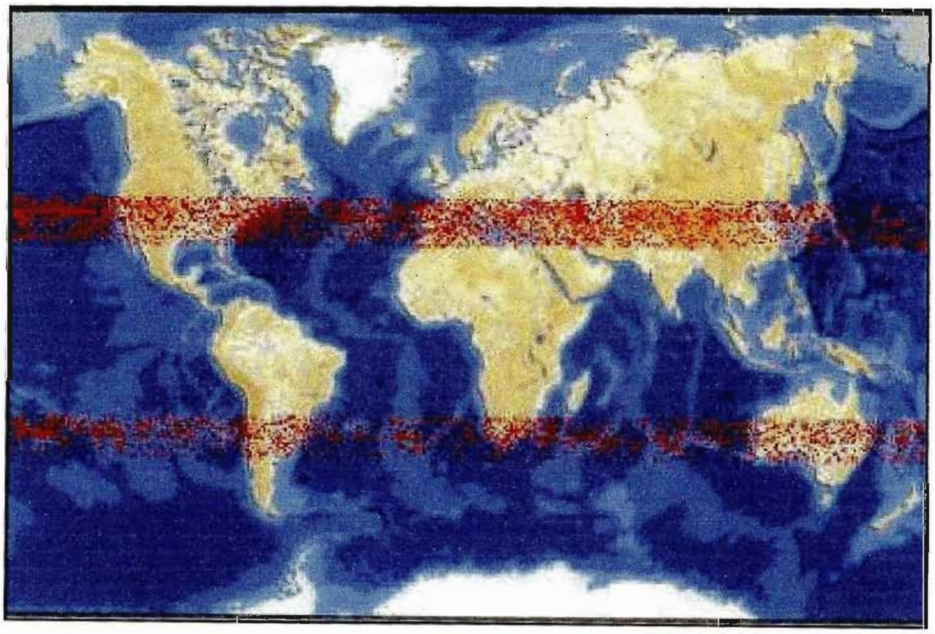


Fig. 1 Main tomato production regions of the world (area close to 40° N and 40° S of Equator as indicated by red colour) (Ahmed, 2000).

Average production figures of these eight countries were, between 1999 and 2001: USA- 9.42 million tons, Italy- 4.87 million tons, Spain- 1.43 million tons, Turkey- 1.33 million tons, China- 1.2 million tons, Brazil- 1.16 million tons, Greece- 1.08 million tons and Portugal- 923,000 tons (FAO, 2002).

1.3 TOMATO PRODUCTION IN ERITREA

A central highland divides Eritrea, a country located in the north-eastern part of Africa, between its eastern and western lowlands. Altitudes vary from 3000 m above sea level in the highlands to below sea level in the eastern lowlands. The highlands have a very rugged topography, and suitable land for annual cultivation is limited to some of its valley bottoms.

Tomato is a popular vegetable in Eritrea and a source of income to small farm operators as well as commercial growers. It also contributes to the nutrition of the Eritrean population. It is one of the "priority crops" according to the Eritrean Ministry of Agriculture production plan and is produced approximately on 20% of the irrigated land, the bulk of which is in the highlands (FAO, 1995). However, the supply of this crop during the cool season and, hence, the contribution to Eritrean nutrition, is limited. Because of the limited supply during this period, the price of the commodity is high and, hence, the economic potential increases during this season. In Asmara, a highland city and the Eritrean capital, farm gate prices reach up to 500 USD/t during this period (Ahmed, 2000).

During the cool season in the highlands, low temperatures cause lower yields – mainly due to improper ovary development, malformation of flowers and production of unviable pollen (Rylski and Aloni, 1994). Furthermore, low temperatures affect basic physiological processes such as photosynthesis, transpiration, nutrient and carbohydrate translocation and ion uptake. Low temperatures affect not only yield but also product quality during the development of the crop (Atherton and Harris, 1986).

Meteorological data show that the highlands of Eritrea experience a cool-season period during October, November, December and January (Ahmed, 2000). The temperatures during these months range between seven (minimum mean daily temperature) and 16°C (maximum mean daily temperature).

1.4 TOMATO PLANT FORM AND CULTURE

1.4.1 TOMATO PLANT FORMS

Cultivated tomatoes can be divided into two basic types, indeterminate and determinate (bushy type). However, semi-determinate types also exist. Determinate tomatoes have one, time-limited, flowering period followed by a period of fruit development. The terminal buds form a flower, restricting further plant growth. Generally, determinate tomatoes require three to four months from the time of seeding to produce the first fruit, after which the plant may continue producing fruit for several months (Mills, 1990). This type of tomato is the commonly grown one in the highlands of Eritrea. Indeterminate tomatoes, however, are mostly trained to maintain a single stem with all side shoots removed (Jones, 1996) and produce inflorescence and flowers continuously throughout their cultivation period (Kinet and Peet, 1997). Hence, they usually produce fruit throughout the entire season. Fruits from indeterminate plants are usually softer and have higher gel content and thinner walls than determinate types. Determinate cultivars display a shorter harvesting period than indeterminate ones and are especially desirable where the growing season is short. Indeterminate plants are used for long-season production because they produce fruit over an extended period of time, if properly maintained (Jones, 1996). Semi-determinate, as the name implies, have characteristics of both, the determinate and indeterminate types.

1.4.2 CULTURE

1.4.2.1 TEMPERATURE

A certain range of temperatures is essential for the metabolic and cellular functions of a tomato plant. The vegetative and reproductive responses of tomato plants are strongly modified by either temperature alone or temperature in conjunction with other environmental factors, such as light, atmospheric gas composition, availability of mineral nutrients and moisture (Aung, 1979).

Tomato is, as a warm-season crop, reasonably resistant to heat and drought. It can be grown in most open, frost-free areas with an average daily temperature above 16°C during the growing period (Calvert, 1959). The crop may not tolerate low temperatures (less than 10°C) (Madhavi and Salunke, 1998), but is hardier than peppers and eggplants (Descomps and Derosche, 1973). Generally, temperatures ranging between 18 and 24°C during the day and 15 and 20°C during the night are best for tomato production (Mills, 1990). A wide diurnal amplitude (between 5 and 10°C) is necessary as it improves flowering, fruit growth and fruit quality (Hussey, 1963a).

It is important to distinguish between air temperature and plant (leaf) temperature, as these may differ due to several environmental factors (Mills, 1990). For example, solar radiation increases leaf temperature more than air temperature, while at night radiation from the plants causes leaf temperatures to be lower than the surrounding air (Calvert, 1973a).

1.4.2.2 MOISTURE

Tomato plants grow best when provided with uniform moisture and good drainage. The plant needs plenty of water but not excess because tomato roots will not function under waterlogged conditions (Jones, 1996). Furthermore, excessive moisture is often conducive to damping-off and root rot diseases (Askew, 1996). Conversely, insufficient water at any growth stage reduces yield and fruit quality. Tomato is most sensitive to water deficit during flowering, somewhat sensitive immediately after transplanting and during fruit development, and least sensitive during vegetative growth (Rick, 1978). Under conditions in the highlands of Eritrea, weekly irrigation for the first month after transplanting followed by a ten-day irrigation interval until crop completion is recommended (Ahmed, 2000). The root zone of young transplants is shallow, so irrigation should be frequent and should allow recharging the root zone with water. As the crop develops, the root zone enlarges and less frequent but heavier irrigation is required. Tomato plants are sensitive to waterlogging and flooded fields should be drained within one to three days (Jones, 1996).

1.4.2.3 PLANT NUTRITION

Tomato plants have strict requirements for balanced fertilization, without which growth and development of the crop is poor and the harvested product has low external quality lacking good colour and shape. The internal quality is also poor which is manifested in the development of physiological disorders. A soil rich in nutrients and organic matter is ideal for tomato plant growth. Rich sandy loams or loamy soils are, therefore, best for tomato production (Rubatzky and Yamaguchi, 1997) as they have a greater water-holding capacity than sandy soils and yet provide higher organic matter than soils with high clay content. The ideal soil pH should be close to neutral but never below 6.0 or above 7.0 (Gould, 1974). Tomato is a heavy nutrient remover; high yields and good fruit quality can only be sustained through the application of comparatively high doses of fertilizers in a balanced proportion (Pellett and Carter, 1981).

Fertilizer applications to tomatoes are determined by the agronomic response of the crop and the price relations between fertilizer prices and tomato fruit prices (Uexkull, 1979). The balance of the fertilizer, i.e., the relative content of nitrogen, phosphorous, potassium and other elements, has a considerable influence on the growth of the plant and the quality of the fruit. Nitrogen fertilization is very critical, especially with determinate types for "once over harvest". Kacar (1984) reported that nitrogen affects vegetative growth and fruit yield more than any other nutrients. Sufficient nitrogen application promotes early vegetative growth and early fruit development, and maintains plant vigour, as most parts of the plant dry matter consists of nitrogenous compounds (Aung, 1979). Sufficient phosphorous is important as it improves plant and fruit growth as well as yield, and final product quality. Phosphorous must be abundant in the growing medium, particularly where low temperatures are expected, because phosphorous uptake is decreased under these conditions as well as under insufficient light. If there is a shortage of phosphorous, the seedlings become purplish and root growth is affected negatively (Aung, 1979). Potassium also tends to improve tomato fruit quality and the plant's resistance to adverse environmental conditions (Uexkull, 1979). The balance between nitrogen and potassium is the establishing factor in determining the quality of growth. A high, unbalanced N: K ratio is associated with poor fruit set and poor carrying quality. According to Geraldson (1985), at the beginning of the season the N: K ratio must be 1:3 and then the ratio should be increased progressively to 1:1. The role of potassium in tomato plant development is discussed further in Chapter Two.

1.5 PROBLEM STATEMENT

Tomatoes, produced for either the fresh or the processing market, are required to have distinct quality characteristics. In order to achieve these, optimum growing temperatures are crucial. In areas where air temperature is below the optimum, soil medium with good temperature-retaining capacity, like sand mixed with composted pine bark (Savage, 1980), are preferred. In such areas, keeping the soil temperature relatively higher than the air temperature favours growth of the crop, especially during early crop development (Swaider *et al.*, 1992). Hurewitz and Janes (1983) found that an increase in plant growth associated with an increase in soil temperature might be the result of an effect on early growth and development of the plant. This, however, holds only true if the air temperature does not drop below the temperature the crop can tolerate. Swaider *et al.* (1992) stated that temperatures of 10°C and below are harmful to tomato production. Therefore, control of root zone temperature is as important as control of ambient temperature, since plant growth and development depends on a root zone temperature in the acceptable range.

Several management practices appear to be effective in maintaining a warmer soil/root zone temperature, both, in greenhouses as well as open fields. In the latter case, the use of variously coloured plastic mulches has become common practice in many countries as they can be used to decrease or increase soil/root temperature.

Another means to induce tomatoes and other vegetable crops to tolerate and grow at lower temperature conditions is by altering plant nutrition. Although results are conflicting, several workers have found a relationship between certain nutrient levels (N and K) and cold hardiness of crops (Bettie and Flint, 1973; Singh, 1980).

In Eritrea, studies are underway to find tomato cultivars that are resistant to the cool season period and to improve cultivation practices so that cultivars may tolerate the low temperature winter conditions and also yield sufficiently high quality produce. This study was intended to contribute to the search for appropriate management practices to improve cold tolerance of tomato.

1.6 OBJECTIVES

The aim of this research was, therefore, to determine the effects of cold temperature on yield and quality of "Rossol" tomatoes and to improve the performance of this crop under cold temperature conditions. With this in mind, the following aspects were studied:

- the effect of low temperature on various growth and development stages of "Rossol" tomatoes
- the effect of application of different potassium levels on cold tolerance of "Rossol" tomato
- the effect of different mulches on cold tolerance of "Rossol" tomato

CHAPTER TWO

EFFECTS OF LOW TEMPERATURE ON THE DURATION OF DEVELOPMENTAL STAGES OF *Lycopersicon esculentum* var. ROSSOL

2.1 INTRODUCTION

Tomatoes are classified as a warm-season crop, which requires a frost-free period from about 90 days - in some determinate cultivars - to over 130 days - in some indeterminate types (Swaider, 1992). Although plants can survive low temperatures - up to 0°C -, and sometimes even -1°C or -2°C, growth will be negatively affected if this exposure is prolonged. Smith and Millett (1964) reported that growth and development of tomatoes is severely restricted when the plants are exposed to 8°C for only two days. Longer exposure can injure and even kill tomato plants through various physiological dysfunctions (Chen and Li, 1980).

Temperatures lower than 10°C can injure many crops of tropical origin, including tomato (Raison, 1974). This injury, which occurs at temperatures above 0°C, is generally called chilling injury (Lyons, 1973). Chilling injury symptoms of tomatoes include, on the cellular basis, alterations in membrane structure (Lyons and Raison, 1970), metabolic modifications (Levitt, 1980), changes in enzyme activities (Byrd *et al.*, 1995; Kumar and Triphaty, 1998), impaired photosynthesis and respiration, and hormonal imbalances (Graham and Patterson, 1982).

When tomato and other chilling sensitive plants are kept under a relatively constant level of "chilling stress", the resulting injury is time-dependent, with changes in physiological activity preceding the development of visual symptoms of injury (Levitt, 1980). Although the physiological aberrations may be reversed if the exposure period was short, such as less than two days at 8°C (Smith and Millett, 1964), recovery in the "post-chilling period" is not immediate and depressed rates of plant growth are commonly noted (Chen and Li, 1980).

Symptoms of chilling injury in tomato plants vary between cultivars, tissue type, physiological age, and time of exposure to cold temperature as well as prevailing environmental conditions other than temperature (Hobson and Davies, 1971). Inherited plant factors (those that are genetically determined or passed from parent plants to offsprings) as well as environmental factors affect the duration of the developmental stages of tomatoes, and the susceptibility of the plant to chilling injury.

2.1.1 INHERITED PLANT FACTORS

2.1.1.1 CULTIVAR

Cultivars of processing tomatoes range widely in fruit shape, size, colour, plant type, disease and insect resistance, ripening time, processing characteristics and adaptation to adverse climatic conditions. Most of the modern processing cultivars, such as "Earliana", "Bonny Best", "Roma VF", "Marglobe", "Rossol", "Stone" and "Pink", are characterized by multiple resistances to various pathological diseases and pests (McGlasson, 1993) and adaptation to a wider range of climates (Kinet and Peet, 1997).

A number of cultivars bred for temperate climates have been introduced into Eritrea. Of these cultivars, "Roma VF", "Rossol", "Marglobe" and "Heinz 1370" show the best adaptation of the tested cultivars, especially to the highland areas (Ahmed, 2000). "Roma VF" is a luxuriant and strong grower. It has firm, large and fairly well-coloured fruit. The fruit matures slowly resulting in an extended harvesting period and high yield production. The plants are resistant to *Fusarium* wilt, but very susceptible to bacterial canker (Oosthuizen and Bosch, 1975). "Rossol" is a cultivar similar to "Roma VF", growing luxuriantly with a very sturdy growth habit and resistance to both *Fusarium* wilt and rootknot nematode (Oosthuizen and Bosch, 1975). This latter attribute is important as soil fumigation is an expensive operation and profits made from fresh market tomatoes are often marginal. Both, “Roma VF” and “Rossol”, are overwhelmingly dominant in the highlands of Eritrea due to being relatively tolerant of cooler growing conditions.

2.1.1.2 EFFECT OF ENVIRONMENTAL CONDITIONS ON TOMATO PLANT DEVELOPMENT AND GROWTH STAGES

Growth and development of cultivated tomato is restricted if the crop is subjected to adverse environmental conditions such as low temperature (Scott and Jones, 1996). The most sensitive developmental stages of tomato plants to such adverse environmental conditions are: seed germination, seedling establishment, juvenile vegetative growth, flowering and fruit set (Lyons, 1973). Although temperature is the most prominent and dominant environmental factor affecting tomato growth and development, other environmental factors such as radiation, humidity and water availability are also important as they can alter growth and development of the crop (Calvert, 1973a).

2.1.1.2.1 EFFECT OF ENVIRONMENTAL CONDITIONDS ON SEED GERMINATION

The tomato seed, three to five mm in diameter, has a silky appearance and contains a large coiled embryo surrounded by a small amount of endosperm (Jones, 1996). The first visible sign of germination is the appearance of the white radicle (Aung, 1979). As the radicle pushes downwards into the growing substrate, the hypocotyl takes on a hook-like form, known as the plumular hook, which grows to the soil surface, where, in response to light, it begins to straighten and turns green. When the seed is firmly anchored in the soil and the plumular hook is straightened, the cotyledons are pulled out of the seed coat, which remains in the soil.

