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YIELD AND QUALITY OF POTATOES AS AFFECTED BY CALCIUM NUTRITION, TEMPERATURE AND HUMIDITY

by

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ABSTRACT

Potato tubers are low in calcium due to limited calcium transport in the xylem and immobility of calcium in the phloem. Low tuber calcium content results in the occurrence of necrotic cells in the medullary tissues, which is a physiological disorder known as internal brown spot (IBS). A high incidence of IBS results in reduced tuber quality and market value. The objective of the study was to apply additional calcium to the potato crop using different calcium sources (gypsiferous mine water, gypsum and calcium rich water) to determine the impact on tuber yield and quality.

Commercial field trials were conducted at Kleinkopje mine on the Mpumalanga Highveld from August 2001 to January 2002 and from September 2002 to January 2003. The response of the potato cultivar Up-to-date to irrigation with gypsiferous mine water as a calcium source was investigated. At Kleinkopje there was no control field (irrigated with normal water) for direct comparison. Another field trial was established at University of Pretoria Experimental Farm where gypsum at four levels was broadcast and incorporated prior to planting. Pot trials were conducted under controlled conditions because calcium uptake is not affected only by the amount of calcium applied or the location of the calcium application. Factors that affect calcium uptake such as temperature and humidity also play a role. Two pot experiments were conducted under controlled conditions from July to October 2002 and from October 2002 to January 2003. In these experiments, the effect of applying increasing calcium concentrations in calcium rich water at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures and humidities (35 % and 85 %) on tuber calcium content and quality were investigated. The parameters measured included growth analysis, leaf and tuber chemical analysis, tuber yield and quality. For the field trials soil sampling was done at the beginning and at the end of the cropping season for chemical analysis.

Irrigation with gypsiferous mine water did not have a negative impact on overall potato growth. Higher levels of calcium (in irrigation water or gypsum) also did not have a negative effect on other nutrient levels. Irrigating potato plants with gypsiferous mine water resulted in high tuber yields of 52 t/ha in 2001 and 62 t/ha in 2002 seasons, which are good yields for Mpumalanga. Applying higher gypsum levels as a preplant broadcast resulted in high tuber yields (52 t/ha), which is a good

yield for Hatfield. Application of gypsum as a preplant broadcast and irrigation with gypsiferous mine water resulted in good quality tubers (SG > 1.075 and chip colour > 45). This implies that gypsiferous mine water can possibly be used for irrigation of potatoes as a calcium source. The calcium nutrition of the potato tubers was not affected by the amount of calcium applied to the plants, calcium uptake or distribution within the plant only. Environmental conditions (temperature and humidity), which affect these functions also played a role. It has been discovered that lowering the temperature (22/14 ^{o}C) and low humidity (35 %) had beneficial effects on the tuber yield. Maintaining plants at low temperature (22/14 ^{o}C) and high humidity (85 %) could improve the tuber quality. However, high humidity (85 %) and high temperature (27/17 ^{o}C) improved calcium uptake by the tubers.

CHAPTER 1

GENERAL INTRODUCTION

Potato (*Solanum tuberosum L.*) tubers have low levels of endogenous calcium as compared to the vegetative parts (Simmons *et al.*, 1988). Calcium is an essential plant macronutrient for maintaining cell wall stability (Ilyama *et al.*, 1994; Bian *et al.*, 1996). The reason for low calcium levels in the tubers is its immobility in the phloem (Bangerth, 1979). Calcium is taken up through the transpiration stream, thus tubers are likely to receive less calcium because of their displacement from the transpiration stream (Kratzke & Palta, 1986; Simmons *et al*., 1988).

Low calcium levels may contribute to the onset of necrotic cells (dead cells) visible in the medullary tissues of tubers (Olsen *et al.*, 1996). Tissue necrosis is a physiological disorder called internal brown spot (IBS), which is associated with calcium deficiency in the tubers (Sterrett & Henninger, 1991; Kleinhenz, 2000). High incidence of IBS reduces tuber quality and its market value (Sterrett & Henninger, 1991; Bian *et al*., 1996).

According to literature, the onset of IBS can be overcome by applying additional calcium to potato crops (Kratzke & Palta, 1985; Locascio *et al*., 1992). Applying additional calcium can increase calcium content of the tubers and result in improved quality (Kratzke & Palta, 1985; Locascio *et al*., 1992; Spillman, 2003).

In recent investigations, different calcium sources were used to apply additional calcium to increase the amount accumulated by the tubers and improve the quality (Kratzke & Palta, 1985; Locascio *et al*., 1992; Kleinhenz, 2000). Calcium is transported with movement of water in the xylem (Kratzke & Palta, 1985), thus calcium uptake may be affected mainly by the location of calcium applications (Kratzke & Palta, 1986). The results of investigations suggest that basal roots contribute less to the accumulation of calcium in the tuber, thus calcium should be placed close to the tubers and the stolon area (Kratzke & Palta, 1985).

Previous work has shown the beneficial effect of applying additional calcium close to the region of tuber formation to improve calcium content of the tubers (Kratzke & Palta, 1985). Calcium transport through the transpiration stream results in more calcium uptake to the vegetative parts, but tubers have the ability to absorb calcium directly from the soil solution through the tuber roots or stolon roots (Bangerth, 1979; Kratzke & Palta, 1985; Spillman, 2003).

The onset of IBS is not only related to the low calcium content of the tubers. Poor calcium uptake and the limited ability of the potato crop to distribute calcium between the vegetative parts and tubers also lead to the problem. The environmental factors (temperature and humidity) that affect calcium uptake and distribution can also lead to the occurrence of IBS (Olsen *et al*., 1996).

Increasing the temperature will increase transpiration rate and result in more calcium transport to the vegetative parts (Bangerth, 1979; Olsen *et al*., 1996). In contrast, Adams & Ho (1993) have discovered that an increase in humidity results in a decreased transpiration rate. The motivation for this study is the concern about the low calcium content of tubers which affects tuber quality. Finding a way of improving the calcium nutrition of potato crops to improve tuber quality and reduce the incidence of IBS was the major focus of this study. Using mine effluent as a calcium source in irrigation water is another way of improving tuber calcium nutrition and quality.

The current study was done with the objectives of determinining how potato yield and quality can be affected by:

- Irrigation with gypsiferous mine water as a calcium source.
- Gypsum (as a calcium source) applied at four levels (3 control, 6, 15 and 40 t/ha) prior to planting.
- Irrigation with increasing levels of calcium (44 control, 176, 352 and 704 mg/l Ca) in calcium rich water evaluated at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures, maintained at 35 % and 85 % humidity.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The potato crop (*Solanum tuberosum L.*) originated in the highlands of the Andes in South America. Potatoes are currently produced in large quantities and consumed worldwide. Potatoes belong to the family Solanaceae and the species tuberosum. This crop is an annual herbaceous dicotyledonous plant, with underground stems that give rise to tubers (Lisinka & Leszcynki, 1989).

2.2 MORPHOLOGY OF THE TUBERS

The morphology of potato tubers is described to give a clear picture of the location of the occurrence of the calcium related disorder (IBS), which will be discussed.

2.2.1 External morphology

Tubers develop when the tip of underground stems called stolons, swell (Lisinka & Leszcyski, 1989). The orientation of the tubers is based on its attachment to the stolon. The tuber end attached to the stolon is called the stolon or the stem end and the distal end is the apical or the bud end (Li, 1985). Tubers comprise of an upper and lower surface. The upper surface, having more hollows called eyes, which comprises of auxiliary buds spirally arranged around the tuber, is more convex compared to the lower surface (Burton, 1989; Lisinka & Leszcyski, 1989).

2.2.2 Internal morphology

The tuber comprises of four primary zones of tissue (Figure 2.1). The first primary outermost zone is the periderm, which covers the tuber. The periderm is made up of three layers, namely, the phellem (rectangular cells orientated in radial rows), the phellogen (a meristematic tissue which gives rise to the phellem) and the phelloderm

which underlies phellogen. The second primary zone is the cortex which lies between the periderm and the vascular tissue. The third zone is called perimedullary tissue which forms the largest part of the tuber and lies between vascular tissue and the pith. The fourth zone is the pith which forms the centre of the tuber and may be angular with rays extending from nodes (Dean, 1994).

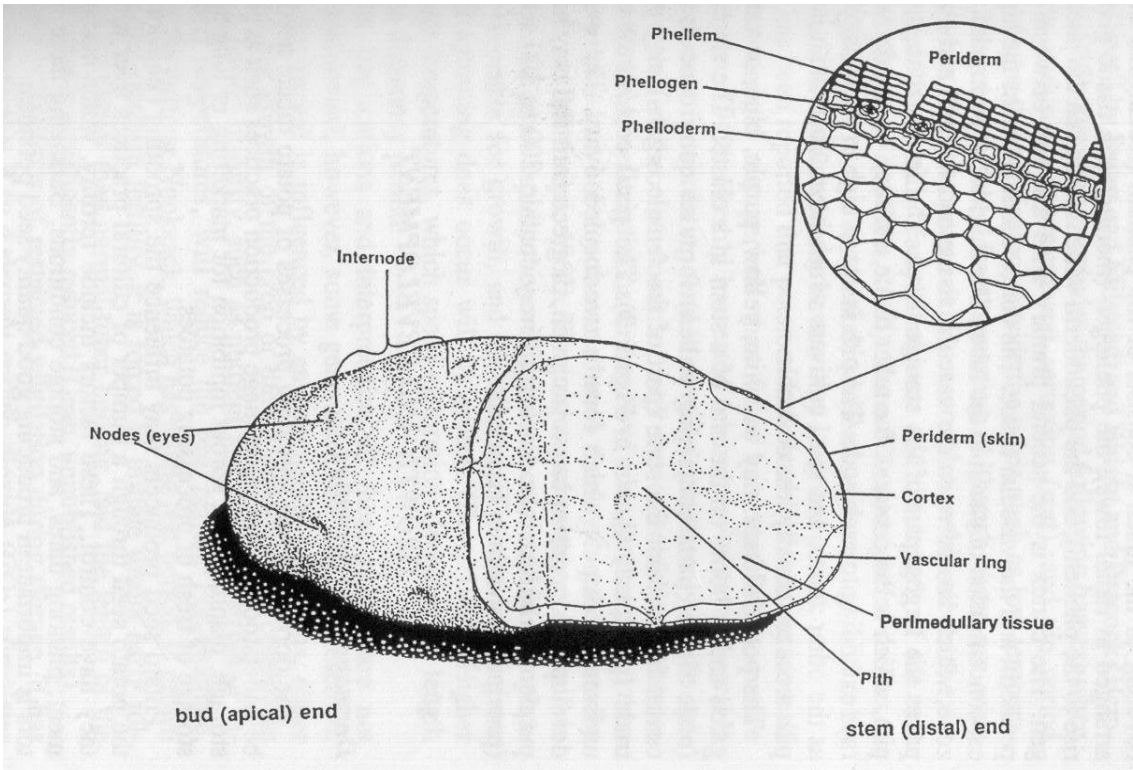


Figure 2.1: Morphology of the potato tuber (Dean, 1994)

2.3. CALCIUM AND ITS IMPORTANCE IN TUBER NUTRITION

2.3.1 Calcium accumulation by tubers

The levels of endogenous calcium in potato tubers are low compared to the leaves and stems (Davies & Millard, 1985; Simmons *et al*., 1988; Olsen *et al*., 1996; Spillman, 2003). Endogenous tuber calcium concentration ranges from 0.009 to 0.066 g Ca/100 g dry matter (Olsen *et al*., 1996). Locascio *et al*. (1992) reported the calcium concentration of potato tubers to be higher in the periderm than in the medullary tissue.

The low calcium content of tubers might be the result of limited calcium transport through the transpiration stream (Kratzke & Palta, 1986; Simmons *et al*., 1988).

Exchange adsorption on the xylem surface, which also regulates xylem transport rate of calcium to the shoots, leads to the low calcium content of the tubers. The low calcium content of the tubers may be magnified when potatoes are grown in sandy soil with low cation exchange capacity (CEC) and low soil calcium (250-300 mg kg^{-1}) content (Tzeng *et al*., 1986; Simmons & Kelling, 1987; Sterrett & Henninger, 1991).

2.3.2 Calcium deficiency of potato tubers

Calcium deficiency in potato tubers is not only due to insufficient calcium uptake by the plant, but also as a result of problems related to calcium distribution within the plant which results in calcium related disorders. Kirkby & Pilbeam (1984) report that the limited ability of the plants to regulate calcium distribution between fast growing tissues (leaves) and low transpiring organs (tubers) result in calcium related disorders. Thus the disorders are the result of inefficient calcium distribution, rather than poor calcium uptake.

Calcium deficiency in potato tubers is associated with Internal Brown Spot (IBS), also known as internal browning, internal necrosis, tuber necrosis, chocolate spot, physiological internal necrosis, internal rust spot and internal brown fleck of the potato tuber (Sterrett & Henninger, 1991; Olsen *et al*., 1996). Tzeng *et al.* (1986); Simmons & Kelling (1987); Sterrett & Henninger (1991); Bian *et al.* (1996); Olsen *et al*. (1996) and Kleinhenz (2000) refer to IBS as a physiological disorder, associated with dense areas of brown necrotic cells, visible mainly in the medullary tissue of the potato tuber.

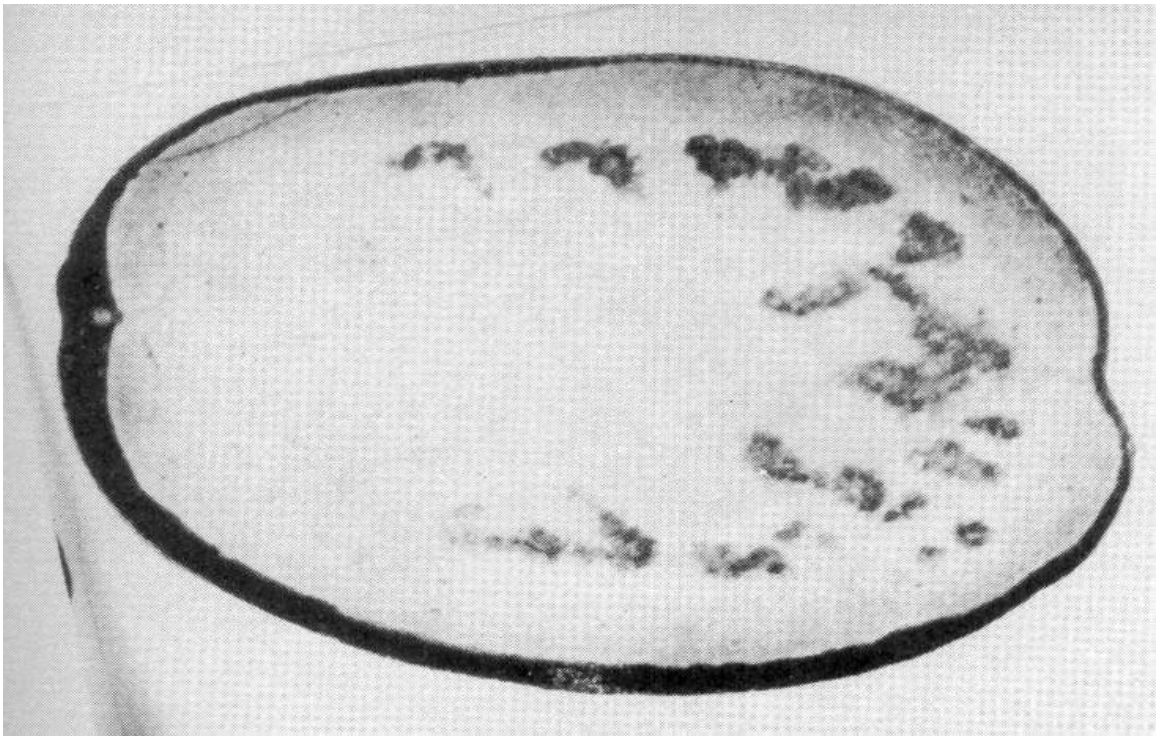


Figure 2.2: Internal brown spot of the potato tuber (Li, 1985)

Referring to Figure 2.2, necrotic cells seem to accumulate more to the bud end than to the stolon end. Li (1985) discovered the occurrence of IBS towards the bud end. This can be due to the distance between the bud end and the point at which calcium is received (the stolons). The other reason could be due to the weakly developed xylem of tubers.

This disorder is an internal defect of potato tubers that shows no external symptoms (Li, 1985; Tzeng *et al*., 1986; Davies, 1998; Olsen *et al*., 1996). Tzeng *et al*. (1986) and Sterrette & Henninger (1991) report that the quality of potato chips and the cooking value of tubers are reduced by the presence of necrotic cells (brown discoloured cells). The affected tubers are worthless for consumption since they become very tough after cooking. A high incidence of IBS results in market rejection of tubers and economic losses to growers (Sterrett & Henninger, 1991).

Glasshouse and field studies indicate tubers with IBS to have lower calcium concentrations than unaffected tubers (Colliar *et al*., 1978; Tzeng *et al*., 1986; Silva *et al*., 1991). Even though IBS is primarily associated with a low calcium content of tubers, other factors (ion imbalances, moisture supply and salinity) that affect calcium

uptake of the crop also lead to the occurrence of the disorder (Olsen *et al.*, 1996; Kleinhenz, 2000).

2.3.3 Calcium uptake

The rate of nutrient supply to plants is more important than knowing nutrient levels in the soil and how they reach the plants. The nutrients may reach the plants but the understanding of how nutrient ions are distributed in various plant organs is also important because it affects the general plant nutrition.

Nutrient uptake follows a trend involving the uptake of ions from the soil solution by the roots, transport across the roots and the xylem vessels and finally, movement towards the aerial part or the storage organs of the plant (Davies, 1998; Robb & Pierterpoint, 1983).

Roots intercept some ions in the soil solution (Foth & Ellis, 1998). Calcium movement to the roots is mainly due to transpiration of the plant, rather than through root elongation and interception (Bangerth, 1979). Ions in soil solution are moved to the roots by mass flow or diffusion, depending on the ion concentration of the soil solution.

When fewer nutrients arrive at the roots, ion concentrations in the root vicinity drop due to their absorption by the roots. From this a concentration gradient is derived, resulting in the diffusion of ions to the roots (Foth & Ellis, 1988). If there is a high concentration of ions in the soil solution the replenishment is faster, and mass flow can supply much of the nutrients to the roots (Foth & Ellis, 1988). Bangerth (1979) also reports that the transport of calcium in the soil solution to the root system is due to mass flow.

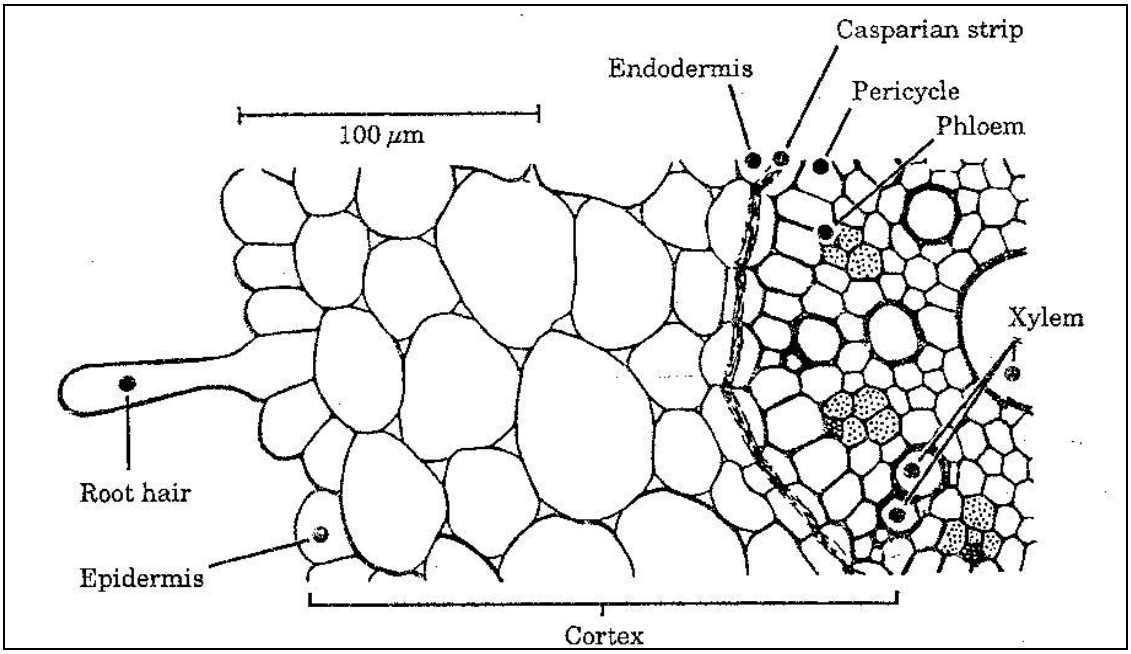


Figure 2.3: Calcium transport in the cell (White, 1998)

Referring to Figure 2.3, when calcium reaches the root surface, it moves across the root cortex either by diffusion, or more likely by displacement exchange in the free space (Bangerth, 1979; White, 1998). Calcium seems to flow in an apoplastic pathway since its transport is well correlated with that of water (Kirkby & Pilbean, 1984). The transport of water and ions has to pass through the endodermis before entering the stele and the xylem (Bangerth, 1979).

