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YIELD AND QUALITY OF TOMATO AS INFLUENCED BY DIFFERENTIAL Ca, Mg AND K NUTRITION

By

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DEDICATION

I fully dedicate this thesis to:

Mireille Lekadiano, my wife

Celestin Bekabisya and ***Anne Marie Karume***, my parents

All my brothers, sisters and cousins

My uncle ***Jean Bakomito*** and his wife ***Dr. Changwa***

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Finally, I remember what the Lord has done for me, and I give him many thanks.

DECLARATION

I, Bombiti NZANZA, hereby declare that this dissertation for the degree MSc (Agric.): Agronomy at the University of Pretoria is my own work and has never been submitted by myself at any other University. The research work reported is the result of my own investigation, except where acknowledged.

B NZANZA

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ABSTRACT

Greenhouse experiments were conducted during 2004/2005, to investigate the effects of different Ca:Mg:K and K:Ca ratios and rates on yield and quality of tomato. In the first trial, four Ca:Mg ratios (20:1, 15:5, 10:10, and 12:8 $mmol_c$. l^{-1}) combined with three levels of K concentrations (1, 6, and 9 $mmol_c$. l^{-1}) were applied to tomato plants growing in a sand coir mixture as a growth medium. The experimental design was a fully randomised design consisting of four replications per treatment (Ca:Mg:K rates and ratios). The test crop used was tomato, cultivar "Money-maker". In the second trial, a factorial experiment involving a combination of two K (6 and 10 $mmol_c$. l^{-1}) and two Ca (12 and 16 $mmol_c$. l^{-1}) rates, giving four K:Ca ratios were used in water culture. High Ca:Mg ratios (20:1) in the nutrient solution decreased tomato fruit pH, titratable acidity (TA), total soluble solid content (TSS), percentage class one fruits, and dry matter yields. This study also indicated that only a Ca:Mg ratio of less than one can cause a significant reduction in yield and fruit quality. Increased K rates resulted in improved fruit quality parameters (pH, TSS, TA) and increase in the percentage of class one fruits. High K rates did not affect fruit dry matter yields and percentage marketable fruits, but marketable dry matter yield was reduced, probably due to an increase in BER incidence (at a low Ca:Mg ratio) with increased K rates. High Ca rates (16 $mmol_c$. l^{1}) combined with low K rates (6 $mmol_c$. l^{-1}) decreased the K concentration in tomato fruits. This study showed that K:Ca ratios are not that important as long as both elements are adequately supplied. Blossom-end rot of tomato fruits was observed only in treatments supplied with a low Ca:Mg ratio, while the incidence of this disorder increased with increasing K rates in the nutrient solution. Blotchy ripening was only observed in treatments supplied with low K rates,

suggesting that this plant nutrient also plays a role on the incidence of this disorder. On the other hand, no relationship was established between these plant nutrients, fruit cracking and cat facing; which considerably affects the marketable yield of tomatoes. The findings of this study also showed the major impact of physiological disorders on greenhouse tomato production.

CHAPTER 1

GENERAL INTRODUCTION

Tomato (*Lycopersicon esculentum* Miller) is one of the most important vegetable crops grown throughout the world under field and greenhouse conditions (Kaloo, 1986). In terms of human health, tomato is a major component in the daily diet in many countries, and constitutes an important source of minerals, vitamins, and antioxidants (Grierson and Kader, 1986).

Tomato belongs to the family Solanaceae and it is believed to have originated in the coastal strip of western South America, from the equator to latitude of about 30^0 South. Indeterminate and determinate plant growth are characteristic of this family, where the former produces three nodes between each inflorescence with the later having fewer than three nodes on the stem, terminating in an inflorescence (Jones, 1999).

Growing tomato is not an easy task since the plant is exposed to many constraints (diseases, climate, nutrition, etc.), while the fruit itself has to meet certain market requirements. Three factors drive consumers preference: physical appearance (colour, size, shape, defects, and decay), firmness and flavour (Jones, 1999). Of the three, appearance has the most immediate and profound effect on consumer choice, and for this reason, produce for the fresh market is principally graded on basis thereof (Cockshull *et al*., 1998).

High yields combined with high fruit quality are a common requirement of tomato growers, and this can only be achieved if critical production factors are taken into consideration. These include proper irrigation management, variety choice, disease prevention, cultural techniques, soil fertility, climate, etc. Numerous authors have studied the effects of different plant nutrients on yield and quality of tomato and it becomes clear that some of these nutrients play a key role in tomato production. For instance, potassium is involved in metabolic and transport processes, charge balances, and generation of turgor pressure in the cells (Dorais *et al.*, 2001). It is also related to

acceptable fruit shape, the reduction of ripening disorders, and the increase of fruit acid concentration (Adams, 1986). Magnesium is a major constituent of the chlorophyll molecule and an enzyme activator for a number of energy transfer reactions. Calcium is a major constituent of cell walls where it helps in maintaining cell wall integrity and membrane permeability; it enhances pollen germination and growth; it activates a number of enzymes for cell mitosis, division, and elongation, and it affects fruit quality (Jones, 1999).

Potassium (K), Mg, and Ca are vital nutrients in tomato production, and deficiencies of these elements usually occur due to undersupply or antagonistic effects on each other thus decreasing growth, yield, and quality of tomato. Generally a lack of a specific element is not only restricted to bad management of the fertilizer program but also to antagonism between elements that is sometimes difficult to prevent. This is the case for K, Mg, and Ca that strongly interfere with each other during the uptake process (Voogt, 1998). Deficiencies of K in the fruit may lead to poor fruit quality and yield losses (Bar-Tal and Pressman, 1996), whereas a lack of Mg may seriously affect the photoassimilate production and supply to other parts of the plant (Sonneveld and Voogt, 1991; Hao and Papadopoulos, 2003). Hao and Papadopoulos (2003) reported that Ca deficiencies cause a decline in the growth of merismatic tissues, reduces leaf size, yields, and causes necrosis of young leaves in extreme cases.

Sufficient K, Mg, and Ca in the nutrient solution could increase yield and improve fruit quality. However, there are some physiological disorders that can occur despite good fertilizer management that, to a certain extent, can be correlated with these plant nutrients, as in the case of blotchy ripening (BR), catfacing (CF), fruit cracking (FC), and blossom-end rot (BER). In the case of BER, which can cause severe economic losses (Taylor and Locascio, 2004), many authors have correlated its occurrence to a local Ca deficiency (Grattan and Grieve, 1999; Bradfield and Guttridge, 1984; Ho *et al.,* 1995; Marcelis and Ho, 1998; Paiva *et al*., 1998a; Taylor and Locascio, 2004) or an interaction between Ca and Mg (Hao and Papadopoulos, 2003; Sonneveld and Voogt, 1996; Franco *et al*., 1999), or K and Ca (Bar-Tal and Pressman, 1996; De Kock *et al.,* 1982), although there are also some strong claims that BER is not related to Ca deficiencies (Nonami *et al*., 1995; Saure, 2001; Franco *et al*., 1999) nor K:Ca ratios (Saure, 2001). Therefore, the nutritionists are faced by a new challenge to

further understand the interaction between K, Mg, and Ca, and to investigate the influence of Ca and K:Ca ratio on BER induction.

The aim of this study is to determine Ca:Mg:K ratios that can lead to high yield and quality and to investigate the relationship between BER as well as other physiological disorders regarding these three plant nutrients.

To accomplish this, the research will attempt to:

1) Investigate the response of tomato to different Ca:Mg: K ratios;

2) Investigate the relationship between K, Mg, and Ca, and BER as well other physiological disorders.

CHAPTER 2

LITERATURE REVIEW

2.1 POTASSIUM, MAGNESIUM, AND CALCIUM NUTRITION

2.1.1 Potassium (K)

Plant nutritionists have identified K as the only monovalent cation essential for all higher plants. It is the most abundant cation in plant tissues and plays a major role in various physiological and biochemical processes, including photosynthesis (Munson, 1985). Potassium ions are involved in merismatic growth, enzyme catalysis (Suelter, 1970) and protein metabolism (Munson, 1985). Potassium plays a major role in the mechanism of stomatal opening and closing by affecting cell water potential and turgor (Rending and Taylor, 1989). It is also associated with carbohydrate chemistry, maintaining ionic balances in the plant and affects fruit quality (Jones, 1999).

Once available in solution, K must diffuse to the plant roots to ensure mineral uptake (Munson, 1985). Its uptake is highly selective and closely coupled to metabolic activity (Marschner, 1995). Plants take up relatively large quantities of K and thus rapidly deplete the K concentration in the root zone (Munson, 1985). The rapid uptake rate of K depends on the relative high permeability of plant membranes to K that probably result from ionophores located in the membrane that facilitate diffusion (Mengel and Pflüger, 1972). Potassium enters the plant mainly through the plasma membrane of the outer cells of the root cortex. Once K accumulates in the cortical cells, it can be stored in the large vacuole of these cells (Munson, 1985). Potassium is characterized by high mobility in plants and in long-distance transport via the xylem and phloem (Marschner, 1995). The phloem sap is rich in K and, since solutes of phloem can be translocated both upwards and downwards in the plant, plant organs such as young leaves and fruits that are preferentially supplied with phloem solutes, are therefore rich in K (Mengel and Kirkby, 2001).

Potassium deficiency merely slows down growth at first, but later the plants stop growing completely and become stunted. Although K^+ ions are mobile, their remobilization from older leaves is not fast or adequate enough to satisfy the high demand in the growing meristem of the shoot and young leaves (Bergmann, 1992). The poor growth of plants observed under conditions of K deficiency is related to the effect of K on ATPase, located in the plasmalemma of merismatic tissues (Scherer *et al*., 1982). Due to growth inhibition, the younger leaves are smaller than those of healthy plants, and the leaf blades are often smaller (Bergmann, 1992). The leaflets of older leaves become scorched and curled margins and interveinal chlorosis occur (Jones, 1999). The leaves retain their normal green colour, but they can sometimes turn dark to bluish-green (Bergmann, 1992). It is generally recognized that, in addition to decreased growth, K deficiency results in reduced rates of net photosynthesis and photosynthtate translocation, and increased rates of dark respiration (Munson, 1985).

2.1.2 Magnesium (Mg)

Magnesium, a major constituent of cell walls (Jones, 1999), is vital for the process of photosynthesis and therefore for the life of the plant in general (Bergmann, 1992). Besides its function in the chlorophyll molecule, Mg^{2+} is required in other physiological processes (Mengel and Kirkby, 2001), especially those implicated in the synthesis and maintenance of chlorophyll. Apart from its implication in photosynthesis, Mg is of importance mainly as co-factor and activator of many enzyme and substrate transfer reactions (Bergmann, 1992). The function of Mg in plants are mainly related to its capacity to interact with strongly nucleophilic ligands through ionic bonding, and to act as a bridging element and form complexes of different stabilities (Marschner, 1995). Magnesium also appears to stabilize the ribosomal particles in the configuration necessary for protein synthesis and is believed to have a similar stabilizing effect in the matrix of the nucleus (Mengel and Kirkby, 2001).

Generally the concentration of Mg^{2+} in the soil solution is higher than that of K^+, but the uptake of Mg^{2+} by root is much lower than the uptake of K^+. This poor ability of roots to take up Mg^{2+}, in comparison to K^+, is probably not only restricted to root

tissue but holds for other plant parts as well (Mengel and Kirkby, 2001). In contrast to Ca^{2+}, Mg^{2+} is very mobile in the phloem and can be translocated from older leaves to younger leaves or to the apex (Steucek and Koontz, 1970).

Plants inadequately supplied with Mg^{2+} often show a delay in the reproductive phase (Ward and Miller, 1969). In tomato plants the leaflets of the older leaves develop interveinal chlorosis that advances inwards from the margins, enveloping even the fine veins, until finally the whole leaf turns yellow (Bergmann, 1992). Slight magnesium deficiency occurs in almost all greenhousecrops grown with all soil types, but more severe deficiencies can be expected on coarse-textured sandy soils. It is promoted by low pH and high potassium status in the soil, and by inadequate supply in nitrogen fertilizer (Jones, 1999).

2.1.3 Calcium (Ca)

Calcium, an essential macronutrient, plays a decisive role in the maintenance of cell membrane integrity (Epstein, 1961; Morard *et al*., 1996) and membrane permeability; enhancing pollen germination and growth; activating a number of enzymes for cell mitosis, division, and elongation; possibly detoxifying the presence of heavy metals in tissue; affecting fruit quality, and health of conductive tissue (Jones, 1999). Calcium is also involved in numerous cellular functions that are regulated in plant cells by changes in cytosolic Ca^{2+} concentrations, such as ionic balance, gene expression, and carbohydrate metabolism (Bush, 1995).

The Ca content in higher plants, is generally about 0.5 % on a dry matter basis. These high Ca concentrations are a result of high Ca^{2+} levels in the soil solution rather than from the efficiency of Ca^{2+} uptake by root cells. Generally the Ca^{2+} concentration of the soil is about 10 times higher than that of K^+ whereas the uptake rate of Ca^{2+} is usually lower than that of K^+ (Clarkson and Sanderson, 1978). Its uptake can also be competitively depressed by the presence of other cations such as K^+ and NH_4^+, since roots usually take these up more rapidly than Ca^{2+} (Mengel and Kirkby, 2001).

Calcium is mainly translocated in the xylem sap and only poorly in the phloem. Marschner (1995) assumed that the extremely low levels of Ca^{2+} in the phloem sap

are a consequence of Ca accumulation in the cells surrounding the phloem. As a result of low Ca^{2+} in the phloem, all plant organs, which are largely provided with nutrients by the phloem sap, are relatively low in Ca (Mengel and Kirkby, 2001). Ca transport to the fruit may also be reduced by development of more foliage that may compete with the fruit for water, particularly under periods of low relative humidity (Nonami *et al*., 1995).

The poor supply of Ca^{2+} to fruits and storage organs can result in Ca deficiency in these tissues (Mengel and Kirkby, 2001). Calcium deficiency brings about the appearance of visual symptoms with the blackening and the peripheral deformation of the blade of the younger leaves and decline in growth of merismatic tissue (Jones and Lunt, 1967; Morard *et al.*, 1996). The deficiency can first be observed in the growing tips and youngest leaves that become deformed and chlorotic and in more advanced stages, necrosis occurs at the leaf margins (Bussler, 1963; Mengel and Kirkby, 2001).

Plant Ca deficiencies are frequently restricted to low transpiring, fast growing tissues such as shoot apex, fruits, and storage organs. Calcium deficiency may lead to early senescence and absence of fructification. Seeds that are deficient in Ca generally have poor germination and produce abnormal, weak seedlings, even when seed are germinated in a complete and balanced nutrient containing media (Keiser and Mullen, 1993; Taylor and Locascio, 2004). Since most mineral soils are rich in available Ca, deficiency occurs infrequently in plants but an undersupply of Ca to fruit and storage tissues may occur (Mengel and Kirkby, 2001). In soilless culture, Ca deficiency is most often due to decreased calcium uptake and transport within the plant as a result of water supply disturbances or excess salinity (Adams and Ho, 1993) rather than the lack of calcium in the nutrient solution (Morard *et al*., 1996).

2.2 INFLUENCE OF K, Mg, AND Ca ON YIELD AND QUALITY OF TOMATO

2.2.1 Potassium

Among the factors that influence the quality of tomato, K plays a key role in metabolic and transport processes, charge balance, and generation of turgor pressure (Dorais *et al*., 2001). Potassium is related to improved fruit shape, the reduction of ripening disorders, and an increase in fruit acid concentration, which improves taste (Adams *et al*., 1978). With proper K nutrition, fruit is generally higher in total soluble solids, sugars, acids, carotenes, and lycopene and has a better keeping quality (Munson, 1985).

Red colour development in tomato fruit is mainly due to synthesis of the carotenoid pigments, and increasing K in the nutrient solution also increases the carotenoid concentration, particularly lycopene (Trudel and Ozbun, 1971). An increased K concentration in the root can increase leaf photosynthetic efficiency possibly by increasing the number of chloroplast per cell, number of cells per leaf and consequently leaf area (Possingham, 1980). Lopez and Satti (1996) observed a great decrease in photosynthetic activity with decreasing supply of K to the roots.

An inadequate K concentration in the nutrient solution reduces plant growth, has a negative effect on fruit set in young reproductive plants (Besdford and Maw, 1975), negatively affects vines and fruit taste (Munson, 1985), and decreases dry matter distribution to leaves and roots of fruiting plants (Haeder and Mengel, 1972). Winsor and Baker (1982) did not find any influence of K on the fruit sugar and dry matter content, but in greenhouse tomato, Davies and Winsor (1967) have observed a positive response of plants to potassium in terms of fruit acidity, sugars, dry matter and organoleptic quality.

Tomatoes are one of the crops that require high levels of K nutrition to achieve quality in addition to higher yields (Munson, 1985). Gunes *et al.* (1998) who investigated critical nutrient elements in young tomatoes found that the K concentration in the plant increases with increasing K in the nutrient solution. With a K range of 4.6; 7.2

and 9.7 mM in the nutrient solution, the number of fruit of uneven coloration was reduced to 40, 21 and 12 % respectively (Gormely and Mayer, 1990; Dorais *et al.*, 2001). Bryson and Barker (2002) reported that in a peat-based growing medium the optimum K concentration leading to maximum plant growth is about 4.1 mM. When K concentration is increased from 2.5 to 10 mM, marketable yield was reduced by 14 % (Bar-Tal and Pressman, 1996). Voogt and Sonneveld (1997) reported that the mean K concentration to obtain optimum yield and product quality is 6.1 mM. In hydroponics, the K levels in the solution should range between 2.56-5.12 mM for growing tomatoes (Jones, 1999). However, it should be emphasized that the references of concentrations depend on system and take into account factors such as recycling frequency and flow rate.