Tomato seed germination occurs, provided the seed is supplied with adequate moisture, aeration and temperature (Smith and Millet, 1964). Temperatures that favour a high percentage of germination within a prescribed time differ between cultivars and between seedlots (Aung, 1979). Temperatures of 24°C on one hand (Brooks, 1969) and 18.5 to 21°C on the other (Mills, 1990) have been reported to be optimal for tomato germination.

According to Thompson (1974), many tomato cultivars germinate rapidly and maximally in the range of 21 to 25°C. Temperatures below and above this optimum retard the germination process, and extreme high and low temperatures are injurious not only to the germination process but also to subsequent plant development (Lewis, 1953). Cold stress affects seed germination in tomato by delaying the onset, reducing the rate and affecting the phases of germination, resulting in poor stand establishment and poor crop performance (Rubatzky and Yamaguchi, 1997).

Variations in cold tolerance of tomato during seed germination occur due to genetic differences of the plant material. Greater understanding of genotypic responses to temperature can be obtained from germinating seeds of various cultivars over a wide range of temperatures (Daie and Campbell, 1981). Under such conditions, criteria for the determination of cold tolerance during seed germination stage are: timing of appearance of physiological events at suboptimal temperatures, minimum germination temperature and germination rates at progressively lower temperatures (Thompson, 1974).

2.1.1.2.2 EFFECT OF ENVIRONMENTAL CONDITIONS ON SEEDLING GROWTH AND EARLY VEGETATIVE DEVELOPMENT

Once the tomato seedling has emerged from the soil, it is capable of continuous and uninterrupted growth until flowering. During this juvenile growth period, which lasts three to four weeks, the plant cannot be induced to flower. Specific environmental conditions are required for rapid seedling development and, subsequently, rapid juvenile vegetative development.

2.1.1.2.2.1 TEMPERATURE

Optimal seedling development and vegetative growth of tomato occurs when day temperatures are 18 to 25°C and night temperatures are about 15 to 18°C, even under low solar irradiance conditions (Calvert, 1973a; Picken *et al.*, 1984). Cotyledons are largest when seeds germinate at 15°C rather than 18.5 or 21°C day temperature, and at 12°C rather than 15 or 18°C of night temperature. Dry matter accumulation in the cotyledon is optimal at either 18 to 20°C day temperature or 12 to 15°C of night temperature, which is lower than the optimum day temperature (25°C) for shoot growth (Mills, 1990).

Internodal length of tomatoes can only be altered by changes in day temperature; but night temperatures do not alter internodal length and, hence, plant height. Lowering the day temperature and raising the night temperature, without altering the average 24 hour temperature, results in shorter tomato plants with an equal number of leaves and trusses (Hussey, 1969).

Night temperatures of 15 to 20°C, along with day temperatures of 20 to 25°C, affect the relative vegetative growth rate positively, possibly due to an increase in photosynthetic surface brought about by the stimulation of cotyledon expansion during the night (Kinet, 1977; Kinet and Peet, 1997). During the early growth phase of the seedling, high night temperatures accelerate cotyledon expansion during the night (Kinet, 1977). Plants with an enlarged cotyledon area accumulate more dry weight as a result of the increased photosynthetic surface area.

It has been long established that tomato plants suffer significant growth reduction if exposed to below optimal day and night temperatures (Bendix and Went, 1956). Low temperatures cause lower yields by negatively affecting the basic physiological processes of the plant such as photosynthesis, transpiration, translocation and ion uptake (Joe and Heins, 1978).

Calvert (1959, 1973a) reported that temperature conditions during young seedling development determine the number of leaves formed below the first inflorescence. Hussey (1965) has shown that the number of leaves formed between the cotyledons and the first inflorescence increases with increasing temperature.

2.1.1.2.2.2 RADIATION

Light is electromagnetic radiation characterized by its quality (wavelength) and intensity (amount of radiation emitted/received). No other physical factor regulates and stimulates the development of tomatoes as strongly as light. Radiation greatly affects the rate of seedling development and, later, vegetative growth. Tomato plants tend to be tall and thin if the solar irradiance is low. However, it has been observed that low irradiance affects vegetative growth to a lesser extent than reproductive growth (Hussey, 1963a).

Vegetative growth of tomato requires fluctuating environments. Continuous light has a number of injurious effects, inducing leaf chlorosis, hypertrophy of palisade cells, alterations of plastid ultrastructure, and starch grains disappearance (Descomps and Deroche, 1973). However, if diurnal temperatures fluctuate with sufficient amplitude, the detrimental influence of continuous light is suppressed (Hillman, 1956).

Solar irradiance also affects the number of leaves produced prior to the appearance of the first inflorescence. Low levels of irradiance induce higher numbers of flowers per plant (Calvert, 1973b). Increasing light intensity, however, reduces the number of leaves below the first inflorescence and stimulates the rate of leaf initiation, and, subsequently, earlier flowering (Kinet, 1977).

The effect of daylength and light intensity on stem elongation is complex (Picken *et al.*, 1984). Under sub-optimal light conditions, daylength reduction increases plant height to a certain degree (Hurd and Thronley, 1974). However, if daylength is further reduced, stem elongation is slowed down by a further decrease in total light received per day (Kinet, 1977). The inconsistent effects of daylength on stem elongation result probably from interactions with irradiance, affecting the daily light integral (Picken *et al.*, 1984).

The interaction between temperature and radiation has also a marked effect on the vegetative growth of tomatoes. Calvert (1958) found that, in tomato, the combination of low solar radiation and high temperature causes a delay in ontogenetic development and in the diurnal pattern of photosynthesis and respiration. This demonstrates the importance of these processes for initial plant growth, as well as the importance of reducing temperature when solar radiation is low. On the other hand, if the plant is supplied with optimal light intensity, a reduction in temperature may have a lesser effect on vegetative growth and will be less detrimental to flower development (Aung, 1979).

2.1.1.2.2.3 HUMIDITY AND WATER AVAILABILITY

Humidity and water availability play an important role for vegetative growth of tomato. Under high humidity, tomato plants tend to be more vegetative than reproductive. When, on the other hand, relative humidity is very low, vegetative growth tends to be greater than reproductive growth (Aung, 1979). Optimal relative humidity for tomato production is in the range of 60-85% (Yamaguchi, 1983).

There are many factors to be considered in determining water requirements for tomatoes. Although tomatoes have a high water requirement, they also have an extensive root system. Under good growing conditions, soil water content should be at field capacity during the vegetative phase. Under low light or high temperature conditions, however, watering transplants excessively results in thin, leggy stems (Calvert, 1958). The most important consideration when watering tomatoes is probably consistency. When water availability fluctuates, or when it is too high or too low at critical stages, fruit disorders are likely to develop (Ahmed, 2000).

2.1.1.2.3 EFFECT OF ENVIRONMENTAL CONDITIONS ON FLOWERING

After several leaves have formed (six to twelve, depending on cultivar), the growing point changes from vegetative to reproductive, and a cluster of flower buds is formed that ultimately develops into the first flower cluster or truss. The ability to produce flower buds and the ability to develop these buds to fully open flowers are two distinct processes. This is particularly relevant for tomato production as environmental conditions can influence the number of flower buds as well as the timing of flower development and the number of viable flowers (Mills, 1990).

The flowering response in tomato is measured in earliness of inflorescence development, the number of developing inflorescences, the time from sowing to the microscopic appearance of the inflorescence, the time to first anthesis, and by the number of flowers within an inflorescence which progress to anthesis (Picken *et al.*, 1984). For all three types of tomato, determinate, semi-determinate and indeterminate, flowering response is more influenced by environmental factors than genetically (Jones, 1996).

2.1.1.2.3.1 TEMPERATURE

Tomato seedlings are thermo-sensitive and can be vernalized to achieve earlier flowering. However, they must have developed sufficient vegetative growth prior to cool temperature exposure for successful vernalization. The vernalization requirement can be met by early planting. Planting too early, however, can cause winterkill. Planting too late results in a lack of vernalization, which limits flowering and, thus, reduces yield. Furthermore, artificial cold treatment can increase the number of flowers in the first or second inflorescence (Aung, 1979). Although the number of leaves produced before floral transition is genetically controlled within a narrow range of environmental conditions (Kinet and Peet, 1997), temperature and other environmental factors can affect the number of leaves formed below the first inflorescence (Wien, 1997). Exposure of tomato seedlings to 14°C, compared to 25 or 30°C, increases the number of flowers in the first inflorescence (Aung, 1979). Both, leaf number and rate of leaf production, increase with higher temperatures (Calvert, 1959; Hussey, 1963a). If the temperature is reduced to 10°C prior to floral initiation, a minimum number of leaves for survival are formed. This number, however, varies with cultivar and depends on whether or not there is sufficient solar radiation (Calvert, 1957).

Furthermore, temperature affects the rate of development of the tomato inflorescence; the higher the temperature within a range from 15 to 34°C, the earlier the opening of the flowers (Calvert, 1964c; Hurd and Cooper, 1970). High temperature (35°C) is particularly detrimental nine to five days prior to anthesis during sporogenesis. In contrast, flower buds are rather tolerant to high temperature (35°C) one to three days before anthesis (Sugiyama, 1966; Sugiyama *et al.*, 1966; Sugiyama *et al.*, 1970). Low temperatures (5 to 10°C) during inflorescence initiation increase inflorescence branching (Kinet, 1989).

The time from floral initiation to first anthesis is also affected by temperature. Aung (1979) found that the time to first anthesis of tomato is reduced with an increase in temperature. As a result, anthesis is earlier at higher temperatures, provided the daily total radiation is considerably high.

2.1.1.2.3.2 RADIATION

The failure of tomato plants to flower and produce fruit may occur in both, determinate and indeterminate cultivars. Evidence created by Aung (1979) and Kinet and Peet (1997) shows that there is no single factor responsible for this failure but that various environmental factors, such as temperature, light, humidity and water availability, interact in a complex manner. However, the daily total radiation appears to have a central role in the control of flower development in tomato (Kinet and Peet, 1997).

Subsequently, subjecting tomato plants to insufficient light at the early developmental stages, prior to flowering, results in delayed floral initiation as well as delayed macroscopic appearance of the inflorescence. This indicates that the rate of growth of the truss is slowed down under insufficient light conditions (Kinet and Peet, 1993). Binchy and Morgan (1970) as well as Kinet (1977a) found, in growth room studies, that flowering is advanced under short days (10hrs of light) as compared to long days (14hrs of light). Nevertheless, tomato is usually considered the model day neutral plant (Mills, 1990).

Tomato flowering is adversely affected by extreme long-day conditions. When tomato plants are provided with more than 20hrs daylight and a four-hour night period, leaf chloroplasts break down - a phenomenon visible as interveinal chlorosis (Mills, 1990). This damage is possibly caused by the lack of time to translocate photosynthates out of the chloroplasts to other plant parts (Mills, 1990), a process taking place at night. Calvert (1973a), however, suggested that this damage could be avoided by subjecting plants to considerably low night temperatures (temperatures 2 to 4°C lower than day temperatures).

The leaf number below the first inflorescence is strongly affected by light (Kinet, 1977). Increasing the light intensity reduces the number of leaves below the first inflorescence and stimulates the rate of leaf initiation, resulting in earlier flowering. It has also been shown that, as light intensity increases, the leaf number to first flowering decreases; the phenomenon depends, however, also on the temperature regime (Hussey, 1963a; Kinet, 1977). Under low temperature conditions, the number of leaves developing below the first inflorescence is greater when the daily radiation is low (Calvert, 1958). Increases in daily radiation also influence the size of flower buds and the number of flowers in the first inflorescence. Saito and Ito (1967) found that, under low daily radiation, flower buds and flowers are smaller and the fruit developing from these flowers have fewer locules and lower mono-, di- and polysaccharide and auxin levels.

2.1.1.2.3.3 HUMIDITY AND WATER AVAILABILITY

Water availability affects flower formation, and, later in the development, fruit enlargement. The average number of flowers per truss decreases as soon as water supply decreases below field capacity (Weller, 1987). Superoptimal water supply (to levels above field capacity) also affects the reproductive processes, delaying flower initiation and reducing the rate of flowering as well as the number of flowers. The effect of water availability on floral development is furthermore modulated by light conditions. Under low light conditions, flower abortion increases. However, it can be reduced if plants are kept under water stress (Klapwijk and de Lint, 1974).

2.1.1.2.4 EFFECT OF ENVIRONMENTAL CONDITIONS ON FRUIT SET

The proportion of flowers that turn into a fruit in a population of healthy flowers is called fruit set (Picken, 1984). Generally, tomatoes flower, set and develop fruit freely but there may be unproductive flowers (flowers which have undergone abnormal development). The failure of sufficient fruit set is a major problem, particularly in marginal areas and under extreme environmental conditions. Unfavourable conditions - before and during flowering - result either in the shedding of flowers soon after anthesis or in the failure of flowers to develop into fruit of marketable size (Mills, 1990).

The development of large fruit requires successful completion of the sexual processes within the tomato flower. Successful transfer of viable pollen from the anthers to the stigma and subsequent fertilization of the ovules and development of the ovary are affected by environmental conditions as well as the concentration of endogenous growth regulators and by inherited characteristics of the flower parts (Kinet and Peet, 1997).

2.1.1.2.4.1 TEMPERATURE

Although tomato plants can grow under a wide range of temperatures, fruit set only occurs at a narrow temperature range. Adverse temperatures can prevent fruit set in a number of ways, affecting various stages of development of the flower and its parts, as well as the pollination and fertilization process (Rick, 1978; Picken, 1984).

Fruit set is usually poor when temperatures are either relatively low or high. Watts (1931) found that fruit set is higher at 24°C than at 16°C. Poor fruit set at low temperatures is caused primarily by poor pollen viability. However, slow pollen tube growth also contributes to low fruit set (Charles and Harris, 1972). If daily maximum temperatures are above 32°C, fruit set is low (Moore and Thomas, 1952). Such poor fruit set at high temperatures is primarily due to stigma exertion, which reduces the opportunity for pollen to be shed onto the stigma. Furthermore, stigma receptivity is poor at temperatures higher than 32°C (Charles and Harris, 1972).

The fruit set response to both, high and low temperatures shows great genetic variability (Went, 1945; 1964; Charles and Harris, 1972; El Ahmadi and Stevens, 1979). Some cultivars (e.g. 'San Marzano') exhibit better fruit set at high temperatures (above 30°C), and others at low temperatures (10 to 15°C) ('Roma VF') (Curme, 1962; Scaible 1962).

Generally, temperatures during the pollination period should not fall below 13°C at night nor exceed 32°C during the day for good fruit set (Wayne, 1997). Went (1944; 1953) reported that the more critical factor in tomato fruit set is the night temperature, the optimal range being 15°C to 20°C.

2.1.1.2.4.2 RADIATION

In general, the influence of radiation on fruit set of tomato is small (Picken *et al.,* 1984). However, one of the main causes of the failure to set fruit is the insufficiency of carbohydrate production which appears under low irradiance (Calvert, 1964a). Furthermore, fruit set is quantitatively dependent on the presence of mature leaves as covering of mature leaves leads to a lower fruit set compared to exposing leaves to light.

Fertilized ovaries may cease to swell rapidly because of low solar radiation, high temperature or an interaction between these factors. Cockshull *et al.* (1992) reported that the fruit number per truss is positively correlated with solar radiation intercept around the time of first anthesis. Low solar radiation during the two weeks following anthesis of the first flower in a truss prevents the growth of most fruits in that inflorescence. However, reducing the temperature to just below 18°C during low solar radiation slightly stimulates fruit growth.

2.1.1.2.4.3 HUMIDITY AND WATER AVAILABILITY

The effect of humidity on fruit set of tomatoes is indirect. High temperature, especially if accompanied by low humidity and moisture, hinders fruit set through failure of pollination and/or fertilization. A relative humidity of 70% is considered optimal for fruit set and fruit development (Goudor, 1974).

Water stress conditions often accompany high temperatures, which can generate high abscisic acid levels, promoting premature flower/fruit senescence and the abscission of reproductive organs (McGlasson and Adato, 1977). Water stress can also result in ovule or embryo abortion if accompanied by a high transpiration rate (Mills, 1990).

2.1.2 AIM OF RESEARCH

As demonstrated, the effects of environmental conditions on various stages of tomato development have been widely recorded. However, only limited research is available describing long-term effects of short-term cold exposure on the growth and development of tomato - and other vegetable seedlings. Low temperatures have been reported to reduce growth of tomato (Paradossi *et al.*, 1988), cucumber (Helmy *et al.*, 1999), watermelon (Bradow, 1990; Hassel, 1979) and muskmelon (*Reticulatus Group*) (Risse *et al.*, 1978) transplants. Unfortunately, results of these experiments are either described too general or, as in the case of tomato, cultivar-specific. Most experiments on tomato have also been carried out using indeterminate cultivars, while this research intended to particularly focus on "Rossol" tomatoes, which display a determinate growing habit. Therefore, the experiments were designed to:

1. Study the long-term effects of short-term cold exposure of "Rossol" tomatoes during various growth stages on vegetative and reproductive characteristics, and
2. Establish the duration and amount of cold exposure resulting in a significant yield reduction by simulating a two to five night long cold spell.