The transport of water and ions through the apoplast is blocked by the suberized Casparian strips of the endodermal cells; thus the transport will be forced to proceed in the symplast (Foth & Ellis, 1988; White, 1998). Bangerth (1979) report limited calcium transport in the symplast. Thus calcium transport into the stele and xylem through the endodermis occurs where the Casparian strips are not fully developed (behind endodermal cell division).

Water potential gradients in the crop favour xylem transport into the vegetative parts, which have high calcium levels. Kratzke & Palta (1985) report calcium to be transported via the xylem, thus the calcium destination is mainly the vegetative parts and less to the tubers. Thus when compared with the leaves, tubers have very low calcium contents.

Calcium is not redistributed via the phloem to other parts of the plant, which may contribute to the onset of tissue necrosis in tubers (Bargerth, 1979).

The low calcium content of tubers is not only affected by a lower calcium supply to the plant. The location of calcium application to the crop should also be taken into consideration since it also affects the calcium content and quality of the tubers (Locascio *et al.*, 1992; Spillman, 2003). According to Emanuelsson (1984) since calcium is not transported through the phloem, it is essential to supply additional calcium to the root meristem for optimum uptake.

The potato crop has various types of roots which contribute to calcium uptake. Referring to Figure 2.4, these are, the roots arising at the base of the main stem (A: basal or main roots), the roots originating from the main stem at the junction with the stolon (B: junction roots), the roots on the stolon (C: stolon roots) and the roots growing directly from the buds of the tuber (D: tuber roots) (Kratze & Palta, 1985).

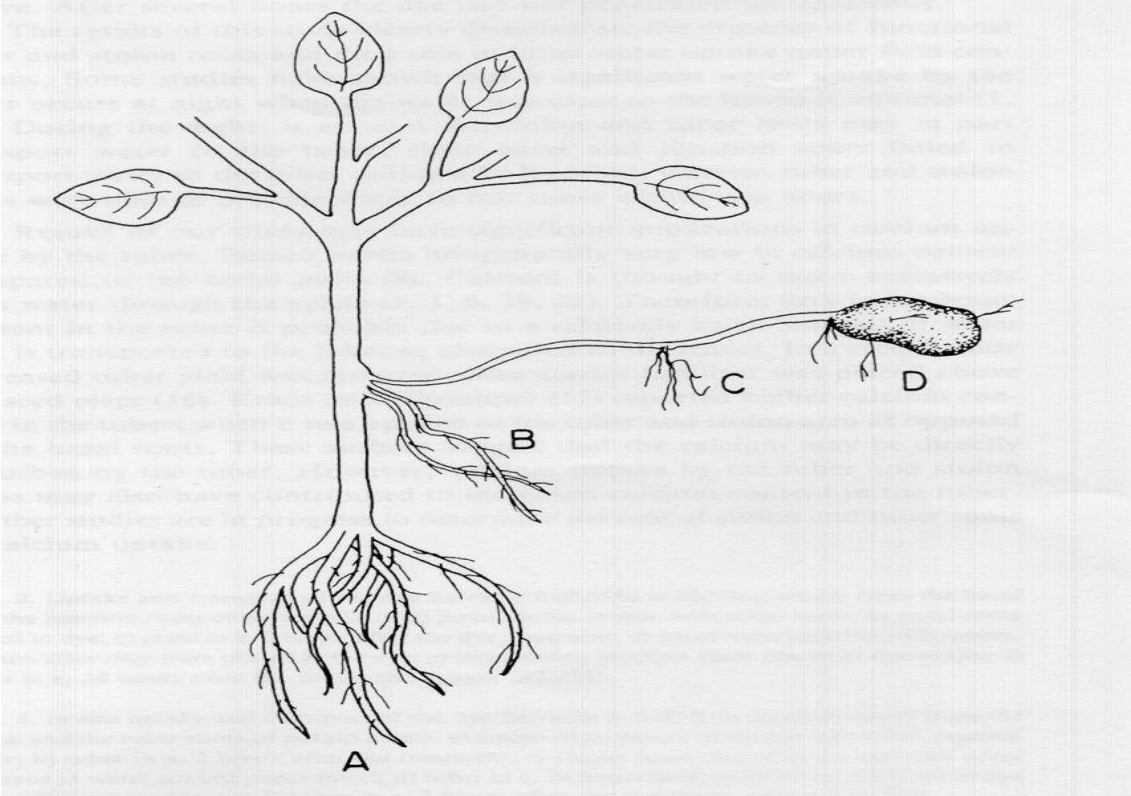


Figure 2.4: Potato plant showing various types of roots. A) Basal roots; B) Stem stolon junction roots; C) Stolon roots; D) Tuber roots. (Kratze and Palta, 1985).

Calcium could be taken up by the tubers mainly through the tuber roots and stolon roots since they are located near the tubers (Bamberg *et al*., 1993; Spillman, 2003). The main roots and the junction roots contribute less to the calcium uptake of the tubers (Davies & Millard, 1985; Kratzke & Palta, 1985; Locascio *et al*., 1992). According to Simmons and Kelling (1987), calcium is distributed by the xylem; thus, the displacement of the tubers from the xylem results in less calcium being transported to the tubers.

The other reason for the low calcium content of the tubers as evidenced by Bamberg *et al*. (1993) and Spillman (2003) is the low transpiration rate of the potato tubers and thus little xylem water is drawn to tubers, because they are surrounded by moist soil compared to the foliage. Thus tubers rely mainly on the roots close to the tuber stolon area for extraction of water from the soil (Palta, 1996; Spillman, 2003). Kratzke & Palta (1985) suggest that calcium might be directly absorbed from the soil through the epidermis. Calcium uptake by the tuber roots and the stolon roots may therefore contribute to increased calcium content of the tubers (Kratzke & Palta, 1986).

2.3.4 The role of calcium in the cell

Potato tubers have a low calcium content due to poor calcium uptake and the limited ability of the crop to distribute calcium between the vegetative parts and storage organs. Calcium plays a major role in tuber quality by developing the membrane and cell wall structures (Kleinhenz & Palta, 2002). Ilyama *et al*. (1994) found calcium to be important in enhancing the membrane structural stability and maintaining the cell wall rigidity and thus increasing plant tissue resistance.

Palta (1996) reports the ability of calcium to bridge phosphate and carboxylate groups of phospholipids at the membrane surface to result in cell membrane stability. Kirkby & Pilbeam (1984) report that none of the cations that can replace calcium from the binding sites can replace its function in membrane stabilization. The replacement of calcium from its binding sites by heavy metals and protons can damage the plasmamembrane surface.

Cell wall rigidity is due to the ability of calcium to provide stable, but reversible, intramolecular linkages between pectic molecules (Palta, 1996). Palta (1996) reports the presence of calcium in the extracellular solution to strengthen the bond between the cell wall and plasmamembrane and to ensure maintenance of structural stability. Kirkby & Pilbeam (1984) established that the leaky membranes which result in loss of solutes from the cytoplasm are the result of the absence of calcium in the membranes.

Bargenth (1979); Palta (1996) and Vega *et al*. (1996) have discovered that the increased efflux rate of ions (potassium) from plant tissues is due to freezing injury. High temperatures may in the same manner, affect cell membrane transport properties, thus ion leakage from the cells can be enhanced (Kleinhentz & Palta, 2002). EL-Beltagy *et al.* (2002) report that the presence of extracellular calcium reduces the efflux rate of ions at extreme temperatures. The same response has also been reported by Kleinhenz & Palta (2002). Calcium also plays a major role in plant growth, development and the maintenance of various cell functions. Emanuelsson (1984) considers calcium to be important for root growth. Calcium related deficiencies can therefore be related to poor root development.

2.4 TEMPERATURE AND HUMIDITY EFFECTS ON CALCIUM NUTRITION

Additional calcium can be supplied to the plant to increase the amount accumulated by the tubers, and thus improve tuber quality (Kratzke & Palta, 1986). Calcium uptake by the potato crop and its distribution between foliage and tubers can be affected by temperature and humidity (Bangerth, 1979; Adams & Ho, 1993; Ruiz *et al.*, 2002)

2.4.1 Temperature

Root temperatures affect many aspects of plant physiology, but mainly water and nutrient uptake. The temperature of the root zone influences the absorption and distribution of cations; calcium being the most affected (El-Beltagy *et al.*, 2002).

Nutrient uptake is reduced directly by low temperature. At low temperatures the supply of nutrients is less due to the reduction in the amounts of nutrients released into the soil solution from the parent material (Bangerth, 1979). Lower temperatures reduce the active transport system in the cells and so do the translocation and the assimilation processes. An increase in root temperature to the maximum of 26 ^{o}C increases calcium uptake. Root absorption of calcium therefore increases with higher transpiration.

High temperature increases the transpiration rate and results in higher calcium uptake to the foliage and less to the tubers (Olsen *et al*., 1996). Extreme root temperatures may decrease calcium uptake and increase the severity of IBS (Ruiz *et al*., 2002).

2.4.2 Humidity

Humidity under both field and controlled environmental conditions affect the uptake of the calcium ion. High relative humidity depresses the rate of transpiration and the distribution of calcium to the leaves, specifically to the growing leaves (Adams & Ho, 1993). Restricted transpiration rate and calcium uptake at high humidity is also evidenced by Bergmann (1992). Most of the absorbed calcium remains available for distribution elsewhere in the plant, which might lead to increased calcium concentrations in the tubers (Adams & Ho, 1993). To the contrary, an increase in transpiration rate can be expected with a decrease in humidity.

2.4.*3 Other factors that can influence calcium uptake*

2.4.3.1 Salinity

A high concentration of sodium and chloride in the soil may cause a deficiency of other ions. A high concentration of sodium ions in the soil solution may result in decreased xylem transport or partitioning of calcium within the plant tissues. A decrease in calcium uptake can be mainly due to restricted water uptake (Adams and Ho, 1995).

2.4.3.2 Ion imbalances

Calcium uptake is influenced by competition with other ions. High concentrations of H^+, Na^+, Mn^{2+}, Al^{3+}, Mg^{2+} and particularly NH_4^+ may reduce calcium uptake within the plant (Bergmann, 1992; Locascio *et al*., 1996). Bangerth (1979) also reports the antagonistic competition among K^+, NH_4^+ and Mg^{2+} uptake to reduce calcium uptake.

2.4.3.3 Moisture supply

Soil moisture may also play a major role in calcium uptake and distribution within the plant (Olsen *et al*., 1996). Under water stress, the transpiration rate within the plant is decreased. Since calcium moves through the plant by transpiration stream, a reduction in movement within the plant reduces the amount of calcium carrying water reaching the developing tubers (Adams & Ho, 1995).

2.5. TEMPERATURE EFFECTS ON POTATO GROWTH

Temperature and humidity do not only affect the quality of the tubers, but also the general growth of the potato crop and tuber yield (Cao & Tibbitts, 1992). Potatoes can be grown in many areas under various climatic conditions, but the crop prefers a specific environment to grow successfully with good yield and quality.

An extreme environment, for example high/low temperature, as well as high/low humidity, on the potato crop, may result in a decrease in the crop growth and tuber yield (Struik *et al*., 1989b; Adams & Ho, 1993; EL-Beltagy *et al*., 2002).

2.5.1 Temperature requirements of potatoes

Potato is categorized as a cool season crop, which requires temperatures between 15 ^oC and 22 ^oC for optimum growth, production and quality (El-Beltagy *et al*., 2002). El-Beltagy *et al*. (2002) and Tawfik *et al*. (1996) report that high temperatures (>28/18 ^oC day/night) affect the potato crop growth and production negatively.

2.5.2 Temperature effects on leaves and stems

Higher temperatures and long days promote vegetative growth and stimulate stem elongation (Tadesse *et al*., 2001; El-Beltagy *et al*., 2002). Increase in temperatures to the optimum range of 20 – 25 ^{o}C enhances stem growth (Tadesse *et al*., 2001). High temperatures (more than 25 - 30 ^{o}C) tend to increase stem length and branching while reducing leaf size and leaf area (Palta, 1996; El-Beltagy *et al*., 2002). Tawfik *et al*. (1996) have found the reduction in potato leaf size to be due to the reduction in cell division, altered cell membrane permeability or reduced stomatal conductance as well as reduced CO_2 supply for assimilate production.

2.5.3 Temperature effects on stolons and tubers

High air temperatures promote development and branching of stolons, even though some reports indicate that number of stolons and stolon yield are decreased by high soil temperatures. Some reports also indicate that the number of stolons or stolon yields are reduced by high soil temperature, while stolon development is delayed (Struik *et al*., 1989a). To the contrary, some reports indicate that high temperatures tend to delay stolon development, while the final number of stolons and final stolon yields are increased (Struik *et al*., 1989b).

Balamani *et al*. (1986) report tuberization to be promoted by short days and low temperatures (< 25 ^{o}C) whereas long days and high temperatures delay or inhibit the process. The optimum temperature for tuber initiation and growth ranges from 15 – 19 ^{o} C (Tadesse *et al*., 2001). Cool temperatures as well as short photoperiods favour partitioning of photosynthates to the tubers (Ewing, 1981). Cao & Tibbitts, (1992) established the highest production of plant dry mass and tuber yield at 20^{o} C.

High temperatures lower tuber yields. This is due to reduced partitioning of photosynthates to the tubers (Tadesse *et al*., 2001; El-Beltagy *et al*., 2002; Kleinhenz and Palta, 2002). According to Basu & Minhas (1991) high temperatures lower tuber yields because they inhibit starch synthesis in tubers and the partitioning of the photosynthates to the tubers. Soil temperatures also affect the number of tubers formed as well as the rate and period of tuber growth as reported by Struik *et al*. (1989c).

2.5.4 Other temperature effects on potato

According to Struik *et al*. (1989a, 1989b), high temperature (> 28/18 ^{o}C day/night) impedes the production of dry matter and its distribution between tubers and haulm, as well as the net amount of photosynthates available for the entire plant (night temperatures are more crucial). High temperatures also affect photosynthesis, respiration and membrane permeability (Tawfik e*t al.*, 1996).

2.6. HUMIDITY EFFECTS ON GROWTH OF THE POTATO

The studies done on the impact of humidity on potato growth are not as numerous as those done on temperature. Humidity, similar to temperature, also affects potato growth and tuber yield. Leaf size as well as colour are affected by humidity. According to Wheeler *et al*. (1989) lowering the humidity results in greater leaf sizes with dark green colour. The investigation done by Wheeler *et al*., (1989) highlights the fact that humidity can also affect potato growth and tuber yield.

Wheeler *et al*. (1989) conducted an experiment on three potato cultivars grown for 56 days in controlled environment rooms under continuous light at 20 ^{o}C and 50 or 85 % relative humidity. The results as shown in Table 2.1, indicate that reducing humidity (50 %) benefits foliage and stem growth; while increasing humidity (85 %) favours increase in tuber yield. This is evidenced by the data obtained which shows higher leaf and stem dry mass, total dry mass as well as leaf area values at 50 % humidity and higher tuber yield values at 85 % humidity (Wheeler *et al*, 1989). Wheeler *et al.* (1989) relates the reason for high tuber yields at high (85 %) humidity to the increase in photosynthate allocation to the tubers.

Table 2.1: Effects of relative humidity on potato growth (Wheeler *et. al*, 1989)

Growth Characteristics	Relative humidity (%)	Cultivars Russet Burbank	Norland	Denali
Leaf dry mass (g)	50	122 ± 18	119 ± 21	106 ± 16
	85	110 ± 9	98 ± 10	89 ± 10
Stem dry mass (g)	50	65 ± 13	51 ± 14	50 ± 14
	85	69 ± 9	40 ± 7	44 ± 7
Tuber dry mass (g)	50	28 ± 25	27 ± 26	66 ± 21
	85	42 ± 21	67 ± 11	105 ± 16
Total plant dry mass (g)	50	223 ± 16	204 ± 15	232 ± 18
	85	229 ± 9	210 ± 14	249 ± 14
Leaf area (m^2)	50	3.57 ± 0.35	3.22 ± 0.64	3.41 ± 0.99
	85	3.13 ± 0.40	2.57 ± 0.38	2.60 ± 0.46

There is a possible benefit in raising humidity levels to increase tuber yields of potatoes. The elevated relative humidity appears to shift the allocation pattern of photosynthates to favour allocation to the tubers over allocation to leaves and the stems (Wheerler *et al*., 1989).

2.7. IMPROVING CALCIUM CONTENT OF POTATO TUBERS

There is benefit in applying additional calcium to potatoes using different calcium sources to improve calcium nutrition of the tubers. In recent research different calcium sources were used to apply additional calcium to the plants to determine how it affects the amount of calcium accumulated by the tubers. Increasing the calcium content generally resulted in improved quality of the tubers.

Simmons e*t al*. (1988) report that a preplant strip application of gypsum in the field in low calcium sandy soils, with side-dressed $Ca(NO_3)_2$ fertilization, resulted in improved tuber grade and size and increased tuber periderm calcium concentration. Silva *et al.* (1991), mention the benefit of preplant gypsum application in the reduction of tuber IBS.

The effluent from coalmines on the Mpumalanga Highveld could also be used for the irrigation of potatoes as a possible source of calcium. Large volumes of gypsiferous mine wastewater are generated by these mines. The growing population demands careful use of all the water resources. A recent approach investigated the use of gypsiferous mine water for the irrigation of agronomic crops and pastures (Annandale *et al*., 2001). The crop response to gypsiferous mine water was investigated in a field trial at Kleinkopje Collieries. Irrigating potatoes with gypsiferous water generally resulted in improved quality of the potato tubers.

In pot experiments, improved tuber quality and reduction in IBS have been reported in response to additional calcium application. The greenhouse pot experiment conducted by Colliar *et al.* (1978), for example, demonstrated that calcium application could increase tuber calcium concentration and reduce IBS.

It has been taken into consideration that calcium accumulation is not only affected by the amount of calcium applied to the potato crop but also to the location of application. Calcium application close to the tuber stolon area may add more value to the calcium nutrition of the tubers (Kratzke & Palta, 1985). Kratzke & Palta (1985) investigated if the placement of calcium in different root areas affects the amount of calcium accumulated by the potato tubers. Calcium is transported with the water flow in the xylem, thus calcium uptake may be affected mainly by the location of calcium additions. This is also confirmed by the results of Kratzke and Palta, (1986), which suggest that applying calcium to the tuber stolon area may increase tuber calcium content.

Simmons & Kelling (1987) and Simmons *et al*., (1988), report possible response of potatoes to calcium fertilization similar to that of peanuts, since they are both under-ground storage organs. Calcium applied to the region of peanut formation can result

in improved peanut yield and quality since calcium can be directly absorbed by the peanut pod. Calcium may also be directly absorbed from the soil solution through the periderm of the tubers (Davies & Millard, 1985; Simmons *et al*., 1988).

2.8. DISCUSSION AND CONCLUSIONS

Calcium is an essential macroelement in maintaining cell membrane stability and cell wall rigidity (Kratzke & Palta, 1986). Calcium nutrition of potatoes is important because it affects the quality of the tubers. Most soil provides enough calcium for plant nutrition. Since calcium is transported through the xylem, more calcium is destined for vegetative parts rather than the tubers (Kratzke & Palta, 1986). Thus less calcium will be accumulated by the tubers, which results in poor quality tubers due to the occurrence of IBS (necrotic cells) (Davies & Millard, 1985; Olsen *et al*., 1996).

The problem of a low calcium content in the tubers and the incidence of IBS can be minimized by applying additional calcium to the crop. In recent research additional calcium from different calcium sources was applied to potato crops to increase the amount of calcium accumulated by the tubers in order to improve quality (Kratzke & Palta, 1986; Silva *et al*., 1991; Locascio *et al*., 1992). Increasing the amount of calcium accumulated by the tubers can increase the calcium content in tubers and thus improve their quality and reduce the incidence of IBS (Kratzke & Palta, 1986; Spillman, 2003).

Improved tuber yield and storage quality are also associated with increasing tuber calcium content (Spillman, 2003). Though additional calcium can improve the amount of calcium accumulated by the crop, the problem could also be the location of the additional calcium. Calcium moves primarily with the water flow in the xylem, thus calcium uptake may be affected greatly by the location of the calcium application (Kratzke & Palta, 1986). This is confirmed by the results of Kratzke & Palta (1985) which suggest that applying calcium as close as possible to the tuber stolon area can increase tuber calcium content. An increase in the calcium content of the tubers is reported when the calcium is applied to the stolon area as opposed to the main roots (Kratzke & Palta, 1985; Spillman, 2003). This suggests that calcium may be directly absorbed from the soil solution by the tuber, probably through the tuber roots. Not

much has been mentioned in the literature about the existence of the tuber roots, although their existence has been identified by Davies & Millard (1985); Simmons *et al*. (1988) and Spillman (2003). The main roots and the junction roots contribute less to calcium uptake of the tubers (Kratzke & Palta, 1985). In further studies, the role of stolon and tuber roots as well as junction roots and main roots in calcium uptake should be critically investigated.