2.2.2 Magnesium

Magnesium deficiencies often occur in greenhouse tomato. It is, however, seldom noticed, because the deficiency symptoms usually occur on the oldest leaves that are generally thought to have little or minor impact on productivity. However, Hao and Papadopoulos (2003) recently found that Mg deficiencies appeared not only on bottom leaves, but also on the top and middle leaves of a greenhouse tomato crop growing during the fall on rockwool as substrate. Sonneveld and Voogt (1991) also observed Mg deficiencies on the middle leaves of a greenhouse tomato crop growing in the fall. These results indicate that Mg deficiencies may affect the photoassimilate production and supply thereof to other parts of the plant (Sonneveld and Voogt, 1991).

Magnesium has an effect on leaf osmotic potential, which decreases with increasing concentrations of this element in the nutrient solution (Carvajal *et al.*, 1999). Increased Mg levels in the nutrient solution increase Mg levels in the plant and decrease fruit dry matter (Gunes *et al.*, 1998). There is no single value as to the optimum concentration of Mg in the nutrient solution in greenhouse tomato fertigation (Chapagain *et al.*, 2003). Jones (1999) stated that the best concentration of Mg is between 2.5-5.83 mM of Mg^{2+}. Chapagain *et al.* (2003) reported that 3.3-4.17 mM Mg^{2+} is optimal for greenhouse tomato production in Israel. A supply of 4 mM Mg^{2+} in a peat-based growth resulted in maximum plant growth and high yields (Bryson

and Barker 2002) whereas the best overall yield and quality in rockwool grown tomato were given as 4.16-6.7 mM of Mg^{2+} by Hao and Papadopoulos (2003). Once again, one of the reasons behind this variation in recommendations is the fertigation system that is used.

2.2.3 Calcium

Calcium is one of the most important mineral nutrients in greenhouse production (Hao and Papadopoulos, 2003) since it has an important function in the integrity and stability of the cell membrane (Paiva *et al*., 1998b; Marschner, 1995). Calcium movement, in the plant, is restricted to the xylem, causing fruit to have less than 2 % of the total calcium in the plant (Ehret and Ho, 1986). The calcium concentration in distal fruit of a cluster tends to be lower than in proximal fruit (Bangerth, 1979; Petersen *et al*., 1998), indicating a higher probability of physiological disorders, associated with Ca, to develop in distal than proximal fruit on the same truss (Dorais *et al*., 2001).

An adequate supply of Ca to the fruit is essential for firmness and shelf life. Increased Ca levels in the nutrient solution increase calcium levels in the fruit, but decrease carotene content and lycopene levels in the tomato fruits (Paiva *et al*., 1998b) and negatively affect their organoleptic quality (De Kreij, 1995). Fruit firmness can be improved by spraying calcium salts (Cooper and Bangerth, 1976) while tomato ripening can be delayed by increasing calcium content of the fruit from 0.11 $mg.g^{-1}$ fresh weight to 40 $mg.g^{-1}$ (Wills *et al*., 1977). Insufficient Ca supply will increase the number of fruits affected by BER and may stimulate ethylene synthesis (Bangerth, 1979) and consequently the biosynthesis of carotenoids (Kays, 1991), which are responsible of tomato fruit colour (Dorais *et.al.,* 2001). Calcium deficiencies reduce leaf size; cause necrosis of young leaves and in extreme cases yields loss (Hao and Papadopoulos, 2003).

According to Hao and Papadopoulos (2003), high Ca concentrations (7.5 mM) in the nutrient solution allow for higher total yields, higher marketable fruit yields, larger fruits, and higher percentages of marketable fruit compared to low Ca concentrations (3.5 mM). For maximum plant growth, Bryson and Barker (2002) suggested that

nutrient solutions should be 5 mM Ca. Bar-Tal and Pressman (1996) observed increased marketable yields with increased Ca levels due to a reduction in BER incidence.

2.3 INTERACTIONS BETWEEN NUTRIENT ELEMENTS

2.3.1 Potassium, magnesium, and calcium antagonisms

In the nutrient uptake processes, K, Mg, and Ca are strongly antagonistic (Voogt, 1998) resulting in a deficiency of the depressed nutrient. It is well known that a deficiency of one element could imply a relative or absolute excess of the others resulting in an ”unbalanced diet” for the plants (Bergmann, 1992). A sufficient Ca concentration in the soil or nutrient solution is important, but frequently major cations interfere with Ca uptake (Barber, 1995). Magnesium may strongly modify the uptake of Ca^{2+} and K^{+} while K^{+} and Ca^{2+} can restrict the uptake and translocation of Mg^{2+} from the roots to the upper plant parts (Schimanski, 1981). According to Bergmann (1992), high K^{+} cause indirect damage by inducing Ca and Mg deficiencies.

2.3.2 Potassium and magnesium antagonism

The antagonistic effect of increased Mg levels on the K uptake could be attributed to differences in their ionic mobility (Ananthanarayama and Hanumantharaju, 1992). High K concentrations in the nutrient solution may result in Mg deficiencies in the plant tissue (Jones, 1999), while the opposite is also true. High Mg concentrations either in soil or plant are often a cause of poor K status in soil (Kirkby and Mengel, 1976). Although high levels of K nutrition often depress total Mg uptake, increased K supply affects the Mg content of different plant organs to a varying extent (Grimme *et al*., 1974). The K:Mg ratio in the soil appears to be important because excessive concentrations of either element can negatively affect plant growth (Bergmann, 1992).

2.3.3 Potassium and calcium antagonism

As far as its physiological effects are concerned, Ca is usually regarded as the counterpart to potassium. The mobility of Ca^{2+} ions is affected by high concentrations

of K^+ ions, not only in the soil, but also in plants themselves, where they influence calcium distribution and can thus exacerbate Ca deficiencies (Bould and Tsai-fua, 1976; Shear, 1975). High levels of potassium in the root environment interfered with calcium uptake (Voogt, 1998; Nukaya *et al.,* 1995; Bar-Tal and Pressman, 1996). On the other hand, excess Ca in the soil may inhibit K absorption due to competition between the two ions (Paiva *et al*., 1998b). However, optimum amounts of calcium may result in an increase in the availability of exchangeable and water-soluble potassium (Ananthanarayama and Hanumantharaju, 1992).

2.3.4 Calcium and magnesium antagonism

The antagonistic effect between Ca and Mg is well known; the rate of Mg uptake can be depressed by Ca and vice versa (Paiva *et al*., 1998b; Hao and Papadopoulos, 2003). Calcium is strongly competitive with Mg, and the bonding sites on the root plasma membrane appear to have less affinity for the highly hydrated Mg^{2+} than for Ca^{2+} (Marschner, 1986). Increased levels of external Ca resulted in decreased Mg uptake due to cationic antagonism or interactions. The decreases in Mg could also be attributed to the withdrawal of Mg from the nutrient solution in order to maintain the balance between cations against the increasing Ca (Carvajal *et al.,* 1999).

Magnesium deficiency symptoms may, to some extent, be due to a high Ca:Mg ratio besides the absolute Mg content of the leaves (Bergmann, 1992). Calcium is also frequently reported as an inhibitor of enzymes that require Mg. Furthermore; a high activity of Ca counteracts the function of Mg (Clarkson & Sanderson, 1978). According to Ananthanarayama and Hanumantharaju (1992) Mg exerts a more depressing effect on Ca uptake than Ca levels does on the uptake of Mg. Grattan and Grieve (1999) reported that excessive leaf Ca concentrations might interfere with CO_2 fixation by inhibition of stroma enzymes, particularly those that are Mg^{2+} activated.

2.4 INFLUENCE OF NUTRIENT INTERACTIONS ON YIELD AND QUALITY OF TOMATO

Much work has been done throughout the world on the antagonism among K, Mg, and Ca on yield and quality of tomato under both field and greenhouse conditions.

Paiva *et al.* (1998b) reported that Mg and K levels decreased with increased Ca concentration in the nutrient solution. Generally, increasing Ca levels in the nutrient solution increase Ca and decrease Mg content of the plants and vice versa (Carvajal *et al.,* 1999). Nukaya *et al.* (1995) reported that potassium levels in the tomato fruit decrease with increasing Ca concentration in the nutrient solution. Later Paiva *et al.* (1998b) confirmed these findings and suggested a competitive effect of Ca for absorption sites in the plant as a consequence of the reduced K concentration in the fruit. Mulholland *et al.* (2000) found a high Ca concentration in leaf tissue where plants were supplied with a nutrient solution containing low K levels. They assumed cation competition at the root/nutrient solution interface and the uptake mechanism of Ca and K by the root to cause the increased Ca in the leaf tissue. Hao and Papadopoulos (2003) found a significant CaxMg interaction on leaf size. Carvajal *et al.* (1999) also observed a significant negative correlation between Ca and Mg in leaves, stems and roots. For example, leaf Ca concentrations were reduced by 40 % when the Mg concentrations in the solution was increased from 0.5 to 10 mM. Excessively high K:Ca and K+Mg:Ca ratios in the fruits, and sometimes in the leaves are related to BER in tomatoes (Bergmann, 1992).

2.5 BLOSSOM-END ROT AND NUTRITION

2.5.1 Causes and symptoms

Blossom-end rot is a common physiological fruit disorder in tomato. In susceptible cultivars, it may cause severe economic losses in some seasons and under certain environmental conditions (Taylor and Locascio, 2004). Blossom-end rot symptoms initially develop as necrotic tissue at the distal part of the placenta (Figure 2.1) and the adjacent locular content as well as the pericarp (Willumsen *et al.*, 1996). The first indication that Ca was involved in BER came from Raleight and Chucka (1944). Lyon *et al.* (1942) who found a correlation between Ca and occurrence of BER, later strongly supported this finding. Since then, the disorder is attributed to an inadequacy of Ca. This is still sustained at present; however, many studies revealed that Ca deficiency is not the only cause of BER. The plant's response to factors such as nutrition, ambient and root environments, that can lower the Ca content of the fruit, may also induce this disorder (Wilcox *et al.*, 1973; Ikeda and Osawa, 1988).

Figure 2.1 Blossom-end rot on tomato fruits

2.5.2 Blossom-end rot and calcium

Evidence for Ca deficiency as the primary cause of BER has been derived from observations that fruit affected by BER always have a lower Ca content as compared to healthy fruit (Saure, 2001). Tomatoes grown in a soilless media, containing no or extremely low amounts of Ca^{2+}, frequently produced various proportions of fruit showing symptoms of BER. These symptoms sometimes are in conjunction with or after the appearance of other Ca^{2+} deficiency symptoms, such as chlorosis or necrosis at the margins of expanding leaves, inhibition of root and shoot tips, etc. (Sonneveld and Voogt, 1991; Saure, 2001).

Investigations on the cause of BER in tomato showed that a low Ca status in the whole plant caused by low supply or uptake of Ca, as well as low transport of Ca to the fruit particularly to the distal fruit tissue, can induce BER. Blossom-end rot can, however, even occur when the Ca status in the plant is high (Bradfield and Guttridge, 1984; Ho *et al*., 1995; Marcelis and Ho, 1998). Franco *et al.* (1999) observed a serious BER incidence despite fairly high levels of Ca^{2+} in the distal part of the fruit, but several authors could not find significant differences in Ca^{2+} content of tissues from healthy and affected fruit (Saure, 2001). An increase in Ca requirement for plasma membrane synthesis as a result of fast cell expansion, brought on by high rates of

sucrose, may increase the deficit between Ca supply and demand, leading to BER (Paiva *et al.,* 1998a).

Since the ratio between water supply to the fruit from the leaves and that directly from the roots via xylem is the dominant factor controlling the Ca supply to the fruit (Ehret and Ho, 1986; Bar-Tal and Pressman, 1996), water stress that reduces Ca uptake, may stimulate BER deficiencies (Adams and Ho, 1992). Obreza *et al.* (1996), however, found infrequent increases in BER with an increase in water stress. According to Saure (2001), BER may be aggravated by the interaction of stress factors causing reduced fruit growth, such as soil water stress together with high transpiration (Obreza *et al.*, 1996), at high temperatures (Gerard and Hipp, 1968); at high NH_4 supply and temperature (Ikeda and Osawa, 1988); and high salinity together with high transpiration (Robins, 1937).

Regarding the susceptibility of cultivars, some authors observed a lower Ca content in BER-susceptible than in less susceptible cultivars (Saure, 2001), while others did not report it (Nonami *et al.*, 1995).

2.5.3 Blossom-end rot and nutrient interactions

A new challenge is a better understanding of the interactions of nutrients in the soil and in the plant, together with synergistic and antagonistic effects (Gunes *et al.*, 1998). Many studies suggest that Ca may strongly interfere with nutrients such as K, Mg and NH_4, causing a local Ca deficiency in fruit and indirectly stimulating BER induction (Robins, 1937; Bradfield and Guttridge, 1984; Ikeda and Osawa, 1988; Ho *et al.*, 1995; Marcelis and Ho, 1998; Saure, 2001).

The incidence of BER is significantly affected by K:Ca ratio (Bar-Tal and Pressman, 1996) and according to De Kock *et al.* (1982), the K:Ca ratio is a better indicator of BER than Ca alone, but Wada *et al.* (1986) did not find a clear relationship between K:Ca ratio and BER incidence (Saure, 2001). Nukaya *et al.* (1995) reported that BER might be a serious problem despite the fairly high levels of Ca in the distal part of the fruit. Their study contradicted the view that BER is frequently linked with a low concentration of Ca in the fruit.

Some authors have correlated the occurrence of BER to a high Mg:Ca ratio. Hao and Papadopoulos (2003) found that the BER incidence increased linearly with increasing Mg concentration in the early stage at low Ca, but BER incidence at high Ca was not affected by the Mg concentration. Franco *et al.* (1999) observed a high Mg:Ca ratio in the soil due to the presence of a high Mg levels in the irrigation water resulting in a high BER incidence. They claimed that antagonism between these two elements could be partly responsible for the development of BER. As previously outlined, the NH_4 uptake process may strongly interfere with that of Ca, and in many references, the effects of using NH_4 as N source has been correlated with the incidence of BER. Taylor and Locascio (2004) reported that Ca uptake is stimulated by the use of NO_3-N rather than NH_4-N. A study conducted by Sandoval-Villa *et al.* (2001) in a greenhouse later supported this view. They found a linearly increase in BER with an increase of NH_4^+:NO_3^- ratio. But, in summer, due to fast transformation of NH_4-N to NO_3^-, Adams (1986) disqualified the adverse effect of NH_4-N on Ca uptake.

2.5.4 Contradiction between blossom-end rot and Ca deficiency

There is also some evidence that Ca deficiency is not the cause of BER, as a critical level of Ca for BER induction was not found. Nonami *et al.* (1995) argued that BER might not be directly related to a Ca deficiency. They supported their view by the fact that there are discrepancies in reported values for Ca in fruits with and without BER. Evans and Troxler (1953) found that Ca concentrations in fruits with and without BER to be 0.10-0.13 % and 0.17 %, respectively. Maynard *et al.* (1957) found the concentrations to be 0.04 and 0.07 %; Van Goor (1968): 0.03-0.04 % and 0.09 %; Wiersum (1966): 0.08 and 0.18 %; Cerda *et al.* (1979) :0.028-0.043 % and 0.039-0.079 % respectively.

Nonami *et al.* (1995) reported higher Ca^{2+} concentrations in fruit affected by BER than normal fruit, despite a difference in susceptibility to BER between the cultivars. Therefore, they reported that the disorder is caused by differences in genetic compositions rather than in Ca nutrition. In an experiment conducted by Marcelis and Ho (1998) with pepper, a negative correlation between Ca concentration of the whole fruit and the incidence of BER were also observed and the finding supported this view

that the disorder is not induced by Ca deficiency. Saure (2001) did not find strong evidence that Ca was the main cause of BER. Therefore, he called for a reassessment of Ca in the development of BER and suggested further work to explore other possibilities.

2.6 OTHER PHYSIOLOGICAL DISORDERS

A number of tomato ripening disorders occur when plants are under K deficiency stress (Winsor *et al*., 1961). This is the case with blotchy ripening (BR). The disorder has both genetic and environmental components, and in many cases the exact cause of the disorder is not well understood as a complex of factors are involved (Kinet and Peet, 1997). Some authors have even correlated BR incidence to K, Mg, and Ca nutrition. There is not strong evidence of a relationship between physiological disorders such as fruit cracking and cat facing, and nutrition, however, the latter seems to play a major role on their prevention.

2.6.1 Blotchy ripening

Of all physiological disorders of tomato, the ripening disorders (blotchy ripening (BR), greywall and internal browning) are the least understood. There is disagreement over whether ripening disorders are physiological, biotic or genetic in origin and whether symptoms represent distinct disorders or manifestations of the same disorder (Kinet and Peet, 1997). The disorder is characterized by green to greenish-yellow to waxy-white areas near the calyx of otherwise normal red tomato (Figure 2.2). Affected areas on the fruit surface do not soften as the fruit ripens. The disorder is not apparent in immature fruit (Seaton and Gray, 1936). The discoloration is usually confined to the outer walls, but in extreme cases, radial walls can also be affected (Grieson and Kader, 1986). Internally, the pericarp and placenta have a whitish discoloration.

Blotchy ripening is most often encountered in the greenhouse, causing significant losses. It has been linked to K or B deficiency and to high levels of N that favour excessive growth (Munson, 1985). Although the exact cause of BR is not known (Grieson and Kader, 1986), the incidence is highest on soils with a low potassium and

nitrogen content (Adams *et al.*, 1978). In extreme cases, fruit symptoms are accompanied by potassium deficiency symptoms on the leaves (Roorda van Eysinga and Smilde, 1981). Picha and Hall (1981) measured BR symptoms on four tomato cultivars at five levels of potassium fertility. Cultivars differed in susceptibility to BR, but adding potassium reduced BR incidence in all cultivars. The levels of K, Ca, Mg and P in the pericarp of the different cultivars were not associated with their susceptibility to BR. Lune and Van Goor (1977) and Bergmann (1992) reported that BR is caused by excessive calcium and inadequate potassium concentrations in the fruit. Their incidence decreased as the (K+Mg):Ca ratio in the leaves and fruit increased. It is also worth noting that different tomato cultivars respond differently to K deficiency (Maynard, 1979) and to BR of the fruit (Winsor, 1966). According to Winsor (1966), the severity of the disorder can be reduced by adding K fertilizer, but where it occurs in fruit grown on soils with high K content it can be reduced by fertilization or spraying with magnesium salts. Hobson *et al*. (1977) stated that the K status is inversely related to the incidence of BR in tomatoes.