2.2 MATERIALS AND METHODS

2.2.1 LOCATION AND CLIMATE OF EXPERIMENTAL SITE

The experiment was conducted near the Faculty of Science and Agriculture, University of KwaZulu-Natal, Pietermaritzburg, South Africa using an existing glasshouse. In the glasshouse, the recorded temperature ranged from 18 to 31.5°C during the day and 7.5 to 16°C during the night. Irradiance levels ranged from 140 to $220\mu mol \bullet m^{-2} \bullet s^{-1}$ during the morning, from 680 to $790\mu mol \bullet m^{-2} \bullet s^{-1}$ during midday and from 700 to $910\mu mol \bullet m^{-2} \bullet s^{-1}$ during the afternoon hours.

2.2.2 PLANT MATERIAL

Seeds of the determinate tomato cultivar "Rossol" were seeded on October 22, 2001 in 24-celled Speedling® trays and transferred into equal-sized pots of 250mm diameter when they had reached the two-leaf stage after approximately eleven days. The plants were kept in the tunnel until November 17, 2001, thereafter plants were subjected to various treatments. Air temperature in the tunnel during germination and seedling establishment period ranged from 17.5 to 30.5°C during the day and 9.5 to 22.5°C during the night.

2.2.3 STANDARD MANAGEMENT

After transplanting, plastic pots were arranged in three rows at a spacing of 0.8m by 0.4m in the tunnel. A sand: composted pine bark (4:1) mixture was selected as a medium, due to its relative heat retaining capacity which would convey better tolerance of the plants to cooler growing conditions (Savage, 1978). Each pot was irrigated by a micro-sprinkler inserted into a main delivery pipe from a tank containing water only. Fertilization was carried out by hand as a side-dressing and the plants were irrigated immediately after each fertilizer application. The seedlings were irrigated three times a day by an automated sprinkler system. N, P, K and micronutrients were applied to all plants based on the Cedara

Computerized Fertilizer Advisory Service Recommendation (FERTREC). A weekly plant protection programme was started after transplanting to guard against disease and pest attacks.

2.2.4 EXPERIMENTAL LAYOUT

The experiments were laid out according to a complete randomised block design with three replicates for each of the five cold exposure treatments in the three growth stages (Table 1).

Table 1: Experimental layout of simulated cold spell trial

Replication	Treatment period (Growth stage)														
	vegetative					1st flowering					1st fruit set				
1	T1	T4	T3	T2	T5	T3	T5	T4	T2	T1	T1	T4	T5	T2	T3
2	T3	T5	T1	T2	T4	T2	T4	T5	T1	T3	T4	T2	T3	T1	T5
3	T2	T1	T5	T4	T3	T5	T1	T2	T3	T4	T3	T5	T1	T4	T2

T1 = control (0hrs of cumulative cold exposure)
T2 = 24hrs (two nights) of cumulative cold exposure (4°C)
T3 = 36hrs (three nights) of cumulative cold exposure (4°C)
T4 = 48hrs (four nights) of cumulative cold exposure (4°C)
T5 = 60hrs (five nights) of cumulative cold exposure (4°C)

2.2.5 COLD APPLICATION

Plants were exposed to a varying number of cold (4°C) nights (two to five, totalling 24 to 60hrs) for 12hrs from 19:00h to 07:00h. They were therefore moved from the glasshouse to a cold room for two, three, four or five subsequent nights and in the morning returned to the glasshouse for the duration of the day (7:00h to 19:00h).

When plants had attained the three-true-leaf stage (21 days after sowing), they were divided into three groups. The first group was transferred to the cold room immediately (vegetative stage). This group again was subdivided into five groups (T1 to T5) depending on the duration of cold exposure (0, 24, 36, 48 and 60hrs) to simulate a two-, three-, four- or five-night cold spell. The second group was exposed to cold when the first flower of the first fruit was visibly mature (1st flowering) (37 days after sowing). Similar to the first group (vegetative stage), these plants were subdivided into five groups and exposed to zero to 60 cold hours. The third group was exposed to the various cold treatments as soon as the first fruitlet was visible (first fruit set stage) (51 days after sowing).

2.2.6 RECORDING OF MORPHOLOGICAL & PHENOLOGICAL CHARACTERISTICS

Following the cold treatment, morphological and phenological parameters were recorded to determine the effect of cold exposure on "Rossol" tomatoes at various developmental stages.

Plant height was measured immediately after exposure to cold temperature and thereafter every two weeks until maturity (red-ripe appearance) of the first fruit. Plant height was determined using a ruler by measuring the distance from the cotyledons to the apex of the plant. Similarly, the internode length of plants was measured by determining the distance from the newly emerged leaf to the preceding leaf. The average internode length was then calculated by adding up measurements and dividing by the number of times measurements were taken.

Further parameters recorded during the subsequent development of plants exposed at the vegetative stage were: number of leaves below first inflorescence, number of days to first anthesis (date of transplanting to date of first fully mature flower), number of days from transplanting to first fruit set, and number of days from transplanting to first harvest (first red-ripe appearance of fruit). Fruits were picked manually on a daily basis at the red-ripe stage and individual fruit mass as well as number of fruit per plant was recorded. Using these values, yield and fruit weight per plant was calculated. The fruit weight per plant was then calculated by dividing the yield of the plant by the number of fruits of that plant. Weight, length and width of all harvested fruit were also measured in order to determine the effect of the cold treatments on fruit quality parameters as well as on the percentage of marketable fruits. Fruits were categorized according to Ahmed (2000) into three weight (less than 80g, 80-200g and more than 200g), three length (less than 30mm length, 30-80mm and longer than 80mm) and three width (less than 30mm, 30-80mm and wider than 80mm) categories. Fruits weighing 80 to 200g, measuring 30 to 80mm in length and 30 to 80mm in width were categorized as "marketable grade".

2.2.7 STATISTICAL ANALYSIS

Results from the experiments were analysed for significant differences between treatments using Genstat (GENSTAT 5, Release 4.1, 4th Edition, © Lawes Agricultural Trust LACR-Rothamsted).

2.3 RESULTS

2.3.1 EFFECTS OF COLD EXPOSURE DURING JUVENILE PHASE ON MORPHOLOGICAL AND PHENOLOGICAL CHARACTERISTICS

2.3.1.1 EFFECTS OF COLD EXPOSURE ON PLANT HEIGHT & INTERNODE LENGTH

The height of tomato plants at harvest declined with increased exposure to chilling during the juvenile phase, but the relationship was not linear, i.e., with every increase in 12hrs of cold exposure, plant height decreased, but not uniformly. Hence, control plants and plants exposed for 24hrs were significantly taller ($p < 0.05$) than those chilled for 36, 48 and 60hrs (Fig. 2). Furthermore, the interaction between hours of cold exposure and plant height was not significant.

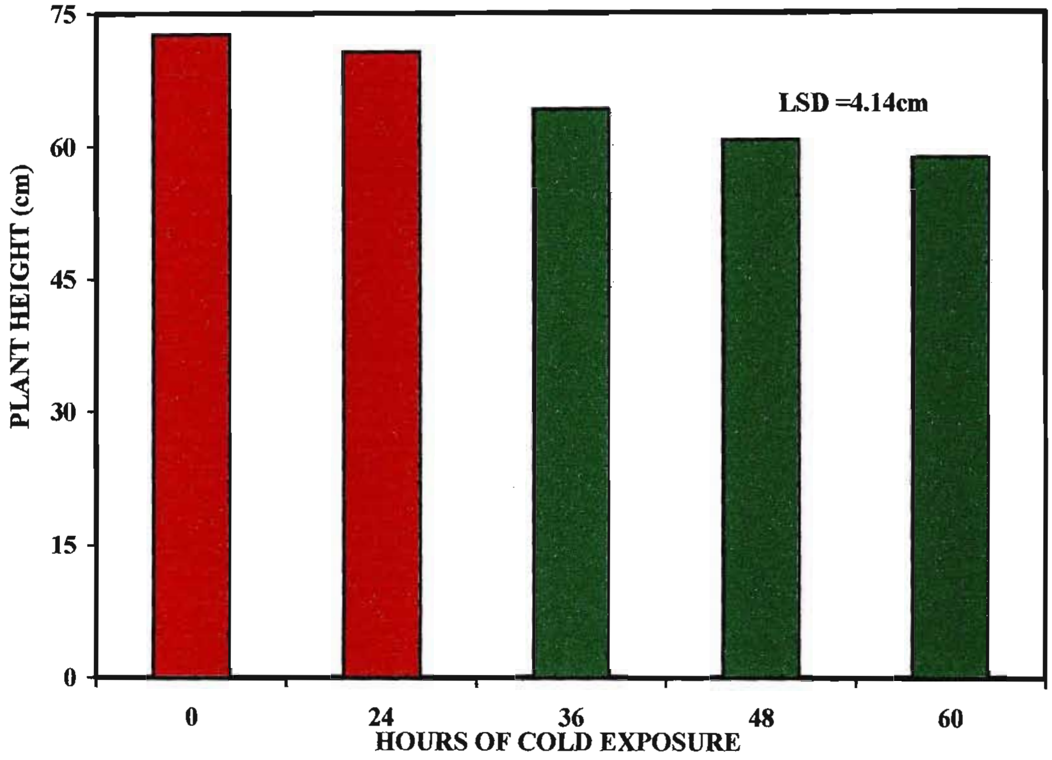


Fig. 2 Effect of cold exposure administered at the juvenile growth phase on height of "Rossol" tomatoes at first harvest. Bars with different colours denote significant differences at $p < 0.05$.

Internode length showed similar trends to plant height, as it decreased with an increase in chilling exposure. Control plants and plants exposed to cold for 24hrs had significantly taller ($p < 0.05$) internodes than those exposed for 36, 48 and 60hrs (Fig. 3). Similar to plant height, the interaction between hours of cold exposure and internode length was not significant.

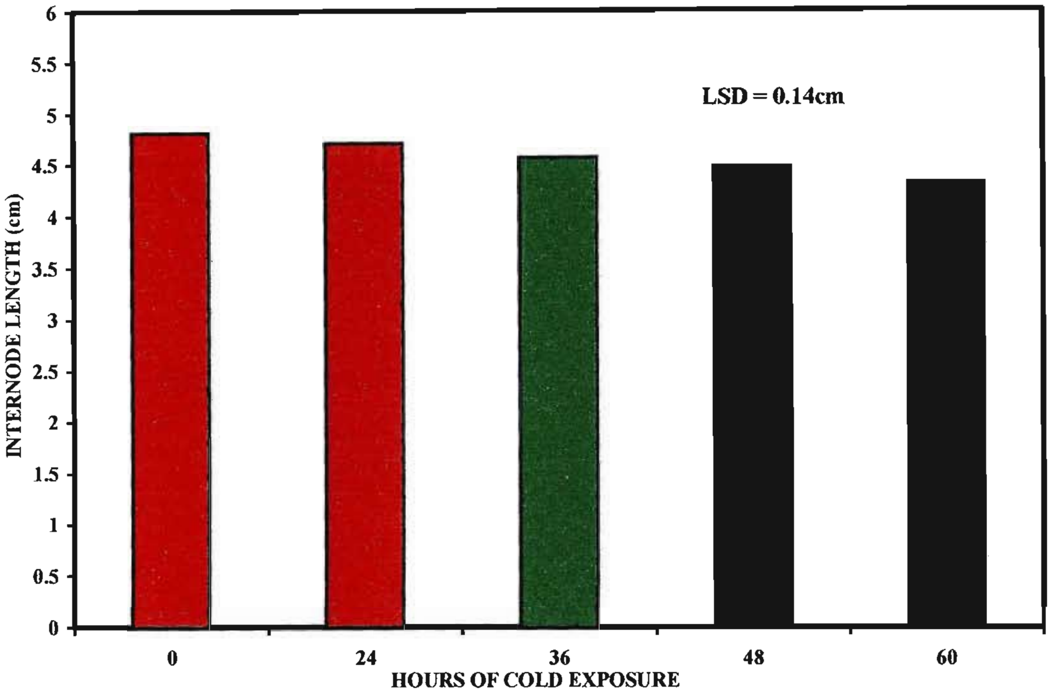


Fig. 3 Effect of cold exposure administered at the juvenile stage on internode length of "Rossol" tomatoes at first harvest.
Bars with different colours denote significant differences at $p < 0.05$.

2.3.1.2 EFFECTS OF COLD EXPOSURE ON NODES BELOW FIRST INFLORESCENCE

The number of nodes below the first inflorescence did not differ between control plants and those exposed to 24 and 36hrs of cold but decreased significantly with a further increase in cold exposure (Table 2).

Table 2 Effect of cold exposure administered at the juvenile stage on number of nodes below first inflorescence, time to first anthesis, first fruit set and first harvest of "Rossol" tomatoes

Exposure to number of cold hours	Number of nodes	Number of days to			Harvesting period (days)
		First anthesis	First fruit set	First harvest	
Control (0)	9^a	29.10^b	51.33^b	99.13^b	22^d
24	9^a	26.33^c	49.27^b	96.47^b	24^d
36	9^a	27.33^c	51.67^b	101.33^b	33^c
48	8^b	31.02^a	53.33^b	105.47^b	41^b
60	6^c	33.10^a	59.33^a	112.10^a	58^a
LSD (0.05)	0.7	1.051	4.810	6.213	2.79
CV	1.10	2.50	1.40	1.51	1.13
SEM±	0.2789	0.2789	0.2789	0.483	0.483

Values followed by different letters within a column denote significant differences at $p < 0.05$.

2.3.1.3 EFFECTS OF COLD EXPOSURE ON TIME TO FIRST ANTHESIS

Plants exposed to cold for 24 and 36hrs flowered significantly earlier ($p < 0.05$) than control plants and those exposed to 48 and 60hrs of cold (Table 2). Tomato plants chilled for 24 and 36hrs averaged 26 and 27 days to first anthesis, respectively, while subjecting plants to 48 and 60hrs of chilling increased the days to the appearance of the first mature flower (first anthesis) to 31 and 33 days, respectively.

2.3.1.4 EFFECTS OF COLD EXPOSURE ON TIME TO FIRST FRUIT SET AND FIRST HARVEST

Despite the significant differences between treatments in time to first anthesis, there were no significant differences in days to first fruit set, except when tomato plants were chilled for 60hrs. Only then first fruit set happened significantly later ($p < 0.05$) than in plants chilled less (Table 2).

The number of days to first harvest did not differ between the control plants and those exposed to 24, 36 or 48hrs of chilling. However, similar to first fruit set, plants chilled for 60hrs reached first harvest significantly ($p < 0.05$) later than less chilled plants.

2.3.1.5 EFFECTS OF COLD EXPOSURE ON YIELD ATTRIBUTES

Although tomato plants chilled for 24hrs produced the highest yield per plant (5187g), followed by the control plants (5087g), yield reduction became significant ($p < 0.05$) only when plants had been exposed to 30 cold hours or more (Table 3).

Table 3 Effect of cold exposure administered during the juvenile stage on yield per plant, number of fruits per plant, fruit size and marketable percentage of fruits of "Rossol" tomatoes

Number of hours of cold exposure	Yield (g/plant)	Number of fruits/plant	Fruit weight (g)	Marketable fruit (%)
Control (0)	5087^a	31.33^a	162.37^a	87.33^a
24	5187^a	31.50^a	162.09^a	85.67^a
36	4867^b	30.25^a	160.89^a	82.00^b
48	4606^c	29.33^a	157.04^b	80.00^b
60	4063^d	26.17^b	152.34^c	63.00^c
LSD (0.05)	108	2.96	3.34	3.52
CV	1.20	1.40	1.60	1.40
SEM±	0.183	0.548	1.652	0.610

Values followed by different letters within a column denote significant differences at $p < 0.05$.

Fruit weight decreased significantly ($p < 0.05$) with increasing hours of cold exposure of plants to 48hrs, and a further significant weight reduction was recorded when plants were cold-exposed for 60hrs. Out of all yield parameters determined, the number of fruits per plant was least affected by the cold treatments; only in plants chilled for 60hrs a significant reduction of this characteristic was observed.

Cold exposure for 36 and 48hrs reduced the percentage of marketable fruit significantly ($p < 0.05$). Increasing the hours of cold exposure further, to 60hrs, resulted in a further significant decrease in the proportion of market-grade fruit.