Calcium nutrition of potatoes is not only affected by the poor calcium uptake but mainly the limited ability of the crop to translocate calcium between the aboveground and underground parts (Kirkby & Pilbeam, 1984). Calcium uptake and translocation within the crop are also affected by factors that affect the transpiration stream such as temperature and humidity (Bangerth, 1979; Adams & Ho, 1993; Ruitz *et al*., 2002). Temperature and humidity contribute to calcium uptake because they affect the transpiration rate through which calcium is transported (Adams & Ho, 1993; Ruitz *et. al*., 2002). An increase in temperature will increase the transpiration rate and calcium uptake to the vegetative parts (Ruitz *et al*., 2002). Contrary to this, Adams & Ho, (1993) discovered an increase in humidity to decrease the transpiration rate. The problem of extreme temperatures and humidity can be overcome by maintaining optimum control of temperature and humidity in controlled conditions (Ewing, 1981). Selecting correct planting dates, when temperature and humidity are optimum for potatoes, might minimize the problem in the field.

Further studies need to investigate the factors that initiate the occurrence of IBS or bring about the manifestation of this disorder. The problem which should be addressed is whether the low calcium content of the tubers is due to: poor calcium uptake, limited ability of the crop to translocate calcium between leaves and tubers or to factors that affect the transpiration rate.

CHAPTER 3

CAN GYPSIFEROUS MINE WATER BE USED FOR IRRIGATION OF POTATOES AS A CALCIUM SOURCE?

3.1 INTRODUCTION

Calcium is important in maintaining cell wall stability (Ilyama *et al*., 1994). Potato (*Solanum tubersolum L.)* tubers have low levels of endogenous calcium compared with other vegetative parts (Davies & Millard, 1985). Tubers' endogenous calcium ranges from 0.009 to 0.06 g Ca/100g dry matter (Collier *et al.*, 1978, Davies & Millard, 1985). Bennet (1993) report the calcium content of the leaves to be greater than 0.15.

The low calcium content of the tubers might be due to the immobility of calcium in the phloem and the limited calcium transport to the tuber because of it's displacement from the main transpiration stream (Kratzke & Palta, 1986; Simmons *et al*., 1988). Low tuber calcium concentrations have been associated with internal brown sport (IBS), which is a physiological disorder, causing necrotic cells in the medullary tissue (Olsen *et al.*, 1996).

In recent research, different calcium sources were used to apply additional calcium to plants to determine how it affects accumulation by the tubers (Simmons *et al*., 1988; Silva *et al*., 1991; Locascio *et al.*, 1992). Kratzke & Palta (1986) report the improvement in tuber quality and the tuber calcium content by applying additional calcium close to the tubers. Therefore the location of calcium applications needs to be considered (applying calcium close to the tuber zone).

The effluent from coalmines on the Mpumalanga Highveld can possibly be used for irrigation and as a possible source of calcium. Large volumes of water are generated in the mining of mineral resources. This water is not suitable for direct discharge into watercourses because it can cause problems to the environment and potential users.

Careful use of all water resources is necessary, since South Africa has limited water resources and there is an increasing demand for water by the growing population.

There are different approaches to the careful use of the mine water. An alternative approach currently being investigated is the use of this water for irrigation of agronomic crops and pastures. The use of gypsiferous mine water for irrigation of agricultural crops is a promising technology that could add value to the water resource through agricultural production. Gypsiferous mine water applied to the soil is beneficial, because gypsum that precipitates in the soil will not be sufficiently soluble to cause salt damage to the crops. An investigation has been done in a Water Research Commission (WRC) project (Annandale *et al*., 2001), where crop response to gypsiferous mine water was investigated and initial results were promising.

For the current study, commercial trials (2001 and 2002) were established at Kleinkopje Collieries to monitor irrigation with gypsiferous water on potatoes. This was done to determine the impact of irrigation with gypsiferous mine water as a calcium source on potato yield and quality. Irrigating with gypsiferous water may increase the calcium content of the potato tuber and improve quality.

3.2 MATERIALS AND METHODS

Potato seeds (*Solanum tuberosum* cv. Up-to-date) were planted on Pivot Fourth at the end of August 2001 and were grown until January 2002 (harvest). Two plant rows were spaced 0.4 m apart on raised beds to form tram rows (1.7m centre to centre). A plant density of 50 000 seeds per ha was established. Fertilization was 300 kg ha^{-1} KCl (50) before planting and 1200 kg ha^{-1} 4:3:4 (33) at planting. The follow-up trial was conducted between September 2002 to January 2003 at Pivot Major. In both trials a centre pivot was set up for irrigation with gypsiferous mine water.

Potato plants were sampled every three weeks for growth analysis and twice during the season for leaf chemical analysis. Growth analysis was done to determine how irrigation with gypsiferous mine water as a calcium source affected potato crop growth. The parameters measured during growth analysis were leaf area, leaf, stem and tuber dry mass and the total dry mass. This also included counting the number of

plants, stems, stolons and tubers. Growth analysis was carried out by randomly sampling $1m^2$ of plant material (three replicates) within the pivot. Leaf area was measured with a LI3100 leaf area meter (Licor, Lincoln, Nebraska, USA). At the end of the growing season, tuber yield, tuber chemical analysis, and tuber quality (by measuring specific gravity and chip colour) were determined. These quality tests were done by ARC- Roodeplaat.

Leaf (during the growing season) and tuber (at harvest) chemical analysis were done to determine the effect of calcium on other nutrient levels. Leaf chemical analysis was done on the leaves sampled from the 4th or 5th nodes from the growing point. According to Walworth & Muniz (1993) sampling is usually done from the 4th and 5th leaves from the growing point because they are considered to be most recently matured. Leaf and tuber chemical analyses were done by determining nitrogen and phosphorus with an auto analyser after a H_2SO_4 digestion was performed. For the determination of Ca, Mg, K, SO_4, Zn, Cu, Fe and Mn, samples were digested using nitric acid and perchloric acid in a digestion block. These nutrients were analysed by atomic absorption spectrometer (analysis done at University of Pretoria Soil Science Lab).

Soil sampling was done at the beginning of the cropping season and at the end of the trial for chemical analysis in the laboratory in order to determine changes in the chemical composition of the soils (Appendix, Table B1.1,B1.2 & B1.3). Bray-1 extractable P, and ammonium acetate extractable, soluble Ca, Mg, K and Na, exchangeable Ca, Mg, K and soluble SO_4 were determined according to standard methods. The soil pH and EC (as a background reference to indicate possible increases in soil salinity of irrigated potatoes) were also determined (analysis done at University of Pretoria Soil Science Lab).

3.3 RESULTS AND DISCUSSIONS

3.3.1 Growth analysis

Referring to the Appendix, Tables A1.1 & A1.2, the number of plants were counted within a $1m^2$ sampled area, as well as the number of stems, stolons and tubers. There was no tuber initiation during the first sampling period and more tubers formed (initially) during the 2001 season than in the 2002. During the final harvest in 2001 more tubers were also recorded in the 2001 season than in the 2002 season.

3.3.2 Leaf area

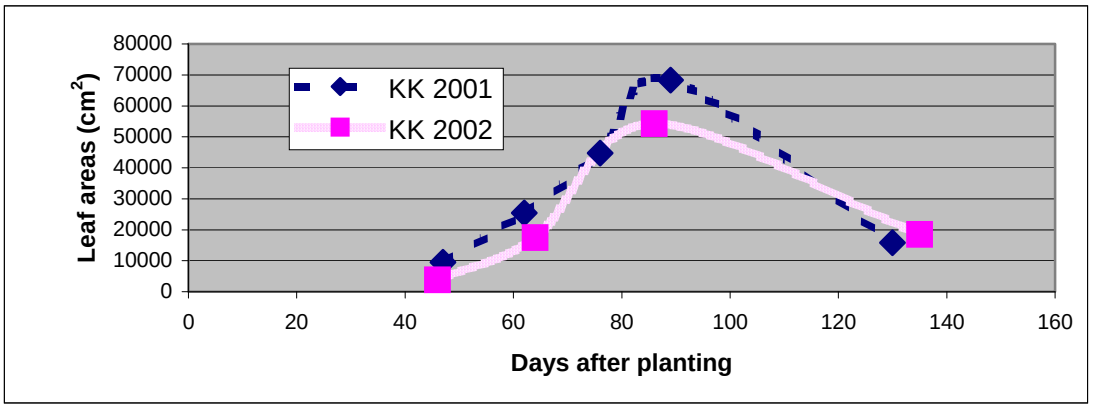


Figure 3.1: Leaf area measured during the growing season of the potato crop for the 2001 and 2002 seasons

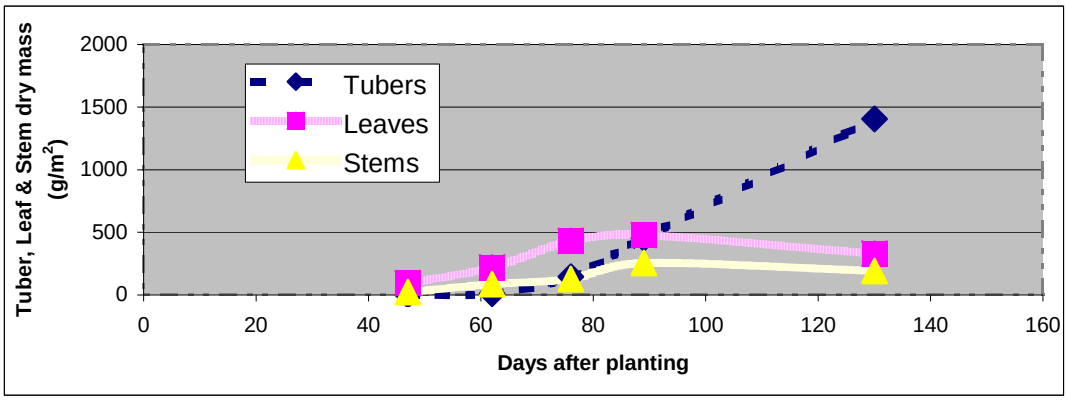
Referring to Figure 3.1, the leaf area generally increased from 47 days after planting until the maximum was reached on day 89, whereafter it declined until harvest (2001 trial). For the 2002 trial the leaf area increased from day 46 until a maximum was reached on day 86, whereafter it declined until harvest. Dawes *et al.* (1983) obtained maximum leaf area values around 65 days after planting in a comparative growth analysis trial. Steyn *et al.* (1992) obtained maximum leaf area values around 52 days after planting. For the current study maximum leaf area values were obtained at a later stage of development as compared to the findings of Dawes *et al.* (1983) and Steyn *et al.* (1992). The possible reason for difference in the findings could be data obtained from different seasons autumn for Steyn *et al.* (1992) while the current study was spring/summer planting. Leaf areas were lower during 2002, this could be due to

the annual change in climatic conditions.

Figure 3.2: Potato fields irrigated with gypsiferous water (2002 trial)

Irrigation with gypsiferous mine water did not have any negative effect on the potato growth. As shown in Figure 3.2 above, the potatoes grew well during the season.

(a)



(b)

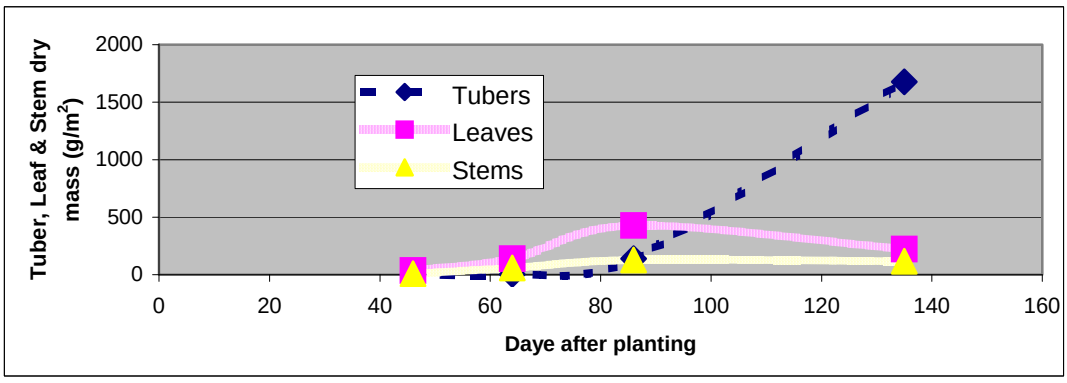


Figure 3.3: Tuber, leaf and stem dry mass measured during potato crop growth during the (a) 2001 and (b) 2002 season

According to Figures 3.3(a) and (b), leaf dry mass was consistently higher than the stem dry mass. These findings are also confirmed by Steyn *et al*. (1992). Wheeler *et al.'s* (1986) findings also indicate higher leaf dry mass than stem dry mass. The leaf and stem dry masses were considerably higher in 2001 compared to 2002. Tuber dry mass increased rapidly with the increase in number of days after planting. Steyn *et al.* (1992) also corroborated the increase in tuber dry mass with an increase in number of days after emergence. The highest tuber dry mass during the growing season was obtained in 2001, however, the highest tuber dry mass at final harvest was obtained in 2002.

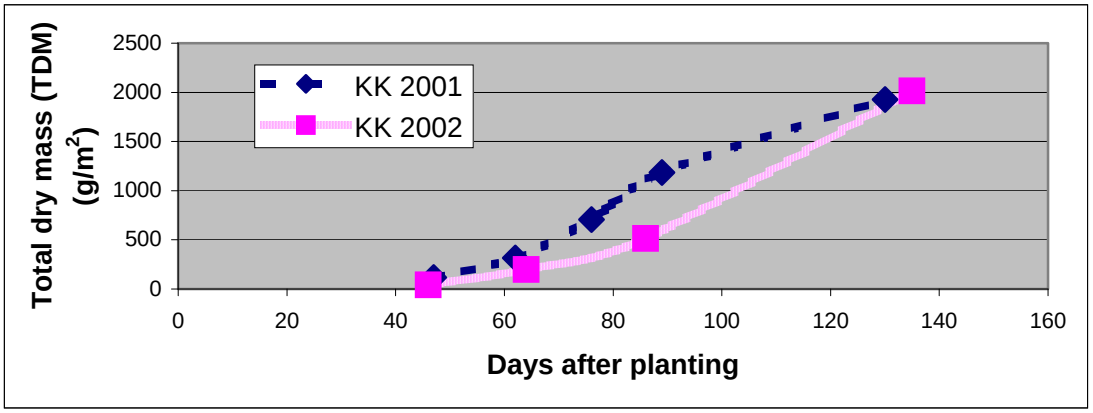


Figure 3.4: Changes in total dry mass (TDM) during potato crop growth for 2001 and 2002 seasons

Referring to Figure 3.4, the increase in total dry mass was initially curvilinear and from approximately day 90, the rate was linear. Total dry mass increased with the increase in number of days after planting during the 2001 and 2002 trials. The total dry mass was higher in 2001 than in 2002, except for the final harvest.

3.3.3 Leaf chemical analysis

Table 3.1 Leaf chemical analysis results of potatoes irrigated with gypsiferous mine water (KK 2001 and 2002).

DAP	N	P	Ca	K	Mg	Na	SO_4	Cu	Fe	Mn	Zn
	%	%	%	%	%	%	%	mg/kg	mg/kg	mg/kg	mg/kg
KK 2001											
89	**5.15**	**0.34**	**1.09**	**4.20**	**4.89**	**0.002**	**1.87**	**10.6**	**620**	**244.8**	**30.4**
100	**4.73**	**0.3**	**1.27**	**3.75**	**1.01**	**0.018**	**2.8**	**35**	**303.5**	**256.7**	**26**
KK 2002											
86	**4.42**	**0.3**	**1.11**	**5.15**	**1.01**	**0.01**	**2.31**	**13**	**489**	**510**	**31**
100	**2.81**	**0.26**	**0.37**	**1.92**	**1.56**	**0.00**	**1.59**	**19.6**	**306.4**	**70.6**	**46.8**
Norms	>3	>0.25	>0.15	>1.5	>0.1		>0.025	>5	>5	>40	>20

Note: Norms according to Bennet (1993)

Tissue nutrient concentrations were determined for leaf blades sampled on 89 and 100 days and 86 and 100 days after planting for the 2001 and 2002 trials, respectively (Table 3.1). There was no sign of any nutrient deficiency on leaves at both sampling periods and all the nutrient levels were within acceptable ranges for potatoes in both seasons (Bennet, 1993). The higher calcium levels in irrigation water did not seem to suppress the uptake of other essential nutrients.

On the second sampling time point (day 100) nitrogen, phosphorus and potassium levels declined (**N**: 5.15 to 4.73, **P**: 0.34 to 0.3 and **K**: 4.20 to 3.75 during 2001 and **N**: 4.42 to 2.81; **P**: 0.3 to 0.26; **K** 5.15 to 1.92 during 2002). It is normal for nitrogen, phosphorus and potassium levels to decline throughout the growing season, though not rapidly (Walworth & Muniz, 1993). Calcium increased slightly during the growing season (from 1.09 to 1.27) during 2001. There was a tendency for calcium to increase with age in the whole aboveground parts of the plant, which agreed with the findings of Walworth & Muniz, (1993). In contrast to that the calcium content declined from (1.11 to 0.37) during the 2002 cropping season (Table 3.1).

3.3.4 Tuber yield

Marketable potato yields of 52 t/ha (2001 trial) and 62 t/ha (2002 trial) were produced. Lower marketable tuber yields obtained in 2001 could be due to a small percentage of tuber malformation (<5 %) observed at harvest. This could be attributed to a lack of irrigation during the late tuber bulking phase (December 2001). There was no irrigation for two weeks in December because of stolen electrical cables on the centre pivot. These yields, however, can be regarded as very good for the Mpumalanga Highveld. Potato tuber yields of 48 t/ha can be expected in this area for a planting date around end of August and the beginning of September (Niederwieser *et al.*, 1999). Unfortunately no control fields (irrigated with normal water) were available for direct comparison.

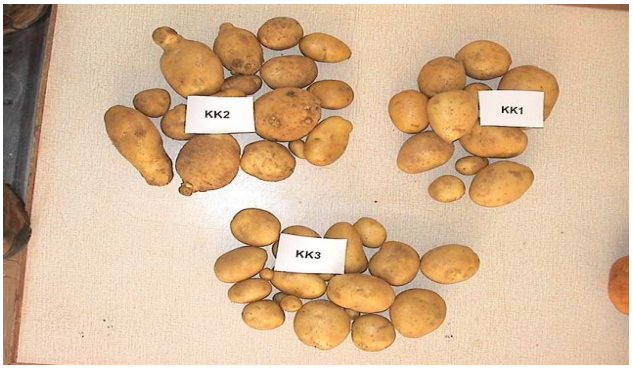


Figure 3.5: Tubers irrigated with gypsiferous mine water during 2001 (three replicates)

Generally, irrigation with gypsiferous mine water had no negative effect on the potato shape and size (Figure 3.5). According to Ozgen *et al*. (2003) the tuber size is not influenced by applying additional calcium. There were a couple of malformed tubers which could be due to the lack of irrigation during the late tuber bulking phase.

3.3.5 Tuber chemical analysis

Table 3.2: Tuber chemical analysis on periderm and medullary tissue 2002 trial, (A – periderm, B – medullary tissue)

	N %	P %	Ca %	K %	Mg %	Na %	SO_4 %	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg
A	1.25	0.2	**0.03**	2.59	0.04	0.003	0.35	9.33	39.7	123	1.2
B	1.35	0.22	**0.02**	2.99	0.04	0	0.6	7.33	21.7	11.3	35
Norms	>1.38	>0.14	0.02-0.04	>1.41	>0.14						

Note: Norms according to Walworth & Muniz, (1993)

Tuber chemical analysis was only done during the 2002 season. Irrigation with gypsiferous mine water as a calcium source did not seem to suppress the uptake of other nutrients. Levels were within acceptable ranges for potatoes (Walworth & Muniz, 1993). However, the nitrogen content was slightly low. Tuber chemical analysis results presented in Table 3.2 indicate that the calcium content of the tubers was lower than the nitrogen, phosphorus and potassium contents. The potassium content of the tubers was higher than the nitrogen and phosphorus content (Table A1.8: Appendix A). Simmons *et. al*, (1988), report the potassium content of the tubers to be higher than the magnesium and calcium contents. This is also evidenced by the findings of Walworth & Muniz, (1993).

The calcium content of the tubers were generally low (lower than the leaves). These was also confirmed by Simmons *et al*. (1988); Olsen *et al*. (1996) and Spillman, (2002). A low calcium content of the tubers in the range of 0.009 to 0.06 g Ca/100g dry matter has also been reported by Olsen *et al*. (1996). The tuber calcium content of the periderm (0.03%) was slightly higher than that of the medullary tissue (0.02 %). Olsen *et al.* (1996) report the calcium content of the periderm to be higher than that of the cortex. The higher calcium content of the periderm could be attributed to the direct availability of calcium in the soil, which suggests that tubers can absorb calcium directly from the soil solution (Olsen *et al*., 1996; Davies, 1998).

3.3.6 Tuber internal quality tests

Tuber internal quality tests were done to determine the impact of irrigation with gypsiferous mine water as a calcium source on tuber quality.

Table 3.3: Tuber specific gravity and chip colour values measured during 2001 and 2002 seasons

Season	Specific gravity	Chip color
2001	1.087	50.8
2002	1.075	50.2
Minimum acceptable values	>1.075	>45

Tuber internal quality tests were done by determining specific gravity and chip colour. Both these measurements have no units. Referring to Table 3.3: for the 2001 trial, high specific gravity values were obtained, ranging from 1.085 to 1.090 with an average value of 1.087. Specific gravity value with an average of 1.075 (range of 1.072 to 1.079) was obtained during 2002. Chip colour values of 48.8 to 52.9 and 47.2 to 52.7, with averages of 50.8 and 50.2 were obtained for the 2001 and 2002 trials, respectively. Higher specific gravity and chip colour values were obtained in 2001 than in 2002. This was in contrast to the yields obtained in 2001 (52 t/ha) and 2002 (62 t/ha). High specific gravity values (>1.075) and chip colour values (> 45) indicate that the tubers were acceptable to the chip processing industry. The results therefore suggest that the tuber quality was good.