Figure 2.2 Blotchy ripening on tomato fruits

2.6.2 Fruit cracking

In nature, fruit cracking can be considered part of the final developmental stage after ripening and before seed dispersal. In commercial production, cracked fruit cannot be marketed and the cracks become sites for fungal penetration and infection (Figure 2.3) (Litchter *et al*., 2002). Fruit cracking reduces fruit appeal (Peet and Willits, 1995), reduces fruit shelf life (Hayman, 1987), and fruit marketability (Peet, 1992). There are several types of fruit cracking, namely: Fruit bursting, radial cracking (star-shaped originating from the peduncle), concentric cracking (circular cracks around peduncle), and cuticle cracking (russeting) (Wien, 1997).

Fruit cracking occurs when there is a net influx of water and solutes into the fruit at the same time that ripening or other factors reduce the strength and elasticity of tomato skin (Peet, 1992; Jones, 1999). Cracking can be minimized by selecting a variety that has resistance to cracking as well as maintaining a consistent soil moisture content to avoid periods of plant moisture stress (Peet, 1992; Peet and Willits, 1995). According to Simon (1978) calcium is important in the prevention of fruit cracking. The percentage of cracking increases with an increased number of fruit per cluster. Furthermore, frequent watering also increases the incidence of cracking (Peet and Willits, 1995).

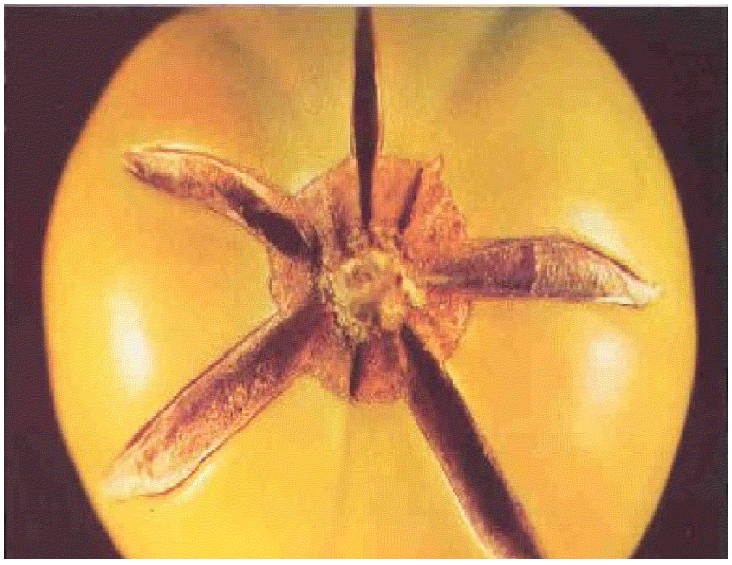

Figure 2.3 Fruit cracking on tomato fruits

2.6.3 Cat facing

A catfaced fruit is misshapen due to abnormal development that begins at the time of flowering, believed to be due, in part, to cool temperatures (less than 12.8 ^{o}C) and cloudy weather at the time of flowering and fruit set. Although cat facing is usually a specific disorder in terms of fruit appearance, any misshapen fruit due to incomplete pollination may be also identified as cat facing (Jones, 1999). Affected fruits are generally flattened on the blossom end (Figure 2.4), while large bands of cork-like, malformed scar tissue can also cover the whole fruit. The scars often criss-cross and the fruit seems to consist of lobes with cavities sometimes forming in healthy tissue (Bergmann, 1992). The effect of nutrition in cat facing occurrence is not reported in literature; however, a study on the possible link between the two seems to be valid.

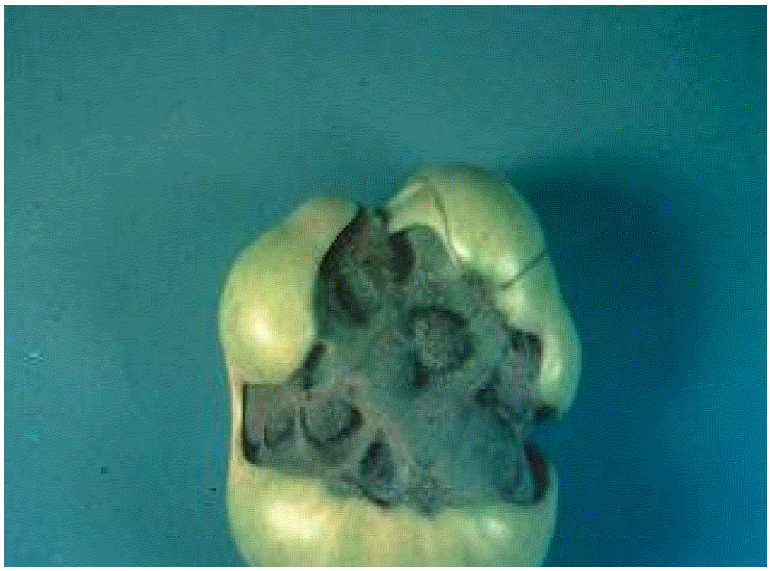

Figure 2.4 Cat facing on tomato fruits

CHAPTER 3

YIELD AND QUALITY OF TOMATO AS INFLUENCED BY K, Mg, AND Ca NUTRITION

3.1 INTRODUCTION

Fruit quality is a crucial factor in the successful production of greenhouse tomatoes. Among factors believed to have a strong effect on tomato fruit quality, are plant nutrients. According to Paiva *et al*. (1998b), the effects of nutrients on plant growth and production are usually attributed to the functions of those nutrients in the plant's metabolism. The roles of some of these plant nutrients such as K, Mg, and Ca, have been widely reviewed in the previous chapter. For high yield and good fruit quality, these three plant nutrients must be in sufficient supply due to their functions in plant metabolism. Unfortunately it happens that Ca, Mg, and K strongly interact on each other. High Ca concentrations have been reported to interfere with K and Mg uptake, and are consequently affecting fruit quality. The same applies to high K or Mg.

It is strongly believed that a link between plant nutrients and the physiological disorders of tomato, namely BER and BR, exists. According to Ho *et al.* (1993), BER is a physiological disorder caused by Ca deficiency in the distal part of the fruit when Ca levels are low. Many researchers support this view. A correlation has also been established between this disorder and rates and ratios of K, Mg, and Ca. Blossom-end rot is not the only physiological disorder in tomato. Links between BR and nutrition, mainly low K availability, have also been reported in literature (Winsor, 1966).

It is clear that K, Mg, and Ca interactions may eventually lead to a decrease in one or two of the elements, depending on the rates of these nutrients in the nutrient solution. It is important to investigate these interactions, as the main consequence of low fruit quality is yield loss. Blossom-end rot is a common greenhouse disorder, causing serious yield losses. Good nutrition management that will favour adequate concentration of these plants nutrients without inducing deficiencies or toxicities seems to be one of the keys to decrease the incidence of physiological disorders and

producing high marketable yield. Therefore a study was carried out in order to obtain information on the optimal ratios and rates of K, Mg, and Ca that will favour high tomato yield and good fruit quality (low pH, high TSS and TA, and low incidence of physiological disorders).

3.2 MATERIAL AND METHODS

3.2.1 Plant culture and experimental design

An experiment was conducted in a greenhouse at the Hatfield Experimental Farm, Department of Plant Production and Soil Science, University of Pretoria, during 2004. Seeds of the tomato cultivar "Money-maker" were sown in seedlings trays on the 19th of April 2004, and transplanted 45 days later when the plants had five to six true leaves. Seedlings were transplanted as individuals in 5-litre pots filled with sand/coir medium (ratio 2:1). The criteria for seedling selection were plant vigour and uniformity. The main stem was trained with a single wire and allowed to grow until five trusses. According to Jones (1999) the setting of four to five trusses results in large fruit as all generated photosynthate goes to fruit already set. The plant was then topped and all lateral shoots were removed but no fruit thinning was carried out. The experimental design consisted out of four replications per treatment in a completely randomised design. Plants were spaced 0.4 m between plants in double row with 1 m between rows, corresponding to approximately 25000 plants ha^{-1} (Chapagain and Wiesman, 2004)

3.2.2 Plant nutrition and treatments

Four Ca:Mg ratios (20:1, 15:5, 10:10, and 12:8 $mmol_c$. l^{-1}) were combined with three K levels (1, 6, and 9 $mmol_c$. l^{-1}) giving 12 Ca:Mg:K ratios. Table 3.1 presents Ca:Mg:K ratio combinations. Details on the stock solution and source of nutrients are given in Tables 3.2 and 3.3.

Table 3.1 K, Mg, and Ca ratios, expressed as $mmol_c$. l^{-1}

Treatment	Ca	Mg	K
1	20	1	1
2	20	1	6
3	20	1	9
4	15	5	1
5	15	5	6
6	15	5	9
7	10	10	1
8	10	10	6
9	10	10	9
10	8	12	1
11	8	12	6
12	8	12	9

Table 3.2 Stock solutions and nutrient sources

Macronutrients		Micronutrients	
Conc.: 1.0 M	Volume (ml)	Conc.: 1000 mg/L	Volume (ml)
$Ca(NO_3)_2$	1000	$FeSO_4$ EDTA	500
$MgSO_4$	1000	H_3BO_4	250
$Mg(NO_3)_2$	1000	$MnCl_2$	250
KNO_3	1000	$ZnSO_4$	250
K_2SO_4	500	$CuSO_4$	250
$NH_4H_2PO_4$	500	$NaMoO_4$	250

Table 3.3 Hoagland No.2 solution

Compound	Volume
$Ca(NO_3)_2$	4 $mmol.l^{-1}$
$MgSO_4$	2 $mmol.l^{-1}$
KNO_3	6 $mmol.l^{-1}$
$NH_4H_2PO_4$	1 $mmol.l^{-1}$
Fe	1 $mg.l^{-1}$
Mn	0.5 $mg.l^{-1}$
Zn	0.05 $mg.l^{-1}$
Mo	0.01 $mg.l^{-1}$
B	0.5 $mg.l^{-1}$
Cl	0.5 $mg.l^{-1}$
Cu	0.02 $mg.l^{-1}$

An excess nutrient solution was added to each pot and the excess collected in a container below each pot (Figure 3.1). The nutrient solution collected in the container below the pot was recycled daily through the pot. Water losses due to evapotranspiration were restored daily with pure water to prevent the build up of nutrients. The nutrient solution was replaced every 14 days.

The pH was adjusted to around 5.8-6.0 by using 1.0 M HNO_3 or 1.0 M NaOH. As reported by Lopez and Satti (1996), the nutrient uptake and availability in the solution is maximal at this pH range. The pH adjustment did not affect the EC that was regularly monitored (2.5-3 $mScm^{-1}$).

Figure 3.1 Pots filled with sand/coir mixture placed on collecting pans to collect excess water

3.2.3 Data collection

During the experiment, plants were regularly inspected for nutrient disorders. At harvest, fruits of each cluster were collected to determine fruit yield and quality. Each fruit was weighted, examined for any physiological disorder, and graded for size. Fruit size was divided in four categories according to fruit diameter in class one (>67mm), class two (67-54 mm), class three (54-47mm), and below grade (<47mm) fruits (Jones, 1999). The marketable yield was calculated as the total fruit mass minus the mass of the fruits affected by physiological disorders, as well as below grade fruits, while the number of marketable fruit was assessed as the total number of fruits per plant minus the number of fruits affected by physiological disorders and small fruits. The number of fruits affected by physiological disorders was recorded to determine the incidence of these disorders. Five to six fruits per plant were selected for fruit quality analysis. The pulp was removed and fruit juice was extracted and homogenized with a centrifuge for 20 minutes. The supernatant juice was then measured for pH by using a pH-meter, total soluble solids by using a digital refracto meter, electrical conductivity using an EC-meter, and titratable acidity by titration with NaOH (0.05 N). These parameters served as indicators for fruit quality.

3.2.4 Statistical analysis

Analysis of variance was done for each parameter at P<0.05 using SAS (SAS Institute Inc., Cary, NC, USA. (Copyright © 1999-2001)). In case of significance the Tukey test was performed to indicate significant differences between treatment means. If the interaction between main factors (A*B) were significant, the interaction was considered instead of main factors. When A*B was not significant, each significant main factor was tested separately. The ANOVA and other statistical data are presented in the Appendix.

3.3 RESULTS AND DISCUSSION

3.3.1 Effects of Ca:Mg ratios

3.3.1.1 Fruit quality

pH

The relationship between pH and Ca:Mg ratios are presented in Figure 3.2. There were significant differences among treatment means.

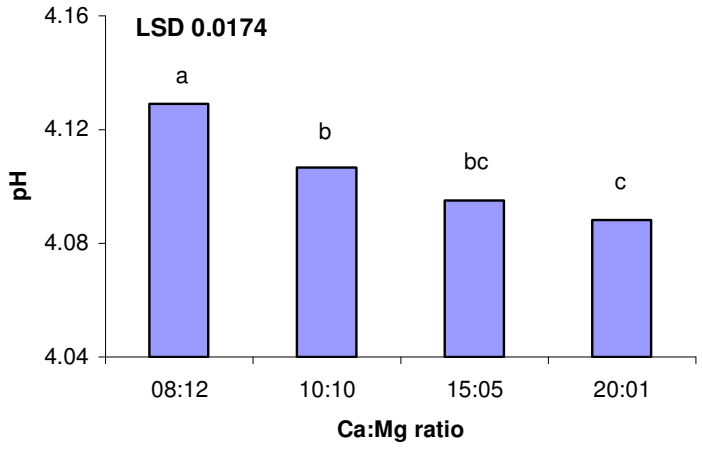

Figure 3.2 Effect of Ca:Mg ratios on the pH of tomato (Appendix Table A.3.1)

The highest pH value (4.13) was at the lowest Ca:Mg ratio (8:12) whereas the lowest pH value (4.09) was obtained at a high Ca:Mg ratio (20:1), suggesting that high Ca:Mg ratios decreased the pH of tomato fruit juice. However, there was no significant pH differences between a Ca:Mg ratio of 15:5 and 10:10, as well as between 15:5 and 20:1. According to Jones (1999) the range of pH for tomato fruit juice is between 4.0 and 4.5 and for most of the fruits the average ranges between 4.3 and 4.4. In the present experiment, although low Ca:Mg ratios (8:12) showed a high pH (4.13) as compared to others ratios, the value is still below 4.3. The lower the pH, the greater the tartness of the fruit, a factor by which some consumers judge the quality of the tomato fruit (Jones, 1999). Based on the findings of this experiment it can be concluded that low rates of Ca combined with high Mg slightly increase the pH of tomato fruit juice.

Total soluble solid content

Although there were no significant differences among treatment means of Ca:Mg ratios of 8:12, 10:10, and 15:5, there were a steady decline in TSS with increasing Ca:Mg ratios (Figure 3.3).

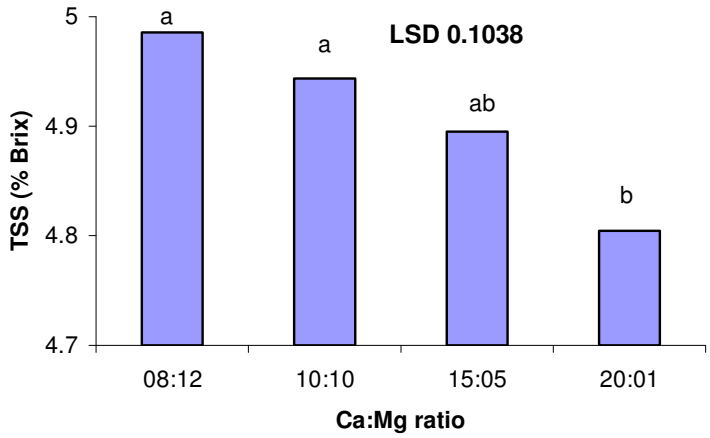

Figure 3.3 Effect of Ca:Mg ratios on total soluble solid content of tomato fruits (Appendix Table A.3.3)

The TSS content of tomato fruit at the lowest Ca:Mg ratios (8:12 and 10:10) did, however, differ significantly from the TSS content of tomato fruit at the highest Ca:Mg ratio (20:1). High Ca concentrations (15 $mmol_c$. l^{-1}) have been found to cause a reduction in fruit soluble solid content of tomato fruit in a fall greenhouse tomato grown on rockwool (Hao and Papadopoulos, 2003). In this experiment, although the TSS decreased with increased Ca:Mg ratios, the tomato fruit quality is still acceptable, as the total soluble solid contents for several cultivars of greenhouse grown in nutrient film technique varies from 4.7 to 5.1 % (Dorais *et al.*, 2001).

3.3.1.2 Fruit size

More than 50% of the crop yield consisted out of class two fruits, followed by class three (22-27%), class one (10-18%) and under grade fruits (<8%) (Table 3.4). Except for class one and two fruit, Ca:Mg ratios had no significant effect on the treatment means (Table 3.4). Ca:Mg ratio of 15:5 produced more class one and less class two and three fruits in comparison to the other Ca:Mg ratios, while at a Ca:Mg ratio of 20:1, more class two and less class one fruits were produced.

Table 3.4 Effect of Ca:Mg ratios on tomato fruit size

Ca:Mg ratio	Class 1	Class 2	Class 3	Under class
8:12	10.49 c	54.94 ab	26.65 a	7.922a
10:10	12.45 b	54.03 ab	27.06 a	6.46 a
15:5	17.29 a	52.35 b	22.74 a	7.62 a
20:1	11.58 bc	56.11 a	25.10 a	7.21 a
LSD	1.76	3.56	4.44	2.18
CV	16.41	7.81	21.11	36.12

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Tables A.3.9, A.3.10, A.3.11, A.3.12)

3.3.1.3 Yield and yield components

Number of fruits

The number of fruits per plant was significantly influenced by Ca:Mg ratios (Figure3.4). Data showed a significant higher number of fruits at a Ca:Mg ratio of 15:5, while the rest of the Ca:Mg ratios did not differ significantly from one another. The number of fruits increased from 42.25 to 47.25 in respect with elevating Ca:Mg ratio from 8:12 to 15:5. At still higher Ca:Mg ratios, the number of fruit decreased again. These results are in line with that of Carvajal *et al*. (1999) who stated that a Ca:Mg ratio lower than one causes a decline in the number of fruits produced. In this experiment, the lower yields at the highest ratios were probably caused by a Mg deficiency and not the ratio as such.