Altogether, at the juvenile stage, plant height and percentage of marketable fruit seemed most sensitive to cold exposure. A cold treatment for subsequent five nights (60hrs) affected all recorded parameters negatively.

2.3.2 EFFECTS OF COLD EXPOSURE DURING APPEARANCE OF FIRST FLOWER ON MORPHOLOGICAL AND PHENOLOGICAL CHARACTERISTICS

2.3.2.1 EFFECTS OF COLD EXPOSURE ON PLANT HEIGHT AND INTERNODE LENGTH

With an increase in cold exposure during the appearance of the first flower from 0 to 60hrs, plant height at first harvest decreased gradually. Unchilled (control) plants and those chilled for 24hrs were significantly taller ($p < 0.05$) than those chilled for 36, 48 or 60hrs (Fig. 4). The interaction between hours of cold exposure and plant height at harvest was, however, not significant.

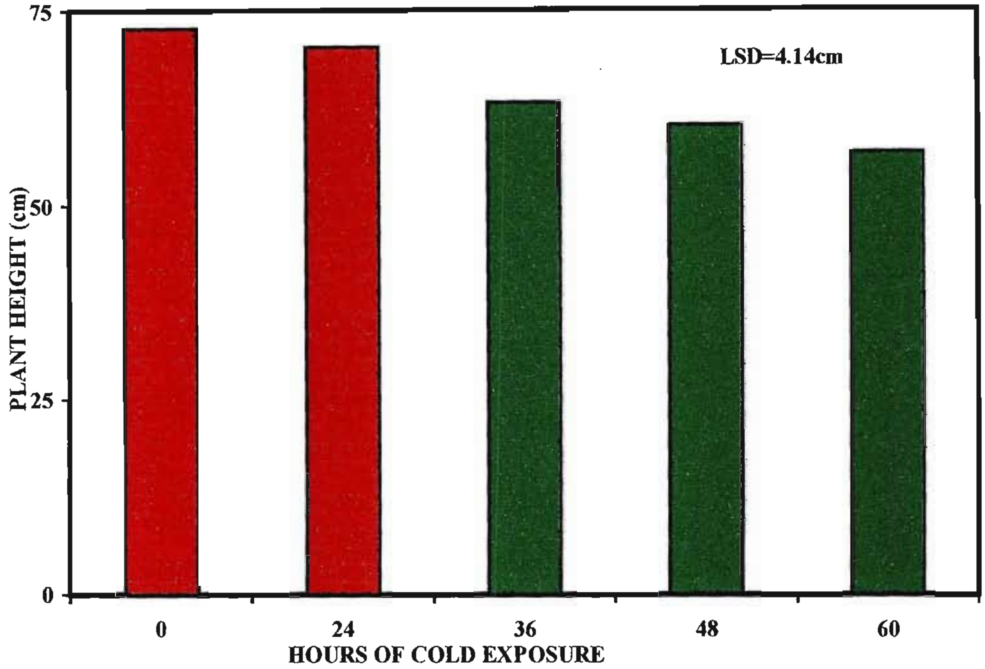


Fig. 4 Effect of cold exposure at first flowering on plant height of "Rossol" tomatoes at first harvest. Bars with different colours denote significant differences at $p < 0.05$.

The internode length of plants was significantly reduced after plants had been exposed to the equivalent of, or more than, 36 cold hours. Non-chilled, control plants and plants chilled for 24hrs had significantly longer internodes compared to plants of the other three treatment durations (Fig. 5). The interaction between hours of cold exposure and internode length at harvest was not significant.

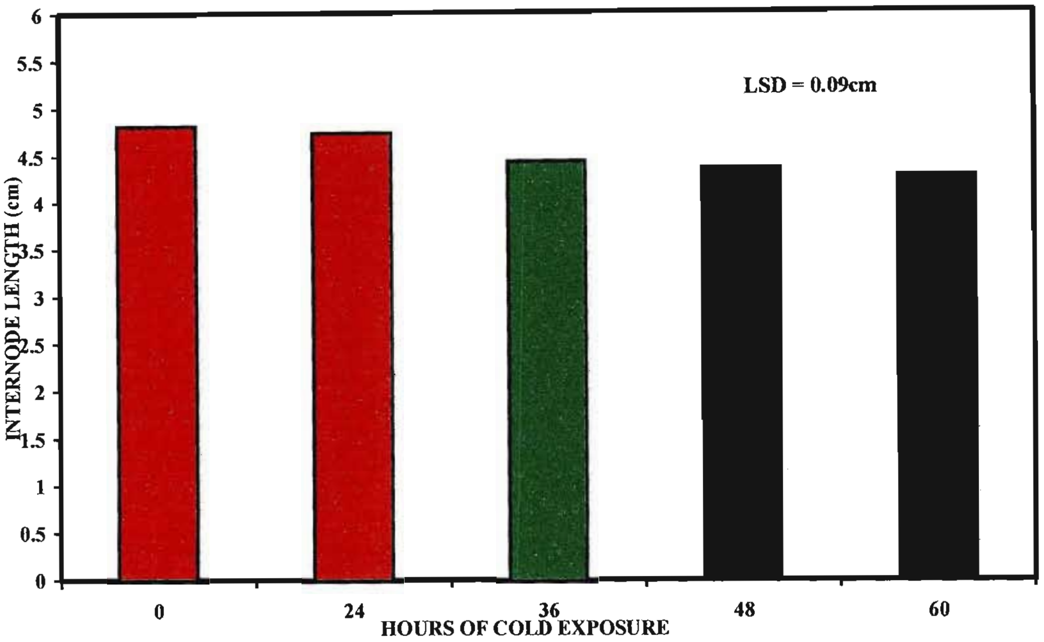


Fig. 5 Effect of cold exposure at first flowering on internode length of "Rossol" tomatoes at first harvest. Bars with different colours denote significant difference at $p < 0.05$.

2.3.2.2 EFFECTS OF COLD EXPOSURE ON TIME TO FIRST FRUIT SET AND FIRST HARVEST

Of the phenological variables determined, time to first fruit set was the one affected most by the duration of cold exposure. The control plants as well as plants exposed to cold for 24hrs set their first fruit significantly sooner ($p < 0.05$) than those exposed for 36, 48 and 60hrs (Table 4).

Table 4 Effect of cold exposure at first flowering on time to first fruit set and first harvest of "Rossol" tomatoes

Numbers of hours of cold exposure	Days from transplanting to first fruit set	Days from transplanting to first harvest	Harvesting period (days)
Control (0)	51.33^a	99.13^a	34^d
24	51.67^a	101.67^a	37^c
36	56.67^b	105.33^b	43^b
48	58.33^b	108.47^b	47^a
60	60.13^b	112.10^c	49^a
LSD (0.05)	3.57	3.37	2.34
CV	0.6	1.58	1.01
SEM±	0.2689	0.2456	0.382

Values followed by different letters within a column denote significant differences at $p < 0.05$.

As exposure to cold was increased from 0 to 60hrs, the time from transplanting to first harvest was delayed by thirteen days (Table 4). Control plants produced mature fruits first. Furthermore, the harvesting period became extended with an increase in duration of cold exposure. In control plants and those chilled for 24hrs, 70-75% of the crop was harvested within one month, while in tomato plants chilled for 36, 48 and 60hrs, only 64, 51 and 41% of the crop was harvested within thirty days, the harvesting period increased by almost 44%, from 34 to 49 days (Table 4).

2.3.2.3 EFFECTS OF COLD EXPOSURE ON YIELD ATTRIBUTES

Plants exposed to cold for 36, 48 and 60hrs had significantly lower ($p < 0.05$) yields than control plants and those chilled for only 24hrs. As chilling increased from 0 to 60hrs, yield per plant decreased progressively from 5087g to 4124g (Table 5). However, a cold exposure for only 24hrs (two nights) did not result in a yield different from the control.

No significant effect on fruit number per plant was observed between control plants, plants chilled for 24, 36 or 48hrs.

Table 5 Effect of cold exposure of "Rossol" tomatoes at first flowering on yield per plant, number of fruits per plant, fruit size and percentage of marketable fruits

Numbers of hours of cold exposure	Yield (g/plant)	Number of fruit/plant	Fruit size (g)	Marketable fruit (%)
Control (0)	5087^a	31.33^a	162.37^a	87.33^a
24	5083^a	32.85^a	152.73^b	71.50^b
36	4787^b	32.00^a	148.59^b	68.50^b
48	4496^c	30.83^a	143.92^c	64.50^b
60	4124^d	28.47^b	141.34^c	59.00^c
LSD (0.05)	105.23	2.26	4.13	5.67
CV	1.87	1.43	0.97	1.25
SEM±	0.3243	0.456	1.327	0.838

Values followed by different letters within a column denote significant differences at $p < 0.05$.

However, plants chilled for 60hrs had significantly lower ($p < 0.05$) number of fruits compared to plants exposed to cold for a shorter period (Table 5).

Fruit size decreased significantly as the number of hours of cold exposure increased. This decrease in fruit size together with the decrease in fruit number per plant resulted in a significant yield reduction. Furthermore, control plants had the highest percentage of marketable fruit (87%), followed by plants chilled for 24hrs (72%). Plants chilled for 36hrs and 48hrs had 69% and 64.5% fruits suitable for marketing. In plants chilled for 60hrs, this percentage declined even further to only 59% (Table 5).

Altogether, the exposure of "Rossol" tomatoes to cold for 24hrs (two nights) did not affect yield or number of fruits per plant significantly but the percentage of marketable fruits decreased significantly. Cold exposure for 36hrs, however, reduced yield significantly, although this treatment did not differ significantly from the 24hrs cold exposure in other characteristics. An exposure for 60hrs, however, resulted in yield, number of fruit per plant, and fruit size declining, while a further extension of the cold exposure to 60hrs worsened all yield attributes significantly. Furthermore, the effect of cold exposure of "Rossol" tomatoes during first flowering had more drastic effects than the exposure at the juvenile stage.

2.3.3 EFFECTS OF COLD EXPOSURE DURING FIRST FRUIT SET ON MORPHOLOGICAL AND PHENOLOGICAL CHARACTERISTICS

2.3.3.1 EFFECTS OF COLD EXPOSURE ON PLANT HEIGHT AND INTERNODE LENGTH

Exposure of tomato plants to a simulated cold spell during first fruit set had very little effect on height and internode length of tomato plants at first harvest. Only control plants were significantly taller than cold treated plants (Fig. 6).

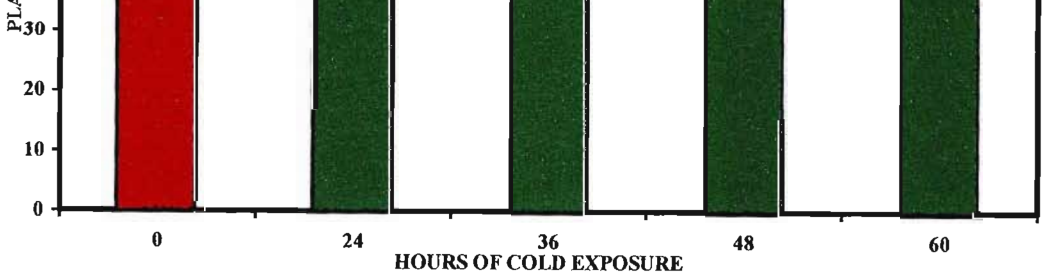


Fig. 6 Effect of hours of cold exposure during first fruit set on plant height of "Rossol" tomatoes. Bars with different colours denote significant differences at $p < 0.05$.

Similarly, there were no significant differences between tomato plants exposed to various hours of cold exposure at first fruit set with respect to internode length. Internodes of control plants were, on average, 4.85cm long, while the internode length of plants exposed for 24, 36, 48 and 60hrs was 4.80cm, 4.65, 4.60 and 4.40cm, respectively.

2.3.3.2 EFFECTS OF COLD EXPOSURE ON TIME TO FIRST HARVEST AND HARVESTING PERIOD

The effect of chilling during first fruit set on days to first harvest was not significant between control and plants chilled for 24 and 36hrs, but the number of days from transplanting to first harvest was significantly increased in plants chilled for 60hrs (Table 6). Control plants produced red-ripe fruit earlier than plants, which were chilled for 24, 36, 48 and 60hrs (Table 6). Furthermore, the harvesting period was significantly extended by cold treatments for 24 and 36hrs. An extension to 48 and 60hrs of cold increased this period even further.

Table 6 Effect of cold exposure at first fruit set on days to first harvest and harvesting period of "Rossol" tomatoes

Numbers of hours of co exposure	Days from transplanting first harvest	Harvesting perio (days)
Control (0)	99.13^{a}	31^{a}
24	101.17^{a}	38^{b}
36	103.33^{a}	41^{b}
48	104.47^{a}	48^{c}
60	110.93^{b}	51^{c}
LSD (0.05)	5.131	4.12
CV	1.58	3.11
SEM±	0.2456	0.2456

Values followed by different letters denote significant differences at $p < 0.05$.

2.3.3.3. EFFECT OF COLD EXPOSURE ON YIELD ATTRIBUTES

There was a marked difference in yield per plant between the five treatments. As chilling hours increased from 0 to 60, yield per plant decreased by 35% (Table 7). A similar pattern was established for fruit size. Unchilled plants bore fruit of the largest size but not significantly different to those of the 24hrs cold treatment. Only when plants were chilled for 36, 48 and 60hrs, fruit size was significantly reduced.

Table 7 Effects of cold exposure administered to "Rossol" tomatoes at first fruit set on yield per plant, number of fruits per plant, fruit size and percentage of marketable fruits

Numbers of hours of cold exposure	Yield (g/plant)	Number of fruit/plant	Fruit size (g)	Marketable fruit (%)
Control (0)	5087^a	32.33^a	162.37^a	87.33^a
24	4879^b	31.00^a	162.63^a	73.41^b
36	4512^c	30.67^a	154.26^b	68.31^b
48	4409^c	30.33^a	150.32^b	60.50^c
60	3316^d	26.67^b	124.33^c	56.50^c
LSD (0.05)	124.12	3.23	5.64	7.78
CV	1.23	1.34	1.82	2.10
SEM	0.2863	0.378	1.234	0.567

Values followed by different letters within a column denote significant differences at $p < 0.05$.

The percentage of marketable fruits was significantly reduced by cold exposure (Table 7). This attribute showed a significant reduction even with cold exposure for only 24hrs as well as a further significant decline as the chilling period was extended to 48 and 60hrs.

Fruit number per plant was only reduced significantly, by fifteen percent, with an exposure to 60 cold hours (Table 7).

2.4 DISCUSSION AND CONCLUSIONS

Temperature control, which is quite easily achieved under greenhouse conditions, represents undoubtedly a powerful tool for manipulating plant growth and development. In tomato plants, exposure to a simulated cold spell during night hours was found to have a marked influence on plant development, yield attributes and fruit quality characteristics. The effect varied, however, with the stage of development at cold exposure and the duration of such a simulated cold spell.

2.4.1 LOW TEMPERATURE EXPOSURE DURING THE JUVENILE STAGE

Exposing plants to cold for the equivalent of or more than three subsequent nights (36hrs) during the juvenile period resulted in dwarfed plants, delayed flowering, delayed fruit set, delayed harvesting, and a reduction in yield, fruit size and percentage of marketable fruit (Fig. 1, Fig. 2, Table 2, Table 3). These findings are similar to those reported for tomatoes by Yamaguchi (1983) and for watermelon by Korkmaz and Dufault (2001). Low temperature may influence growth of tomato plants by affecting metabolic rates, photosynthesis and/or the integrity of membranes (Graham and Patterson, 1982). Low temperature, by affecting sugar metabolism and sugar translocation (Ho and Baker, 1982; Hurewits and Janes, 1983; Kayat and Ziesling, 1986, 1987; Paradossi, 1989), decreases the rate of seedling growth, thus reducing total leaf surface area as well as plant height (Franco, 1990). Similarly, in our experiments internode length decreased to a greater degree in plants exposed to the cold treatments compared to unchilled (control) plants. This also affirms results by Gianfagna *et al.* (1999) who found that internode length as well as tomato plant height decreased after a chilling period. The delay in flowering after a cold spell, and thus the delay of fruit set and fruit maturity, suggests that the carbon assimilation was seriously reduced by the cold treatment. Symptoms of chilling injury of tomato during the juvenile phase vary with the tissue involved, but extended hours of cold exposure have been found to cause a reduction in photosynthate production and changes in chloroplast ultrastructure (Togoni, 1990), an impairment in metabolic functions, a cessation of growth and ultimately plant death (Bradow, 1990). The loss of photosynthetic activity can be caused either by a reduced CO_2-uptake, the loss of chlorophyll during and following cold exposure or by an impaired oxidation-reduction chain linking Photosystem II and Photosystem I (Markhart, 1986).