3.4 CONCLUSIONS

It seems as irrigation with gypsiferous mine water had no negative effects on potato crops in terms of growth, leaf and tuber chemical composition and tuber quality and yield. Irrigating potatoes with gypsiferous mine water resulted in high tuber yields (52 t/ha in 2001 and 62 t/ha in 2002) of good quality. The good quality of the potato tubers was indicated by high specific gravities (>1.075) [1.087 in 2001 and 1.075 in 2002] and chip colour (> 45) [50.8 in 2001 and 50.2 in 2002] values, which are acceptable to the chip processing industry. This implies that gypsiferous mine water can possibly be used for irrigation of potatoes with the added benefit of serving as a

calcium source. Unfortunately, no control fields (irrigated with normal water) were available for direct comparison.

CHAPTER 4

TUBER YIELD AND QUALITY AS INFLUENCED BY APPLICATION OF GYPSUM AS A CALCIUM SOURCE

4.1 INTRODUCTION

Low tuber calcium content may result in necrotic cells in the medullary tissue, which is a physiolocal disorder called internal brown spot (IBS) (Bian *et al*. 1996; Olsen *et al*., 1996; Kleinhenz, 2000). A high incidence of physiological disorders results in reduced tuber quality which leads to economic losses for potato growers (Sterrett & Henninger, 1991). In recent investigations, different calcium sources ($CaCl_2$, $CaCO_3$, $CaSO_4$ and $Ca(NO_3)_2$ were applied to potato crops, to increase the amount of calcium accumulated by the tubers and thus improve tuber quality (Silva *et al*., 1991; Locasio *et al*., 1992). Results form initial work (chapter 3) indicated that gypsiferous water can be applied as a calcium source to improve the calcium nutrition of the tubers. Follow-up study was recommended since there were no control fields (irrigated with normal water) available for direct comparison at Kleinkopje colliery. This study was conducted at Hatfield, where gypsum was applied as a preplant broadcast at four levels (3 (control), 6, 15, 40 t/ha of gypsum). The 40 t/ha gypsum was equivalent to the amount in gypsiferous mine water at Kleinkopje. The trial was conducted in a different environment (Hatfield) and thus was not a direct comparison. However, it could give an indication of how the application of increasing levels of gypsum could influence tuber yield and quality. The objective of this trial was to determine whether tuber yield and quality can be influenced by application of gypsum as a preplant broadcast.

4.2 MATERIALS AND METHODS

Potato seed tubers were planted in field plots grown (between September 2002 and January 2003) at the University of Pretoria Experimental Farm (Hatfield). Field plots were set up in a completely randomised block design. Each plot had an area of 24 m^2 (6 m x 4 m). Seed tubers were planted 14cm deep at an in-row spacing of 0.3 m and rows were spaced 0.9 m apart.

Gypsum at four levels was broadcast and incorporated prior to planting at rates of 3 (control), 6, 12 and 25 t/ha, with five replicates resulting in a total number of 20 plots. In the 12 and 25 t/ha treatments, a gypsum top dressing was applied (3 and 15 t/ha respectively) again after planting, resulting in a total of 15 and 40 t/ha of gypsum. The gypsum top dressing applied was done (two weeks after planting) to equal the amount of calcium (40 t/ha of gypsum) to the gypsiferous water at Kleinkopjie mine. Crops were irrigated with overhead sprinklers. Cultural management (fertilizer, pesticides and weeding) was practiced to optimize plant growth.

Potato plants were sampled every three weeks for growth analysis and once for leaf chemical analysis. Growth analysis was done to determine how gypsum applied at four levels affected the potato crop growth. Growth analysis was carried out by randomly sampling $1m^2$ of plant material within the plot. The leaf area was measured with an LI3100 leaf area meter (Licor, Lincoln, Nebraska, and USA). At the end of the growing season, the tuber yield, tuber chemical analysis and the tuber quality (by measuring specific gravity and chip colour) were determined. The quality tests were done by ARC Roodeplaat.

Leaf (during the growing season) and tuber (at harvest) chemical analyses were done to determine the impact of calcium on other nutrient levels when increasing gypsum rates were applied. Leaf chemical analysis was done (57 days after planting) on the leaves sampled from the 4th or the 5th nodes from the growing point. According to Walworth & Muniz (1993) sampling is usually done from the 4th and 5th leaves from the growing point because they are considered to be the most recently matured. Leaf and tuber chemical analysis were done by determining nitrogen and phosphorus with an auto analyser after a H_2SO_4 digestion. For the determination of Ca, Mg, K, SO_4, Zn, Cu, Fe and Mn, samples were digested using nitric acid and perchloric acid in the digestion block. The nutrients were analysed by atomic absorption spectrometer (analysis done at University of Pretoria Soil Science Lab).

Soil sampling was done at the beginning and at the end of the cropping season for chemical analyses in the laboratory in order to determine changes in chemical composition of the soils at the University of Pretoria Experimental Farm in Hatfield (Appendix, Table B1.4 & 1.5). Bray-1 extractable P and ammonium acetate

extractable, soluble Ca, Mg, K and Na, exchangeable Ca, Mg, K and soluble SO_4 were determined according to standard methods. The soil pH and EC were also determined (analysis done at University of Pretoria Soil Science Lab).

4.3 RESULTS AND DISCUSSION

4.3.1 Growth analysis

The parameters measured during the growth analysis were leaf area, leaf, stem and tuber dry mass, as well as the total dry mass. The number of plants, stems, stolons and tubers were also counted at different sampling times. There was no relation between number of stems, stolons and tubers with increasing gypsum levels (Appendix, Table A1.3).

4.3.2 Leaf area

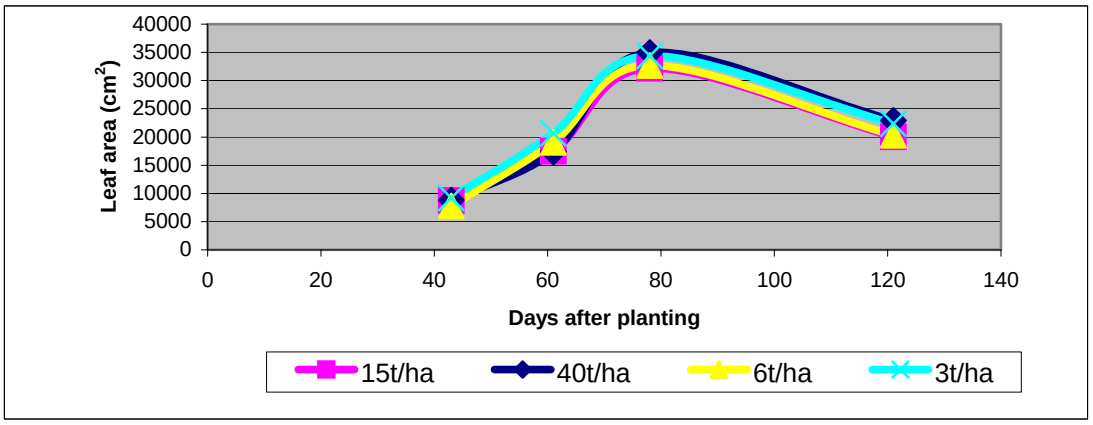


Figure 4.1: Change in leaf area measured at four gypsum application rates

Leaf area increased from day 43 and reached maximum values on day 78, whereafter it declined until day 121 at harvest (Figure 4.1). The maximum leaf area values between 32 000 cm^2 and 34 972 cm^2 (were obtained) (Appendix, Table A1.3). The application of 40 t/ha gypsum (equivalent to gypsiferous mine water) resulted in lower leaf area values (34 972 cm^2) compared with the values (54 303 cm^2 in 2002 and 68 296 cm^2 in 2001) obtained when the potatoes were irrigated with gypsiferous water (Figure 3.1; Appendix, Tables A1.1& A1.2). Steyn *et al.* (1992) obtained maximum leaf area values between 4 500 and 6 500 cm^2 at different soil water

regimes. These maximum values were obtained around 52 days after planting. There was no particular trend in increasing leaf area with increasing gypsum levels. The overall F test was not significant, thus the least significant difference test did not proceed (Appendix, Table A1.3).

4.3.3 Leaf dry mass

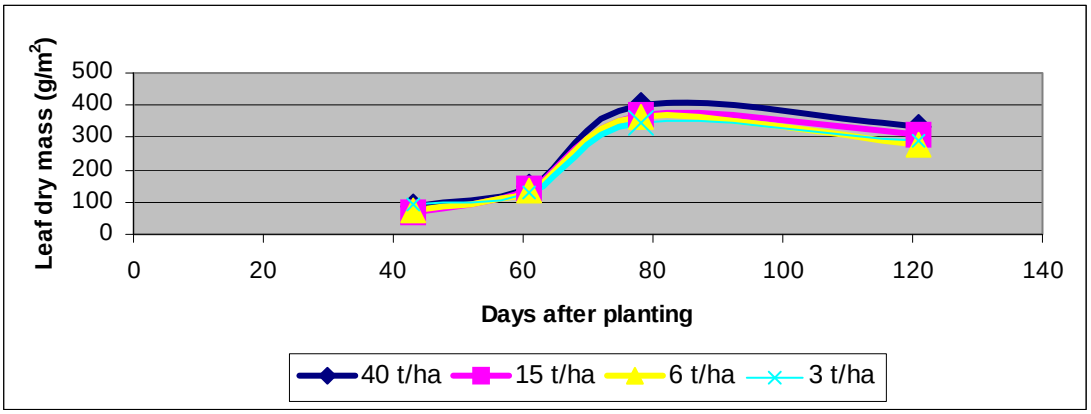


Figure 4.2: Leaves dry mass measured at four gypsum application rates

Referring to Figure 4.2, leaf dry mass increased from day 43 and reached a maximum on day 78, whereafter it declined until day 121 (at harvest). The leaf dry mass was significantly higher than the control with the application of 15 and 40 t/ha of gypsum at 78 and 121 days after planting (Appendix, Table A 1.3). Steyn *et al.* (1992) found maximum leaf dry mass values between 25 g/m^2 and 38 g/m^2 around 52 days after planting. The leaf dry mass obtained by Steyn *et al.* (1992) were lower than those (between 345 g/m^2 and 402 g/m^2 at 78 days after planting) obtained in this trial. The highest leaf dry mass was obtained when 40 t/ha of gypsum was applied. The value was lower than the values (478 g/m^2 in 2001, 427 g/m^2 in 2002) obtained when the potatoes were irrigated with gypsiferous water (Appendix, Table A1.1 & A1.2).

4.3.4 Stem dry mass

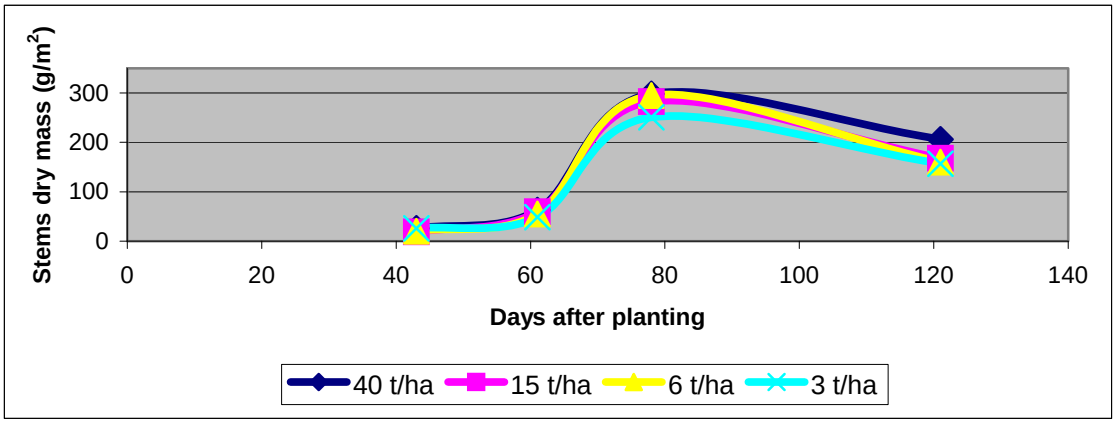


Figure 4.3: Stem dry mass measured at four gypsum application rates

Referring to Figure 4.3, the stem dry mass increased from day 43, reached a maximum on day 78, then decreased until day 121. The highest stem dry mass values obtained were between 251 g/m^2 and 298 g/m^2. The stem dry mass was higher than that obtained when potatoes were irrigated with gypsiferous water (255 g/m^2 in 2001 and 129g/m^2 in 2002). Stem dry mass for the Hatfield trial was high compared with the findings (35g/m^2 g to 50g/m^2) of Steyn *et al.* (1992). The least significant difference test for the stem dry mass did not proceed because the overall F test was not significant.

4.3.5 Tuber dry mass

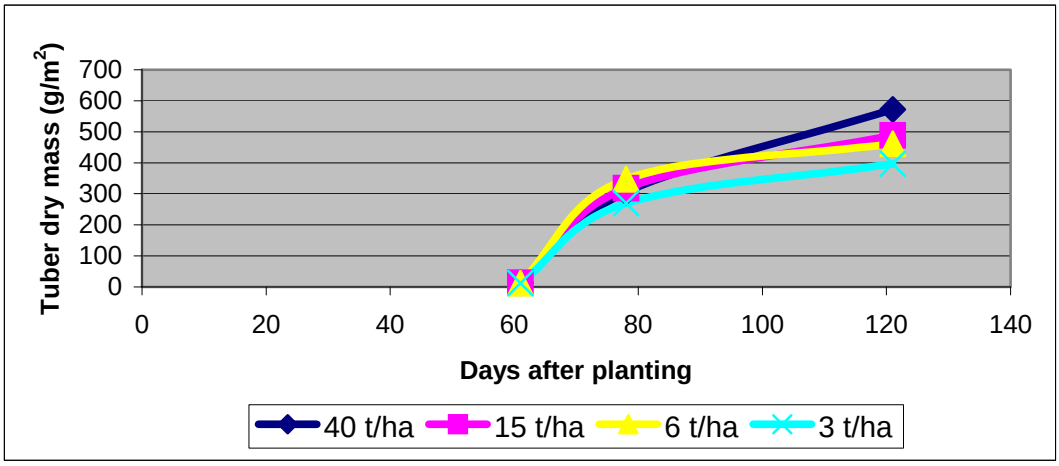


Figure 4.4: Tuber dry mass measured at four gypsum application rates

Steyn *et al.* (1992) found the tuber dry mass to increase with the number of days after planting. Similar results were found when potatoes were irrigated with gypsiferous mine water (Figure 3.3a & 3.3b). However, in this trial (Figure 4.4), the tuber dry mass increased with the number of days after planting and the increase was gradual from 90 days after planting. At 70 days after planting, Steyn *et al*. (1992) obtained tuber dry mass values between 100 g/m^2 and 200 g/m^2. Similar findings were obtained in this trial. The highest tuber dry mass was obtained at the highest gypsum application. There were indications that applying gypsum might increase the tuber dry mass. The overall F test was not significant, thus the least significant, difference test did not proceed.

4.3.6 Total dry mass

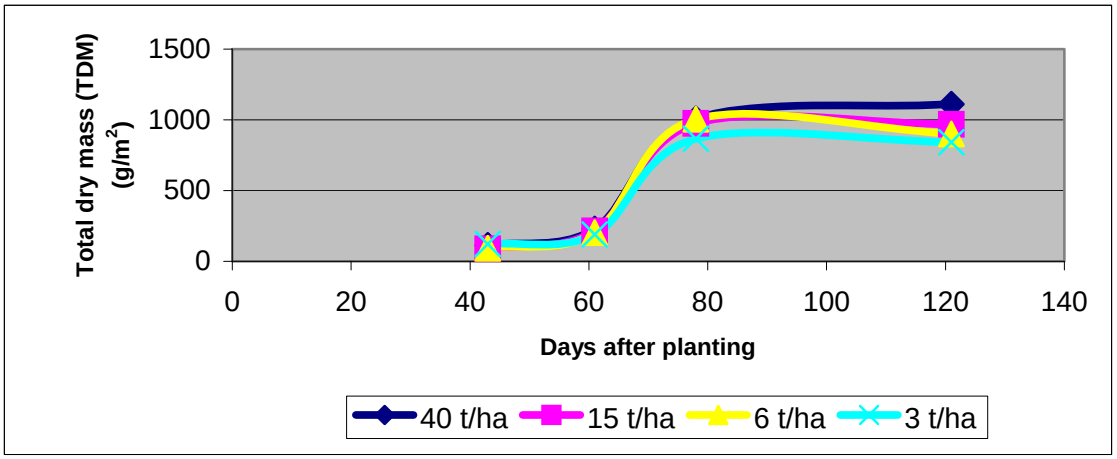


Figure 4.5: Changes in total dry mass (TDM) determined at four gypsum application rates

Figure 4.5 shows the total dry mass increasing with the number of days after planting. The increase in total dry mass remained almost constant from 80 days after planting. However, the total dry mass increased continuously until harvesting, when plants were irrigated with gypsiferous mine water. There were indications that applying higher gypsum levels might have a positive effect on the total dry mass (Appendix, Table A1.3). The overall F test was not significant, thus the least significant test did not proceed.

4.3.7 Leaf chemical analysis

Table 4.1: Potato leaf chemical analysis determined at four gypsum application rates (80 DAP)

TRT t/ha gypsum	N %	P %	Ca %	K %	Mg %	Na %	SO_4 %	Cu mg/kg	Fe mg/kg	Mn mg/kg	Zn mg/kg
3	**4.85**	**0.50**	**0.59**	**3.42**	**0.42**	**0.01**	**1.17**	**20**	**267**	**90**	**60**
6	**5.19**	**0.58**	**0.61**	**3.30**	**0.45**	**0.01**	**1.17**	**24**	**237**	**108**	**42**
15	**4.90**	**0.54**	**0.72**	**3.57**	**0.48**	**0.00**	**1.32**	**17**	**245**	**93**	**35**
40	**4.76**	**0.57**	**0.75**	**3.38**	**0.45**	**0.01**	**1.50**	**20**	**215**	**101**	**60**
Norms	>3	>0.25	>0.15	>1.5	>0.1		>0.025	>5	>50	>40	>20

Note: Norms Bennet (1993)

Table 4.1 shows no sign of any nutrient deficiencies and all the nutrients are within acceptable ranges for the potato crop (Bennet, 1993). Applying higher gypsum levels had no negative effect on other leaf nutrient elements. There was a slight increase in the calcium level of the leaves with increasing gypsum levels. Nitrogen levels were higher than potassium and phosphorus levels. These agree with Walwortha & Muniz (1993) findings. The leaf chemical analysis was done on only one replicate, thus statistical tests were not performed.

4.3.8 Tuber yield

The effect of applying increasing gypsum levels on tuber yield was determined per treatment and per plot and the averages were taken.

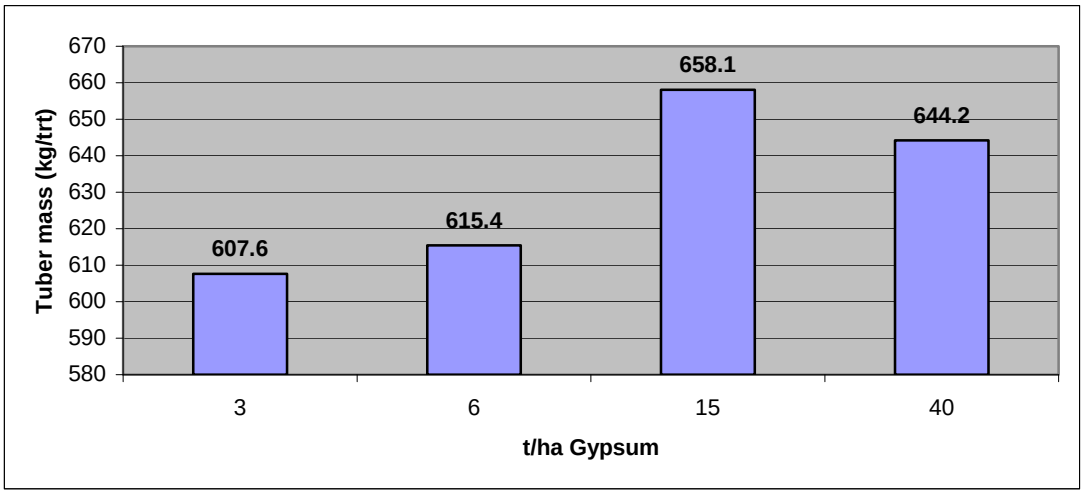


Figure 4.6: Potato tuber yield measured at four gypsum application rates

According to Figure 4.6, tuber yields were slightly higher at higher gypsum levels (6, 15, 40 t/ha), relative to the control (3 t/ha). Applying 15 t/ha of gypsum resulted in a higher tuber yield, but the yield decreased when the highest (40 t/ha) gypsum level was applied. In contrast, Sterrett & Henninger (1991) report tuber yield not to be affected by soil applied calcium. However, El-Beltagy *et al.* (2002) found tuber yield to increase with increasing calcium to medium levels.