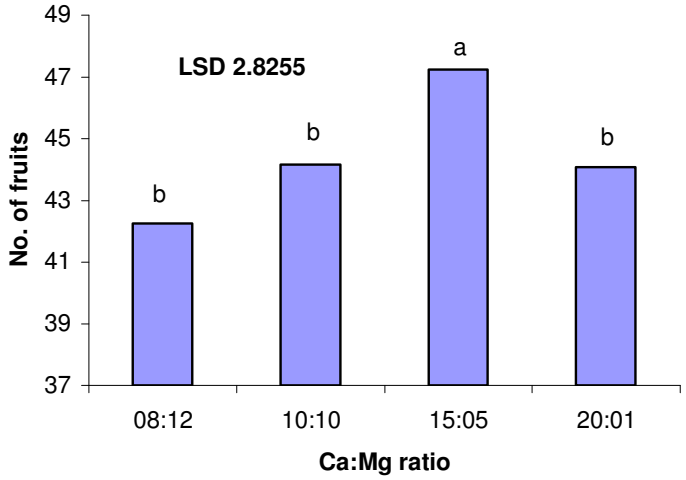

Figure 3.4 Effect of Ca:Mg ratios on number of tomato fruits (Appendix Table A.3.4)

Marketable fruits

A Ca:Mg ratio lower than one, significantly decreased the percentage marketable fruits (Figure 3.5). These findings clearly show that a low rate of Ca combined with a high rate of Mg could significantly affect the percentage marketable tomato fruits. A higher incidence of BER (Figure 3.10) at low Ca:Mg ratios could have attributed to this lower percentage marketable fruit. These findings again support the results of

Carvajal *et al.* (1999) who found that the percentage of marketable fruit decreases with increasing Mg concentrations from 5 to 10 $mmol_c$. l^{-1}.

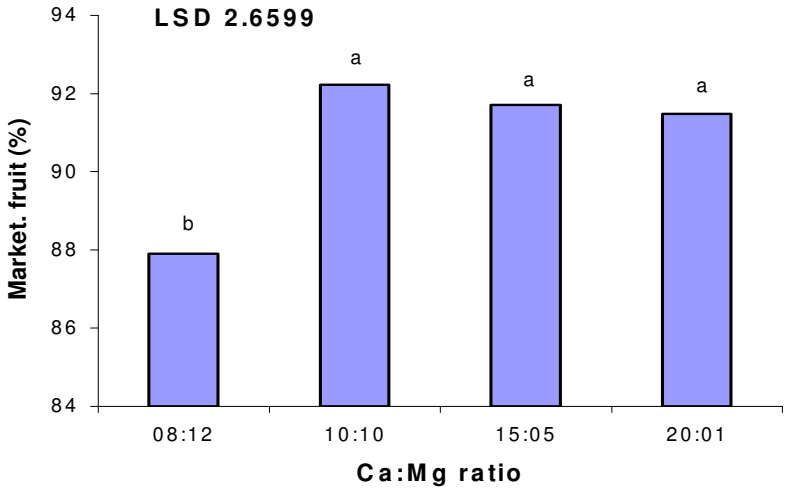

Figure 3.5 Effect of Ca:Mg ratios on marketable tomato fruits (Appendix Table A.3.8)

Fruit mass

It was only ratios of less than one, which significantly reduced fruit mass (Figure 3.6). The lowest weight per fruit (89.49 g) was at a Ca:Mg ratio of 8:12 whereas the highest weight per fruit (97.98 g) was obtained at a Ca:Mg supply of 15:5. The lower fruit mass at the highest ratio was rather due to the Mg deficiency than the ratio itself.

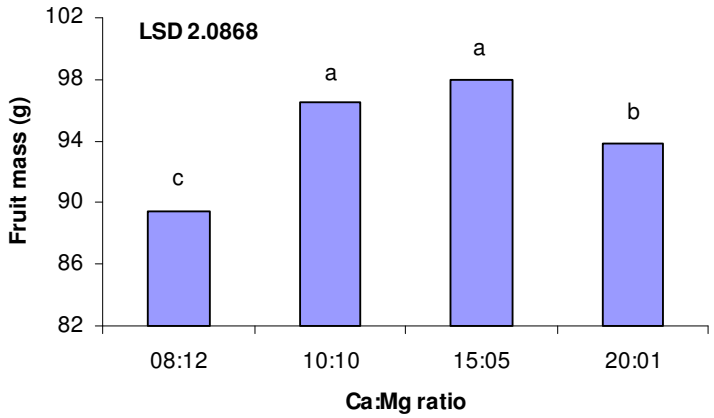

Figure 3.6 Effect of Ca:Mg ratios on tomato fruit mass (Appendix Table A.3.5)

Yield per plant

An increased Ca:Mg ratio in the nutrient solution from 8:12 to 15:5 resulted in increased yields of 3.78 kg to 4.62 kg per plant respectively (Figure 3.7). Increased Ca:Mg ratios from 15:5 to 20:1 caused a reduction in yield of 0.46 kg per plant. The best yield was obtained at a Ca:Mg ratio of 15:5 due to more and also heavier fruits (Table 3.4 and Figure 3.5) produced at this ratio. No differences have been observed between Ca:Mg ratios of 10:10 and 20:1. From these results it is obvious that a ratio of less than one causes a significant reduction in yield. Higher ratios also had a significant effect, but did not lower the yield as much as with as ratio of less than one.

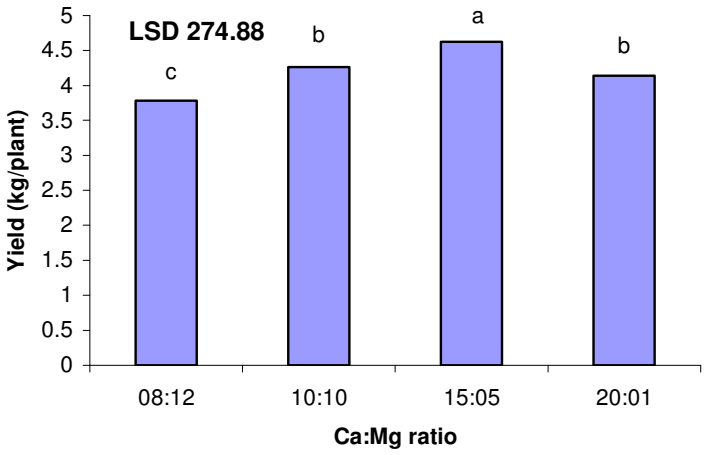

Figure 3.7 Effect of Ca:Mg ratios on tomato yield (Appendix Table A.3.6)

Marketable yield

In terms of marketable yield (Fig 3.8), there was only a significant difference between the lowest Ca:Mg ratio (8:12) and the rest of Ca:Mg ratios. This is due to the incidence of BER that only affected tomato fruit supplied with a solution containing a low Ca:Mg ratio, causing a decline in marketable yield. A decrease in marketable yield due to the incidence of BER has been reported by several researchers (Sonneveld and Voogt, 1996). Similar results have been reported on by Hao and Papadopoulos (2003), who observed higher marketable yields at high Ca concentrations in the nutrient solution (15 $mmol_c$. l^{-1}) as compared to lower Ca concentrations (7.5 $mmol_c$. l^{-1}). This study indicates that only a Ca:Mg ratio of less

than one reduces the marketable yield. Above a Ca:Mg ratio of one, the ratio becomes less relevant, while other factors, like deficiencies, come into play.

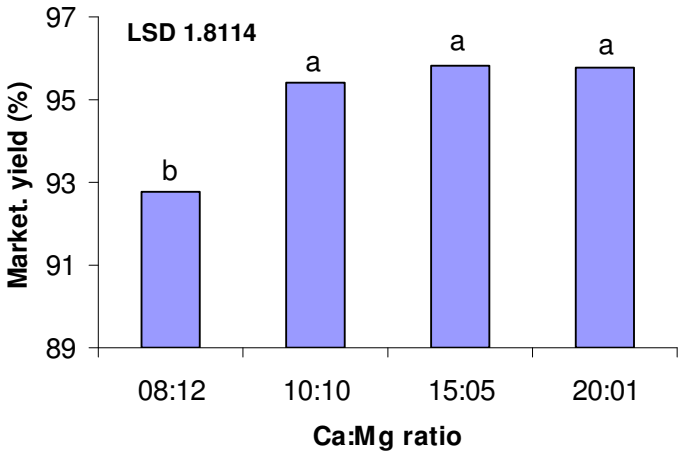

Figure 3.8 Effect of Ca:Mg ratios on marketable tomato yields (Appendix Table A.3.7)

3.3.2 Effect of K application rate

3.3.2.1 Tomato fruit quality

Tomato fruit pH

The pH of tomato fruits (Figure 3.9) was significantly reduced by an increase in the K concentration in the nutrient solution, but Yurtseven *et al.* (2005) did not observe any influence of K application the pH of tomato fruit. The increased fruit pH due to low K did not influence the fruit quality as all values fall within the acceptable range (4.0-4.5).

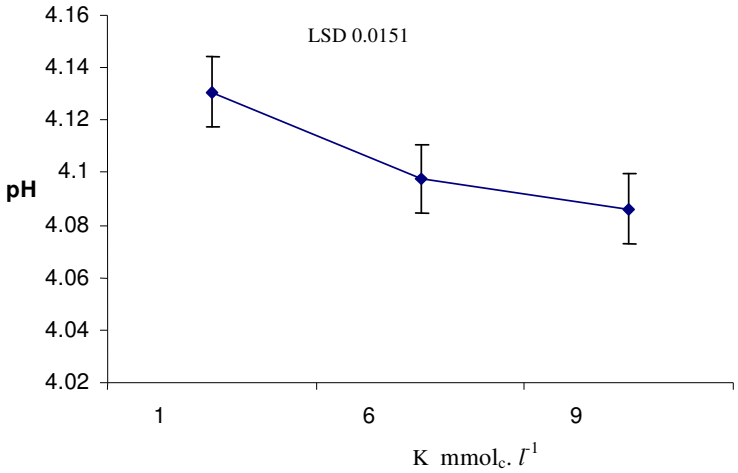

Figure 3.9 Effect of K concentration on pH of tomato fruits (Appendix Table A.3.1)

Total soluble solids (TSS)

The total soluble solid content of tomato fruits significantly increased with increased rates of K in the nutrient solution (Figure 3.10).

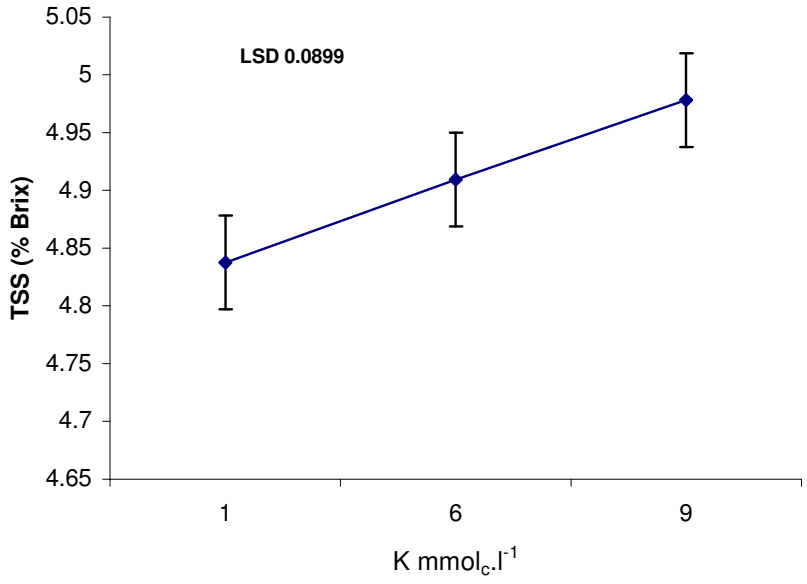

Figure 3.10 Effect of K concentration (mmol$_c$. l^{-1}) on total soluble solid content of tomato fruits (Appendix Table A.3.2)

This data indicate a reverse of the pH results. It could therefore be concluded that the TSS consists out of cation components that are acid. Factors that may also influence the solids content of tomato fruit include: number of fruits, the rate of assimilates export from leaves; rate of import of assimilates by fruits; and fruit carbon metabolism (Herwitt *et al.,* 1982, Young *et al*., 1993, Al-Lahlam *et al.,* 2003).

3.3.2.2 Fruit size

More than 50% of the crops consisted out of class two fruits, followed by class three (25%), class one (11-14%) and under grade fruits (<9%) (Table 3.5). Increased K rates significantly increased the percentage of class one fruit and reduced the under grade fruits. The highest yields were from class two. There were no interactions between Ca:Mg and K supply (A.3.5).

Table 3.5 Effect of K rates on tomato fruit size

K ($mmol_c$. l^{-1})	Class 1	Class 2	Class 3	Under class
1	11.15 b	55.18 a	25.09 a	8.57 a
6	13.64 a	53.99 a	25.73 a	6.64 b
9	14.06 a	53.90 a	25.39 a	6.70 ab
LSD	1.52	3.046	3.85	1.89
CV	16.41	7.81	21.11	2.64

Means followed by different letters in columns are significantly different at P<0.05 (Appendix A. 3.5).

3.3.2.3 Yield and yield components

Number of fruits

There were no significant differences between the number of fruits per plant at different levels of K in the nutrient solution, again without an interaction between K level and Ca:Mg ratio (Table 3.6) .

Marketable fruits

The percentage of marketable tomato fruits (Table 3.6) was not influenced by the levels of K applied in the nutrient solution. The percentage marketable fruits ranged

from 91.68 % at K level of 6 $mmol_c$. l^{-1} to 90 % at the lowest K (1 $mmol_c$. l^{-1}) level, whereas the highest level of K (9 $mmol_c$. l^{-1}) resulted in 90.79 % marketable fruits.

Fruit mass

The average fruit weight increased significantly with increased K application rates (Table 3.6). Although these fruit weights differ significantly, in practise the weight difference in grams (5g) is insignificant.

Yield per plant

No significant relationship was established between K nutrition and yield per plant (Table 3.6). These results are in agreement with that of Yurtseven *et al*. (2005), who found significant yield increases with increasing K application but reported that the effect was not enough to state that increased K^+ levels have a positive effect on yield. On the other hand, Adams and Ho (1992) observed a reduced yield at low K concentration (1.25 $mmol_c$. l^{-1}).

Marketable yield

None of the K application had any significant effect on marketable tomato yields (Table 3.6).

Table 3.6 Effect of K rates on tomato yield and yield components

K ($mmol_c$. l^{-1})	No. of fruits	Marketable fruits (%)	Fruit weight (g)	Yield (kg/plant)	Marketable yield (%)
1	44.88 a	90.00 a	91.80 b	4.12 a	94.88 a
6	44.25 a	91.68 a	95.03 a	4.21 a	95.46 a
9	44.19 a	90.79 a	96.53 a	4.28 a	94.48 a
LSD	2.45	2.30	1.81	238.06	1.57
CV	7.70	3.54	2.67	7.90	2.30

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Table A.3.6)

3.3.3 Effect of Ca:Mg:K ratios

3.3.3.1 Incidence of blossom -end rot (BER)

Blossom-end rot only occurred in treatments supplied with the lowest Ca:Mg ratio (8:12). At this Ca:Mg ratio, the incidence of BER increased with increasing K levels in the nutrient solution (Figure 3.11). These findings indicate that BER occurrence does not only depend on Ca:Mg ratios as such, but also on the K concentration in the nutrient solution. By elevating the Ca:Mg ratio in the nutrient solution, BER occurrence in tomato was prevented. The fact that BER has been observed only in the lowest Ca:Mg treatment strongly support the view of most of the researcher that BER is a Ca related disorder, however, this study clearly showed that K could also play a role in the occurrence of this disorder due to a possible suppresion of Ca uptake by the plant.

The incidence of BER was low (only 2.25 %) for low Ca:Mg ratios (8:12) and high K concentrations (9 $mmol_c$. l^{-1}). Similar results were also found by Hao and Papadopoulos (2003) and Bar-Tal and Pressman (1996).

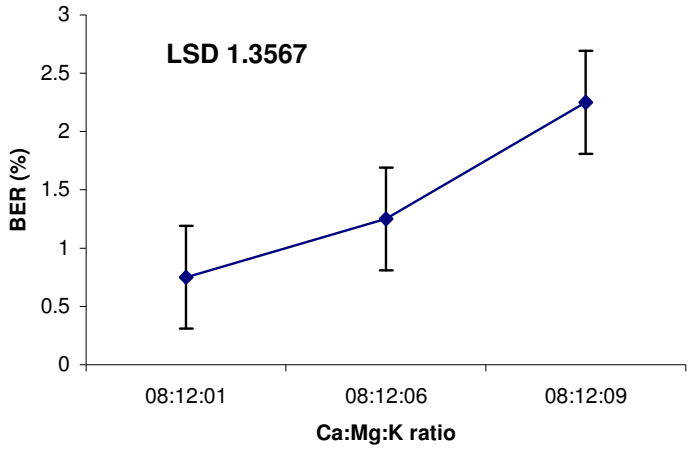

Figure 3.11 Effect of Ca, Mg, and K rates on the incidence of blossom-end rot in tomato fruits (Appendix A.3.14)

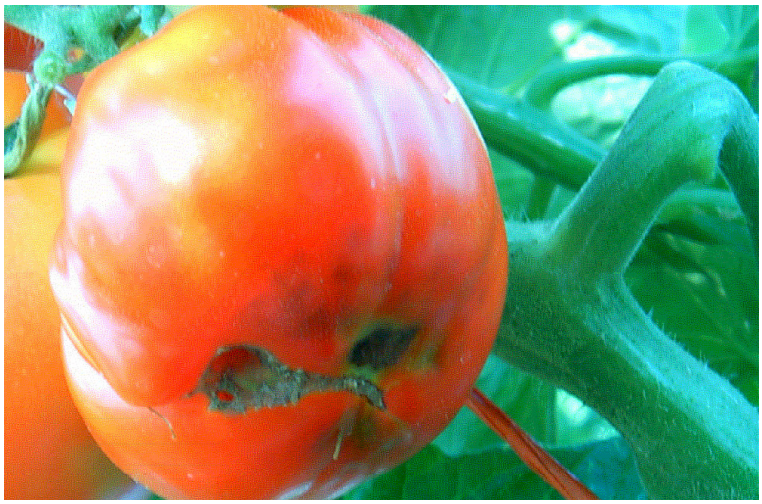

Figure 3.12 Blossom-end rot in tomato fruits at low Ca:Mg ratios (8:12)

3.3.3.2 Cat facing

Cat facing (Figure 3.13) and BER were the only physiological disorders observed during this trial. No clear relationship was established between cat facing and Ca, Mg and K nutrition. The disorder was not restricted to a certain Ca:Mg:K ratio, but occurred at all treatment combinations, suggesting that cat facing is not a nutritional disorder.