Calvert (1959) found that a slight reduction in temperature during early vegetative growth results in earlier flowering, fruit set and harvest. Extended hours of cold exposure, however, result in a reduced metabolic activity of tomato plants and, thus, in the lengthening of the time to plant maturity (Calvert, 1959; Graham and Patterson, 1982). A significant reduction of yield, fruit size and fruit number was also observed when plants were exposed to cold for three or more subsequent nights during the juvenile phase (Table 3). Plants exposed to 60hrs of cold showed a 20% reduction in yield. Furthermore, fruit size and percentage marketable fruit decreased by 8 and 28%, respectively. This is in alliance with earlier results by Hassel (1979) who found that exposing two-week-old watermelon seedlings to 4.4°C for four and eight nights reduced yield per plant by 12 and 20% respectively. Hall *et al.* (1993) found that watermelon seedlings yielded more fruit when planted later than those planted very early, due to warmer soil temperature during the later planting. This phenomenon might be explained by the effect of a short period of low temperature exposure (24hrs) during the juvenile phase, which hastens flower initiation, and consequently shortens the time to first fruit maturity (Table 2).

Calvert (1959) found that a slight reduction in temperature during early vegetative growth results in earlier flowering, fruit set and harvest. Extended hours of cold exposure, however, result in reduced metabolic activity of tomato plants and, are, thus, lengthening the time to maturity of the plant (Calvert, 1959; Graham and Patterson, 1982). Wittwer and Honma (1979) similarly found that exposure of tomato plants to 5°C for 28hrs (about two cold nights) during the juvenile stage results in earlier flower initiation, fruit set and maturity. Hurd and Cooper (1970) found that a short period of low temperature during early growth of tomato plants results in a fifteen percent increase of yield per plant compared to unchilled plants. A possible explanation for this yield increase following early chilling may be that an increased flower number results from a change from vegetative to reproductive growth during the low temperature period (Hurd and Cooper, 1967). It is possible that, besides increasing flower number, other changes in favour of reproductive growth take place during early vegetative plant development, such as an increased vascularization to the flower initials or changes in hormone synthesis or distribution, which could be of benefit to reproductive development.

A short cold exposure during the night at the vegetative growth stage of tomato can increase the number of fruits on the first truss, thus allowing a higher early yield (Wittwer and Honma, 1979). Results from our study confirm that there is no significant difference in days to first fruit set and first harvest between control plants and those chilled for 24, 36 and 48hrs (Table 2). This suggests that recovery from cold exposure (up to a certain level) is possible at an early growth stage. The number of nodes below the first inflorescence was the little affected when tomato plants were exposed to cold during the early vegetative growth. This number (six leaves below first inflorescence) was fairly constant up to 36hrs of cold exposure but increased with increasing the cold exposure beyond 36hrs. This is not surprising as the number of leaves preceding floral development is under genetic control (Kinet and Peet, 1997). However, environmental conditions, particularly light intensity and, as shown in our experiments, temperature, as well as the interaction of these factors, can alter morphological characteristics by influencing the plastochrome rhythm (Kinet, 1977a).

2.4.2 LOW TEMPERATURE EXPOSURE DURING FIRST FLOWERING

Flower initiation in tomato can already begin a few days after cotyledon expansion, depending on cultivar and prevailing environmental conditions (Aung, 1979). Warmer temperatures during this stage enhance flower development and fruit set and result in earlier harvest, while temperatures below or above optimal can retard growth and development of flowers and/or fruit (Moe and Heins, 1990). The results obtained confirm this finding in that cold exposure of "Rossol" tomatoes during the first flowering stage, when new flowers are still initiated, resulted in dwarfed plants (Fig. 4) with shorter internodes (Fig. 5), delayed flower development, fruit set and maturity (Table 4), and lower yield and poorer fruit quality (Table 5) - depending, however, on the length of the cold exposure. Cold temperatures have been found to delay the process of flower primordia formation (Korkmaz and Dufault, 2001).

Cold exposure for up to 48hrs did not have any effect on the number of fruit per plant, extending the cold hours further (to the equivalent or to more than 60hrs), however, decreased the number of fruits per plant, probably through a reduction in the number of viable flowers per plant. Cold treatment resulted in a reduction in fruit number, probably because some of the newly formed flowers failed to develop into fruits, as some damage must have occurred during the prolonged cold exposure.

Hurd and Cooper (1970), in their experiment on indeterminate tomatoes, found that low temperature - exposure to less than 10°C - during flower initiation increases inflorescence branching, the number of floral organs - especially petals, stamens and ovary locules - and the number of fruits per plant. Plants chilled for 24hrs had a yield per plant similar to that of control (unchilled) plants. The percentage of marketable fruits, however, was significantly lower in chilled plants (Table 5). The relatively high yield of tomatoes chilled for 24hrs can be attributed to the higher number of flowers and hence higher number of fruits produced following the low temperature treatment. Extending the cold treatment further - above 24hrs - resulted in a yield reduction per plant, while fruit size and the percentage of marketable fruits stayed similar (Table 5).

In plants exposed to a three night cold spell simulation during first flowering significant differences, compared to the control, were found in the following parameters: time to fruit set and harvest (Table 4), yield per plant, fruit size, and percentage of marketable fruit (Table 5). Plant height and internode length at harvesting were only significantly affected if the cold temperature treatment lasted three or more nights at this stage of development. These findings could be explained with results obtained by Mills (1990), who found that, once tomato plants bear fruit, vegetative growth ceases and resources are used for reproductive growth. This could, hence, be a reason for the non-significant differences in vegetative parameters (plant height and internode length) between control plants and those exposed to cold during first fruit set.

2.4.3 LOW TEMPERATURE EXPOSURE DURING FRUIT SET

Cumulative growth of tomato fruit is divided into three phases: an initial two-week period during which absolute growth of the plant is slow and, a three to five week period of rapid growth up to the mature green stage and, finally, a period of slow growth for two further weeks (Monselise *et al.*, 1978). Cell division is limited to the early slow growth phase during which cell elongation starts (Kinet and Peet, 1997). Exposure of tomato plants to very low temperatures during fruit set, had therefore, a greater effect on fruit characteristics than an earlier exposure. Most likely, an extended period of cold during fruit set affected cell elongation negatively and, hence, resulted in smaller fruit. Environmental conditions prevailing during the fruit growth phase strongly affect ultimate fruit size (Kinet and Peet, 1997). Hence our results confirm previous findings that, under adverse environmental conditions, fruit size is greatly compromised (Aung, 1979). Similarly, as the hours of cold exposure increased from 0 to 60, yield decreased by 34.8% (Table 7). Our findings are furthermore in line with the report by Davis *et al.* (1965) that tomato fruit may abscise or cease growth if plants are exposed to very low temperatures.

In our study, cold exposure during first fruit set reduced plant height to the same degree independent of the length of cold exposure while internode length was not affected. However, the duration of developmental stages was affected. Control plants and plants chilled for 24 and 36hrs reached first harvesting significantly sooner compared to those chilled for five subsequent nights. This result confirms the suggestion by Ahmed (2000) that fruit growth is detrimentally affected by unfavourable temperature conditions, particularly in later developmental stages.

By far the most sensitive stages to low temperatures fall into the reproductive phase (flowering and fruit set). During the juvenile phase, cold exposure of tomato plants for 24 and 36hrs does not affect most of the morphological and phenological parameters determined negatively. However, cold exposure at this early stage of development for four subsequent nights has a significant, detrimental effect on yield, fruit weight and days to harvest.

From these experiments, it can be concluded that 60hrs of cold exposure at 4°C, independent of the stage of plant development, detrimentally affect vegetative and reproductive parameters as well as yield attributes. A short (24hrs) exposure to 4°C during first flowering of "Rossol" tomato plants lowered the number of days to fruit set but did not have any significant effect on any of the other parameters measured. This cold exposure resulted possibly in a vernalization effect, as Junge (1954) found that tomato seedling can be vernalized during or just before flower development, a stage prior to first flowering. This cold exposure also hastens fruit initiation and, consequently, shortens the life cycle. Extending the treatment beyond 24hrs, however, resulted in dwarfed plants, delayed maturity and reduced yield. Therefore, a significant yield reduction occurred when plants were exposed to three or more subsequent nights.

Based on the results presented, exposure of plants during fruit set has a more detrimental effect than the exposure during the early flowering stage and the juvenile stage. Although extended cold exposure (for more than 36hrs) reduces both, yield and quality of the produce, plants exposed to cold during the juvenile stage can recover quickly and ultimately perform well. As a recommendation, therefore, in the highlands of Eritrea, seedlings should be transplanted late during the cold season so that they can recover from a potential cold-induced growth disorder by the later warmer temperatures and performance of the crop is not compromised.

CHAPTER THREE

EFFECTS OF SOIL POTASSIUM LEVEL AND MULCHING ON COLD TOLERANCE OF *Lycopersicon esculentum* var. ROSSOL

3.1 INTRODUCTION

The primary effect of cold temperatures on plants (temperatures below those for optimal plant growth and development) is a reduction in the rate of growth and in the speed of metabolic processes. Consequently, the length of time required for completion of the developmental stages and, hence, the growing cycle increases as temperatures decrease (Tranquillini, 1979). The subsequent slow growth may be a consequence of impaired photosynthesis, respiration, membrane integrity, and hormonal imbalances (Graham and Patterson, 1982). Plants exposed to lower temperatures can also exhibit wilting and leaf necrosis, increased disease susceptibility as well as a reduction in the harvestable product (Rickin *et al.*, 1976). A prolonged exposure to very low temperatures may even result in the death of the plants (Breidenbach and Waring, 1977).

In order to survive at lower temperatures, tomato plants must obtain cold hardiness in a process termed acclimation. Cold hardiness in tomatoes can be increased artificially by gradually lowering the temperature the crop is exposed to (Tumanov, 1931; Dantuma and Andrews, 1960; Levitt, 1972). Factors such as K fertilization and mulching may also influence the degree to which tomato plants can withstand cold conditions (Levitt, 1969, Singer *et al.*, 1999).

3.1.1 RESPONSE OF TOMATO TO K FERTILIZATION

3.1.1.1 ROLE OF K IN TOMATO

Potassium (K) is one of the sixteen essential nutrients required in nearly all physiological processes needed to sustain plant growth and reproduction (Auxell, 1979). It is absorbed in larger amounts than any other nutrients by tomato. Total K uptake ranges from 150-300 kg

K_2O ha^{-1} for outdoor crops yielding 40-50t • ha^{-1}, and 600-1000kg K_2O ha^{-1} for greenhouse crops yielding over 100 t • ha^{-1} (IFA, 1992).

While K is not a constituent of any plant structure or compound - different to N and P which are constituents of proteins, nucleic acids, phospholipids and ATP- it is involved in many aspects of vegetable crop physiology (Marschner, 1995). K exists as a free or absorptive cation, which makes it to be displaced very easily on a cellular as well as on a whole plant level (Lindhauer, 1985). This high mobility of K explains its major functional characteristic: the main cation involved in the neutralization of charges, and an important osmotic factor (Clarkson and Hanson, 1980).

K activates more than sixty enzymes, including synthetases, oxidoreductases, dehydrogenases, transferases and kinases, necessary for essential plant processes such as energy utilization, starch synthesis, N metabolism and respiration (Wallingford, 1980). Mengel and Kirkby (1987) found that K is the most efficient cation stimulating the enzyme responsible for the synthesis of starch, starch synthase. According to these findings, optimum K nutrition results in a higher concentration of starch in the plant, and in improved crop quality. The high-energy status provided by starch accumulation is important for water stress tolerance as well as cold hardiness (Mengel, 1997).

Numerous studies have demonstrated that K-deficient plants have reduced rates of photosynthesis (Jackson and Volk, 1968) and typically transpire less than unstressed plants (Huber, 1985). K affects photosynthesis in plants by influencing ATP synthesis and photorespiration in the leaves. ATP is required for all synthetic processes of tomato metabolism, resulting in the production of carbohydrates, proteins and lipids as well as secondary metabolites, like vitamin C. All these are important quality parameters of tomato fruit (Huber, 1981).

K, furthermore, balances electric charges needed for photophosphorylation in chloroplasts and serves as the counter-ion to the protons accumulating in the thylakoid membranes (Marschner, 1995).

K plays an important role in the transport of assimilates and nutrients. Photosynthetic products must be transported from the leaves (sources) to the site of their use or storage (sinks). K promotes the phloem transport of such photosynthates, mainly sucrose and amino acids, to the sinks (Mengel, 1997). It is furthermore involved in phloem loading of sucrose, by increasing the transport rate of phloem sap solutes, as well as in phloem unloading (Herlihy, 1989).

Hence, adequate K nutrition increases the protein and starch content of fruits, as well as their vitamin C and total soluble solid content, improves fruit size, colour and flavour, and increases peel thickness. It furthermore reduces physiological disorders (Table 8), enhances storage quality and extends shelf life (Usherwood, 1985).

Table 8: Role of potassium in physiological disorders of tomato (Kinet and Peet, 1997)

Disorder	**Symptoms**	**Cause**
Puffiness	Puffy fruits lack some or all of the gel normally surrounding the seed leaving a gap between the placental tissue and the outer wall of the locule. Externally, fruits are angular rather than round.	Low K in fruit tissue
Blotchy Ripening Complex	Green to greenish-yellow to waxy-white areas occur near the calyx of the otherwise normal, red tomato fruit. In some cases, fruit symptoms are accompanied by foliar symptoms of deficiency.	Low K particularly in low K soils
Greywall	The outer locular wall turns brown or grayish brown and the area may become slightly depressed and roughened. Internally severe browning appears in the outer pericarp, especially in regions associated with vascular bundles.	Promoted by low K levels, increasing the K level reduces incidence of greywall
Gold Fleck or Fruit Pox	Gold specks or flecks are observed around the calyx and shoulders of mature fruit. These specks decrease the attractiveness of fruit and reduce their shelf life.	Excess Ca in the fruits Symptoms can be reduced by increasing the soil K: Ca ratio
Greenback Yellow shoulder	Lack of uniform ripening	Most severe in K-deficient plants

The primary cause of chilling injury to plant leaves seems to be a damage to the plasma membranes, which leads - after some time - to plant desiccation and death (Singer *et al.*, 1999). Applications of a 50mM KCl solution, two days prior to cold exposure, have provided evidence that KCl treatment increases membrane permeability in response to chilling. Chilled plants treated with KCl had a significantly higher chlorophyll content and higher yield than non-treated, chilled plants (Singer *et al.*, 1999).

3.1.1.2 EFFECTS OF K OVER- AND UNDERSUPPLY ON TOMATO GROWTH AND DEVELOPMENT

3.1.1.2.1 K DEFICIENCY

K deficiency expresses itself in tomato plants through bluish-green leaves, appearing similar to an over-supply of nitrogen. K-deficient plants have more slender leaves, shorter internodes, and retarded plant development (von Uexkull, 1979). Nightingale (1943) reported that in potassium deficient plants actively dividing cells are limited to the apical tissue, the region where potassium is found predominantly when external supply is low. The cambial activity decreases so that growth occurs only lengthwise and there is secondary thickening. If fruits are present on the tomato plant under deficient conditions, a large part of the potassium in the plant is transferred to these and the demand of the entire plant for potassium will subsequently exceed the supply. Marginal necrosis and loss of older leaves occur as potassium is translocated from the leaves to the developing fruit. Older leaves tend to be worst affected (Eysinga and Smilde, 1981). Younger leaves have a higher tolerance to potassium deficiency; symptoms appear only at 1% K in the leaf FW, while the value for older plants is 2.0-2.6% K in the leaf FW (Adams, 1982). The younger developing leaves of tomatoes display a wrinkled surface and are warped and turned under (Papadopoulos, 1991). In addition to discolouration of leaves and formation of necrotic areas, potassium deficiency results in a reduction in yield and in the percentage of marketable fruits (Usherwood, 1985).

3.1.1.2.2 K TOXICITY

Potassium toxicity is rare in tomato production because plants do usually not absorb the nutrient excessively (Parsons and McKinziel, 2001). However, very high rates (more than 500ppm in the soil) of potassium may induce Ca or Mg deficiency or high salt damage (Geraldson, 1985). K-induced calcium deficiency can lead to blossom end rot (Imas, 1999). Reductions in yield occur at very high levels of K, when the K: N ratio is very high, or when both N and K are too high (Ohlrogge, 1962). In such cases, the yield reduction is attributed to an increased salinity in the growing medium.