An average marketable tuber yield of 52 t/ha was produced, which can be regarded as a good yield for Hatfield. According to Niederwieser *et al.* (1999) the expected yield is 44 t/ha when cultivar BP 1 is planted around mid September. The tuber yield was higher when potatoes were irrigated with gypsiferous mine water (62 t/ha in 2002 and 52 t/ha in 2001). The results imply that applying additional gypsum (15 t/ha) might significantly increase the tuber yield, but further increase in the gypsum rate (40 t/ha) might not have a positive effect on the tuber yield.

Figure 4.7: Potato tubers at four gypsum application rates (C1:3 t/ha, C2:6 t/ha, C3:15 t/ha, C4:40 t/ha of gypsum)

Figure 4.7 shows the potato tubers at four levels of gypsum application. There was no relation between the tuber size and number and the gypsum rate applied. Sterrett & Henninger (1991) also showed that calcium application did not alter tuber size distribution.

4.3.9 Tuber chemical analysis

The tuber chemical analysis was done to determine the impact of calcium on other nutrient levels when increasing levels of gypsum were applied. Generally the calcium content of the tubers (cortex) was higher at the higher gypsum levels (15 and 40 t/ha).

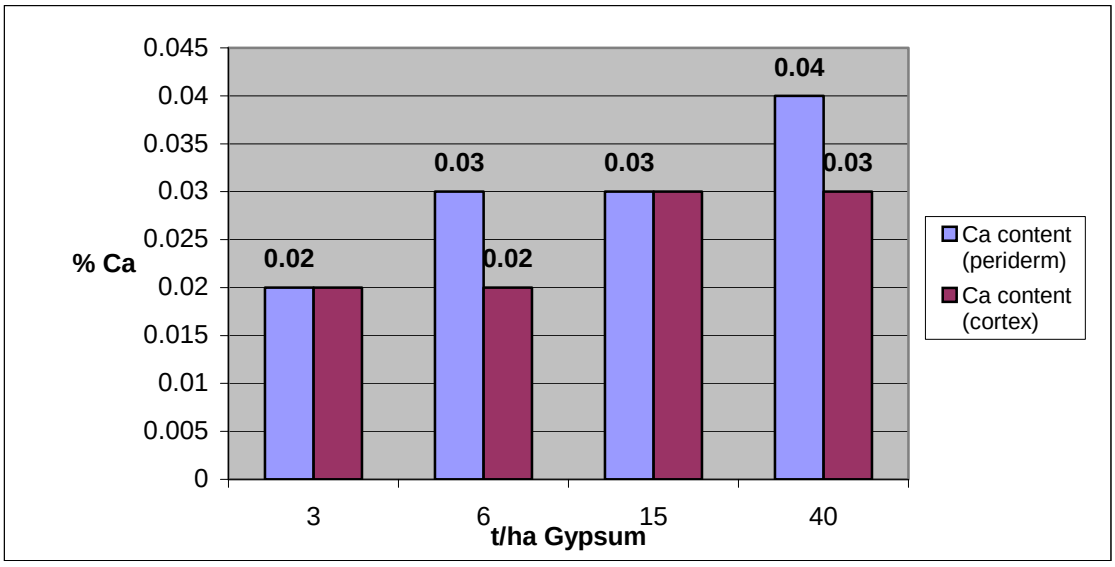


Figure 4.8: Tuber calcium content determined at four gypsum application rates

Generally the calcium content of the tubers was lower than that of the leaves (Table 4.1; Figure 4.8). Lower calcium content of tubers, ranging from 0.009 to 0.06g Ca/100g dry matter was also reported by Olsen *et al.* (1996). The tubers display a low calcium content because they are underground storage organs and have a low transpiration rate, thus the water uptake by the xylem is limited (Bamberg *et al*., 1993; Ozgen, 2003). In the present study sufficient calcium content of the tubers (0.02 to 0.04 %) was obtained, which agrees with the findings of Walworth & Muniz (1993). Referring to Figure 4.8, the calcium content of the periderm was higher than that of the cortex, at 6 t/ha and 40 t/ha gypsum applications, but the calcium contents of the cortex and the periderm were found to be equal at 3 t/ha (control) and 15 t/ha gypsum. In some studies the calcium content of the periderm was reported to be higher than that of the cortex (Olsen *et al*., 1996).

The high calcium content of the periderm can be attributed to the direct availability of calcium in the soil, which suggests that tubers can absorb calcium directly from the soil solution (Olsen *et al*., 1996; Davies, 1998). This suggests that the high calcium content of the periderm (0.03 %) at 6 t/ha and 15 t/ha, but especially at 40 t/ha (0.04 %) was probably due to direct absorption of calcium from the soil solution by the tubers.

The results indicate that applying additional calcium to potatoes might result in

improved calcium content of tubers. The results were also confirmed by Kratzke & Palta (1986) and Spillman, (2003). Tuber chemical analysis was only done on one replicate thus the data was not statistically analyzed.

4.3.10 Tuber internal quality tests

The results have shown an increase in specific gravity with increasing gypsum levels (Figure 4.9). Referring to Figure 4.10, there was no particular trend in increasing chip colour with increasing gypsum levels. Applying higher levels of gypsum (6, 15 t/ha) resulted in increased chip color values relative to the control (3 t/ha). However, a further increase in gypsum levels (40 t/ha) resulted in lower chip colour values.

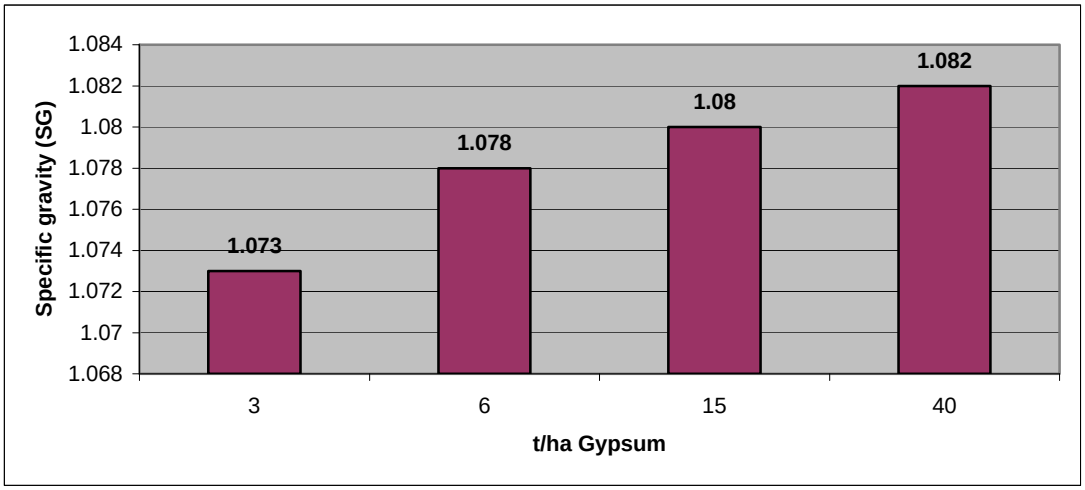


Figure 4.9: Specific gravity as a tuber quality characteristic, as influenced by level of gypsum

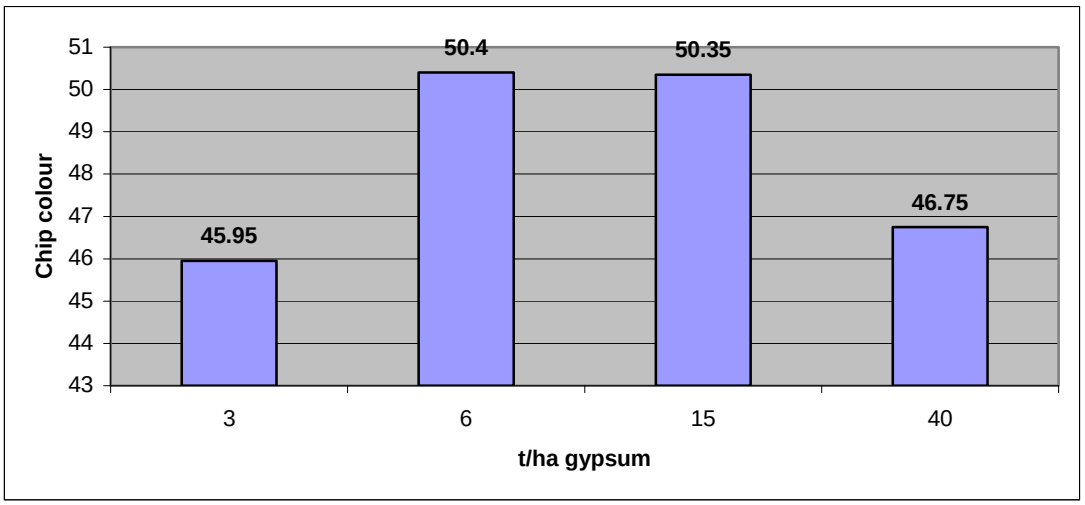


Figure 4.10: Chip colour as a tuber quality characteristic, as influenced by level of gypsum

The high specific gravity (> 1.075) and chip colour (> 45) values at higher gypsum levels (6, 15 and 40 t/ha) indicated that good quality tubers were produced, which should be acceptable to the potato chip processing industry. The lower specific gravity and chip colour values obtained at 3t/ha indicated the beneficial effect of applying additional gypsum as a calcium source on tuber quality. These results contradict the findings of Sterrette & Henninger (1991), who indicate that specific gravity and chip colour are not influenced by soil applied calcium. Tuber internal quality tests were only done on one replicate thus the data was not statistically analyzed.

4.4 CONCLUSIONS

Application of increasing gypsum levels had no negative impact on the potato crop. All the nutrient levels were within the acceptable ranges for the potato crop, as indicated by leaf and tuber chemical analysis results. Other morphological parameters (leaf and stem dry mass and the total dry mass) were positively influenced by applying increasing gypsum levels. The exception was the leaf area. Higher gypsum applications had a beneficial effect on the tuber dry mass. Applying a higher gypsum level (15 t/ha), resulted in increased tuber yield, however, further increases in gypsum (40 t/ha) did not have a positive effect.

Applying additional calcium using gypsum as a calcium source resulted in improved tuber quality characteristics of specific gravity (> 1.075) and chip color (> 45). These quality test results indicate that good quality tubers can be obtained, which should be acceptable to the chip processing industry. A lower calcium content of the tubers may result in tubers of lower quality. Applying additional gypsum as a calcium source had a beneficial effect on the amount of calcium accumulated by the tubers and the tuber quality.

CHAPTER 5

CALCIUM NUTRITION OF POTATOES MAINTAINED AT LOW AND HIGH CONTROLLED TEMPERATURES AT LOW HUMIDITY

5.1 INTRODUCTION

Potato tubers (*Solanum tubersolum L.)* have low levels of calcium due to the limited calcium transport in the xylem and the immobility of calcium in the phloem (Kratzke & Palta, 1986; Simmons *et al*., 1988). Potato calcium content is not only influenced by the amount of calcium applied, but also by environmental factors which affect calcium uptake. Temperature has an influence on the calcium content because it affects the absorption and distribution of calcium within the crop. Potatoes prefer a cool temperate climate with temperatures between 15 ^{o}C and 22 ^{o}C for optimum production and quality (EL-Beltagy e*t al.,* 2002). High temperatures increase the transpiration rate and result in greater calcium transport to the vegetative parts, relative to the tubers (Olsen *et al.,* 1996). This experiment was conducted to determine how potato tuber yield and quality can be influenced by applying additional calcium to the plants maintained at high and low controlled temperatures at low humidity.

5.2 MATERIALS AND METHODS

Potato plants (cultivar BP-1) were started from individual seed pieces approximately 1cm^3 in size, each containing a single eye. Seed pieces were planted in a vermiculite medium until the stem lengths were about 8 cm, when they were transferred to sand. Potato plants were transplanted on the 25th September (one per pot) in pots (27.5 cm diameter by 31.5 cm tall), containing sand as growth medium. This was a factorial experiment with two factors: four calcium levels and two temperature regimes.

The four calcium treatments were concentrations of 44 mg/l (control), 176 mg/l, 352 mg/l and 704 mg/l Ca (calcium rich water). Calcium sulphate was used as a calcium source. Each calcium concentration treatment was assigned to pots arranged in a completely randomised design with twelve replicates each. Pots were watered every

second day to avoid water stress. Pots were placed in two separate temperature controlled glasshouses; each room containing 48 pots, resulting in a total of 96 pots. Day and night temperatures for each of the two glasshouses were maintained at 22/14 °C and 27/17 °C and approximately 35 % humidity throughout the experiment.

Growth analysis was done (on one plant per treatment) after every 30 days, from 30 days after transplanting. At the same time stem lengths were measured. The dry mass was determined by measuring dry matter of plant organs after drying in an oven at 60 ° C for 4 to 5 days (until constant mass was reached). Growth analysis was done to determine how increasing levels of calcium in calcium rich water applied at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures affected crop growth. Leaf chemical analysis was done once during the growing season. Leaf chemical analysis was done to determine the impact of calcium on other nutrient levels when increasing calcium levels in calcium rich water were applied. Leaf chemical analysis was done on the leaves sampled from the 4th or the 5th nodes from the growing point. According to Walworth & Muniz (1993) sampling is usually done from the 4th and 5th leaves from the growing point because they are considered to be the most recently matured. At the end of the growing season the tuber yield, tuber chemical analysis and quality (by determining chip colour and specific gravity) were determined. The quality tests were done by ARC-Roodeplaat.

Leaf and tuber chemical analysis were done by determining nitrogen and phosphorus with an auto analyser after a H_2SO_4 digestion was done. For determination of Ca, Mg, K, SO_4 , Zn, Cu, Fe and Mn, samples were wet digested using nitric acid and perchloric acid in a digestion block. The nutrients were analysed by atomic absorption spectrometer (analysis done at University of Pretoria Soil Science Lab).

5.3 RESULTS

5.3.1 Growth analysis

The parameters measured during growth analysis were leaf area, stem lengths, leaf, stem and tuber dry mass, as well as the total dry mass. The number of stolons and tubers were also counted. There were more stolons and tubers formed at a low

temperature (22/14 ^{o}C) than at a high temperature (27/17 ^{o}C). The number of stolons and tubers formed were not influenced by the amount of calcium applied (Appendix, Tables A1.4 & A1.5). Khedher & Ewing (1985) also found fewer tubers produced under cool conditions than at high temperatures.

Figure 5.1: Potato plants maintained at 22/14 ^{o}C (right) and 27/17 ^{o}C (left) controlled temperatures at 35 % humidity

There was a more rapid plant top growth at a high (27/17 ^{o}C) temperature than at a low (22/14 ^{o}C) temperature (Figure 5.1). The production of taller stem heights at high temperature was also evidenced by Dawes *et al*. (1983); Khedher & Ewing (1985); Struik *et al*. (1989); Tadesse *et al*. (2001) and El-Beltagy *et al.* (2002). No differences in growth were noticed with increasing calcium application rates.

Figure 5.2: Potato leaves maintained at 22/14 ^{o}C and 27/17 ^{o}C at 35 % humidity

The fifth leaves from the growing tip were sampled from plants maintained at 22/14 ^{o}C and 27/17 ^{o}C controlled temperatures at 35 % humidity. The leaves were narrower at high (27/17 ^{o}C) controlled temperature and thicker at low (22/14 ^{o}C) controlled temperature (Figure 5.2). This agrees with the findings of Khedher & Ewing (1985);

Struik *et al*. (1989); Tadesse *et al*. (2001) and El-Beltagy *et al.* (2002) who reported that leaves tend to be smaller when plants are grown at high temperatures.

5.3.2 Leaf area

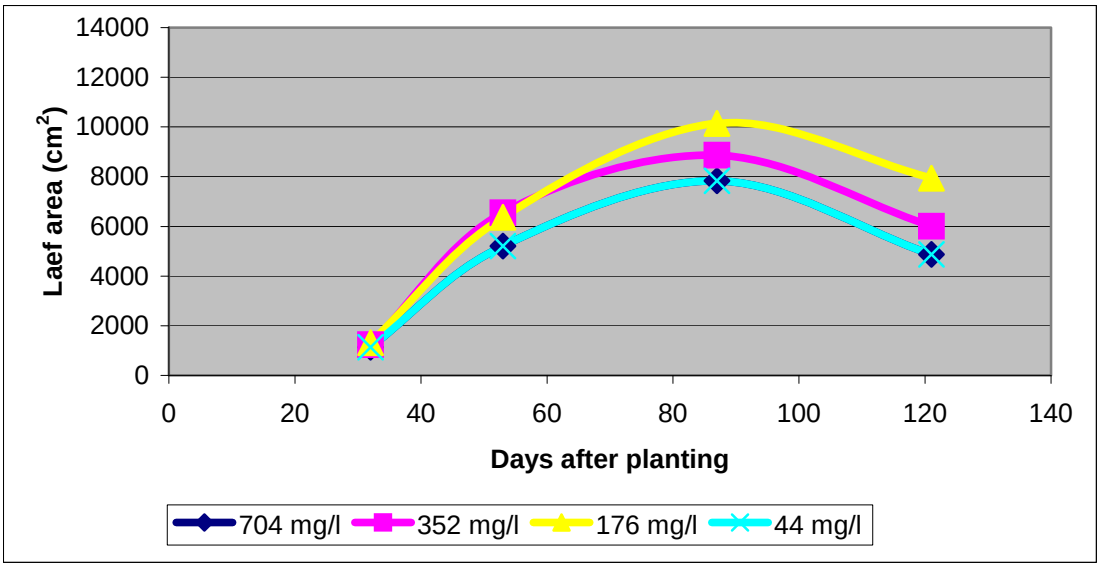


Figure 5.3a: Leaf area measured for different calcium levels in irrigation water at 22/14 ^{o}C controlled temperature at 35 % humidity

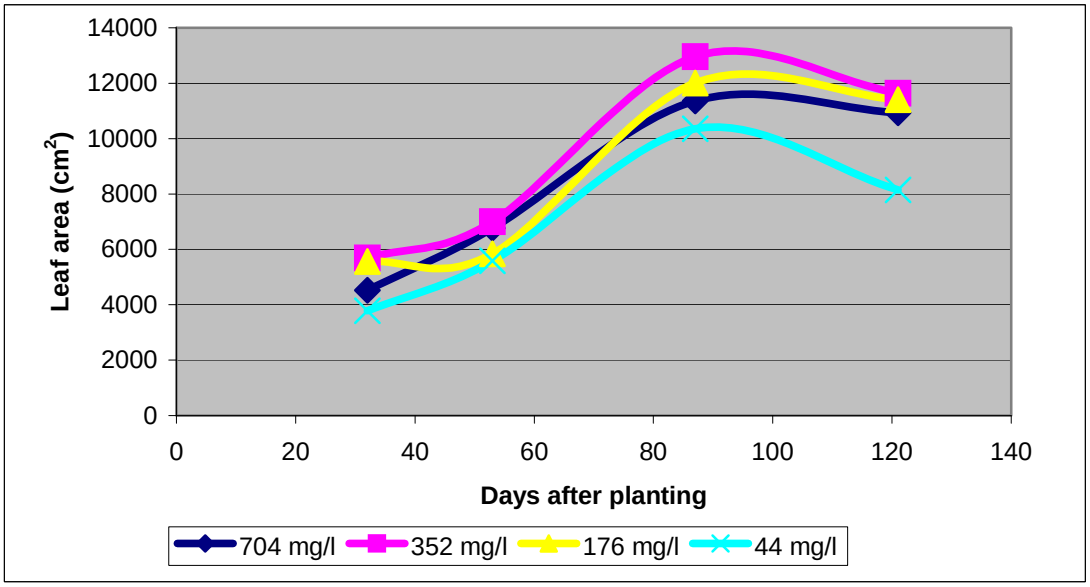


Figure 5.3b: Leaf area measured for different calcium levels in irrigation water at 27/17 ^{o}C controlled temperature at 35 % humidity

Referring to Figures 5.3a and 5.3b, the maximum leaf areas were reached at 87 days, at both low and high controlled temperatures. The field trials indicated maximum leaf

area values at 89 (2001) and 86 (2002) days after planting for Kleinkopje and 78 days after planting for Hatfield. However, Steyn *et al.* (1992) obtained maximum leaf area values at 52 days after planting. At 22/14 ^{o}C and 27/17 ^{o}C the leaf area values were significantly higher when 176 and 352 mg/l Ca were applied (Appendix, Tables A1.4 & A1.5). The leaf area values were lower at 702 mg/l Ca and lowest for the control (44 mg/l.). A similar trend in the increased leaf area values, at low and medium calcium rates, were found by El-Beltagy *et al.* (2002). Although the leaves were narrower at 27/17 ^{o}C, the total leaf area values were higher than those in 22/14 ^{o}C treatment. These findings agree with Manrique's (1990) results, which show that the total leaf area increased significantly with temperature increase up to 35 ^{o}C.