Figure 3.13 Cat facing on tomato fruits

3.3.3.3 Class one tomato fruit

There was a significant interaction between Ca:Mg ratios and rates of K (Appendix A.3.9) on the percentage class one fruit (Figure 3.14). A too high Ca:Mg ratio (20:1) considerably decreases the class one fruits as compared to a Ca:Mg ratio of 15:5. Regardless of the Ca:Mg ratio, increased levels of K in the nutrient solution resulted in an increase in the percentage of class one tomato fruits but only significantly in the 15:5, Ca:Mg ratio.

As discussed previously, too high a Ca:Mg ratio decrease the percentage of class one fruits, probably due to a Mg deficiency. At this Ca:Mg ratio, increased K levels did not aggravate the Mg deficiency. From these results it could be concluded that the lowest K rate (1 $mmol_c$. l^{-1}) was insufficient, while both the 6 and 9 $mmol_c$. l^{-1} K levels were sufficient in maintaining the yield . These results are in line with that of Hao and Papadopoulos (2003) who noticed a marked increase in percentage of class one fruits in respect to high Ca level (15 $mmol_c$. l^{-1}) in the nutrient solution as well with Munson (1985) who reported that proper K nutrition increased the size of tomato fruit. However, Yurtseven *et al.* (2005) did not find any significant effect of different K levels on tomato fruit size.

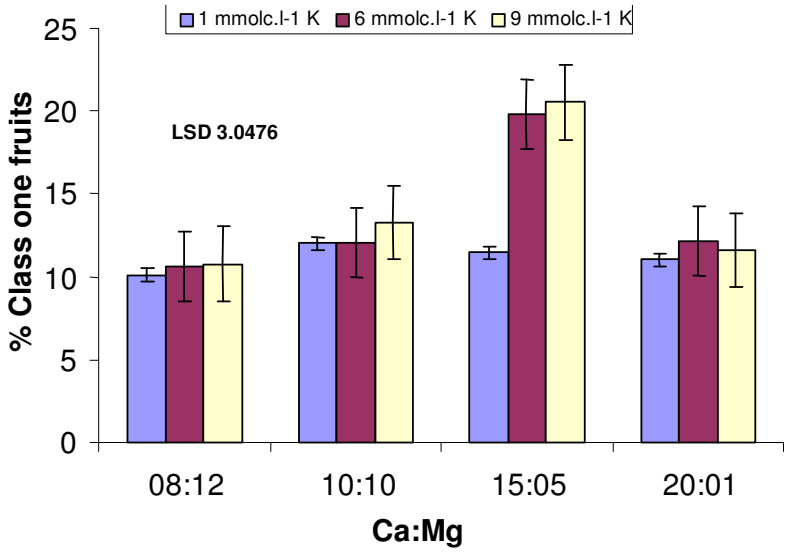

Figure 3.14 Effect of Ca:Mg:K ratios on class one fruits (Appendix Table A.3.9)

3.4 CONCLUSIONS

The findings of this study showed that K, Mg, and Ca rates and ratios affect fruit quality, total yield and marketable yield of tomato. Low Ca:Mg ratios (8:12) negatively affected fruit quality and decreased the marketable yield due to BER occurrence. High Ca:Mg ratios (20:1) reduced the total number of fruits and consequently affected the total yield, propably due to a Mg deficiency. Increased K levels (6 and 9 $mmol_c$. l^{-1}) in the nutrient solution resulted in the improvement of fruit quality. The findings of this study revealed that blossom-end rot is a nutritional disorder due to low Ca:Mg ratios (8:12) only but that it could be aggravated by increased K in the nutrient solution. According to the results of this study, for high tomato fruit quality and yield, the Ca:Mg ratios should range between 10:10 and 15:5 whereas K must be maintained at high rates (6 and 9 $mmol_c$. l^{-1}). Further studies are needed to investigate the effects of K:Ca ratios on yield and quality without fluctuating rates of Mg in the nutrient solution.

CHAPTER 4

YIELD AND QUALITY OF TOMATO AS AFFECTED BY RATES AND RATIOS OF K AND Ca IN A WATER CULTURE SYSTEM

4.1 INTRODUCTION

Fruit quality is a crucial factor in the production of fresh market tomatoes. Among the factors that strongly influence the quality of tomato, K plays a key role since it is involved in metabolic and transport processes, charge balance, and generation of turgor pressure (Dorais *et al*., 2001). Potassium is related to a nice fruit shape, the reduction of ripening disorders, and the increase of fruit acid concentration (Adams *et al*., 1978). With proper K nutrition, fruit is generally higher in total solids, sugars, acids, carotene, and lycopene and has a better keeping quality (Munson, 1985).

According to Voogt and Sonneveld (1997) the absorption of potassium is relatively greater than that of any other nutrient. It coincides with the growth of the tomato plant, leading to improved fruit quality with increasing K supply. However, the main concern of elevated K levels in the nutrient solution seems to be the cationic competition with Ca^{2+}, Mg^{2+}, and NH_4^+. It has been reported that a high K:Ca ratio in fertilizing tomato plants increases the proportion of fruit showing BER (Bar-Tal and Pressman, 1996).

The aim of this experiment was to investigate the effects of increased K and Ca rates and ratios on yield and quality of tomato.

4.2 MATERIAL AND METHODS

An experiment was conducted in a greenhouse at the Hatfield Experimental Farm of the Department of Plant Production and Soil Science, University of Pretoria from October 2004 to April 2005. The experiment consisted of a randomised block less design with four replications. One-month old tomato seedlings, cultivar “Money-maker”, were placed in 10-liter containers filled with nutrient solution. The containers

were placed on a rotating table. The main stem was trained to a single wire and allowed to grow until five trusses. All the lateral shoots were removed and no fruits were thinned. The treatment consisted of combination of two levels of K (6 and 10 $mmol_c$. l^{-1}) with two levels of Ca (12 and 16 $mmol_c$. l^{-1}) giving four K:Ca ratios (6:12, 6:16, 10:12, 10:16). The choice of the treatments was justified by the fact that in the previous experiment Ca levels (10 and 15) and K (6 and 9) preformed well but only when Ca:Mg ratio was greater than one. Thus there was a need to further investigate whether increased levels of both nutrients play major roles on yield and quality, irrespectively of Ca:Mg ratios. KNO_3, K_2SO_4, or $KHPO_4$ were used as sources of K, $Ca(NO_3)_2$ and $CaSO_4$ as sources of Ca, and $MgNO_3$ and Mg_2SO_4 as sources of Mg. A Hoagland No.2 nutrient solution was used as basis to compile the different ratios as well as the other elements.

At harvest, fruits of each cluster were collected to determine yield and quality. Each fruit was weighed, examined for any physiological disorder, graded for size (as described in 3.2.3), and analysed for fruit quality (pH, TSS, TA, EC, dry matter). In addition, the K, Mg, Ca, N, and P content of the leaves and fruits were determined. Analysis of variance was done for each parameter at $P<0.05$ using SAS (SAS Institute Inc., Cary, NC, USA. When the F value was significant, the Tukey test was performed to illustrate significant differences between means. The statistical data is presented in the Appendix.

4.3 RESULTS AND DISCUSSION

4.3.1 Fruit quality

Tomato fruit pH

A strong relationship was found between K levels and pH of the tomato fruits (Table 4.1). Fruit pH at low K and high K levels differed significantly. The pH of the fruits decreased with increasing K levels in the nutrient solution from pH (4.19) at the high K level (10 $mmol_c$. l^{-1}) and was lowest at the low K level (6 $mmol_c$. l^{-1}). Still, the values found for different levels are indicators of good fruit quality (See previous

chapter). On the other hand, the levels of Ca did not significantly affect fruit pH. No interaction was observed between the K and Ca levels.

Table 4.1 Effect of K and Ca rates on tomato fruit pH

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	4.16	4.19	4.18 a
10	4.08	4.08	4.077 b
Mean	4.12 a	4.13 a	4.13
CV			0.75
LSD Tukey (0.05)		K	0.034
		Ca	0.034
		K*Ca	0.05

Means followed by different letters in columns and rows are significantly different at P<0.05. (Appendix Table A.4.7)

Total soluble solid (TSS) of tomato fruits

There was evidence that K levels influenced the TSS of tomato fruits (Table 4.2).

Table 4.2 Effect of K and Ca rates on total soluble solid (% Brix) of tomato fruit

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	4.90	4.92	4.91 b
10	5.07	5.06	5.06 a
Mean	4.98a	4.99 a	4.99
CV			2.60
LSD Tukey (0.05)		K	0.14
		Ca	0.14
		K*Ca	0.20

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.8)

Increasing K levels from 6 to 10 $mmol_c$. l^{-1} in the nutrient solution resulted on a significant increase in TSS from 4.92 to 5.07 $mmol_c$. l^{-1}. The level of Ca in the

nutrient solution did not affect the TSS and no significant interaction between K and Ca was observed. Voogt (1998), however, found an increase in TSS with increasing K:Ca ratio in the nutrient solution. Increased TSS of tomato fruit improves the flavour of tomato fruits (Hobson and Kilby, 1990), though none of the treatments negatively affected the TSS, as values obtained ranged between 4.7 and 5.1 %.

Titratable acidity of tomato fruits

The TA of tomato fruits was significantly increased with increasing K levels in the nutrient solution (Table 4.3). According to Dorais *et al.* (2001) the titratable acid for cultivars of greenhouse tomato vary between 77 and 85 mmol.l^{-1}. This experiment showed similar results. These findings are also in agreement with Munson (1985) who found an increase in TA as the level of K was increased in the nutrient solution. No relationship could be established between the level of Ca and TA in the fruits.

Table 4.3 Effect of K and Ca rates on titratable acidity (mmol.l^{-1}) of tomato fruit

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	66.75	67.50	67.13 b
10	71.75	72.25	72 a
Mean	69.25 a	69.88 a	69.56
CV			5.65
LSD Tukey (0.05)		K	4.28
		Ca	4.29
		K*Ca	6.05

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.9)

Electrical conductivity (EC) of tomato fruit juice

There was a significant increase in EC with respect to increasing K and Ca levels in the nutrient solution (Figure 4.1); however, there was no significant K:Ca ratio interaction. Treatments with low K and Ca (6:12) levels showed the lowest mean EC

value (4.69 dSm^{-1}) whereas the highest EC value (4.83 dSm^{-1}) was measured at high K and Ca levels in the nutrient solution.

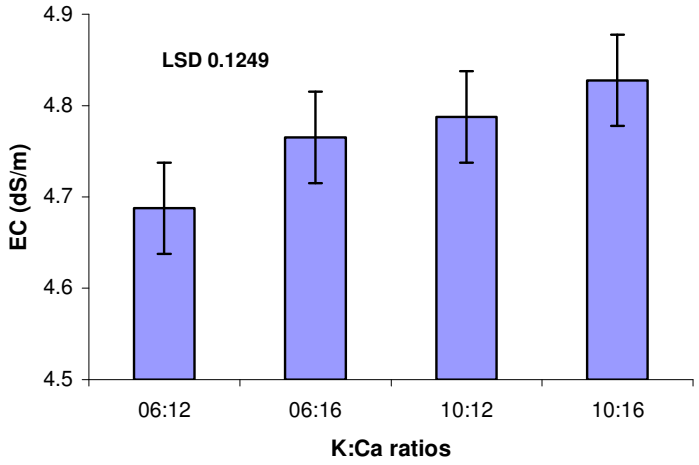

Figure 4.1 Effect of K:Ca ratios on electrical conductivity of tomato fruit juice (Appendix Table A.4.10)

Dry matter content of fruit

There was no evidence that either K or Ca levels affected dry matter content of tomato fruits, as no significant differences were observed among treatment means. However, there was a tendency of increased dry matter with increased K levels in the nutrient solution (Table 4.4).

Table 4.4 Effect of K and Ca rates on tomato fruit dry matter (%)

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	5.40	5.36	5.38 a
10	5.59	5.57	5.58 a
Mean	5.50 a	5.46 a	5.48
CV			4.39
LSD Tukey (0.05)		K	0.26
		Ca	0.26
		K*Ca	0.37

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.6)

4.3.2 Fruit size

There was only a positive response of percentage of class one and two fruits with respect to K:Ca ratios (Table 4.5) while the other classes were not affected by treatments. About half of the fruits could be classified as class two fruits, about 29% fall in class three and 12% in class one. Only a few (5 %) small fruits were recorded.

Table 4.5 Effect of K and Ca rates on tomato fruit size

K:Ca ratio	Class one fruits (%)	Class two fruits (%)	Class three fruits (%)	Below grade fruits (%)
6:12	12.02 a	52.77 ab	30.09 a	5.11 a
6:16	10.23 b	53.43 ab	30.75 a	5.11 a
10:12	13.30 a	51.94 b	28.82 a	5.52 a
10:16	11.89 a	54.77a	28.09 a	5.73 a
LSD	1.56	2.67	3.49	1.10
CV (%)	8.55	3.26	7.70	13.30

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Tables A.4.11, A.4.12, A.4.13, A.4.14)

4.3.3 Incidence of physiological disorders

Blossom-end rot (BER)

There is evidence that BER of tomato is a nutritional disorder due to a local Ca deficiency (Ho *et al*., 1999). Blossom-end rot of tomato fruits markedly decreased from 2.5 to 0.7 % when Ca levels were increased in the nutrient solution from 12 to 16 $mmol_c$. l^{-1} (Table 4.6). Increasing K levels in the nutrient solution have also resulted in a decrease of BER incidence, though no significant difference was found between treatments means supplied with different levels of K. Although high K and Ca levels decreased the incidence of BER, no interaction was established between the two nutrients with respect to this disorder. These findings are in agreement with the two views of researchers found in literature. Sonneveld and Voogt (1991) relates to BER as being a nutritional disorder accented by low Ca in the nutrient solution, while

Nonami *et al.* (1995) state that BER can also appear on fruits grown with high levels of Ca, indicating that low Ca is not the only cause of BER incidence.

Table 4.6 Effect of K and Ca rates on blossom- end rot (%) in tomato fruit

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	2.75	0.96	1.85 a
10	2.28	0.46	1.37 a
Mean	2.51 a	0.71 b	1.61
CV			76.35
LSD Tukey (0.05)		K	1.34
		Ca	1.34
		K*Ca	1.90

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.15)

Blotchy ripening (BR)

Among the physiological disorders recorded during this experiment, the incidence of BR (Figure 4.2) was very low (Table 4.7).

Table 4.7 Effect of K and Ca rates on blotchy ripening (%) in tomato fruit

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	0.46	0.96	0.71 a
10	0	0	0 b
Mean	0.23 a	0.48 a	0.36
CV			300.42
LSD Tukey (0.05)		K	1.16
		Ca	1.16
		K*Ca	1.64

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.16)

Blotchy ripening appeared only in treatments supplied with low level of K and it increased from 0.46 to 0.96 % in respect to increased levels of Ca in the nutrient solution (Table 4.7). These results indicated that rates of K play a role on its occurrence, but level of K (6 $mmol_c$. $l^{-1)}$ may not be the main cause of its occurrence. According to Adams (1986) an inadequate supply of K to the tomato plant will result in uneven ripening of the fruit. Grierson and Kader (1986) observed that as the level of available K to the plant increased, the percentage of unevenly ripened (blotchy) fruits decreased. Davies and Winsor (1967) stated that K deficiency might result in BR. According to Winsor (1966), BR is not only affected by K nutrition but also by cultivar. Based on these findings it can be speculated that high levels of K in the nutrient solution limit the occurrence of this physiological disorder though nutrition is not the only cause for its induction. There is also a tendency of increased BR with increased Ca levels in the nutrient solution. On the other hand one can say low K:Ca ratio in the nutrient solution will favour the incidence of BR.

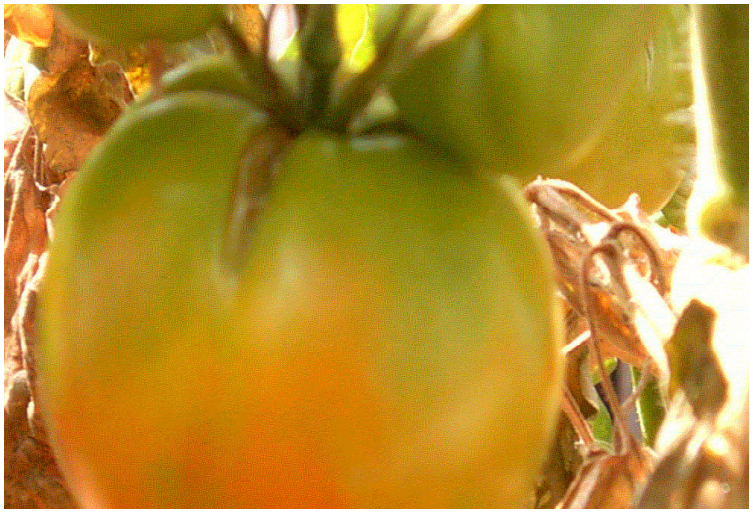

Figure. 4.2 Blotchy ripening in tomato at low K rates

Fruit Cracking (FC)

There was no correlation between the incidence of fruit cracking (Figure 4.3) and K:Ca ratios (Table 4.8). There was, however, a higher incidence of fruit cracking at a K:Ca ratio of 10:16. The incidence of this disorder was the highest for all the disorders reported on, and it occurred in all treatments. According to Dorais *et al.*

(2001), fruit: leaf ratio is an indicator of FC occurrence, but in this study no relationship was established between fruit: leaf ratio and FC.