High potassium application, either by banding at planting or application via the transplant water can injure young seedlings and reduce crop yield and quality. The danger of soil application of fertilizer is greater on sands and sandy loams than on silt loam and clay loam soils (Maynard, 1980). On coarse textured sand and sandy loams, part of the K fertilizer should be broadcast and worked into the soil before planting.

Although high K application seems toxic to tomato plants, studies have been reported on the relationship between high dosage of K nutrition and cold hardiness of tomato. Bettie and Flint (1973), working with *Forsythia*, proposed that, "Potassium levels within or above the optimum range for growth are necessary for full development of frost hardiness".

3.1.2 MULCHING OF TOMATO

Mulch is any layer of suitable material, including plant debris, which is applied to, but not incorporated into, the soil (Turney and Mengel, 1994). The purpose of any mulching is to enhance crop growth by changing the soil and air microclimate. This includes manipulation of soil temperature, root environment, water conservation, weed competition, soil texture and structure, and soil biological activity (Swaider *et al*., 1992).

Mulch materials can generally be grouped into two categories: natural (organic) and synthetic (inorganic) mulches (Farias-Larios *et al.*, 1994). Commonly used natural mulches include plant residues such as straw or grass, fresh leaves, corn cobs, shredded or pruned branches, peanut hulls and pine needles, peat, as well as animal manure and wood products such as bark, wood chips and sawdust as well as sugarcane filtercake, sand and gravel (Wilson, 1979; van Niekerk, 2000). The most commonly used synthetic mulches are clear and black polyethylene plastics (Cooper, 1973). Metal foils, paper, and coloured (silvery, green, red, blue) plastic mulches have also been used in some situations.

Different types of mulches may vary in their effect on tomato plant development and production (Ham *et al.*, 1983), especially when the crop is under irrigation (Bhella, 1988; Tindall *et al.*, 1991). Plastic mulches significantly affect soil temperature and other physical factors playing a role in root development (Cooper, 1973). Soil temperature itself affects root extension, branching and diameter. Mulches also enhance crop production through soil and water conservation and weed control, and they improve biological, physical and chemical properties of the soil (Lal *et al.*, 1980).

Generally, the effects of mulching are greatest under adverse environmental conditions (Swaider, 1992). To achieve the desired effect, it is also important to consider the timing of the mulch application. Applying mulch early in the season may not always be effective because it may result in delayed development of tomato plants due to a too low soil temperature, for example, when wheat straw is used as mulch (Shoemaker, 1947). The most suitable time for mulching depends on the nature of the soil and type of mulch. Heavy soils warm up more slowly and will tend to retain moisture better than light soils, and therefore should be covered later in the season. Tomatoes respond most favourably to soil warming mulches applied early in the season (Rubeiz and Freiwat, 1995) as this allows the development of an extensive root system under the protective covering.

3.1.2.1 SPECIAL EFFECTS OF MULCHING

3.1.2.1.1 YIELD

One of the main reasons for using mulch is to promote faster crop development to allow for an earlier harvest and to increase early yields (Perry and Sanders, 1986). Earliness is an economically pressing goal for farmers in temperaturewise marginal climates, such as the highlands of Eritrea, where farmers compete with growers in areas with frost-free climate. Furthermore, yield increases with mulching in tomatoes are due to an increase in soil temperature, the conservation of soil moisture or of soil fertility (Iguchi, 1977; Rowe, 1957). The increase in soil temperature as a result of mulching is due to the suppression of latent heat loss through evaporation (Ashworth and Harrison, 1983). The extent of this increase in soil temperature, on the other hand, depends on the type and colour of mulch material and the intensity of solar radiation (Tindall *et al.*, 1991).

3.1.2.1.2 WEED CONTROL

Mulching can control weed growth effectively, thereby reducing the necessity for herbicide application. When black, silvery, red, or blue mulch is used, very little weed growth occurs under the mulch (Turney and Mengel, 1994). These mulches either prevent light penetration to the soil to such an extent that chlorophyll production in seedlings under the mulch is inhibited or they exclude certain wavelengths necessary for plant germination and growth (Iguchi, 1977). Black polyethylene film gives effective weed control by cutting solar radiation by more than 90%, resulting in etiolated growth and eventually death of weeds under the film (Djigma and Diemkouma, 1986). Stephen and Harrison (1983), on evaluating mulches for the use in home gardens, found that black polyethylene, woven polypropylene and “heavy-duty” green plastic mulches remained intact throughout the tomato-growing season and, thus, provided the most effective weed control. The germination of many annual weed species can also be prevented by application of organic mulches such as composted mulch to bare soil surfaces (Al-Assir *et al.*, 1992). Mulches applied around growing plants or prior to seedling development should provide 100% ground cover. The thickness of the mulch should be adequate to prevent emergence of targeted weeds.

3.1.2.1.3 SOIL MOISTURE/ SOIL CRUSTING

Mulching affects various soil hydrological properties and processes that result in reduced evaporation from the soil, reduced run-off and erosion, increased permeability of the soil surface to air and water, and increased soil water-holding capacity (van Niekerk, 2000). The soil moisture content of bare soil in tomato fields fluctuates with rainfall. Bare soil may become unstable through soil aggregate breakdown resulting in soil crusting on the unprotected soil surface. Crusting decreases the infiltration rate of the soil, resulting in high run-off and erosion on sloping land (Tisdall, 1989). Therefore, mulching maintains a more uniform soil moisture regime allowing the irrigation frequency to be reduced (Gallardo-Laro and Nogales, 1987).

3.1.2.1.4 PESTS AND DISEASES

Mulch reduces rain-splashed deposits of soil as well as the spread of disease organisms. Reflective mulches can also reduce the incidence of diseases and insect pests. The silver colour acts as a repellent to aphids (Nishitani, 1979).

Mulching, furthermore, helps to control root diseases and nematodes. Turney and Mengel (1994) argued that this control can be due to the following effects: increased populations of soil organisms which compete with or inhibit fungal pathogens, reduction in toxin production such as saponins and organic acids, increase in host resistance by induced phytoalexin production by the crop, and creating a better environment for root growth by enhancing aeration and drainage. Furthermore, the soil temperature achieved by mulching may not be suitable for development of diseases or pests (van Niekerk, 2000).

Whilst no attempt has been made to encompass all aspects of the benefits of mulching, this brief overview has shown that there are many advantages of mulching. Nevertheless, a few potential problems also exist.

3.1.2.2 DISADVANTAGES OF MULCHING

3.1.2.2.1 COSTS

Depending on the type of mulch used, both, the application of the mulch, which includes labour and/ or machinery, and the mulch itself might be costly (Turney and Mengel, 1994).

3.1.2.2.2 DISPOSAL

The biggest problems associated with plastic mulches are their removal and disposal. Since these mulches are not biodegradable, they must be removed from the field after the cropping season. The most common method is removal by hand, which involves cutting the mulch down the centre of the row and pulling it to each side and out of the ground. In Roma tomatoes this is done before the strings are burned, and the plants are dropped onto the mulch. The heat of burning these strings ruins the integrity of the mulch and would make it difficult to pull the mulch up. There are machines available for mulch lifting and removal, but these usually require that the crop is removed first and the rows are reasonably clean (Tindall, 1993).

3.1.2.2.3 UNFAVOURABLE MICROCLIMATE

Excess moisture may accumulate under fine textured mulches, organic and inorganic. Also, mulches used over poorly drained soils can result in nitrogen loss (denitrification), since some mulches are tilled into the soil before planting a new crop, and therefore may have a negative effect on soil fertility and soil chemistry. In the short term, mulches may decrease nitrogen availability for a given crop. A mulch material that has a high carbon content and is very low in nitrogen and other nutrients may temporarily "bind" or immobilize plant-available nitrogen. This occurs because soil microorganisms use available nitrogen to metabolise and decay the organic material. The immobilized organic nitrogen can be made available (mineralised) later as the organic matter continues to decompose (Nishitani, 1979). Excess moisture and oxygen deficiency are major problems under plastic mulches. If plastic mulches are used, they must have holes to allow for sufficient gas exchange.

Mulches that reflect light and heat can also radiate an amount of heat sufficient to injure plants. Dark-coloured mulches can absorb solar radiation during the day and radiate heat in the evening. These mulches can stress plants and increase energy needs for transpiration (Bhargava *et al.*, 1993).

3.1.3 AIM OF RESEARCH

Potassium has been found to play a number of indispensable roles in tomato production (Wallingford, 1980; Usherwood, 1985; Marschner, 1995). The multiple functions of K in a variety of metabolic processes explain the necessity of adequate K fertilization to increase root growth, improve drought resistance, reduce water loss and wilting, enhance cold hardiness and improve resistance to pests and diseases. In addition to adequate K supply, mulching promotes healthy, even root growth which will not only ameliorate stressful conditions for root development and function but also alleviate stressful growing conditions (such as low temperature) for the plant as a whole. A study on cold tolerance of tomatoes, without considering both, K fertilization and mulching, would therefore be incomplete. Thus, an attempt was made to separately investigate the effects of various levels of soil K applications, and the effects of different mulches on cold tolerance of "Rossol" tomatoes.

3.2 MATERIALS AND METHODS

3.2.1 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON COLD TOLERANCE OF *Lycopersicon esculentum* var. "ROSSOL"

3.2.1.1 LOCATION OF EXPERIMENTAL SITE

The experiment was undertaken using a glasshouse and a new 30% shadecloth structure near the Faculty of Science and Agriculture, University of Natal, Pietermaritzburg, South Africa (refer to section 2.2.1 for details).

Over the experimental period, meteorological equipment was used for monitoring environmental conditions. For the duration of the experiment, the temperature in the greenhouse ranged from 21 to 35°C during the day and from 9 to 16.5°C at night. Irradiance levels ranged from 140 to 185μmolm^{-2}s^{-1} during the morning, from 330 to 650μmol•m^{-2}•s^{-1} during midday and from 560 to 910μmol•m^{-2}•s^{-1} during the afternoon. Maximum and minimum average daily irradiances were 760 and 430μmol•m^{-2}•s^{-1}, respectively.

The black shadecloth (30%) was a kit form, pitched-roof, mansard shape, and movable design mounted on a wooden frame. The structure was held under tension by means of 10mm diameter wood attached to stays and anchors in the ground. Temperature recorded at plant height ranged from 12.5 to 26.5°C (min-max) during the day and 3.5 to 11.5°C (min-max) during the night. Irradiance levels recorded ranged from 180 to 375μmol•m^{-2}•s^{-1} during the morning and from 820 to 1210μmol•m^{-2}•s^{-1} during the afternoon. Maximum and minimum average daily irradiances were 820 and 530μmol•m^{-2}•s^{-1}, respectively.

3.2.1.2 PLANT MATERIAL

"Rossol" tomato seeds were germinated in 24-celled Speedling® trays filled with composted pine bark and placed in a tunnel near the Faculty of Science and Agriculture, University of Natal. Seedlings were irrigated by microjet sprinklers three times a day for 300 seconds and received 1g of triple superphosphate per plant, twice a week as fertigation to improve foliage colour. Air-temperature in the tunnel during the seed germination and early growth period till transplanting ranged from 14 to 29.5°C. The plants were kept in the tunnel until they were fully established (23 days) and 64 vigorous and healthy seedlings were selected for transplanting thereafter. These seedlings were transplanted into 250mm diameter plastic pots when they had reached the two true-leaves stage. Eleven days after transplanting, on March 2, 2001, when the seedlings were fully established, they were divided into two groups of 32 seedlings each. One group was placed outside, under the black shadecloth (30%) structure and the other group was taken to a glasshouse, where temperature during the experiment ranged from 21 to 35°C during the day and from 9 to 16.5°C during the night. The plants kept under shadecloth were subjected to low temperature conditions, as they were experiencing outside winter conditions from May 12, 2001 to July 21, 2002.

3.2.1.3 STANDARD MANAGEMENT

Two soil types (clay loam: sand (2:1) and sand: composted pine bark (4:1)) were used for the experiment. Clay loam: sand (2:1) is the best-suited soil for tomato cultivation under optimum environmental conditions in KwaZulu-Natal (Askew, 1996). The clay loam was obtained from Ukulinga Research Farm of the University of Natal, Pietermaritzburg. Composted pine bark: sand (1:3) has a higher temperature retaining capacity than clay loam: sand (2:1) (Savage, 1978) and may therefore allow the tomato plant to tolerate cooler growing conditions better. A basal application of 100kg/ha N as urea and of 50kg/ha Ca as $CaSO_4$ were given to the plants monthly, based on soil test results from the Cedara Computerized Advisory Service (FERTREC). Cultural practices including irrigation and application of pesticides and insecticides were carried out as described in Section 2.2.3.

3.2.1.4 EXPERIMENTAL DESIGN AND LAYOUT

The experiment was laid out in a randomised complete block design within each environment (tunnelhouse and shadecloth (30%)) with four replications and one plant per replication. Four K levels and two soil types, and, thus, eight treatments per replication were employed in both environments (Table 9).

3.2.1.5 APPLICATION OF POTASSIUM

Potassium was applied at rates of 52.5kg, 105kg, 157.5kg and 210kg of total K per hectare in the form of K_2SO_4 and KNO_3 (1:1) to plants in both growing conditions. K_2SO_4 was given to tomato plants in order to fulfil the sulphur requirements, to minimize the effect of nitrogen and to maintain a high K availability in the soil. The applied K levels were based on FERTREC recommendation. Applications were split as 1/3 at transplanting, 1/3 at first flowering and 1/3 at first fruit set.

Table 9: Experimental layout to determine effect of K level and soil temperature on vegetative and reproductive development of tomato (identical in both plots)

REP1	**REP2**	**REP3**	**REP4**
S1K1	S1K3	S1K2	S2K2
S2K3	S2K1	S2K2	S1K4
S1K2	S2K4	S1K1	S1K2
S2K1	S2K2	S2K4	S2K3
S1K4	S1K1	S1K3	S1K3
S2K2	S2K3	S1K4	S2K4
S2K4	S1K2	S2K3	S1K1
S1K3	S1K4	S2K1	S2K1

↓
N

Recommended soil K for S1 and S2 were 105 kg/ha and 95 kg/ha respectively.

S1= Clay: sand (2:1) **S2**= Sand: composted pine bark (4:1)

K1= 50% of recommended K level (RKL) **K2**= 100% of recommended K level (RKL)

K3= 150% of recommended K level (RKL) **K4**= 200% of recommended K level (RKL)

3.2.2 EFFECTS OF MULCHING ON COLD TOLERANCE OF *Lycopersicon esculentum* var. ROSSOL

3.2.2.1 PLANT MATERIAL

"Rossol" tomato seeds were sown into 24-celled Speedling® trays containing moist composted pine bark. Trays were placed in a tunnel with average day and night temperatures of 24/16°C, near the Faculty of Science and Agriculture, University of Natal, Pietermaritzburg on May 3, 2002. The seedlings were allowed to grow to the two true-leaf stage in the tunnel and transplanted on May 24, 2002 into a field at the Ukulinga Research Farm. Germination conditions provided as well as transplanting were carried out according to recommendations by Askew (1996). The entire field was irrigated 30 minutes after transplanting using an automated pivot sprinkler system.

Pietermaritzburg is described as a cool, subtropical, summer rainfall area (Wolstenholme, 1977). The average annual rainfall, according to the Pretoria Weather Bureau, is 733.2mm, with the main period of rain from September to April. The maximum monthly rainfall occurs in January. During winter (May to August), rainfall averages approximately 20mm per month. Rain can be expected on approximately 109 days per annum (Mills, 1990).

According to the meteorological records of the Pretoria Weather Bureau, the mean monthly temperature at the nearby Ukulinga Agricultural Research Station is 18.3°C with 23.7°C and 13.0°C mean monthly maximum and mean monthly minimum respectively. The highest and lowest recorded temperatures in the area are 40°C and 1°C, respectively. Savage (1982a), however, has recorded that there are approximately 13 days of frost per annum at the experimental site.

The relative humidity is higher in the rainy months and the weather is drier in winter. In summer, average monthly maximum and average monthly minimum humidity are approximately 90% and 50% respectively, while in winter corresponding values are approximately 70% and 30%.

3.2.2.2 STANDARD MANAGEMENT

The seedlings were raised in composted pine bark and transplanted into a field at the Ukulinga Research Station. The mineral composition of the soil is presented in table 10.