5.3.3 Stem lengths

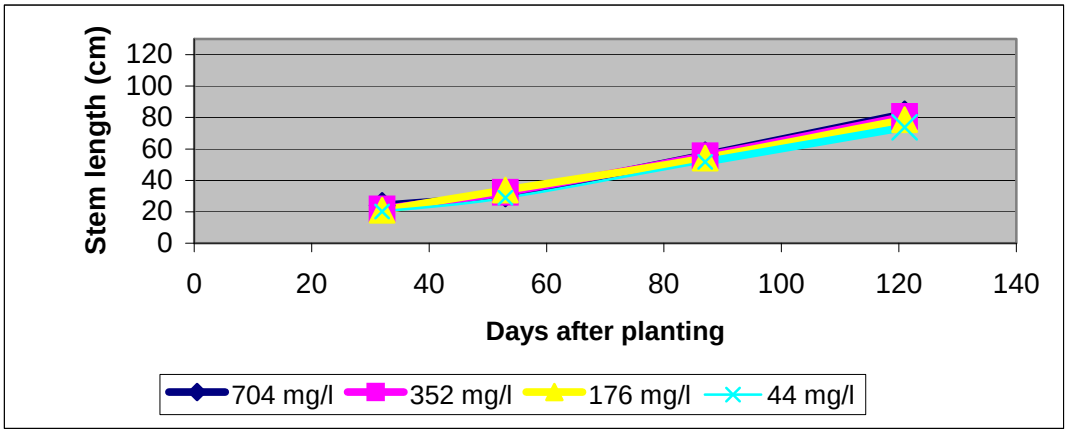


Figure 5.4a: Stem length measurements recorded at 22/14 ^{o}C controlled temperature and 35 % humidity

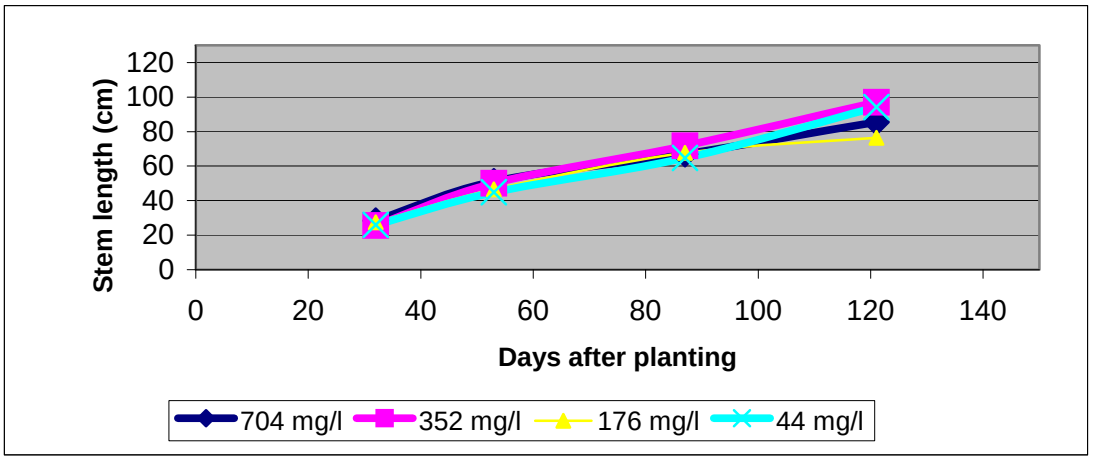


Figure 5.4b: Stem length measurements recorded at 27/17 ^{o}C controlled temperature and 35 % humidity

There was a rapid increase in stem length at high controlled temperature (27/17 ^{o}C) compared to low controlled temperature (22/14 ^{o}C) (Figures 5.4a and 5.4b). According to Davies (1983); Benoit *et al*. (1986) and Manrique (1990) high stem lengths are expected at higher temperatures. However, Khedher & Ewing (1985) mention high temperatures to have little effect on the stem lengths. At both 22/14 ^{o}C and 27/17 ^{o}C controlled temperatures the increase in stem lengths were not significantly influenced by increasing calcium levels. These results are also evidenced by the findings of El-Beltagy *et al*. (2002). The stem lengths were influenced more by temperature than by calcium application rates (Figure 5.4a & 5.4b).

5.3.4 Leaf dry mass

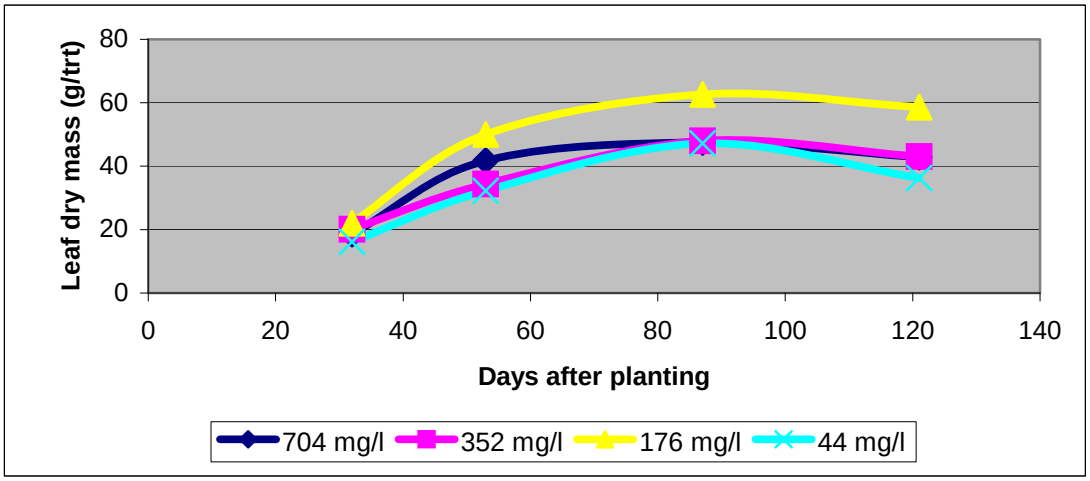


Figure 5.5a: Leaf dry mass measured at 22/14 ^{o}C controlled temperature at 35 % humidity

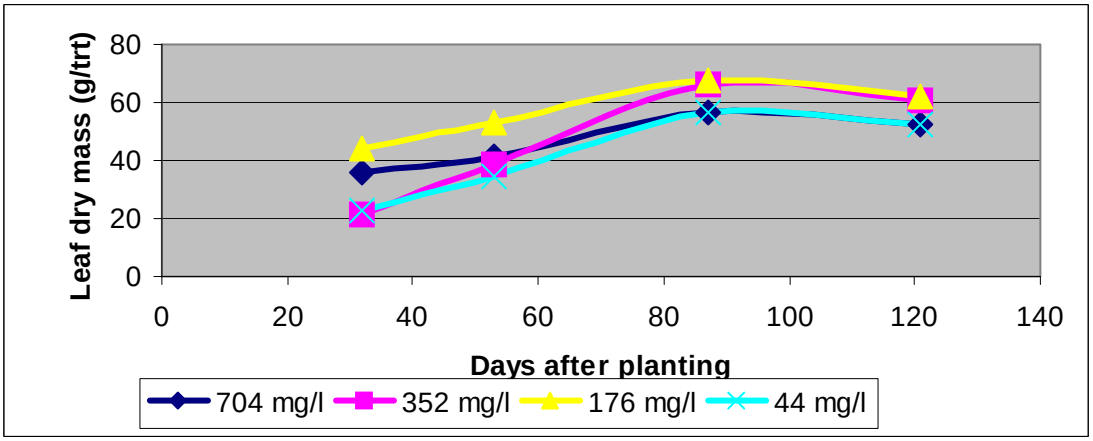


Figure 5.5b: Leaf dry mass measured at 27/17 ^{o}C controlled temperature at 35 % humidity

Figure 5.5a & 5.5b, indicate an increase in leaf dry mass with applying higher calcium levels. However the leaf dry mass was significantly higher with 176 mg/l calcium application rate (Appendix, Tables A1.4 & A1.5). Higher leaf dry mass values were obtained at high tmperature (27/17 ^{o}C) than at low temperature (22/14 ^{o}C). The findings of Khedher & Ewing (1985) and Wheeler *et al.* (1986) also revealed that the dry leaf mass is higher in hot environmental conditions.

5.3.5 Stem dry mass

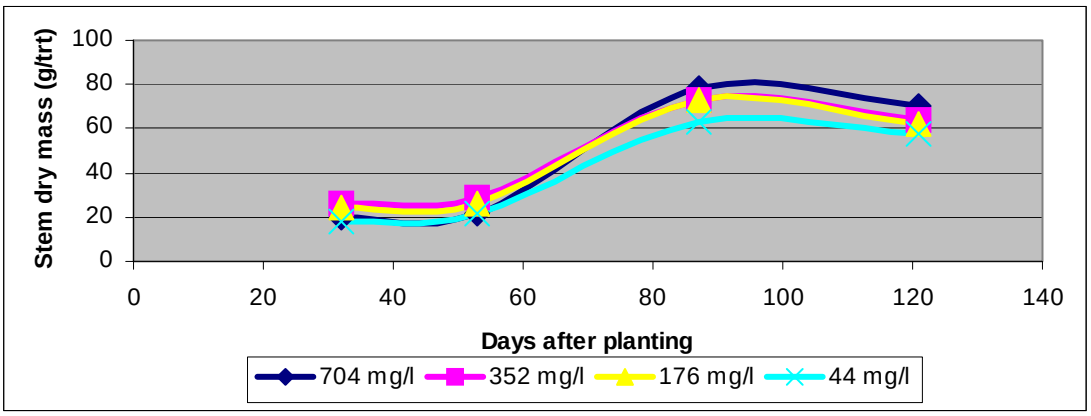


Figure 5.6a: Stem dry mass measured at 22/14 ^{o}C controlled temperature at 35 % humidity

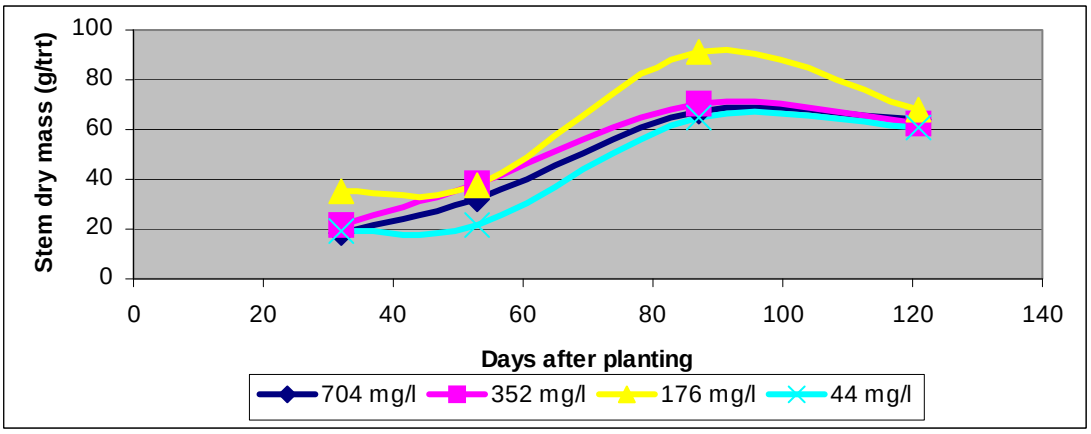


Figure 5.6b: Stem dry mass measured at 27/17 ^{o}C controlled temperature at 35 % humidity

At 22/14 ^{o}C the stem dry mass was significantly higher than the control at 704, 352 and 176 mg/l calcium application rates, except when 704 mg/l Ca was applied at 57 days after planting (Appendix, Table A1.4). At 27/17 ^{o}C the stem dry mass was significantly higher than the control at 176 mg/l calcium rate, except for the control (Appendix, Table A1.5). The stem dry mass was less influenced by the temperature treatments (Figures 5.6a & 5.6b). However, Khedher & Ewing (1985) and Wheeler *et al.* (1986) concluded that the stem dry mass, like the leaf dry mass, are expected to be higher at high temperatures.

5.3.6 Tuber dry mass

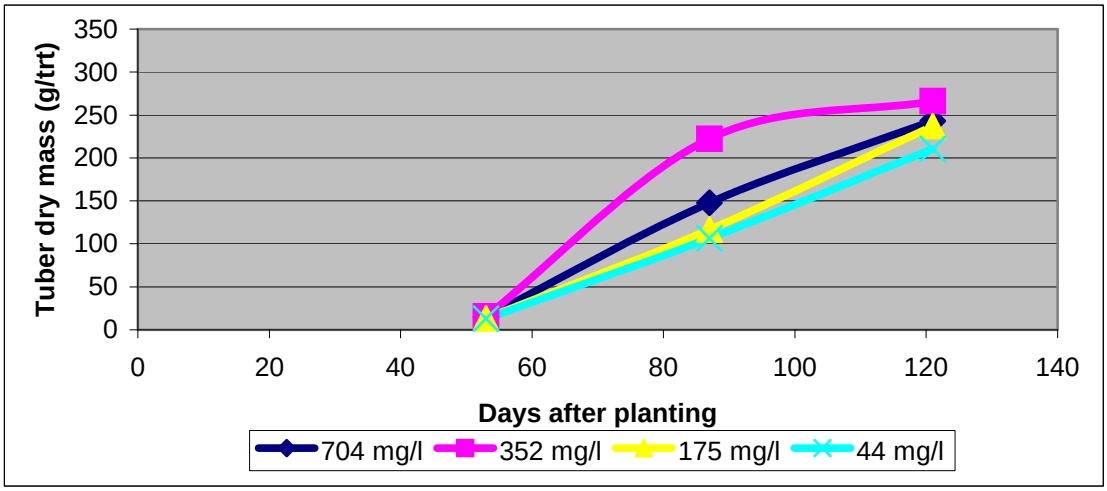


Figure 5.7a: Tuber dry mass determined at 22/14 ^{o}C controlled temperature at 35 % humidity

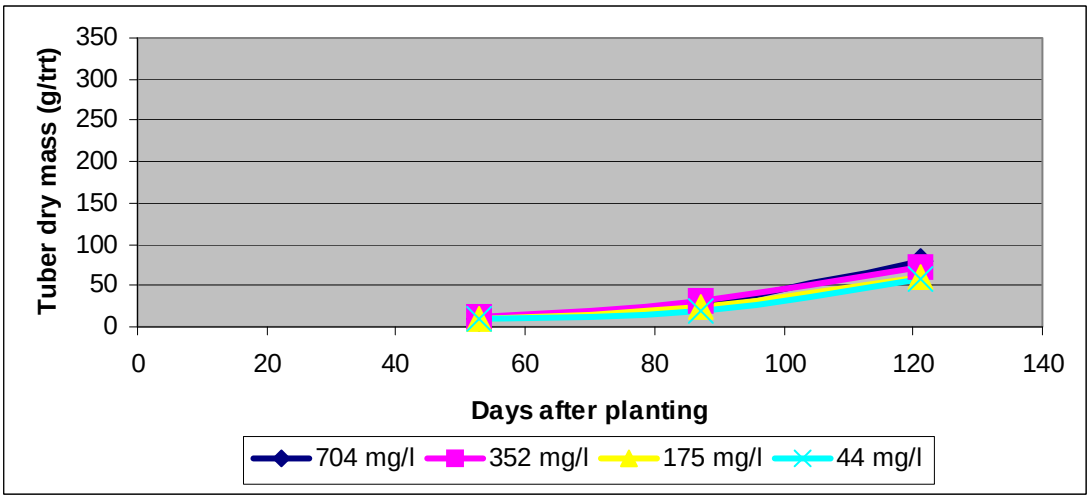


Figure 5.7b: Tuber dry mass determined at 27/17 ^{o}C controlled temperature at 35 % humidity

Figures 5.7a & 5.7b show an increase in tuber dry mass from initiation until harvest. The field trials (Kleinkopje and Hatfield) also showed an increase in the tuber dry mass until harvest. This is also confirmed by the findings of Steyn *et al*. (1992). High tuber dry mass was produced at low controlled temperature (22/14 ^{o}C). Khedher & Ewing (1985) report a significant reduction in tuber dry mass at higher temperature conditions, which agree with the above results. At both temperatures (22/14 ^{o}C and 27/17 ^{o}C) high tuber dry mass was produced at average and high calcium levels (176, 352 and 704 mg/l) compared to the control (44 mg/l). The overall F test was not significant thus the least significant difference test did not

proceed (Appendix, Tables A1.4 & A1.5). These results imply that lowering the temperature (22/14 ^{o}C) at low humidity and applying higher calcium levels to have a beneficial effect on the tuber dry mass.

5.3.7 Total dry mass

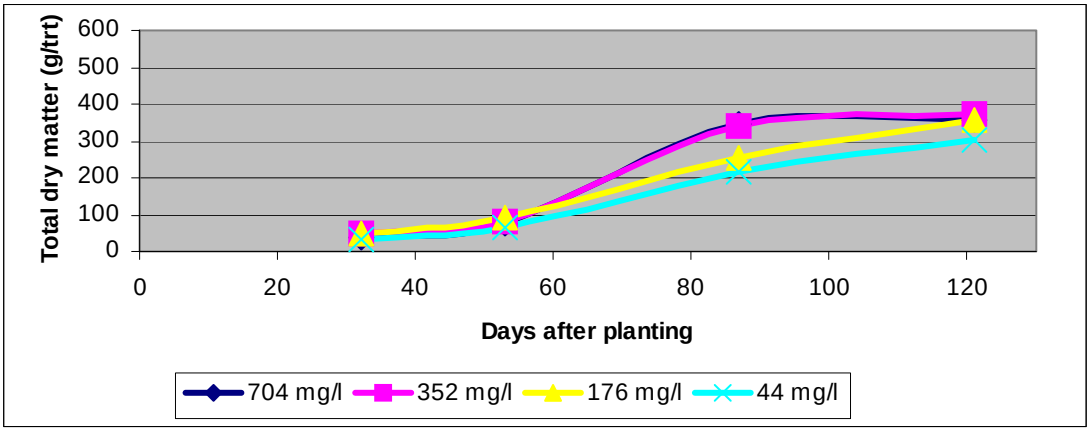


Figure 5.8a: Total dry mass determined at 22/14 ^{o}C controlled temperature at 35 % humidity

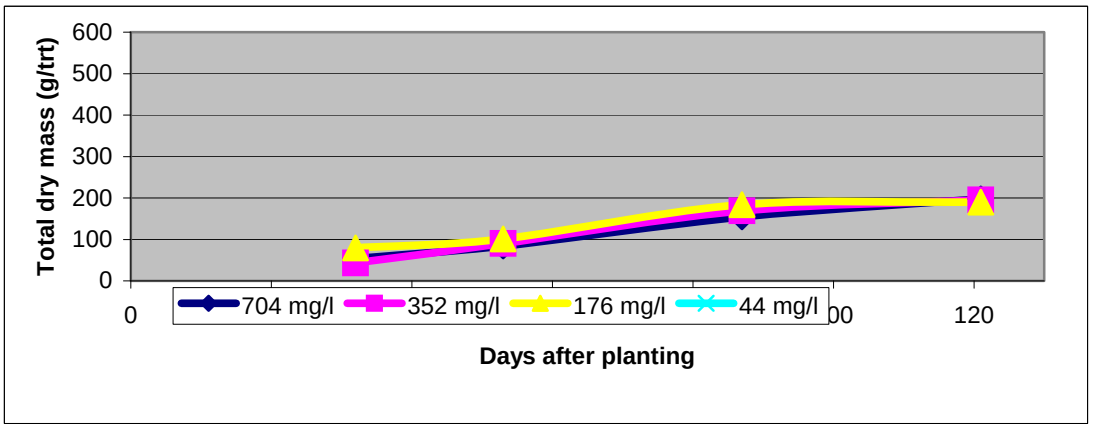


Figure 5.8b: Total dry mass determined at 27/17 ^{o}C controlled temperature at 35 % humidity

The total dry mass increased with an increase in the number of days after planting. The total dry mass was higher at a low controlled temperature (22/14 ^{o}C) than at a high controlled temperature at (27/17 ^{o}C). A significant increase in the total dry mass at cool temperatures, as opposed to higher temperatures, was also evidenced by Manrique (1990). The total dry mass significantly increased with applying lower calcium level (176 mg/l Ca) at 27/17 ^{o}C. However, the further increase in calcium levels (352 and 704 mg/l Ca) did not seem to have a positive effect except for the final harvest. Contrary to that, at 22/14 ^{o}C the total dry mass was slightly higher at the

average and highest calcium levels (176, 352 and 704 mg/l) compared to the control (Figure 5.7a & 57b). Applying high levels of calcium and lowering the temperature at 35 % humidity had a positive effect on the total dry mass of the potato crop. The overall F test was not significant; thus the least significant difference test did not proceed (Appendix, Table A1.4 & A1.5).