Table 4.8 Effect of K:Ca ratios on fruit cracking in tomato fruit

K:Ca ratio	Fruit: leaf ratio	Fruit Cracking
6:12	2.25	2.33 a
6:16	2.24	2.30 a
10:12	2.27	2.31 a
10:16	2.19	2.86 a
LSD		1.48
CV		39.31

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Table A.4.19)

Figure. 4.3 Fruit cracking in tomato fruits

Cat facing (CF)

There was no significant evidence (Tabel 4.9) that K:Ca ratio affected the incidence of cat facing (Figure 4.4), though the incidence of this disorder tended to be higher at low K level (6 $mmol_c$. l^{-1}). At high level of K, rates of Ca did not affect the incidence of this disorder.

Table 4.9 Effect of K:Ca ratios on cat facing in tomato fruit

K:Ca ratio	Cat facing
6:12	0.90 a
6:16	0.96 a
10:12	0.46 a
10:16	0.46 a
LSD	1.55
CV	143.97

Means followed by different letters in columns are significantly different at P<0.05. (Appendix Table A.4.21)

Figure 4.4 Cat facing in tomato fruits

4.3.4 Yield and yield components

Yield per plant

The number of fruits and fruit weights were not affected by rates and ratios of K and Ca in the nutrient solution (Table 4.10). These results confirm findings of Bar- Tal and Pressman (1996) who also observed no significant effects of these plant nutrients on number and weight of fruits.

No yield differences were obtained among treatment means at any K:Ca ratio, suggesting that the K:Ca ratio does not affect yield of tomato. However, there was a tendency for higher yields with higher K levels while higher Ca levels tend to suppress yield.

This may indicate a slight suppression of K uptake by Ca. These findings are in agreement with Nukaya *et al*. (1995) and Voogt (1998) who reported that extremely low K:Ca ratios might adversely affect tomato yields, though Adams and Ho (1992) suggested that if a K and Ca concentration of 10 $mmol_c$. l^{-1} were used for commercial tomato production, no deficiencies of these nutrients should occur, as it would be available well above the critical level needed.

This data certainly indicated that different K:Ca ratios should not cause problems, as long as both elements are adequately supplied.

Table 4.10 Effect of K:Ca ratios on tomato yield and yield components

K:Ca ratios	Number of fruit	Fruit weight (g)	Yield (kg/plant)
6:12	54 a	86.34 a	4.66 a
6:16	53.75 a	83.88 a	4.50 a
10:12	54.50 a	86.37 a	4.71 a
10:16	52.50 a	88.37 a	4.64 a
LSD	4.19	5.56	398.26
CV	5.07	4.18	5.59

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Table A.4.3)

Marketable yield

There were no significant differences among treatment means (Table 4.11) in terms of marketable yield. The different K:Ca ratios did not significantly affect the marketable yield. The incidence of physiological disorders (± 6 %) were the main reason for a decrease in percentage marketable yield, while the percentage under-grade fruits contributed about 3 % to the reduction in marketable yield. This study supports the view that under greenhouse condition the main factor controlling the marketable yield is the incidence of physiological disorders.

Table 4.11 Effect of K:Ca ratios on marketable tomato yields

K:Ca ratios	Blossom-end rot (% fruit)	Blotchy Ripening (% fruit)	Fruit Cracking (% fruit)	Cat Facing (% fruit)	Under-grade fruits (% fruit)	Mark. Yield (%)
6:12	2.75	0.42	2.14	0.89	3.19	90.62 a
6:16	0.93	0.96	2.20	0.91	3.23	91.77 a
10:12	2.32	0	2.18	0.53	3.35	91.62 a
10:16	0.41	0	2.59	0.40	3.28	93.32 a
LSD	1.90	1.64	1.48	1.55	1.10	3.5702
CV	76.35	300.42	39.31	143.97	13.30	2.52

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Table A.4.24)

Marketable fruit

The percentage marketable fruit was reduced by about 5 % as a result of the high percentage of under-grade fruits produced (Table 4.12). The percentage of fruits affected by physiological disorders also affected the percentage of marketable fruit. With a K:Ca ratio of 6:12, the percentage under-grade fruits contributed 5.11 % to the total number of fruit whereas the incidence of physiological disorders affected another 6 % of the total number of fruits produced. High Ca rates increased the percentage marketable fruit by lowering the incidence of BER. Bar-Tal and Pressman (1996) observed similar results in an aerohydroponic system.

The highest marketable yield (90.49%) was obtained when the supply of both, K and Ca was high (10 and 16 $mmol_c$. l^{-1}) whereas the lowest percentage of marketable fruits (88.46) was recorded at the lowest K and Ca supply.

Table 4.12 Effect of K:Ca ratios on marketable tomato fruits

K:Ca ratios	Blossom-end rot (% fruit)	Blotchy ripening (% fruit)	Fruit cracking (% fruit)	Cat facing (% fruit)	Under grade fruit (% fruit)	Mark. fruit (% fruit)
6:12	2.75	0.46	2.33	0.90	5.11	88.46 a
6:16	0.96	0.96	2.30	0.96	5.11	89.70 a
10:12	2.28	0	2.31	0.46	5.52	89.43 a
10:16	0.46	0	2.86	0.46	5.72	90.49 a
LSD						3.74
CV						2.71

Means followed by different letters in columns are significantly different at P<0.05 (Appendix Table A.4.23)

4.3.5 Nutrient content of leaves

Nitrogen

The nitrogen content in leaf tissue was significantly reduced at high K level (Figure 4.5).

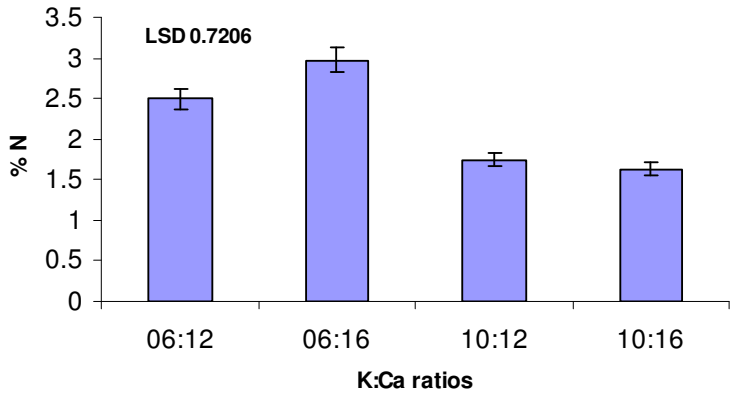

Figure 4.5 Effect of K:Ca ratios on nitrogen content of tomato leaves (Appendix Table A.4.25)

At low K rates, the leaf nitrogen content increased from 2.5 to 2.98 % as the Ca level in the nutrient solution was increased from 12 to 16 $mmol_c$. l^{-1} but not significantly so. The normal range of nitrogen in tomato leaves is 2.8-6.0 % (Jones, 1999). By increasing the rate of K in the nutrient solution, leaf nitrogen content was markedly decreased. This study clearly indicated that high level of K decreases nitrogen content on the leaf irrespective of increased Ca levels. Gunes *et al.* (1998) also did not find any negative effect of increasing Ca levels on the N content of leaves.

Phosphorus

The influence of the K:Ca ratio on the phosphorus content in leaves is presented in Figure 4.6. Although the differences are not significant, there was a tendency for higher P in leaves at the high Ca level but values obtained were lower than those reported (0.3-0.9 %) by Jones (1999). In a study conducted by Gunes *et al.* (1998), the P content in tomato leaves decreased with increasing Ca in the nutrient solution. In this experiment the high rates of K and Ca used could be the main reason behind the results observed.

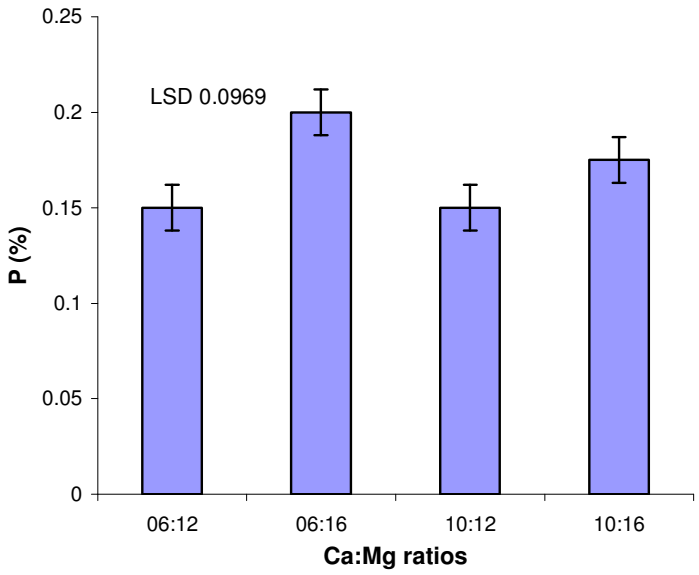

Figure 4.6 Effect of K:Ca ratios on phosphorus content of tomato leaves (Appendix Table A.4.26)

Calcium

The rates of Ca in the nutrient solution did not significantly affect the Ca content in the leaf (Table 4.13), although increasing the Ca level has resulted in slightly increased levels of Ca in the leaves. The Ca content of the leaves was, however, strongly affected by the levels of K in the nutrient solution. Elevating K level in the nutrient solution from 6 $mmol_c.l^{-1}$ to 10 $mmol_c.\ l^{-1}$ resulted in a marked increase (1.49 to 3.83 % respectively) in the Ca content of the tomato leaves. According to Jones (1999), the acceptable range for Ca content in leaves is between 0.9 and 7.2 %. The way in which high K rates could increase the Ca leaf content of tomato is not well understood. Because the Ca+K supply was high, the influence that these elements may have on each other is masked. These findings are not in agreement with many researchers who found that high K^+ might reduce Ca^{2+} in the plant (Paiva *et al.*, 1998b, Nukaya *et al.*, 1995).

Table 4.13 Effect of K and Ca rates on calcium content (%) of tomato leaves

K $mmol_c.\ l^{-1}$	Ca $mmol_c.\ l^{-1}$		
	12	16	Mean
6	1.14	1.83	1.49 b
10	4.05	3.62	3.83 a
Mean	2.59 a	2.72a	2.66
CV			11.67
LSD Tukey (0.05)		K	0.35
		Ca	0.35
		K*Ca	0.49

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.27)

Potassium

Neither K nor Ca rates affected leaf K content of tomato (Figure 4.7). Many researchers argued that increasing K levels in the nutrient solution should result in the increase of K in the plant (Gunes *et al.* 1998). It is also widely reported in literature that high Ca levels interact with K in the leaf. Since the normal range for K in leaves

is between 2.5 and 6.0 %, it could be concluded that higher rates of Ca used in this experiment strongly reduced the K content in the leaves.

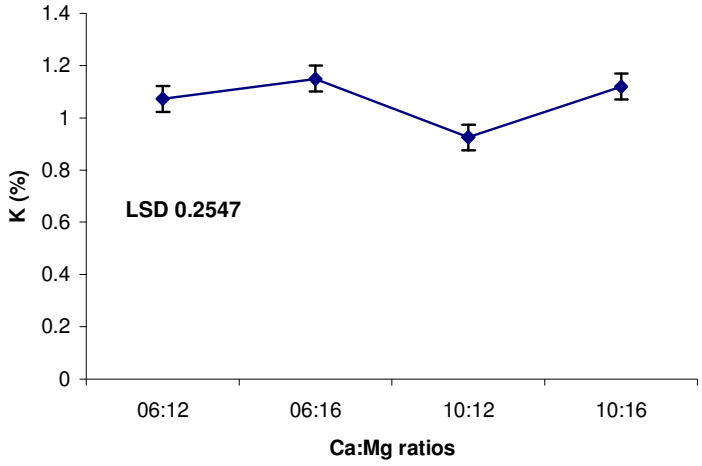

Figure 4.7 Effect of K:Ca ratios on potassium content of tomato leaves (Appendix Table A.4.28)

Magnesium

As in the case of Ca, the levels of K significantly increased the Mg content in tomato leaves (Table 4.14).

Table 4.14 Effect of K and Ca rates on magnesium content of leaves

K mmol$_c$. l^{-1}	Ca mmol$_c$. l^{-1}		
	12	16	
6	0.40	0.46	0.435 b
10	0.69	0.57	0.63 a
Mean	0.55 a	0.51 a	0.53
CV			16.18
LSD Tukey (0.05)		K	0.09
		Ca	0.09
		K*Ca	0.13

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.29)

There was, however, no relationship between leaf Mg content and Ca levels in the nutrient solution. Values obtained in this experiment fell within the acceptable range (0.4-1.3 %) (Jones, 1999). The absence of the so-called interaction between K and Mg was probably due to the high supply of both nutrients.

4.3.6 Nutrient content of fruit

Nitrogen

Potassium did not significantly affect the fruit nitrogen content (Table 4.15), whereas increased Ca level in the nutrient solution resulted in a significantly lower level of nitrogen content in the fruit. This value was still much higher than the average range of nitrogen in fruit (0.6%) (Jones, 1999). The higher rates of K and Ca used in this experiment have probably leaded to a remobilisation of nitrogen to the fruits, away from the leaves. That could also be the reason for the low N observed in leaves (around 2 %). These observations may be important for further investigations into the remobilising of nutrients in the plant.

Table 4.15 Effect of K and Ca rates on nitrogen content of fruits

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	2.43	2.13	2.28 a
10	2.53	2.25	2.39 a
Mean	2.48 a	2.19 b	2.33
CV			11.16
LSD Tukey (0.05)		K	0.28
		Ca	0.28
		K*Ca	0.40

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.29)

Phosphorus

The phosphorus content of fruit was decreased by increasing rates of Ca in the nutrient solution (Table 4.16), however, not significantly so. No relationship was

established between K rates and fruit P content. The level of P content (0.48 %) at lower K was higher than that reported by Jones (1999) (0.4 %).

Table 4.16 Effect of K and Ca rates on phosphorus content of tomato fruits

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	0.48	0.35	0.41 a
10	0.43	0.40	0.41 a
Mean	0.45 a	0.38 a	0.41
CV			14.85
LSD Tukey (0.05)		K	0.07
		Ca	0.07
		K*Ca	0.28

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.29)

Calcium

The fruit Ca content was not significantly affected by neither K nor Ca rates in the nutrient solution (Figure 4.8), but high Ca level tended to increase the Ca content of fruit.

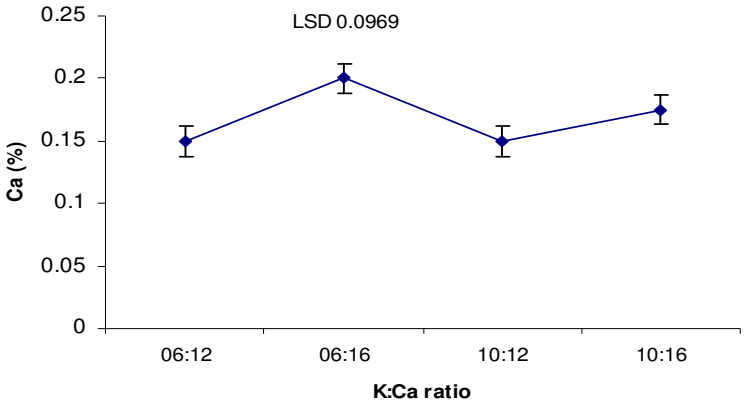

Figure 4.8 Effect of K:Ca ratios on calcium content of tomato fruits (Appendix Table A.4.32)

Paiva *et al*. (1998b) found that Ca levels in tomato fruit increased with increasing Ca levels in the nutrient solution reaching a maximum value of 0.17 % at a Ca concentration of 19.79 mmol.l^{-1}.

Potassium

Different K and Ca rates and ratios did not significantly affect the K content of tomato fruit (Table 4.17). In contrast to K, Ca had a more pronounced effect on the K content in tomato fruit. Increased Ca levels in the nutrient solution have resulted in a decrease in K content in tomato fruits, though values obtained were all acceptable, as they ranged between 3 and 4 % (Jones, 1999)**.** These findings are in agreement with that of Paiva *et al*. (1998b), who observed similar results.

Table 4.17 Effect of K and Ca rates on potassium content of tomato fruits

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	3.58	3.00	3.29 a
10	3.44	3.15	3.30 a
Mean	3.51 a	3.07 a	3.29
CV			9.95
LSD Tukey (0.05)		K	0.338
		Ca	0.35
		K*Ca	0.50

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.33)

Magnesium

There was no significant evidence that K or Ca rates affected the Mg content of tomato fruits (Table 4.18). According to Paiva *et al*. (1998b), Mg levels in tomato fruit decrease linearly with increasing Ca in the nutrient solution. Voogt (1998) suggested an increase in fruit Mg content with respect to increasing K:Ca ratios.