Table 10: Mineral composition of topsoil (20cm) of the experimental field (Cedara Computerized Advisory Services, Pietermaritzburg, South Africa)

P (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Exchangeable Acidity (cmol/L)	Total cations (cmol/L)	Acid saturation (%)	pH (KCl)	Zn (mg/L)	Mn (mg/L)	Clay %
88	554	3194	1216	0.20	27.56	1	5.94	9.8	4	54

Therefore, 200kg•ha^{-1} N, 40kg•ha^{-1} P and 0kg kg•ha^{-1} K were recommended to be applied. Prior to covering the beds with mulches, 67kg•ha^{-1} N was applied as urea and ammonium nitrate (1:1) and 40 kg•ha^{-1} P as single super phosphate. The fertilizer was disked into the top 0.20m of the soil. This application comprised 100% of the P and 33% of the N fertilizer recommended for application during the growing season. The remaining N was applied manually in two split dressings, 67kg•ha^{-1} N at first flowering and further 67kg•ha^{-1} N at first fruit set.

Seedlings were transplanted into 10cm-diameter holes in a single row in the centre of mulched and unmulched beds. Irrigation was applied via a dripper system underneath the mulch three times a day for 300 seconds each. Standard cultural and pesticide application practices for commercial tomato production, including staking, were followed as described by Askew (1996). Hand weeding was carried out when required.

3.2.2.3 APPLICATION OF MULCH

After land preparation had been completed, the beds, except for the unmulched (control) one, were covered either with black plastic (B) or maize stover (M) mulch. The black plastic mulch was anchored using U-shaped wire pins and the maize stover mulches was spread to a 5cm thick layer.

3.2.2.4 EXPERIMENTAL DESIGN AND LAYOUT

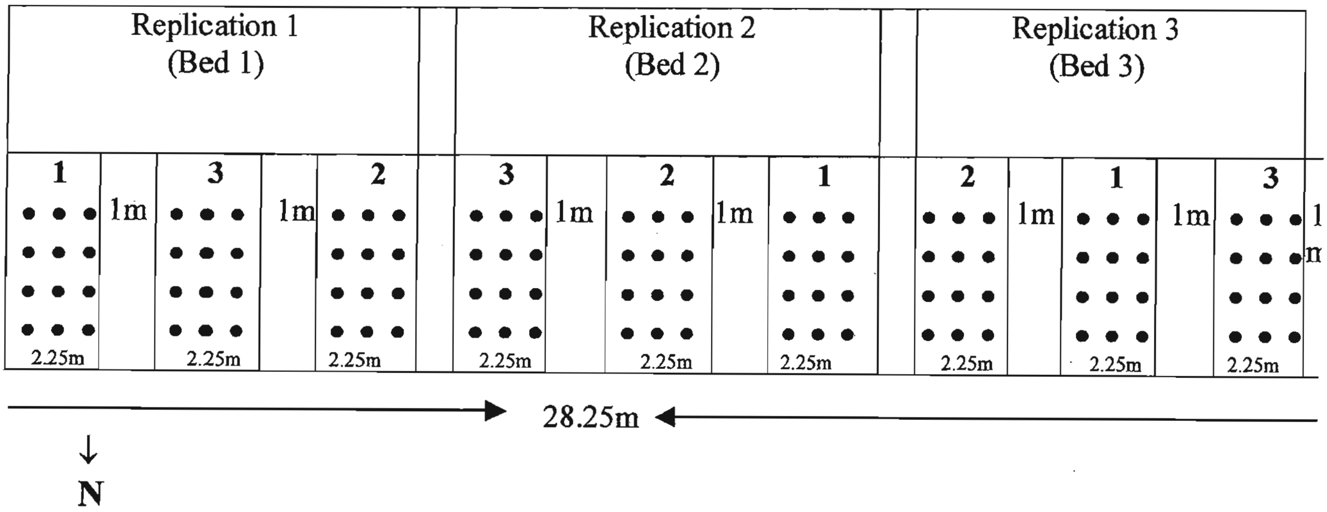
The field measuring 4 × 28.25m had three beds of 4 × 8.75m marked equidistantly. One-meter alleyways separated adjacent beds. Each bed had three treatments (unmulched, maize stover and black plastic mulch) randomised along it. Treatments were arranged in a randomised complete block design with three replicates. Each treatment consisted of twelve plants spaced 1m by 0.75m and the six plants at the centre (lengthwise) were used for data collection (Table 11). The beds were irrigated by drip irrigation with lines 75cm apart.

3.2.3 DETERMINATION OF MORPHOLOGICAL, PHENOLOGICAL AND PHYSIOCHEMICAL CHARACTERISTICS

3.2.3.1 MORPHOLOGICAL AND PHENOLOGICAL CHARACTERISTICS

Plant height, internode length, number of nodes below the first inflorescence, days to first anthesis, days to first fruit set, days to first harvest, yield per plant, number of fruits per plant, fruit size and marketable percentage of harvested fruits were determined as described in Section 2.2.6.

Table 11: Experimental layout of mulching trial



1 Denotes Unmulched (Control) (U)

2 Denotes Black polyethylene mulch (B)

3 Denotes Maize stover mulch (M)

3.2.3.2 PHYSIOCHEMICAL CHARACTERISTICS

3.2.3.2.1SPECTROPHOTOMETRIC DETERMINATION OF TOTAL CAROTENOID CONCENTRATION

3.2.3.2.1.1 PIGMENT EXTRACTION

All extraction and purification procedures were carried out at low temperature and reduced light intensity to avoid photo-oxidation and isomerisation of the compounds of interest. Gross (1987) found that the high degree of unsaturation in carotenoids renders the compounds heat and light sensitive.

Freeze-dried samples of about 25g which had been stored in airtight containers in a deep freezer, were thawed in the storage containers, weighed and homogenized to a powder after adding a small amount of liquid nitrogen. Dried samples were milled in a bench top mill (Analysenmuehle A 10, Janke and Kunkel, IKA Labortechnik, Staufen, Germany) and stored at -20°C, until required.

In order to find the most efficient solvent for carotenoids extraction from "Rossol" tomatoes, a number of solvents were evaluated (Table 12). One g of the sample was homogenized in 10ml solvent. The homogenates were centrifuged for 5min at 3800rpm in a Hermle Z510 centrifuge (Hermle, Gosheim, Germany). The carotenoid containing supernatant was removed and the extraction process repeated with the remaining pellet to ensure complete extraction of carotenoids. Extracts were then pooled and subjected to spectrophotometric analysis. As extraction with 95% ethanol (v/v) gave the highest carotenoid concentration of a pooled sample, this solvent was used for sample extraction (Table 12).

Table 12: Comparative efficiency of various solvents for carotenoid extraction

Solvent for extraction	Carotenoid content of given sam (μg β-carotene•g DW^{-1})
Methanol (MeOH)/chloroform (2:1, v/v)	84.37 ± 0.36
90% aqueous ethanol (v/v)	91.67± 0.27
95% aqueous ethanol (v/v)	92.78± 0.13
80% acetone (v/v)	82.40 ± 0.16
100% methanol (v/v)	87.54 ± 0.48

3.2.3.2.1.2 SPECTROPHOTOMETRIC ANALYSIS

The carotenoid concentration in tomato tissue was determined spectrophotometrically at 470, 649, and 664nm as described by Lichtenthaler (1987) using a Beckman DU-65 spectrophotometer (Beckman Instruments Inc., Fullerton, CA, USA). Absorbance values were computerized to calculate the concentrations of chlorophyll *a* (C_a), chlorophyll *b* (C_b), total chlorophylls (C_{a+b}) and total carotenoids (C_{x+c}) using the following equations:

$Ca = 13.36A_{664} - 5.19A_{649}$ $\qquad$ $C_b = 27.43A_{649} - 8.12A_{664}$

$C_{a+b} = 5.24A_{664} + 22.24A_{649}$ $\qquad$ $C_{x+c} = \dfrac{1000A_{470} - 2.13C_a - 97.64C_b}{209}$

Pigment concentrations obtained were expressed as μg•ml^{-1} plant extract solution (equivalent to μg• (g DW)$^{-1}$).

3.2.4 STATISTICAL ANALYSIS

Results from the experiments were analysed for significant difference between treatments using GENSTAT 5 (4.1 Release, 4th Edition, © Lawes Agricultural Trust IACR-Rothamsted).

3.3 RESULTS

3.3.1 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON COLD TOLERANCE OF *Lycopersicon esculentum* var. ROSSOL

Because there was no significant effect of the two soil types on any of the parameters in this experiment, a location•potassium level two-way ANOVA was used for analysis, instead of location•potassium level•soil type, three-way ANOVA.

3.3.1.1 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON PLANT HEIGHT AND INTERNODE LENGTH

Generally, plants in the greenhouse were significantly taller ($p < 0.05$) than those under the shadecloth (Table 13). In the greenhouse, varying levels of potassium applied to the soil did not have any significant effect on the growth (determined as final plant height) of tomato plants (Table 13). Similarly, there was no evidence of any significant differences in internode length due to the different amounts of potassium supplied to plants grown under greenhouse conditions (Table 13). Under the 30% black shadecloth, however, plants supplied with 150% RKL and with 100% RKL were significantly taller compared to those supplied with 50 and 200% RKL. Similarly, under 30% shadecloth, the internode length of plants supplied with 100% RKL and 150% RKL was significantly extended ($p < 0.05$) compared to those supplied with 50% RKL and 200% RKL (Table 13). The internode length of plants kept in the greenhouse tended to be greater than of those kept under shadecloth.

Table 13: Effect of soil K fertilization on plant height and internode length of "Rossol" tomatoes under greenhouse and field conditions

Treatment	Greenhouse Plant height at harvest (cm)	Greenhouse Internode length at harvest (cm)	Field (Shadecloth) Plant height at harvest (cm)	Field (Shadecloth) Internode length at harvest (cm)
K1	121.3^a	5.96^a	101.0^a	5.38^a
K2	122.8^a	6.01^a	116.5^b	5.88^b
K3	122.4^a	6.00^a	117.3^b	5.90^b
K4	121.7^a	5.98^a	100.5^a	5.28^a
LSD	2.72	0.32	3.24	0.21
CV%	4.76	3.20	5.77	5.93

- Means within the same column followed by different letters denote significant differences at 5% probability level
- K1, K2, K3 and K4 denote 50%, 100%, 150% and 200% of the recommended soil K levels (RKL)

3.3.1.2.1 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON NODES BELOW FIRST INFLORESCENCE

Varying the soil K fertilization level did not have any significant effect ($p < 0.05$), in either location, on the number of nodes below the first inflorescence (Table 14). However, plants kept in the greenhouse tended to have a higher number of nodes below the first inflorescence than those grown under field conditions (Table 14).

Table 14: Effect of soil K fertilization on number of nodes below first inflorescence, time to first anthesis, first fruit set and first mature fruit of "Rossol" tomatoes under greenhouse and field conditions

	Greenhouse				Field (Shadecloth)			
Treatment	Nodes below 1st inflor.	Days to anthesis	Days to fruit set	Days to maturity	Nodes below 1st inflor.	Days to anthesis	Days to fruit set	Days to maturity
K1	8.5^{a}	19.3^{a}	47.0^{a}	80.3^{a}	7.0^{a}	23.5^{a}	53.0^{a}	88.5^{a}
K2	9.0^{a}	20.5^{a}	47.5^{a}	79.7^{a}	7.5^{a}	22.5^{a}	52.0^{a}	87.5^{a}
K3	9.0^{a}	20.0^{a}	46.7^{a}	80.0^{a}	7.5^{a}	23.0^{a}	52.0^{a}	88.0^{a}
K4	8.5^{a}	19.3^{a}	47.5^{a}	80.5^{a}	7.7^{a}	23.5a	54.0^{a}	88.0^{a}
LSD	1.21	1.43	1.57	2.11	1.12	1.21	2.18	2.37
CV%	3.67	4.87	4.56	4.89	4.43	5.48	5.98	4.62

- Means within the same column followed by different letters denote significant differences at 5% probability level
- K1, K2, K3 and K4 denote 50%, 100%, 150% and 200% of the recommended soil K levels (RKL)

3.3.1.3 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON TIME TO FIRST ANTHESIS, FIRST FRUIT SET AND FIRST MATURE FRUIT

Plants grown in the greenhouse flowered, bore fruits and reached maturity significantly earlier ($p < 0.05$) than those in the field (Table 14). On average, greenhouse plants flowered 3.2 days, set fruit 5.6 days and matured 7.8 days earlier than plants in the field.

Varying levels of soil K fertilization, however, did not have any significant effect ($p < 0.05$) on the time when plants reached the above three developmental stages in either location (Table 14).

3.3.1.4 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON YIELD ATTRIBUTES

Although “Rossol” tomato plants grown in the greenhouse produced significantly higher ($p < 0.05$) yields than those grown under field conditions yields varied with varying K levels, in both locations. In the greenhouse K-deficient plants (K1) produced the lowest yield per plant, similar to that of plants supplied with 200% RKL. Plants supplied with 100% RKL and 150% RKL produced the highest yield per plant under greenhouse conditions (Table 15). Under cold field conditions, however, plants supplied with 150% RKL produced the highest yield per plant followed by those supplied with 100% RKL, which yielded significantly better than those supplied with 200% and 50% RKL (Table 15).

Table 15: Effect of soil K fertilization on yield per plant, number of fruits per plant, fruit size and percentage marketable fruits of “Rossol” tomatoes under greenhouse and field conditions

	Greenhouse				Field (Shadecloth)			
Treatment	Yield (g/ plant)	No. of fruits per plant	Fruit size (g)	Marketable fruit (%)	Yield (g/ plant)	No. of fruits per plant	Fruit size (g)	Marketable fruit (%)
K1	5986^a	32.5^a	184.2^a	59.5^a	5775^a	32.5^a	177.7^a	54.5^a
K2	6306^b	32.0^a	197.1^b	72.0^b	6039^b	32.0^a	188.7^b	81.0^c
K3	6292^b	32.0^a	196.6^b	71.0^b	6122^c	31.5^a	194.3^b	78.0^c
K4	5999^a	32.0^a	184.5^a	70.5^b	5778^a	32.0^a	180.6^a	66.0^b
LSD	70.4	2.09	5.31	2.13	70.2	2.11	5.69	5.03
CV%	5.36	5.12	4.09	4.67	4.36	5.73	6.02	4.87

- Means within the same column followed by different letters denote significant difference at 5% probability level
- K1, K2, K3 and K4 denote 50%, 100%, 150% and 200% of the recommended soil K levels (RKL)

The number of fruits per plant was not significantly affected by either location or soil K fertilization level (Table 15). Fruit size of plants supplied with 100% RKL and 150% RKL was, in both locations, significantly higher ($p < 0.05$) compared to those supplied with 50% RKL and 200% RKL (Table 15). Compared to tomato plants under shadecloth, those grown in the greenhouse tended to have a greater fruit size (Table 15).

Plants, which were grown under greenhouse conditions, tended to have a higher the percentage of marketable fruits than those grown in the field (shadecloth) (Table 15). Furthermore, varying the K fertilization levels had a significant effect on the percentage of marketable fruits under greenhouse and field conditions. In plants supplied with 100% RKL and 150% RKL the highest proportion of fruit was marketable under both conditions. Furthermore, plants supplied with 50% RKL gave the least percentage of marketable fruits under both conditions. Although the application of 200% RKL did not affect the percentage of marketable fruit under greenhouse conditions, it resulted in a reduction of the percentage of marketable fruit under field conditions.

3.3.1.5 EFFECTS OF VARYING POTASSIUM FERTILIZATION LEVELS ON TOTAL CAROTENOID AND CHLOROPHYLL CONCENTRATIONS

Under greenhouse as well as under field conditions, carotenoids showed the tendency to increase during ripening. At either, the green or the red stage of maturity, increasing the K fertilization levels of plants grown in the field increased the fruit carotenoid concentration, i.e., fruits from tomato plants supplied with 200% RKL had the highest carotenoid concentration, followed by those supplied with 150% and 100% RKL. Under greenhouse conditions this trend was also established, with the exception of the 200% RKL level, which did not result in fruit carotenoid concentrations significantly different from those fertilized with 150% RKL.

Table 16: Effect of soil K fertilization on carotenoid (μg•g^{-1}) concentration of "Rossol" tomatoes fruit at the green and red stages of plants kept under greenhouse and field conditions

	Greenhouse		Field (Shadecloth)	
Treatment	Green	Red	Green	Red
K1	71.84 ± 7.64^a	74.38 ± 7.90^a	71.23 ± 7.57^a	74.13 ± 7.71^a
K2	73.45 ± 6.60^b	76.61 ± 7.89^b	73.18 ± 7.23^b	75.42 ± 7.66^b
K3	76.65 ± 6.23^c	78.23 ± 8.00^c	75.21 ± 6.73^c	77.63 ± 7.98^c
K4	77.21 ± 6.12^c	79.02 ± 8.04^c	76.96 ± 6.72^d	78.89 ± 8.05^d
LSD	1.12	1.09	0.89	1.03
CV%	5.36	4.82	3.02	4.87

- Means within the same column followed by different letters denote significant differences at 5% probability level
- K1, K2, K3 and K4 denote 50%, 100%, 150% and 200% of the recommended soil K levels (RKL)

In both locations, increasing soil K levels also increased the chlorophyll concentration significantly, when the fruits were at the green stage, and decreased it when the fruits were red-ripe (Table 17).