5.3.8 Leaf chemical analysis

Table 5.1: Leaf chemical analysis measured at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 35 % humidity (sampled at 80 DAP)

Trt	**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
mg/lCa	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
22/14 ^{o}C											
44	**2.63**	**0.26**	**0.73**	**2.74**	**0.38**	**0**	**0.66**	**14**	**66**	**65**	**20**
176	**2.53**	**0.21**	**0.89**	**2.2**	**0.53**	**0**	**1.3**	**15**	**65**	**56**	**32**
352	**3.1**	**0.23**	**1.1**	**1.38**	**0.62**	**0**	**0.84**	**17**	**62**	**59**	**17**
704	**2.98**	**0.2**	**1.12**	**2.32**	**0.58**	**0**	**1.32**	**17**	**99**	**60**	**41**
27/17 ^{o}C											
44	**3.7**	**0.48**	**0.94**	**3.33**	**0.53**	**0.01**	**1.66**	**23**	**86**	**87**	**36**
176	**2.95**	**0.22**	**1.27**	**2.53**	**0.57**	**0**	**1.25**	**20**	**92**	**96**	**36**
352	**3.53**	**0.37**	**0.91**	**2.07**	**0.45**	**0**	**1.44**	**23**	**86**	**60**	**33**
704	**3.84**	**0.45**	**0.96**	**2.52**	**0.43**	**0**	**1.66**	**23**	**74**	**60**	**33**
Norms	>3	>0.25	>0.15	>1.5	>0.1		>0.025	>5	>5	>40	>20

Note: Norms according to Bennet (1993)

The leaf chemical analysis was only done on one replicate, thus statistical analysis was not done. There were no signs of any nutrient deficiencies. All the nutrients were within the acceptable ranges for the potato crop (Bennet, 1993), however, nitrogen levels were slightly low. The calcium content of the leaves was lower at 22/14 ^{o}C with low calcium level (44, 176 mg/l) applications. The calcium levels of the leaves were slightly higher at 22/14 ^{o}C than at 27/17 ^{o}C and at higher calcium level (352 and 704 mg/l Ca) applications (Table 5.1). Leaf nitrogen levels were higher than potassium and phosphorus levels. This was also confirmed by the findings of Walworth & Muniz (1993).

5.3.9 Tuber yield

The tuber yield increased with increasing calcium levels at a high controlled temperature (27/17 ^{o}C). At a low controlled temperature (22/14 ^{o}C) the tuber yield was lower at 176 mg/l Ca, but generally the results showed a beneficial effect on the potato tuber yield (Figure 5.9) when applying higher calcium levels (352 and 704 mg/l Ca). Locascio *et al.* (1992) also mentioned the increase in tuber yield with a concomitant increase in calcium level. Conversely, El-Beltagy *et al.* (2002) report a reduction in tuber yield with further increase in calcium levels (34.8 g Ca/plant).

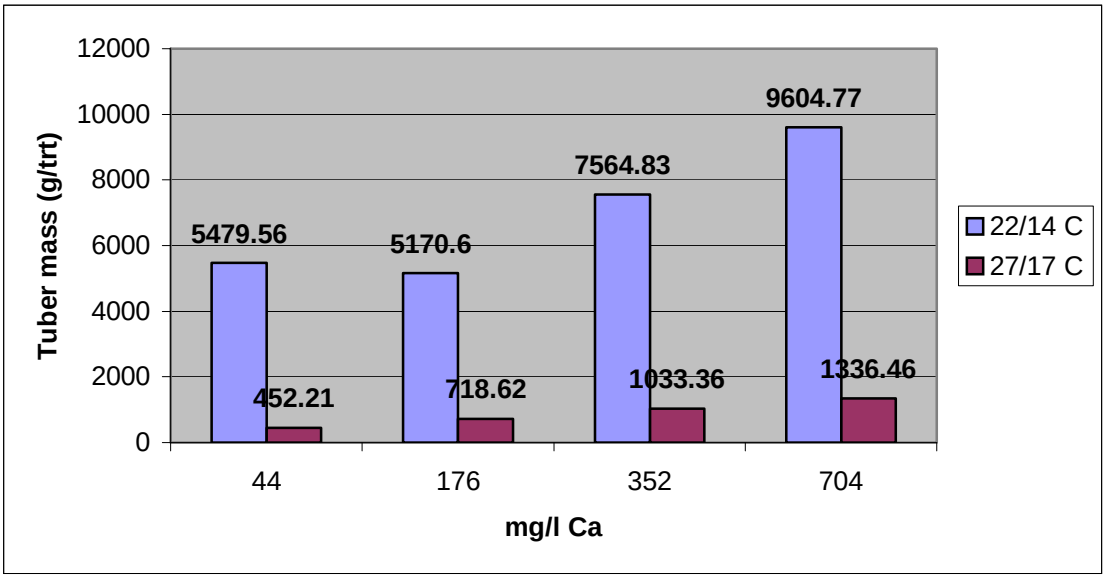


Figure 5.9: Tuber yield (g/trt) measured at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 35 % humidity

Referring to Figure 5.9, the tuber yields were significantly higher at a low temperature (22/14 ^{o}C) than at a high controlled temperature (27/17 ^{o}C). According to Basu & Minhas (1991), Tadesse *et al*. (2001), El-Beltagy *et al*. (2002), and Kleinhenz & Palta (2002), high temperatures lower the tuber yields due to the inhibition of starch in the tubers and the partitioning of the photosynthates in the tubers.

5.3.10 Tuber chemical analysis

The tuber chemical analysis was done to determine the impact of calcium on other nutrient levels when increased levels of calcium in calcium rich water were applied to plants maintained at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures at 35 % humidity. Additional calcium resulted in improved tuber calcium content at low controlled temperatures (22/14 ^{o}C) (Figure 5.10). However, at high controlled temperatures, there was no relation between applying additional calcium and improving the tuber calcium content.

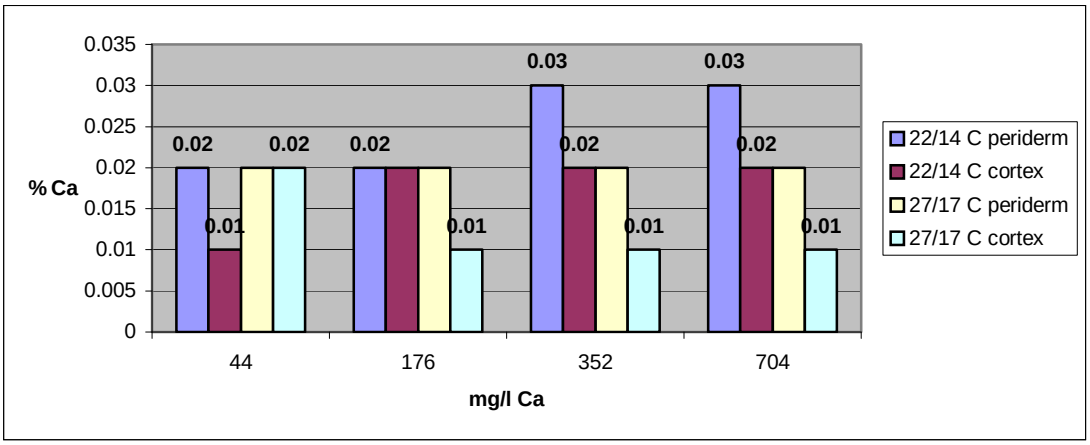


Figure 5.10: Tuber calcium content measured at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 35 % humidity

Tuber chemical analysis was only done on one replicate and thus no statistical analysis was done. The calcium contents (cortex) at 22/14 ^{o}C were slightly higher than at 27/17 ^{o}C, even though the calcium content of the control seemed to be as high at 27/17 ^{o}C. Olsen *et al.* (1996) also found the lower tuber calcium content to be due to high temperature. Walwoth & Muniz (1993) reported the calcium content of 0.02 to 0.04 % to be significant for potato tubers. The calcium content of the tubers was sufficient at 22/14 ^{o}C; however, for the control calcium content of the cortex was low (0.01 %). A low calcium content of the cortex (0.01 %) was found at 27/17 ^{o}C, though the control had sufficient calcium content. The calcium content of the periderm (A) was higher than that of the cortex (B), except for the control at 27/17 ^{o}C and 176 mg/l at 22/14 ^{o}C (Figure 5.10). The calcium content of the periderm is also

reported to be higher than that of the cortex (Olsen *et al*., 1996). The high calcium content of the periderm can be attributed to the direct availability of calcium in the soil, which suggests that the tubers can absorb calcium directly from the soil solution (Olsen *et al*., 1996; Davies, 1998).

5.3.11 Tuber internal quality tests

Tuber internal quality tests were done to determine how applying increasing levels of calcium in calcium rich water at 27/17 ^{o}C and 22/14 ^{o}C controlled temperatures, maintained at 35 % humidity affected tuber quality. Tuber internal quality test was only done on one replicate thus no statistical analysis was done. Specific gravity (SG) and chip colour were evaluated as quality characteristics.

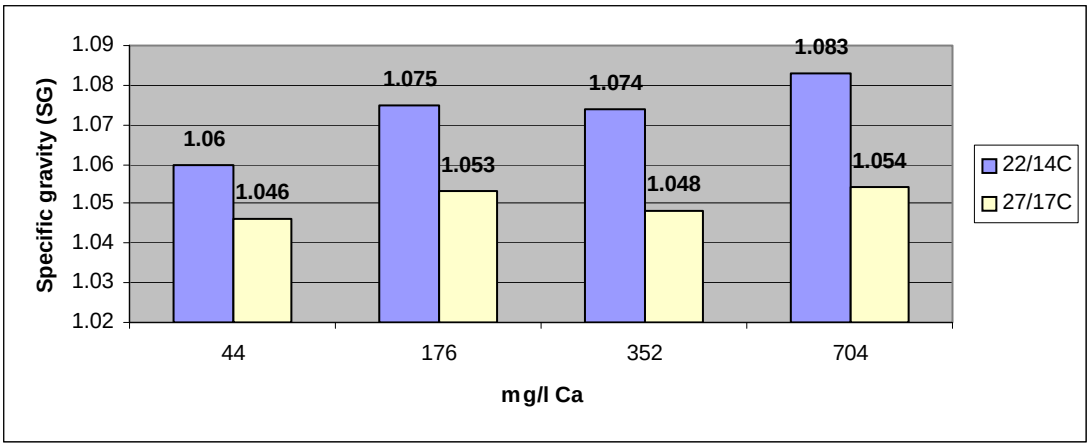


Figure 5.11: Specific gravity evaluated as quality characteristics at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature and 35 % humidity

Evaluating a quality characteristic such as specific gravity has shown that good quality tubers (SG > 1.075) resulted at low controlled temperatures (22/14 ^{o}C) (acceptable to the chip processing industry) and relatively poor tuber quality resulted at high temperature (27/17 ^{o}C) (Figure 5.11). There was a beneficial effect of improving the tuber quality by applying higher calcium levels (176, 352 and 702 mg/l Ca) to the potato plants, as compared to the low specific gravity value of the control (44 mg/l Ca). However El-Beltagy *et al.* (2002) found the specific gravity to increase with medium calcium application rates (not significant) and that a further increase in calcium levels do not have a positive effect.

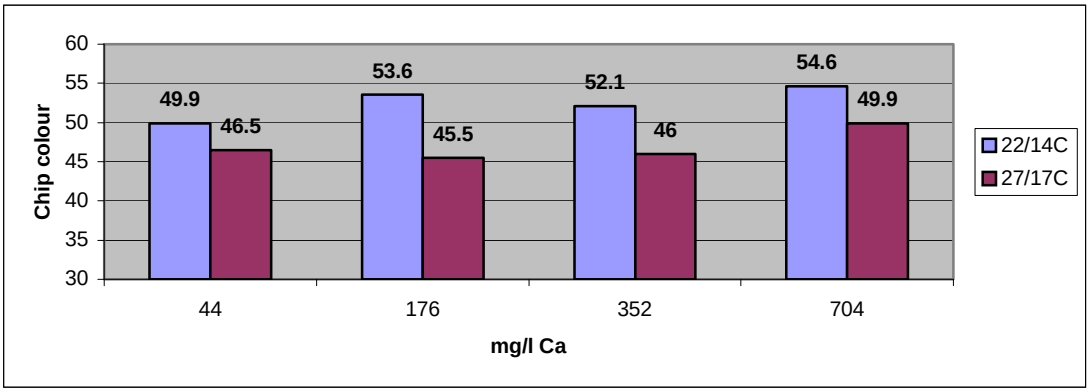


Figure 5.12: Chip colour evaluated as quality characteristics at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature and 35 % humidity

Chip colour has shown a positive effect as a result of applying higher calcium levels (176, 352 and 704 mg/l) (chip colour > 45). Lowering the temperature (22/14 ^{o}C) resulted in better tuber quality (chip colour ranging from 52.1 to 54.6) than at 27/17 ^{o}C controlled temperature (chip colour ranging from 45.5 to 49.9).

5.4 CONCLUSIONS

High controlled temperatures (27/17 ^{o}C) had a more detrimental effect on vegetative growth than on tuber growth. This was evidenced by the high leaf area, stem length and leaf dry mass values at 27/17 ^{o}C as compared to 22/14 ^{o}C, although the stem dry mass did not show a significant variation as a result of temperature treatment.

Tuber dry mass and total dry mass were favoured by lowering the temperature (22/14 ^{o}C) and applying higher calcium levels. Leaf and tuber chemical analysis results indicated no negative effect on the other nutrient elements by applying additional calcium. Generally, the calcium content of the tubers was lower than that of the leaves but low temperature (22/14 ^{o}C) favored higher calcium accumulation in the tubers, compared with high temperature 27/17 ^{o}C. Applying additional calcium and lowering the temperature (22/14 ^{o}C) had a beneficial effect on the tuber yield and quality. This was indicated by high tuber yields as well as high specific gravity (>1.075) and chip colour (> 45) obtained at 22/14 ^{o}C. It seems that at higher temperature (and high transpiration rate) more calcium was probably not taken up and transported to the leaves (Table 5.1) although all other nutrients seem to be higher at

high temperature.

CHAPTER 6

CALCIUM NUTRITION OF POTATOES MAINTAINED AT LOW AND HIGH CONTROLLED TEMPERATURES AT HIGH HUMIDITY

6.1 INTRODUCTION

Potatoes (*Solanum tubersolum L.)* can grow in many areas of diverse climatic conditions. Specific environmental factors (soil type, water supply, salinity, temperature, humidity) are required by the crop to grow successfully with good yield and quality.

Temperature and humidity play a major role in regulating potato growth, yield and quality of the tubers. Temperature and humidity also affect the transpiration rate and thus calcium distribution within the crop (Bergmann, 1992; Adams & Ho, 1993; Olsen *et al*., 1996). According to Olsen *et al*. (1996) high temperatures increase transpiration rate and result in more calcium being transported to vegetative parts relative to the tubers. In contrast high humidity depresses rate of transpiration and the distribution of calcium to the leaves (Bergmann, 1992 and Adams & Ho, 1993). In this study increased calcium concentrations (as calcium rich water) were applied to plants maintained at high (27/17^{o} C) and low (22/14^{o} C) controlled temperatures at high humidity (85 %) to investigate if calcium uptake is affected by temperature only, or transpiration rate as well (strength of the transpiration stream).

6.2 MATERIALS AND METHODS

Potato plants (cultivar BP-1) were started (October 2002) from individual seed pieces approximately 1cm^{3} in size, each containing a single eye. Seed pieces were planted in a vermiculite medium until the stems lengths were about 8 cm and were then transferred to a sand medium. Potato plants were planted one per pot of 27.5 cm in diameter and 31.5 cm tall containing sand as growth medium.

This experimental layout was a factorial design with two factors: calcium concentration at four levels and two temperature regimes controlled at high humidity

(85 %). Each of the calcium concentration treatments (176, 352 and 704 mg/l Ca), including the control (44 mg/l Ca) were assigned to pots arranged in a completely randomised design, with twelve replicates each. Plants were watered every second day to avoid water stress. Pots were placed in two separate temperature controlled glasshouses, each room containing 48 pots, thus a total of 96 pots.

Day and night temperatures for each of the two glasshouses were maintained at 22/14 °C and 27/17 °C and controlled at high humidity (> 85 %) throughout the experiment. During the growing season, growth analysis was done after every 30 days, as from 30 days after transplanting. At the same time stem lengths were measured. Growth analysis was done to determine how increased levels of calcium applied to potato plants at high (27/17 °C) and low (22/14 °C) controlled temperatures, maintained at high humidity (85 %), affected crop growth. Leaf chemical analysis was also done during the growing season. Leaf chemical analysis was done to determine how applying increased levels of calcium at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures maintained at high (85 %) humidity affected other nutrients levels. Leaf chemical analysis was done on the leaves sampled from the 4th or the 5th nodes from the growing point. According to Walworth & Muniz, (1993), sampling is usually done from the 4th and 5th leaves from the growing point because they are considered to be the most recently matured. At the end of the growing season (January 2003), the tuber chemical analysis and tuber quality (chip colour and specific gravity) were determined.

Leaf (during the growing season) and tuber (at harvest) chemical analysis were carried out by analysing nitrogen and phosphorus with an auto analyser after a H_2SO_4 digestion was done. For determination of Ca, Mg, K, SO_4, Zn, Cu, Fe and Mn, samples were wet digested using nitric acid and perchloric acid in a digestion block. These nutrients were analysed by atomic absorption spectrometer (analysis done at University of Pretoria Soil Science Lab).

6.3 RESULTS AND DISCUSSIONS

6.3.1 Growth analysis

The parameters measured included leaf area, stem lengths, leaf, stem and tuber dry mass as well as the total dry mass. The number of tubers and stolons were counted. There were more tubers and stolons formed at the 22/14 °C temperature regime than the 27/17 °C regime, especially at 122 days after planting (Appendix, Tables A1.6 & A1.7).

Figure 6.1: Potato plants mantained at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity

Visual observation was done on the plants irrigated with increasing calcium levels at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures. There was no noticeable difference in plant growth with respect to calcium levels, but differences were noticed for the temperature treatments. Plants grew taller at high (27/17 ^{o}C) controlled temperature, compared with low (22/14 ^{o}C) controlled temperatures (85 % humidity) (Figure 6.1). The temperature treatments at low humidity (35 % humidity) have also shown plants to be taller at 27/17 ^{o}C compared to 22/14 ^{o}C. However, the plant growth was stunted at 85 % humidity, compared to plants grown at 35 % humidity. Similar findings were evidenced by Wheeler *et al*. (1989) namely, that reducing humidity has a positive effect on stem and foliage growth.

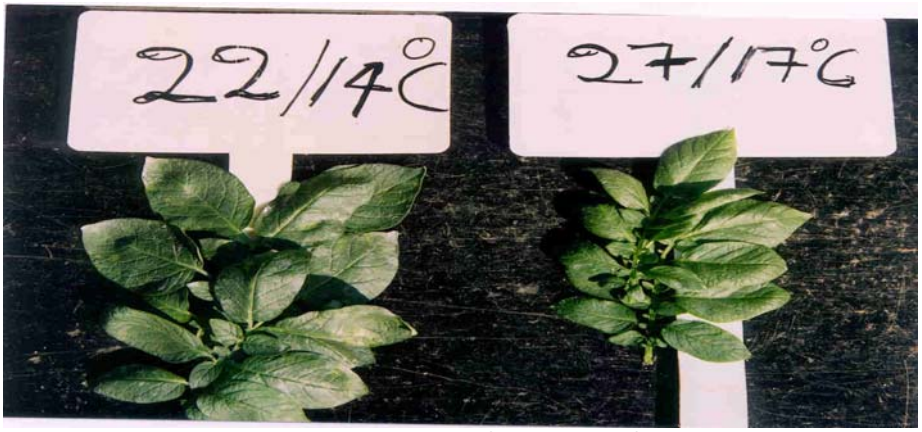


Figure 6.2: Potato leaves mantained at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity

The leaves were darker and thicker at a low (22/14 ^{o}C) controlled temperature compared to the high (27/17 ^{o}C) controlled temperature (Figure 6.2). According to Khedher & Ewing (1985) the leaves tend to be smaller when plants are grown at high temperatures. However, at both controlled temperatures, the leaf sizes were larger at high humidity (85 %) (Figure 6.2) as opposed to low (35 %) humidity (Figure 5.2).