Table 4.18 Effect of K and Ca rates on magnesium content of tomato fruits

K $mmol_c$. l^{-1}	Ca $mmol_c$. l^{-1}		
	12	16	Mean
6	0.12	0.11	0.11 a
10	0.12	0.11	0.12 a
Mean	0.12 a	0.11 a	0.12
CV			8.80
LSD Tukey (0.05)		K	0.01
		Ca	0.01
		K*Ca	0.01

Means followed by different letters in columns and rows are significantly different at P<0.05 (Appendix Table A.4.34)

4.4 CONCLUSIONS

The findings of this study convincingly show that when K and Ca are adequately supplied their ratios are not as important. High K rates 10 ($mmol_c$. l^{-1}) increased TA, TSS, EC, and decreased fruit pH. However this study did show the beneficial effect of elevating K in the nutrient solution respectively with improving fruit quality at higher rates. Fruit quality parameters did not vary much with different levels of K, suggesting that low K (6 $mmol_c$. l^{-1}) was already sufficient. The same was true for Ca where no improvement was obtained at higher Ca rates. There was no evidence that K:Ca ratios are good indicators for good fruit quality and yield since when both elements are well supplied their ratios do not have much impact.

On the other hand, it appeared that proper K nutrition improves fruit quality and reduces the incidence of blotchy ripening, whereas adequate supply of Ca markedly reduces the incidence of BER. High K (10 $mmol_c$. l^{-1}) increased the Ca and Mg leaf content but significantly reduced the N leaf content. Increased Ca (16 $mmol_c$. l^{-1}) resulted in the decreases of the N, P, and K fruit content. Two physiological disorders namely, fruit cracking and cat facing, considerably affected the marketable yield. Contrary to BR and BER, FC and CF were not correlated with the availability of plant nutrients.

CHAPTER 5

GENERAL DISCUSSION AND CONCLUSIONS

The aim of this experiment was to investigate the effects of K, Mg, and Ca rates and ratios on yield and fruit quality of tomato. To reach the goal, two trials were conducted, one in that different Ca:Mg ratios were combined with three K rates and one where different K:Ca ratios were applied. The results of this study show that K, Mg, and Ca rates and ratios affect yield and quality of tomato.

Since tomato fruits play an important role in human health, the quality of the nutritional components of this major fruit crop, are of particular concern to producers throughout the world (Chapagain and Wiesman, 2004). Although customers are interested in the appearance of the fruit, important fruit quality indices with respect to taste are also important and include aspects such as total soluble solid content, insoluble solids, pH, acidity, juice viscosity, juice serum viscosity and electrical conductivity (Tuzel *et al*., 1994). The findings of this study clearly indicate that fruit quality of tomato is strongly dependant on K, Ca and Mg in the nutrient solution.

Increasing K in the nutrient solution resulted in a decrease in the pH of tomato fruit juice. Low fruit pH has been reported to be a critical factor by which consumers judge the quality of fruits. It is referred to as fruit tartness, and the lower the fruit pH, the higher the fruit's acceptability by the consumer (Jones, 1999). Increased Ca:Mg ratios in the nutrient solution have positively affected the tartness of the fruit by decreasing the fruit pH. High K rates (6 and 9 $mmol_c$. l^{-1}) in the nutrient solution increased the total soluble solids as well the titratable acididty, whereas high Ca:Mg ratios (20:1) decrease it. However, for all parameters analysed (pH, TSS, TA, and EC), the obtained values were acceptable. This means that ratios are not that important for good fruit quality.

In the first experiment, the number of fruits as well the weight of fruits were affected by the three plant nutrients. Results showed that low Ca:Mg ratios (8:12) had the lowest mean weight and significantly differ from other treatments. This could be

explained by the fact that low Ca combined with high Mg supply did not allow proper plant growth, thus leading to poor fruit production. Visual deficiency symptoms of Ca were observed in these treatments. The fact that Ca is not easily translocated in the plant seems to be one of the reasons for this low production. In fact it seems as if high levels of Mg in the solution, did not allow for easy uptake of Ca by the roots. It has been reported that Ca and Mg usually interact during the uptake process and that high Mg levels in the solution depress Ca uptake. Eventually, a low number of fruits produced, together with low fruit weight, at low Ca:Mg ratios (8:12), markedly reduced tomato yields. These observations were also made at a high Ca:Mg ratio of 20:1 in the nutrient solution. This was most probably due to Mg deficiency rather than the Ca:Mg ratio. On the other hand, it can be speculated that an inadequate supply of Ca, negatively affects tomato yields, and that it is useful to increase the Ca rates in the nutrient solution, but to ensure that it is in balance with other plant nutrients such as K and Mg.

The marketable yield of tomato was strongly affected by K, Mg, and Ca nutrition. Physiological disorders observed during this study have been considered as unmarketable fruits. Another indicator of unmarketable fruit was the percentage of small fruits.

This study clearly shows a strong relationship between plant nutrients and two physiological disorders namely BER and BR. The incidence of BER was linearly correlated to Ca status in the nutrient solution. The disorder is believed to occur due to a local Ca deficiency, and does not depend on the Ca concentration in the solution alone. In the first trial, the disorder only occurred in treatments supplied with low Ca rates (or in other words at a low Ca:Mg ratio), and it increased linearly with increased K concentrations in the nutrient solution. Potassium probably suppressed the excess Mg as low Ca:Mg ratios (8:12), and this minimised the negative effect of Mg on Ca uptake. However, during the second trial, BER occurred not only at low Ca but at high Ca rates as well, with a lower rate as compared to the first trial. Based on this study, it can be concluded that BER is a not strictly due to a low Ca content in the nutrient solution only, but an interaction of factors such as high Mg in combination with low Ca level.

Blotchy ripening of tomato occurred only at low K level (6 $mmol_c$. l^{-1}), in the second experiment. The incidence was very low and may not be enough to state that BR is a K related disorder, however, tomato growers should take this into account when planning the concentration of K in the nutrient solution. There is no doubt that high levels of K increase fruit quality as it has resulted in the clearance of BR.

Fruit cracking in tomatoes can cause serious economic losses under field production conditions. Cracks decrease the attractiveness of the fruit and offer an entry point for insects and decay organisms. Although this can cause significant income losses in fresh market and processing tomatoes (Calbo, 1990; Cotner *et al*., 1969, Walter, 1967; Peet and Willits, 1995), little is known about the causes of fruit cracking in greenhouses grown tomatoes (Koske *et al*., 1980). The incidence of fruit cracking was relatively high in this experiment, but no correlation was established between this disorder and nutrition. In the first experiment where the plants were grown in a sand/ coir mixture as growing medium, no cracked fruits were recorded whereas in the second trial conducted in water culture the incidence was high. One can thus speculate that growing medium plays a role in the occurrence of this disorder by affecting the availability of water to the plants. According to Peet and Willits (1995) a rapid increase in soil moisture of water-stressed plants is not sufficient to explain the real cause of the disorder under greenhouses conditions where water supply is constant, rarely causing water stress conditions to occur. Based on the findings of this study it can be concluded that fruit cracking of tomato does not have any correlation with nutrition. The same applied for cat facing of tomato. The disorder appeared on fruits of all treatment combinations.

Tomato fruit size is important for production. It is obvious that the fruit price will increase with increased fruit size. During this study, no correlation was found between under-grade fruits that markedly decrease the marketable yield, and plant nutrients. However K rates strongly influences the percentage of class one fruits. High Ca:Mg ratios, also increased the percentage of class one fruits. Based on this study, it can be concluded that proper nutrition improves the size of tomato fruit.

Potassium and Ca in the nutrient solution did not show any interaction regarding their effects on fruit quality, yield, and leaf mineral content. This study showed that these

plant nutrients played a key role in tomato production and that their effects are independent. The fact that parameters responded differently to the different K:Ca and K:Ca:Mg ratios confirmed the view that these plant nutrients interact on each other.

Increased Ca in the nutrient solution negatively affected the N, P, and K fruit content but had no significant effect in other plants nutrients either in leaves or fruits. High K significantly increased the Ca and Mg leaf content but decreased the N leaf content. That is contradictory to what is found in literature. This is probably due to the excessive Ca, Mg, and K supply in the nutrient solution. It has been reported that increased levels of K and Mg in the nutrient solution increase the specific element in the plant organ. Results from the current trials, however, do not support this view.

In conclusion it can be said that nutrition strongly influences fruit quality and yield. High yield and good quality can be achieved by a proper K, Mg, and Ca nutrition. This study shows that there is no ideal ratio for high and good fruit quality instead this study calls for the notion of proper nutrition characterized with an increase of K in the nutrient solution respectively with Ca and Mg concentrations. For instance it was observed that high levels of K only induce BER when Ca level is low.

For further investigations, the interactive effects of K, Mg, and Ca on yield and fruit quality of tomato through factorial experiment involving combination of two more levels of K, Mg, and Ca could be carried out.

SUMMARY

Although tomato has been studied for many years, some challenges are still facing researchers (mineral interaction, physiological disorders, etc.). The objective of this study was to investigate the effect of K, Mg, and Ca rates and ratios on yield and quality of tomato, and to establish a relationship between these plant nutrients and physiological disorders (blossom-end rot, blotchy ripening, cat facing, and fruit cracking).

Two trials were conducted under greenhouse condition. In the first trial a factorial experiment involving a combination of four Ca:Mg ratios (20:1; 15:5; 10:10; 8:12 $mmol_c$. l^{-1}) and three levels of K (1, 6, and 9 $mmol_c$. l^{-1}). In the second trial, two rates of K (6 and 10 $mmol_c$. l^{-1}) were combined with two rates of Ca (12 and 16 $mmol_c$. l^{-1}). The yield and quality response of tomato to these different ratios were investigated.

The results showed that K, Mg, and Ca rates and ratios strongly influence yield and quality of tomato. No interactive effects of these plant nutrients have been observed. Increasing Ca:Mg ratios in the nutrient solution to a ratio of 15:5, have increased the yield and quality, however, the increase of these ratios up to 20:1 often caused a reduction in these parameters . It seems that Ca:Mg ratio can be increased but the increment should not reach a very high ratio (20:1). The same applies to low Ca:Mg ratios (8:12) that resulted in poor performance . Ca:Mg ratios should be maintained around one however, this will also depend on other parameters such as irrigation, temperature, cultivar etc. Increased K levels in the nutrient solution resulted in improved fruit quality. High K levels decreased the pH of fruit, increased the titratable acidity, as well the total soluble solid content of the fruits.

A clear relationship has been established between Ca and blossom-end rot of tomato. However, the study showed that low Ca level is not the only cause of the disorder. Low Ca (8) level combined with high Mg (12) level have induced the disorder, and it increased with increased K levels in the nutrient solution. When Ca:Mg ratios increased, the disorder was prevented. This means that BER might be regarded as a nutritional disorder due to low Ca level as well as high Mg. In the second trial,

although BER appeared at low Ca (12) as well as high level (16), the incidence was very low in the second case suggesting that other external factors also play a vital role on the incidence of the disorder. This study clearly showed that, low Ca level in the nutrient solution is detrimental for fruit quality. Blotchy ripening was only observed at low K (6) level in the second trial, but the incidence was very low. This means that high levels of K in the nutrient solution can reduce the risk of the disorder. There is no evidence that cat facing and fruit cracking are due to a nutritional problem. During the investigation, the disorder appeared in almost all the treatments. In the first trial, no fruit cracking was observed and the incidence of cat facing was considerable, but during the second trial, both disorders appeared and fruit cracking was very high in comparison to the other disorders.

Except for N, P, and K in fruit, and N, Mg and Ca in leaf, which were affected by high rates of Ca and K in the nutrient solution, the mineral content of leaves and fruits were not actually correlated with the rates of K and Ca.

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APPENDIX

TABLE A 3.1 ANOVA Table for the effect of K, Mg, and Ca on tomato fruit pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.03012292	0.00273845	6.21	<.0001
Error	36	0.01587500	0.00044097		
Corrected Total	47	0.04599792			
	R^2	C.V	Root MSE		Mean
	0.654876	0.511581	0.020999		4.104792
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	0.01157292	0.00385764	8.75	0.0002
K	2	0.01702917	0.00851458	19.31	<.0001
Ca:Mg * K	6	0.00152083	0.00025347	0.57	0.7477

TABLE A 3.2 ANOVA Table for the effect of K, Mg, and Ca on titratable acidity of tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	2430.729167	220.975379	29.38	<.0001
Error	36	270.750000	7.520833		
Corrected Total	47	2701.479167			
	R^2	C.V	Root MSE		Mean
	0.899777	3.990175	2.742414		68.7291
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	876.062500	292.020833	38.83	<.0001
K	2	1337.791667	668.895833	88.94	<.0001
Ca:Mg * K	6	216.875000	36.145833	4.81	<.0001

TABLE A 3.3 ANOVA Table for the effect of K, Mg, and Ca on total soluble solids of tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.48689167	0.04426288	2.82	0.0093
Error	36	0.56550000	0.01570833		
Corrected Total	47	1.05239167			
	R^2	C.V	Root MSE		Mean
	0.462653	2.554122	0.125333		4.907083
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	0.21904167	0.07301389	4.65	0.0076
K	2	0.16687917	0.08343958	5.31	0.0095
Ca:Mg * K	6	0.10097083	0.01682847	1.07	0.3976

TABLE A 3.4 ANOVA Table for the effect of K, Mg, and Ca on number of tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	172.5625000	15.6875000	1.35	0.2400
Error	36	419.2500000	11.6458333		
Corrected Total	47	591.8125000			
	R^2	C.V	Root MSE		Mean
	0.291583	7.679548	3.412599		44.43750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	154.7291667	51.5763889	4.43	0.0095
K	2	4.6250000	2.3125000	0.20	0.8208
Ca:Mg * K	6	13.2083333	2.2013889	0.19	0.9780

TABLE A 3.5 ANOVA Table for the effect of K, Mg, and Ca on average tomato fruit weight

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	768.1497167	69.8317924	10.99	<.0001
Error	36	228.6779500	6.3521653		
Corrected Total	47	996.8276667			
	R^2	C.V	Root MSE		Mean
	0.770594	2.668355	2.520350		94.45333
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	497.4426167	165.8142056	26.10	<.0001
K	2	186.5561292	93.2780646	14.68	<.0001
Ca:Mg * K	6	84.1509708	14.0251618	2.21	0.0647

TABLE A 3.6 ANOVA Table for the effect of K, Mg, and Ca on tomato yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	4676392.698	425126.609	3.86	0.0010
Error	36	3968063.765	110223.993		
Corrected Total	47	8644456.463			
	R^2	C.V	Root MSE		Mean
	0.540970	7.903299	332.0000		4200.778
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	4324760.020	1441586.673	13.08	<.0001
K	2	193213.457	96606.729	0.88	0.4249
Ca:Mg * K	6	158419.221	26403.203	0.24	0.9604

TABLE A 3.7 ANOVA Table for the effect of K, Mg, and Ca on marketable tomato yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	113.1582229	10.2871112	2.15	0.0415
Error	36	172.3035750	4.7862104		
Corrected Total	47	285.4617979			
	R^2	C.V	Root MSE		Mean
	0.396404	2.304376	2.187741		94.93854
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	77.72425625	25.90808542	5.41	0.0035
K	2	7.88450417	3.94225208	0.82	0.4469
Ca:Mg * K	6	27.54946250	4.59157708	0.96	0.4662

TABLE A 3.8 ANOVA Table for the effect of K, Mg, and Ca on number of marketable fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	235.1245229	21.3749566	2.07	0.0495
Error	36	371.5410250	10.3205840		
Corrected Total	47	606.6655479			
	R^2	C.V	Root MSE		Mean
	0.387569	3.537006	3.212567		90.82729
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	140.1580729	46.7193576	4.53	0.0086
K	2	22.3726292	11.1863146	1.08	0.3491
Ca:Mg * K	6	72.5938208	12.0989701	1.17	0.3426

TABLE A 3.9 ANOVA Table for the effect of K, Mg, and Ca on extra large sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	535.1775667	48.6525061	10.77	<.0001
Error	36	162.5798000	4.5161056		
Corrected Total	47	697.7573667			
	R^2	C.V	Root MSE		Mean
	0.766997	16.40908	2.125113		12.95083
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	324.1064500	108.0354833	23.92	<.0001
K	2	78.4059542	39.2029771	8.68	0.0008
Ca:Mg * K	6	132.6651625	22.1108604	4.90	0.0009

TABLE A 3.10 ANOVA Table for the effect of K, Mg, and Ca on large sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	285.4343417	25.9485765	1.44	0.1986
Error	36	649.5124500	18.0420125		
Corrected Total	47	934.9467917			
	R^2	C.V	Root MSE		Mean
	0.305295	7.814233	4.247589		54.35708
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	90.5694083	30.1898028	1.67	0.1900
K	2	16.4315542	8.2157771	0.46	0.6378
Ca:Mg * K	6	178.4333792	29.7388965	1.65	0.1624

TABLE A 3.11 ANOVA Table for the effect of K, Mg, and Ca on medium sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	258.557973	23.505270	0.82	0.6237
Error	36	1035.662175	28.768394		
Corrected Total	47	1294.220148			
	R^2	C.V	Root MSE		Mean
	0.199779	21.11331	5.363618		25.40396
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	137.3844729	45.7948243	1.59	0.2083
K	2	3.2887542	1.6443771	0.06	0.9445
Ca:Mg * K	6	117.8847458	19.6474576	0.68	0.6644

TABLE A 3.12 ANOVA Table for the effect of K, Mg, and Ca on small sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	100.9986000	9.1816909	1.32	0.2539
Error	36	250.5127000	6.9586861		
Corrected Total	47	351.5113000			
	R^2	C.V	Root MSE		Mean
	0.287327	2.637932	2.637932		7.302500
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	14.51895000	4.83965000	0.70	0.5609
K	2	38.47523750	19.23761875	2.76	0.0764
Ca:Mg * K	6	48.00441250	8.00073542	1.15	0.3544

TABLE A 3.13 ANOVA Table for the effect of K, Mg, and Ca on leaf: fruit ratio in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	0.35855625	0.03259602	1.42	0.2084
Error	36	0.82907500	0.02302986		
Corrected Total	47	1.18763125			
	R^2	C.V	Root MSE		Mean
	0.301909	7.730324	0.151756		1.963125
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Ca:Mg	3	0.29110625	0.09703542	4.21	0.0118
K	2	0.02686250	0.01343125	0.58	0.5633
Ca:Mg * K	6	0.04058750	0.00676458	0.29	0.9360