Table 17: Effect of soil K fertilization on chlorophyll ($\mu g \bullet g^{-1}$) concentration of "Rossol" tomatoes at the green and red stages of plants kept under greenhouse and field conditions

	Greenhouse		Field	
Treatment	Green	Red	Green	Red
K1	43.33 ± 3.40^{a}	48.11 ± 4.4^{a}	46.12 ± 4.37^{a}	48.78 ± 4.46^{a}
K2	47.24 ± 4.60^{b}	46.56 ± 4.16^{b}	48.34 ± 3.83^{b}	46.56 ± 4.43^{b}
K3	49.81 ± 5.11^{c}	43.21 ± 3.91^{c}	49.78 ± 3.73^{c}	45.23 ± 4.12^{c}
K4	52.02 ± 6.12^{d}	40.45 ± 3.18^{d}	52.56 ± 3.62^{d}	44.36 ± 3.98^{d}
LSD	1.82	1.73	1.37	1.71
CV%	4.24	4.78	4.36	4.71

- Means within the same column followed by different letters denote significant differences at 5% probability level
- K1, K2, K3 and K4 denote 50%, 100%, 150% and 200% of the recommended soil K levels (RKL)

3.3.2 EFFECTS OF MULCHING ON COLD TOLERANCE OF *Lycopersicon esculentum* var. ROSSOL

3.3.2.1 EFFECTS OF MULCHING ON REFLECTED LIGHT

Light reflectance from the mulches was measured on June 1, 2001, two weeks after transplanting. At this time, plants were not large enough to influence or shade each other. The PPFD (photosynthetic photon flux density) from the mulches were similar; but, as expected, 85% lower than sky radiation. Thus, there were no significant differences among the mulches in reflected light.

3.3.2.2 EFFECTS OF MULCHING ON SOIL TEMPERATURE

The minimum soil temperature (at 10cm depth) over this period generally occurred between 6 and 7AM and, although there were significant differences among the mulches, the difference was less than 5°C, with plastic mulch producing the highest daily minimum temperature (Table 18). At the time of transplanting all mulches produced a minimum soil temperature greater than 12°C.

Table 18: Average maximum and minimum monthly soil temperatures at 10cm depth at the study site during the cold period

	Average monthly temperature (°C)					
	May		June		July	
Treatment	Max.	Min.	Max.	Min	Max.	Min.
Bare soil	34.2^{b}	22.8^{b}	32.8^{b}	23.1	30.0^{b}	21.4^{b}
Maize stover	32.6^{a}	21.7^{a}	31.4^{a}	21.6	28.4^{a}	19.6^{a}
Black plastic mulch	39.3^{c}	25.3^{c}	38.7^{c}	25.1	38.0^{c}	23.3^{c}
LSD	0.97	0.94	1.14	1.63	1.21	1.18
CV%	3.36	3.42	3.61	3.51	3.12	3.09

- Numbers within the same column followed by different letters denote significant differences at 5% probability level

Maximum daily soil temperatures occurred between 4 and 5PM and differences among the mulches were highly significant. Average monthly temperatures, for the three months, for bare soil, maize stover and black plastic mulches were 31.0, 32.5 and 38.5 °C, respectively. As expected, plastic mulches showed a 7.5°C soil temperature increase compared with maize stover (38.5°C vs 31.0°C) and a 6°C increase over the control (38.5°C vs 32.5°C) (Table 18).

3.3.2.3 EFFECTS OF MULCHING ON PLANT HEIGHT, INTERNODE LENGTH AND NUMBER OF NODES BELOW FIRST INFLORESCENCE

Tomato plant height at harvest was significantly affected by mulch treatment (Table 19). Plants mulched with maize stover were significantly shorter than those planted into bare soil and the latter were significantly shorter than those mulched with plastic materials. Similarly, there was a significant difference in internode length between plants mulched with maize stover and the other two treatments (Table 19).

Table 19: Effects of mulching on plant height, internode length and number of nodes below first inflorescence of "Rossol" tomatoes

Treatment	Plant height (cm)	Internode length	Number of nodes below 1st inflorescence
Bare ground	108.75^b	6.12^b	8.5^a
Maize stover	105.25^a	5.54^a	8.0^a
Black plastic mulch	111.50^c	6.51^b	8.5^a
LSD	2.11	0.53	1.23
CV %	0.36	1.01	1.11

- Means within the same column followed by different letters denote significant differences at 5% probability level

3.3.2.4 EFFECTS OF MULCHING ON NUMBER OF DAYS TO FIRST ANTHESIS, FIRST FRUIT SET AND FIRST HARVEST

Mulching with black plastic speeded up plant development, so that these plants reached anthesis, fruit set and fruit maturity first (Table 20). Mulching with maize stover, on the other hand, delayed first flowering and the development of the first mature fruit compared to tomato plants grown with black plastic or in bare soil. Application of maize stover resulted in the appearance of the first flower 23.5 days from sowing, whereas control plants and those planted into black plastic mulch began flowering earlier, on average 21 days and 17.5 days after sowing, respectively (Table 20). A significant difference was also observed in days to first fruit set. Plants in black polyethylene mulch reached the fruit set stage significantly earlier (49 days after transplanting) than those planted into bare soil (56 days) and plants covered with maize stover (59 days) (Table 20). This advantage in early development was still detectable when the first fruit matured, as plants in black plastic mulch bore the first red-ripe fruit significantly earlier than those grown in bare soil and those grown with maize stover.

Table 20: Effect of mulching on number of days from transplanting to first anthesis, first fruit set and first mature fruit of "Rossol" tomatoes

Treatment	Number of days to 1st anthesis	Number of days to 1st fruit set	Number of days to 1st harvest
Bare soil	21.0^{b}	56.0^{b}	91.5^{b}
Maize stover	23.5^{c}	59.0^{b}	101.0^{c}
Black plastic mulch	17.5^{a}	49.0^{a}	86.5^{a}
LSD	2.11	3.13	5.43
CV %	1.46	3.01	3.61

- Means within the same column followed by different letters denote significant differences at 5% probability level

3.3.2.5 EFFECTS OF MULCHING ON YIELD PER PLANT, NUMBER OF FRUITS PER PLANT, FRUIT SIZE AND PERCENTAGE OF MARKETABLE FRUITS

The effect of both mulches on all determined yield attributes of "Rossol" tomato plants were significant (Table 21). Yield improved 1.09 times under the black plastic mulch compared to maize stover treatment, and 1.16 times with maize stover treatment over the unmulched soil (Table 21). The difference in yield between black plastic mulch and maize stover was also significant ($p < 0.05$) (Table 21).

Although the number of fruits per plant was not significantly different between the mulch treatments, control plants bore a significantly lower number of fruit compared to plants of the two mulch treatments. On average, there was a difference of 3.7 fruits per plant between control and black plastic mulch treatments, and 3.4 fruits between control and maize stover treatments (Table 21).

Fruit size was also significantly affected by the application of mulches. Plants under black plastic mulch averaged 181g per fruit, while plants under maize stover and in unmulched soil averaged 178g and 145g, respectively (Table 21).

Of plants grown under black plastic mulch 87.2% of the harvested fruits were suitable for marketing, which was not significantly different from 83.6% for plants under maize stover (Table 21). Plants in unmulched soil, however, had a 20% lower ($p < 0.05$) (67.3%) percentage of marketable fruits (Table 21).

Table 21: Effects of mulching on yield per plant, number of fruit per plant, fruit size and percentage of marketable fruits of "Rossol" tomatoes

Treatment	Yield per plant (g)	Number of fruit per plant	Fruit size (g)	Marketable fruit (%)
Bare soil	5386.50^{a}	29.3^{a}	145.4^{a}	67.3^{a}
Maize stover	6234.50^{b}	32.7^{b}	177.7^{b}	83.6^{b}
Black plastic mulch	6824.00^{c}	33.0^{b}	181.0^{b}	87.2^{b}
LSD	432.11	2.43	5.43	4.86
CV %	6.36	4.01	3.61	5.11

- Means within the same column followed by different letters denote significant differences at 5% probability level

3.4 DISCUSSION AND CONCLUSIONS

Potassium fertilization had a significant effect on both, vegetative as well as reproductive, characters of "Rossol" tomatoes developing under low temperature winter conditions. The effect, however, was more pronounced on reproductive than on vegetative parameters. The impact of varying soil K fertilization levels on plant growth was evaluated by measuring height and internode length of plants at various developmental stages. These characteristics provide a good indication of the plant growth rate and have previously been used to identify differences among treatments, including differences in plant nutrition (Balliu and Ibro, 1998). According to these authors varying the level of K does not have any significant effect on the plant growth rate under greenhouse conditions. Similar results were reported by other authors (Mengel and Kirkby, 1987; Marschner, 1990; Mengel, 1992). Balliu and Ibro (1998) also did not find any significant role of K application on plant height or internode length. This absence of response of plant height and internode length to K fertilization under optimal greenhouse growing conditions indicates that these plant characteristics are shaped by factors unrelated to soil K fertility. Under outside, low temperature conditions, however, increasing the soil K level to the recommended amount as well as to 150% of the recommended soil K level increases vegetative development (height and internode length) of tomato plants (Table 13). Similar results were obtained when levels of K fertilization of alfalfa plants were increased (Chadler and MacLeod, 1966). This increased vegetative development under lower temperature conditions might be a direct K effect, as K plays a crucial role in the energy status of plants and maintenance of tissue water relations during adverse conditions (Clarkson and Hanson, 1980). This effect on plant growth might also be indirect, as K interacts positively with other nutrients (especially with nitrogen) to enhance plant development (Usherwood, 1985).

The experimental data presented prove that different levels of soil K supply affect yield and other related characteristics (Table 15). Under field conditions, 150% RKL supply increased yield significantly. However, doubling the recommended K level resulted in a significant reduction of these parameters (Table 15). Potassium plays an important role in fruit growth and development of tomato plants. The findings of this experiment suggest that increasing the K level to 150% of the RKL results in plants with the highest cold tolerance, as determined by an increase in yield per plant. However, the level of K must not reach 200% of the recommended dosage, otherwise the beneficial effects of K will be lost. Furthermore, an improvement of other yield attributes, besides yield per plant, might also be achieved by a different application method. A foliar spray of K onto plants grown under RKL might result in a "short term frost protection" and the surplus K can be used to improve fruit quality, as the super-optimal K application resulted in a higher fruit carotenoid concentration (Table 16).

The carotenoid concentration generally increased with increasing K levels, regardless of the growing location. This is consistent with previous findings that K deficiency lowers the rate of carotenoid synthesis, particularly of lycopene (Trudel, 1969). However, an application exceeding the recommended level might be of further benefit, as it improves fruit colouring. Furthermore, under both growing conditions the carotenoid concentration tended to increase with ripening, and the chlorophyll concentration – with the exception of the 50% of the recommended rate have suggested a biosynthetic connection between chlorophylls and carotenoids, and their relationships with the ripeness of fruits. The carotenoid concentration of tomato fruits is highest when the fruit has just reached the red stage and is lowest when the fruit is mature green (Trudel and Ozbun, 1970). The K status of the fruit seems to alter the relationship between the two pigment systems during ripening. When synthesis of carotenoids had been low (green stage), the chlorophyll concentration of fruit increased with increasing K fertilization. When, on the other hand, the rate of carotenoid synthesis was relatively high (red stage), K-deficient fruit had a higher chlorophyll concentration than fruit from plants fertilized with high K fruit. These results indicate that K plays an important role in the process of alternation of the pigment pattern during tomato fruit ripening, possibly by acting on the biosynthesis and/or metabolism of tetraterpenoid and/or by the transformation of chloroplasts to chromoplasts. Further investigations, however, are necessary to understand the process.

Similarly to K fertilization, mulching significantly affected the performance of tomato plants as determined by various vegetative and reproductive parameters. The type of mulch used is very critical for either a positive or a negative performance and depends on the prevailing environmental conditions. Mulching a late planting with maize stover decreases plant growth (plant height and internode length), compared to unmulched soil (Table 19). Furthermore, it delays the onset of flowering, fruit set and harvest (Table 20), as plants in bare soil experience a higher soil temperature than plants mulched with maize stover. This increase in soil temperature must have hastened plant growth and development and, hence, resulted in taller "Rossol" tomatoes. Agele *et al.* (1999) similarly found that under field conditions, tomato plants in bare soil are taller and reach certain developmental stages earlier than those mulched with hay. Plants grown in bare soil experience a higher soil temperature than those grown with hay mulch (Agele *et al.*, 1999), which results in faster plant development. Similarly, mulching with maize stover resulted in significantly higher yield per plant, number of fruits per plant, fruit size per plant and percentage of marketable fruits than those grown in bare soil (Table 21). These findings are consistent with those of other researchers who attribute the lower yield of plants grown in bare soil to problems during fruit set caused by heat build up and low moisture content of the growing medium (Perry and Sanders, 1986; Wolfe *et al.*, 1989). High soil temperature and low soil moisture content can become detrimental for tomato production, as these factors are associated with insufficient pollination and blossom drop (Sugiyama *et al.*, 1966, 1970) as well as abortion (Peterson and Taber, 1991).

Tomato plants grown under black plastic mulch experienced the highest soil temperature during the winter growing season. Furthermore, yield per plant increased significantly compared with those grown either in bare soil or under maize stover (Table 21). It seems that the improved hydrothermal regime under black plastic led to an earlier and better leaf canopy development throughout tomato plant growth. This vegetative development is essential for high assimilation rates, and thus higher rates of vegetative and reproductive growth (Zamman and Choudhuri, 1995) as well as dry matter accumulation (Ojeniyi and Adetoro, 1993).

Although the number of fruits per plant and fruit size did not differ significantly between the two mulch treatments, both, maize stover and black plastic mulch, showed significant improvement in these characteristics over the control. Fruit size was highest in plants grown under black plastic mulch, even with the higher number of fruits produced, while it was lowest in plants in bare soil, even though these had the lowest number of fruits per plant. Decoteau *et al.* (1989) recorded similar results on tomato plants under field conditions. Both mulch materials increased the percentage of marketable fruits when compared to the unmulched soil (Table 21), most probably because these treatments kept fruits off the ground. This obviously resulted in fewer infections from soil borne diseases. Soil temperatures under the mulch fluctuated less, preventing fruit cracking. Hence, Kromer (1982) and El-Hassan (1986) found reduced fruit rotting and a reduced percentage of defective fruits with the use of plastic mulches. Plants grown under black plastic mulch were not significantly different from those grown with maize stover in this aspect, substantiating the assumption that avoiding contact with the soil is the main reason for the increased percentage of marketable fruit.

This study indicates that both, maize stover and black plastic mulch, enhance yield and yield attributes. Black plastic mulch, furthermore, results in earlier development of tomato fruit and, hence, earlier production. Maize stover can, on the other hand, retard plant development but ultimately perform better than bare soil. Hence, it can be used as a means to increase the performance of tomato plants under low temperature field conditions, as it is more viable to rural farmers such as those in Eritrea. The timing of the planting seems, therefore, of prime importance to reap the benefit of high quality fruit produced under maize stover in the colder months.

4.0 OUTLOOK

This research has demonstrated that tomato plant growth and development as well as ultimately tomato production can be improved under winter conditions. The means investigated are relatively simple and, hence, also well applicable to less developed agricultural areas. However, testing the results in larger scale trials will be necessary before the techniques tested can be implemented in rural as well as commercial farming enterprises. For either technique, K fertilization as well as mulching, further research is necessary prior to commercial application. Such investigations should aim at:

- Comparing the efficiency of various forms of K fertilization
- Comparing the timing of K application (pre- or post-establishment)
- Evaluating various means of K application (discing in, furrow application, foliar application)
- Comparing various types (polyethylene, woven plastics, reflective) and various colours of synthetic mulching material
- Evaluating various types of organic mulching material

Furthermore, the techniques applied to increase tomato performance under cold winter conditions did certainly not only affect the internal quality parameters tested. A more thorough investigation, which would have stretched beyond the frame of the MSc (agric) research presented, should analyse why the methods employed to increase winter performance had a positive effect. A first step to such a more scientific approach would be ultrastructural analyses of vegetative and, more importantly, reproductive structures of tomatoes treated to improve cold season performance. Furthermore, certain products are now commercially available to increase winter performance/ cold hardiness of tomato. The efficacy of such products should be compared and their effect on crop performance, as well as fruit quality parameters evaluated.

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