TABLE A 3.14 ANOVA Table for the effect of K, Mg, and Ca on blossom-end rot incidence in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	28.35011549	14.17505774	4.67	0.0407
Error	9	27.32617232	3.03624137		
Corrected Total	11	55.67628780			
	R^2	C.V	Root MSE		Mean
	0.509196	51.14828	1.742481		3.406725
Source	DF	Type III SS	Mean Square	F Value	Pr > F
TRT	2	28.35011549	14.17505774	4.67	0.0407

TABLE A 4.1 ANOVA Table for the effect of K and Ca on number of fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.68750000	2.89583333	0.39	0.7613
Error	12	88.75000000	7.39583333		
Corrected Total	15	97.43750000			
	R^2	C.V	Root MSE		Mean
	0.089160	5.065477	2.719528		53.68750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.56250000	0.56250000	0.08	0.7874
Ca	1	5.06250000	5.06250000	0.68	0.4242
K*Ca	1	3.06250000	3.06250000	0.41	0.5320

TABLE A 4.2 ANOVA Table for the effect of K and Ca on tomato fruit weight

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	40.3896250	13.4632083	1.03	0.4126
Error	12	156.2963500	13.0246958		
Corrected Total	15	196.6859750			
	R^2	C.V	Root MSE		Mean
	0.205351	4.184743	3.608974		86.24125
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	20.34010000	20.34010000	1.56	0.2352
Ca	1	0.20250000	0.20250000	0.02	0.9028
K*Ca	1	19.84702500	19.84702500	1.52	0.2407

TABLE A 4.3 ANOVA Table for the effect of K and Ca on tomato yield

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	94234.7402	31411.5801	0.47	0.7087
Error	12	801871.6176	66822.6348		
Corrected Total	15	896106.3578			
	R^2	C.V	Root MSE		Mean
	0.105160	5.586254	258.5007		4627.444
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	32864.25123	32864.25123	0.49	0.4965
Ca	1	52867.80490	52867.80490	0.79	0.3912
K*Ca	1	8502.68410	8502.68410	0.13	0.7275

TABLE A 4.4 ANOVA Table for the effect of K and Ca on tomato plant height

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.01001875	0.00333958	0.10	0.9596
Error	12	0.40837500	0.03403125		
Corrected Total	15	0.41839375			
	R^2	C.V	Root MSE		Mean
	0.023946	9.296409	0.184476		1.984375
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.00140625	0.00140625	0.04	0.8423
Ca	1	0.00680625	0.00680625	0.20	0.6627
K*Ca	1	0.00180625	0.00180625	0.05	0.8217

TABLE A 4.5 ANOVA Table for the effect of K and Ca on tomato stem diameter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.01250000	0.00416667	0.10	0.9567
Error	12	0.48500000	0.04041667		
Corrected Total	15	0.49750000			
	R^2	C.V	Root MSE		Mean
	0.025126	12.46753	0.201039		1.612500
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.01000000	0.01000000	0.25	0.6279
Ca	1	0.00250000	0.00250000	0.06	0.8078
K*Ca	1	0.00000000	0.00000000	0.00	1.0000

TABLE A 4.6 ANOVA Table for the effect of K and Ca on tomato fruit dry matter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.16915000	0.05638333	0.97	0.4368
Error	12	0.69425000	0.05785417		
Corrected Total	15	0.86340000			
	R^2	C.V	Root MSE		Mean
	0.195912	4.389214	0.240529		5.480000
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.16402500	0.16402500	2.84	0.1180
Ca	1	0.00422500	0.00422500	0.07	0.7916
K*Ca	1	0.00090000	0.00090000	0.02	0.9028

TABLE A 4.7 ANOVA Table for the effect of K and Ca on tomato fruit pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.04026875	0.01342292	13.98	0.0003
Error	12	0.01152500	0.00096042		
Corrected Total	15	0.05179375			
	R^2	C.V	Root MSE		Mean
	0.777483	0.751173	0.030991		4.125625
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.03900625	0.03900625	40.61	<.0001
Ca	1	0.00050625	0.00050625	0.53	0.4817
K*Ca	1	0.00075625	0.00075625	0.79	0.3923

TABLE A 4.8 ANOVA Table for the effect of K and Ca on total soluble solids of tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.09231875	0.03077292	1.84	0.1935
Error	12	0.20062500	0.01671875		
Corrected Total	15	0.29294375			
	R^2	C.V	Root MSE		Mean
	0.315142	2.592826	0.129301		4.986875
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.09150625	0.09150625	5.47	0.0374
Ca	1	0.00005625	0.00005625	0.00	0.9547
K*Ca	1	0.00075625	0.00075625	0.05	0.8351

TABLE A 4.9 ANOVA Table for the effect of K and Ca on titratable acidity of tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	96.6875000	32.2291667	2.09	0.1553
Error	12	185.2500000	15.4375000	281.9375000	0.342939
Corrected Total	15	281.9375000			
	R^2	C.V	Root MSE		Mean
	0.342939	5.648242	3.929058		69.56250
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	95.06250000	95.06250000	6.16	0.0289
Ca	1	1.56250000	1.56250000	0.10	0.7558
K*Ca	1	0.06250000	0.06250000	0.00	0.9503

TABLE A 4.10 ANOVA Table for the effect of K and Ca on Electrical conductivity in tomato fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.04161875	0.01387292	2.11	0.1524
Error	12	0.07892500	0.00657708	0.12054375	0.345258
Corrected Total	15	1.701308			
	R^2	C.V	Root MSE		Mean
	0.345258	1.701308	0.081099		4.766875
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.02640625	0.02640625	4.01	0.0682
Ca	1	0.01380625	0.01380625	2.10	0.1730
K*Ca	1	0.00140625	0.00140625	0.21	0.6521

TABLE A 4.11 ANOVA Table for the effect of K and Ca on extra large sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	19.02687500	6.34229167	6.17	0.0088
Error	12	12.33350000	1.02779167	31.36037500	0.606717
Corrected Total	15	31.36037500			
	R^2	C.V	Root MSE		Mean
	0.606717	8.547165	1.013801		11.86125
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	8.61422500	8.61422500	8.38	0.0134
Ca	1	10.27202500	10.27202500	9.99	0.0082
K*Ca	1	0.14062500	0.14062500	0.14	0.7179

TABLE A 4.12 ANOVA Table for the effect of K and Ca on large sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	17.13900000	5.71300000	1.90	0.1833
Error	12	36.06730000	3.00560833	53.20630000	0.322124
Corrected Total	15	53.20630000			
	R^2	C.V	Root MSE		Mean
	0.322124	3.257093	1.733669		53.22750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.25000000	0.25000000	0.08	0.7780
Ca	1	12.18010000	12.18010000	4.05	0.0671
K*Ca	1	4.70890000	4.70890000	1.57	0.2345

TABLE A 4.13 ANOVA Table for the effect of K and Ca on small sized fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1.12445000	0.37481667	0.74	0.5509
Error	12	6.11805000	0.50983750		
Corrected Total	15	7.24250000			
	R^2	C.V	Root MSE		Mean
	0.155257	13.30282	0.714029		5.367500
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	1.04040000	1.04040000	2.04	0.1787
Ca	1	0.04202500	0.04202500	0.08	0.7789
K*Ca	1	0.04202500	0.04202500	0.08	0.7789

TABLE A 4.14 ANOVA Table for the effect of K and Ca on medium fruit

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	17.41976875	5.80658958	1.13	0.3757
Error	12	61.62037500	5.13503125		
Corrected Total	15	79.04014375			
	R^2	C.V	Root MSE		Mean
	0.220391	7.698034	2.266061		29.43688
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	15.50390625	15.50390625	3.02	0.1079
Ca	1	0.00455625	0.00455625	0.00	0.9767
K*Ca	1	1.91130625	1.91130625	0.37	0.5532

TABLE A 4.15 ANOVA Table for the effect of K and Ca on the blossom-end rot incidence in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	13.89212500	4.63070833	3.06	0.0694
Error	12	18.16165000	1.51347083	32.05377500	0.433401
Corrected Total	15	32.05377500			
	R^2	C.V	Root MSE		Mean
	0.433401	76.35265	1.230232		1.611250
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.93122500	0.93122500	0.62	0.4480
Ca	1	12.96000000	12.96000000	8.56	0.0127
K*Ca	1	0.00090000	0.00090000	0.00	0.9809

TABLE A 4.16 ANOVA Table for the effect of K and Ca on weight of fruit affected by blossom-end rot in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	32976.26303	10992.08767	3.40	0.0535
Error	12	38788.92655	3232.41055	71765.18957	0.459502
Corrected Total	15	71765.18957			
	R^2	C.V	Root MSE		Mean
	0.459502	76.12418	56.85429		74.68625
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	1767.78202	1767.78202	0.55	0.4738
Ca	1	31191.09210	31191.09210	9.65	0.0091
K*Ca	1	17.38890	17.38890	0.01	0.9427

TABLE A 4.17 ANOVA Table for the effect of K and Ca on the blotchy ripening incidence in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	2.52441875	0.84147292	0.74	0.5471
Error	12	13.60117500	1.13343125		
Corrected Total	15	16.12559375			
	R^2	C.V	Root MSE		Mean
	0.156547	300.4239	1.064627		0.354375
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	2.00930625	2.00930625	1.77	0.2078
Ca	1	0.25755625	0.25755625	0.23	0.6421
K*Ca	1	0.25755625	0.25755625	0.23	0.6421

TABLE A 4.18 ANOVA Table for the effect of K and Ca on fruit weight affected by blotchy ripening in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	5060.56437	1686.85479	0.75	0.5425
Error	12	26948.30438	2245.69203	32008.86874	0.158099
Corrected Total	15	32008.86874			
	R^2	C.V	Root MSE		Mean
	0.158099	302.6704	47.38873		15.65688
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	3922.203756	3922.203756	1.75	0.2110
Ca	1	569.180306	569.180306	0.25	0.6238
K*Ca	1	569.180306	569.180306	0.25	0.6238

TABLE A 4.19 ANOVA Table for the effect of K and Ca on the fruit cracking incidence in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.91136875	0.30378958	0.33	0.8054
Error	12	11.12332500	0.92694375		
Corrected Total	15	12.03469375			
	R^2	C.V	Root MSE		Mean
	0.075728	39.30714	0.962779		2.449375
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.29430625	0.29430625	0.32	0.5835
Ca	1	0.28355625	0.28355625	0.31	0.5904
K*Ca	1	0.33350625	0.33350625	0.36	0.5598

TABLE A 4.20 ANOVA Table for the effect of K and Ca on weight of fruit affected by fruit cracking in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1217.24922	405.74974	0.24	0.8643
Error	12	19995.17295	1666.26441		
Corrected Total	15	21212.42218			
	R^2	C.V	Root MSE		Mean
	0.057384	38.73361	40.81990		105.3863
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	590.9761000	590.9761000	0.35	0.5625
Ca	1	294.1225000	294.1225000	0.18	0.6818
K*Ca	1	332.1506250	332.1506250	0.20	0.6632

TABLE A 4.21 ANOVA Table for the effect of K and Ca on the cat facing incidence in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.88551875	0.29517292	0.29	0.8295
Error	12	12.07862500	1.00655208		
Corrected Total	15	12.96414375			
	R^2	C.V	Root MSE		Mean
	0.068305	143.9671	1.003271		0.696875
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.87890625	0.87890625	0.87	0.3685
Ca	1	0.00330625	0.00330625	0.00	0.9552
K*Ca	1	0.00330625	0.00330625	0.00	0.9552

TABLE A 4.22 ANOVA Table for the effect of K and Ca on weight of fruit affected by cat facing in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1555.65282	518.55094	0.25	0.8626
Error	12	25291.54555	2107.62880		
Corrected Total	15	26847.19838			
	R^2	C.V	Root MSE		Mean
	0.057945	145.9917	45.90892		31.44625
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	1476.864900	1476.864900	0.70	0.4189
Ca	1	45.495025	45.495025	0.02	0.8856
K*Ca	1	33.292900	33.292900	0.02	0.9021

TABLE A 4.23 ANOVA Table for the effect of K and Ca on marketable fruit in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	8.40061875	2.80020625	0.47	0.7059
Error	12	70.84907500	5.90408958		
Corrected Total	15	79.24969375			
	R^2	C.V	Root MSE		Mean
	0.106002	2.714310	2.429833		89.51938
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	3.08880625	3.08880625	0.52	0.4834
Ca	1	5.27850625	5.27850625	0.89	0.3630
K*Ca	1	0.03330625	0.03330625	0.01	0.9414

TABLE A 4.24 ANOVA Table for the effect of K and Ca on marketable yield in tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	15.58101875	5.19367292	0.97	0.4400
Error	12	64.43937500	5.36994792		
Corrected Total	15	80.02039375			
	R^2	C.V	Root MSE		Mean
	0.194713	2.522265	2.317315		91.87438
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	6.69515625	6.69515625	1.25	0.2860
Ca	1	8.45355625	8.45355625	1.57	0.2335
K*Ca	1	0.43230625	0.43230625	0.08	0.7815

TABLE A 4.25 ANOVA Table for the effect of K and Ca on the nitrogen leaf content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	4.89250000	1.63083333	7.46	0.0044
Error	12	2.62500000	0.21875000		
Corrected Total	15	7.51750000			
	R^2	C.V	Root MSE		Mean
	0.650815	21.13931	0.467707		2.212500
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	4.41000000	4.41000000	20.16	0.0007
Ca	1	0.12250000	0.12250000	0.56	0.4687
K*Ca	1	0.36000000	0.36000000	1.65	0.2238

TABLE A 4.26 ANOVA Table for the effect of K and Ca on the phosphorus leaf content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00687500	0.00229167	0.58	0.6399
Error	12	0.04750000	0.00395833		
Corrected Total	15	0.05437500			
	R^2	C.V	Root MSE		Mean
	0.126437	37.28313	0.062915		0.168750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.00062500	0.00062500	0.16	0.6981
Ca	1	0.00562500	0.00562500	1.42	0.2563
K*Ca	1	0.00062500	0.00062500	0.16	0.6981

TABLE A 4.27 ANOVA Table for the effect of K and Ca on the calcium leaf content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	20.22426875	6.74142292	66.53	<.0001
Error	12	1.21587500	0.10132292		
Corrected Total	15	21.44014375			
	R^2	C.V	Root MSE		Mean
	0.943290	11.67316	0.318313		2.726875
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	19.51430625	19.51430625	192.60	<.0001
Ca	1	0.00015625	0.00015625	0.00	0.9693
K*Ca	1	0.70980625	0.70980625	7.01	0.0213

TABLE A 4.28 ANOVA Table for the effect of K and Ca on the potassium leaf content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.09062500	0.03020833	1.11	0.3850
Error	12	0.32795000	0.02732917		
Corrected Total	15	0.41857500			
	R^2	C.V	Root MSE		Mean
	0.216508	15.39607	0.165315		1.073750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.02250000	0.02250000	0.82	0.3821
Ca	1	0.06002500	0.06002500	2.20	0.1641
K*Ca	1	0.00810000	0.00810000	0.30	0.5961

TABLE A 4.29 ANOVA Table for the effect of K and Ca on the magnesium leaf content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.19312500	0.06437500	8.79	0.0023
Error	12	0.08785000	0.00732083		
Corrected Total	15	0.28097500			
	R^2	C.V	Root MSE		Mean
	0.687339	16.18191	0.085562		0.528750
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.16000000	0.16000000	21.86	0.0005
Ca	1	0.00422500	0.00422500	0.58	0.4621
K*Ca	1	0.02890000	0.02890000	3.95	0.0703

TABLE A 4.30 ANOVA Table for the effect of K and Ca on the nitrogen fruit content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.38187500	0.12729167	1.88	0.1868
Error	12	0.81250000	0.06770833		
Corrected Total	15	1.19437500			
	R^2	C.V	Root MSE		Mean
	0.319728	11.16175	0.260208		2.331250
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.05062500	0.05062500	0.75	0.4042
Ca	1	0.33062500	0.33062500	4.88	0.0473
K*Ca	1	0.00062500	0.00062500	0.01	0.9250

TABLE A 4.31 ANOVA Table for the effect of K and Ca on the phosphorus fruit content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.03250000	0.01083333	2.89	0.0795
Error	12	0.04500000	0.00375000		
Corrected Total	15	0.07750000			
	R^2	C.V	Root MSE		Mean
	0.419355	14.84539	0.061237		0.412500
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.03250000	0.01083333	2.89	0.0795
Ca	1	0.04500000	0.00375000	0.07750000	0.419355
K*Ca	1	14.84539	0.061237	0.412500	0.00000000

TABLE A 4.32 ANOVA Table for the effect of K and Ca on the calcium fruit content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00525000	0.00175000	1.12	0.3796
Error	12	0.01875000	0.00156250		
Corrected Total	15	0.02400000			
	R^2	C.V	Root MSE		Mean
	0.218750	26.35231	0.039528		0.150000
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.00062500	0.00062500	0.40	0.5390
Ca	1	0.00302500	0.00302500	1.94	0.1894
K*Ca	1	0.00160000	0.00160000	1.02	0.3315

TABLE A 4.33 ANOVA Table for the effect of K and Ca on the potassium fruit content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.75761875	0.25253958	2.39	0.1192
Error	12	1.26537500	0.10544792		
Corrected Total	15	2.02299375			
	R^2	C.V	Root MSE		Mean
	0.374504	9.947615	0.324727		3.264375
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.00680625	0.00680625	0.06	0.8038
Ca	1	0.60450625	0.60450625	5.73	0.0339
K*Ca	1	0.14630625	0.14630625	1.39	0.2617

TABLE A 4.34 ANOVA Table for the effect of K and Ca on the magnesium fruit content of tomato

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	0.00016875	0.00005625	0.51	0.6832
Error	12	0.00132500	0.00011042		
Corrected Total	15	0.00149375			
	R^2	C.V	Root MSE		Mean
	0.112971	8.802457	0.010508		0.119375
Source	DF	Type III SS	Mean Square	F Value	Pr > F
K	1	0.00000625	0.00000625	0.06	0.8160
Ca	1	0.00015625	0.00015625	1.42	0.2572
K*Ca	1	0.00000625	0.00000625	0.06	0.8160