6.3.2 Leaf areas

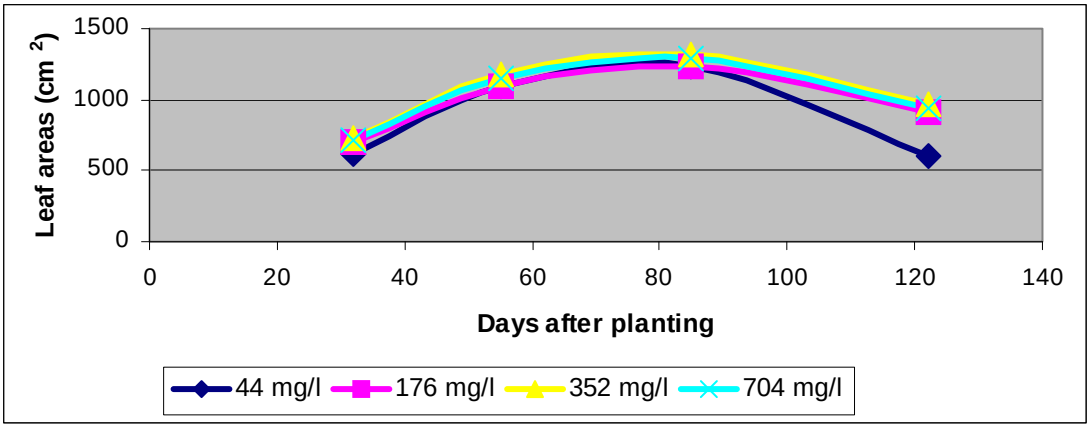


Figure 6.3a: Leaf area measured at temperature mantained at 22/14 ^{o}C at 85 % humidity

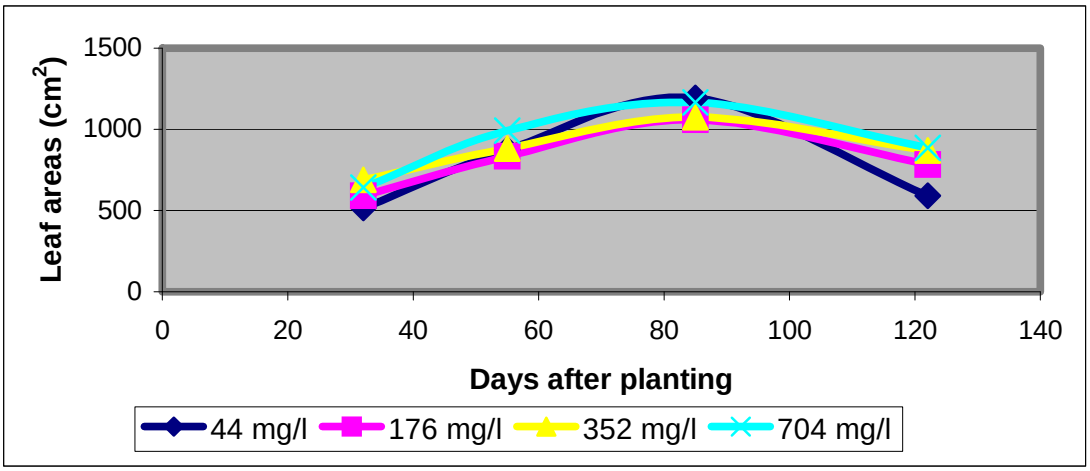


Figure 6.3b: Leaf area measured at temperature maintained at 27/17 ^{o}C at 85 % humidity

In Figures 6.3a and 6.3b, the leaf area values reached a maximum 85 days after planting. There were indications that applying medium and higher calcium levels (176, 352 mg/l Ca) might have a detrimental effect on the total leaf area. However, a further increase in calcium (704 mg/l) had no positive effect (Appendix, Tables A1.6 & A1.7). The increase in the total leaf area at low and medium calcium levels was also evidenced by El-Beltagy et al. (2002). In contrast at high temperature (27/17 ^{o}C) applying high calcium level (704 mg/l Ca) seemed to have a positive effect on the total leaf area (Appendix, Table A1.7). The total leaf area values were lower at 27/17 ^{o}C than at 22/14 ^{o}C (Appendix, Tables A1.6 & A1.7). However, the total leaf area were higher at 27/17 ^{o}C controlled temperature than at 22/14 ^{o}C when plants were grown at low humidity (35 %) (Appendix, Tables A1.4 & A1.5). The overall F test was not significant, thus the least significant different test did not proceed. Lowering humidity (35 %) had a positive effect on the total leaf area compared with high humidity (85 %) (Figures 5.3a & 5.3b; Figures 6.3a & 6.3b).

6.3.3 Stem lengths

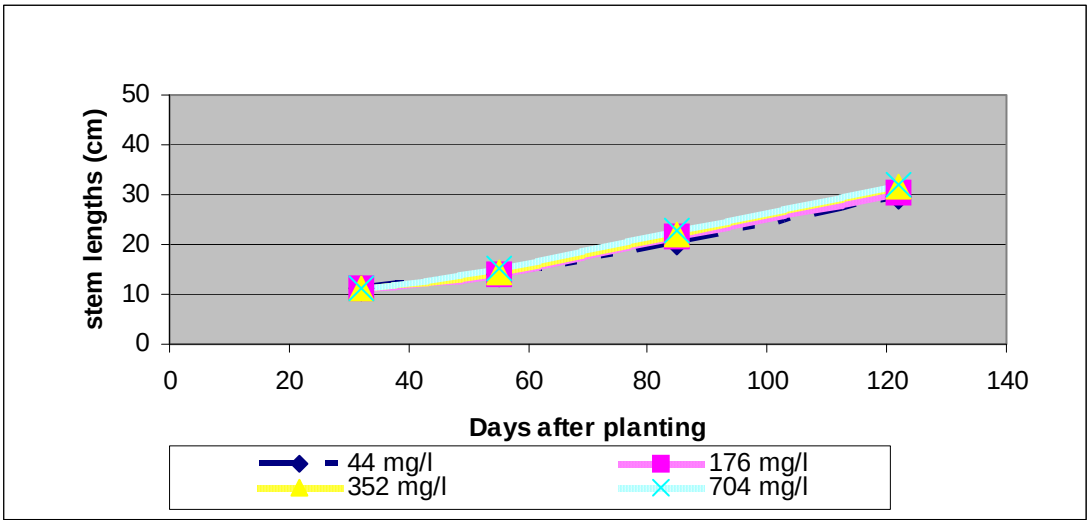


Figure 6.4 a: Stem lengths measured at 22/14 ^{o}C controlled temperature at 85 % humidity

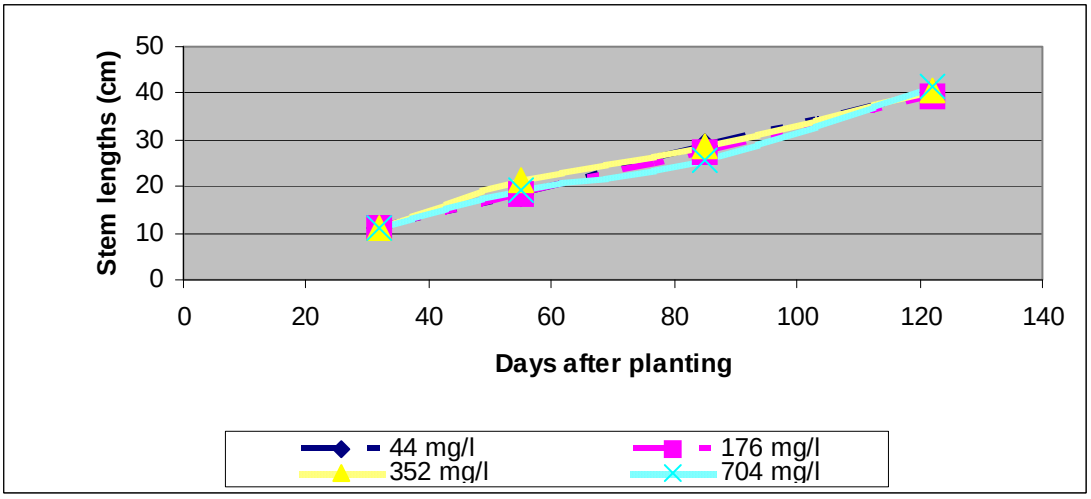


Figure 6.4 b: Stem lengths measured at 27/17 ^{o}C controlled temperature at 85 % humidity

Referring to Figures 6.4a & 6.4b, the plants had stunted growth at high humidity (85 %), compared with plants grown at 35 % humidity (Figures 5.4a & 5.4b). Increased stem growth at low humidity compared with high humidity was also evidenced by Wheeler *et al.* (1989). The stem growth was promoted by high controlled temperature (27/17 ^{o}C) as opposed to the 22/14 ^{o}C temperature regime (Figures 6.4a & 6.4b). A similar trend was found when plants were grown at low humidity (35 %) (Figure 5.4a & 5.4b). Davies (1983); Kedher & Ewing (1985) and Benoit *et al.* (1986) also reported high stem lengths to be expected at higher temperatures. There were indications that stem length might be promoted by lowered humidity (35 %) and

increased temperatures (27/17 ^{o}C). The stem growth was not significantly influenced by applying increasing calcium levels (Appendix, Tables A1.6 & A1.7). El-Beltagy *et al.* (2002) also evidenced similar results.

6.3.4 Leaf dry mass

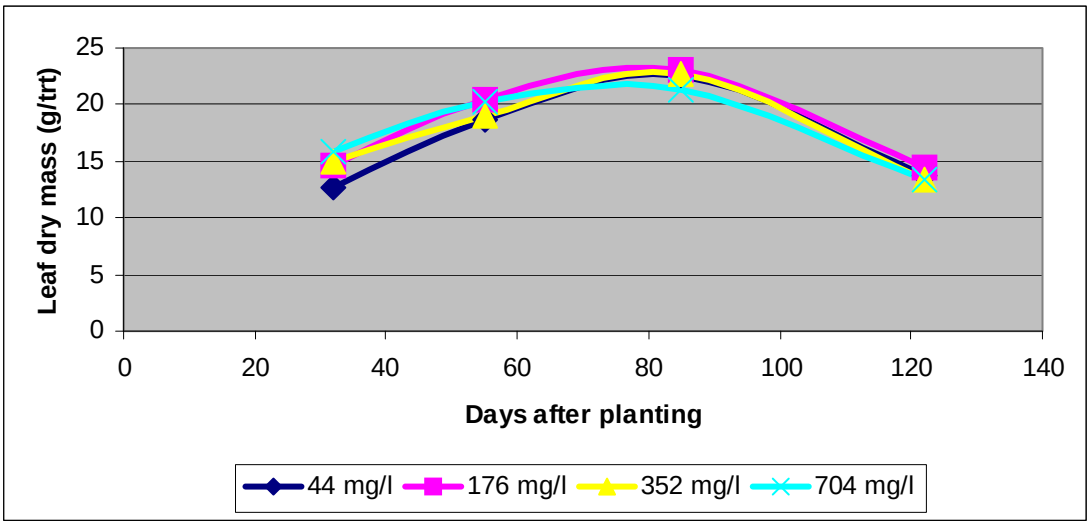


Figure 6.5a: Leaf dry mass measured at 22/14 ^{o}C controlled temperature at 85 % humidity

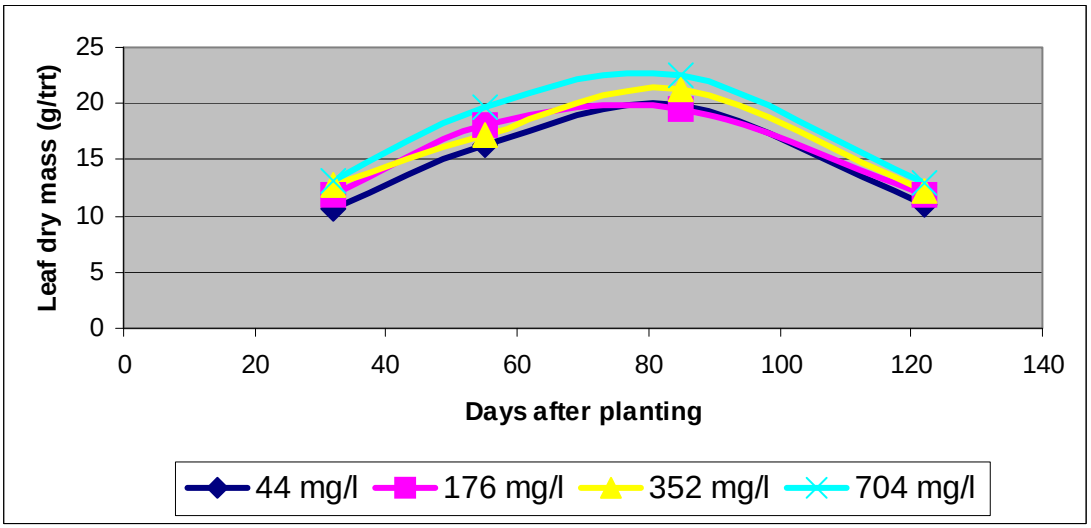


Figure 6.5b: Leaf dry mass measured at 27/17 ^{o}C controlled temperature at 85 % humidity

At high humidity (85 %) leaf dry mass was higher at 22/14 ^{o}C as compared to 27/17 ^{o}C (Appendix, Tables A1.6 &1.7). In contrast, at low humidity (35 %), higher leaf dry mass was obtained at high temperature 27/17 ^{o}C (Appendix, Tables A1.4 &1.5). Khedher & Ewing (1985) and Wheeler *et al.* (1986) also found the leaf dry mass to be

high at high temperature, which contradict with the findings at high humidity (85 %). However, the leaf dry mass was high at low humidity (35 %) (Figures 5.5a & 5.5b) relative to high humidity (85 %) (Figures 6.5a & 6.5b), which agrees with the findings of Wheeler *et al*. (1989). At 27/17 ^{o}C the leaf dry mass was significantly increased by applying higher calcium levels (176, 352, 704 mg/l Ca) compared to the control (Appendix, Table A1.7). The results indicated that the leaf dry mass might be increased by lowering humidity (35 %) and increasing the temperature (27/17 ^{o}C). The least significant difference test did not proceed at 22/14 ^{o}C (Appendix, Table A1.6).

6.3.5 Stem dry mass

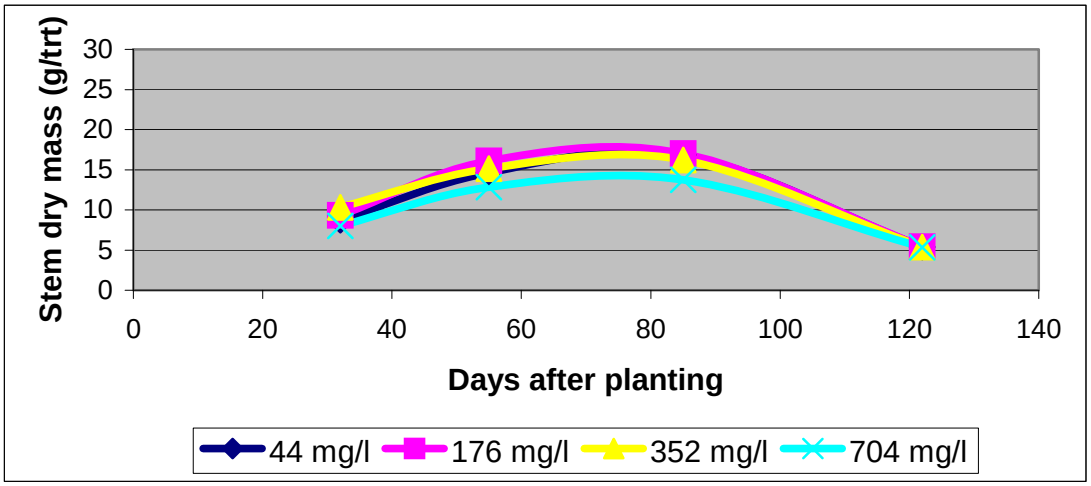


Figure 6.6a: Stem dry mass measured at 22/14 ^{o}C controlled temperature at 85 % humidity

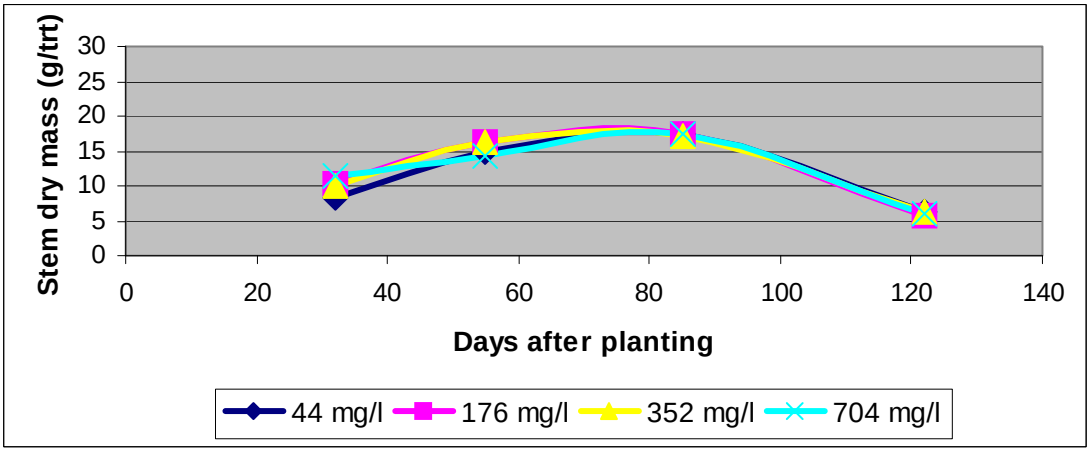


Figure 6.6b: Stem dry mass measured at 27/17 ^{o}C controlled temperature at 85 % humidity

The stem dry mass was not significantly influenced by temperature treatments at both humidities (35 %) (Figures 5.6a & 5.6b) and (85 %) (Figures 6.6a & 6.6b). Khedher & Ewing (1985) found the stem dry mass to be lower at low temperatures. The stem dry mass was higher at low humidity low (35 %) (Figure 5.6a & 5.6b) compared with high humidity (85 %) (Figures 6.6a & 6.6b). Wheeler *et al.* (1986) also found the increase in stem dry mass to be favored by low humidity. At 22/14 ^{o}C controlled temperature the stem dry mass was significantly higher at lower calcium levels compared with 704 mg/l Ca (Appendix, Table A1.6). The least significant difference test did not proceed at 27/17 ^{o}C (Appendix, Table A1.7).

6.3.6 Tuber dry mass

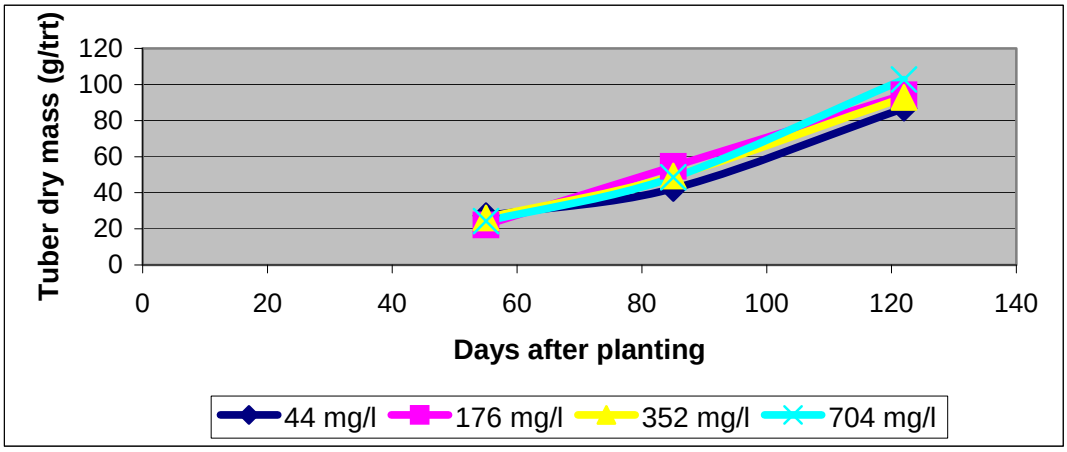


Figure 6.7a: Tuber dry mass measured at 22/14 ^{o}C controlled temperature at 85 % humidity

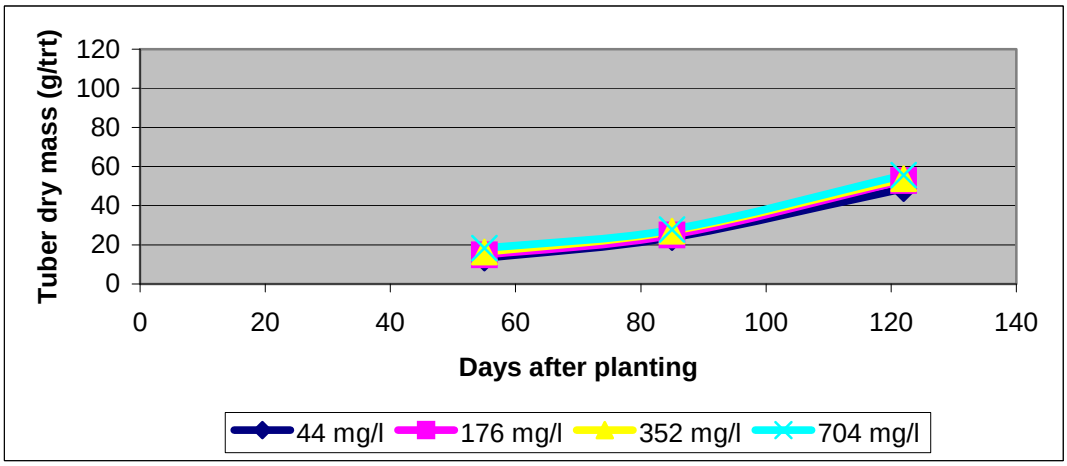


Figure 6.7b: Tuber dry mass measured at 27/17 ^{o}C controlled temperature at 85 % humidity

According to Figures 6.7a & 6.7b, the tuber dry mass increased throughout the growing season. In the field trials (Kleinkopje and Hatfield) as well as the controlled humidity (35 %) pot trial the same pattern was found. These was also confirmed in the findings of Steyn *et al*. (1992). Low temperature (22/14 ^{o}C) had a positive effect on the tuber dry mass, compared with the high controlled temperature (27/17 ^{o}C). A similar trend was also seen when plants were grown at low (35 %) humidity (Figures 5.7a & 5.7b). Khedher & Ewing's (1985) findings confirmed these results. At 27/17 ^{o}C the tuber dry mass was significantly higher at higher calcium levels, compared to the control (Appendix, Table A 1.7). Higher tuber dry mass was obtained at low humidity (35 %) (Figures 5.7a & 5.7b) than at a high humidity (85 %) (Figures 6.7a & 6.7b). These results contradict the findings of Wheeler *et al*. (1989), in which high tuber dry mass were obtained at high humidity. There was a beneficial effect from a lowered temperature (22/14 ^{o}C) and humidity (35 %) on the increase of tuber dry mass. The least significant difference test did not proceed at 22/14 ^{o}C (Appendix, Table A 1.6).

6.3.7 Total dry mass

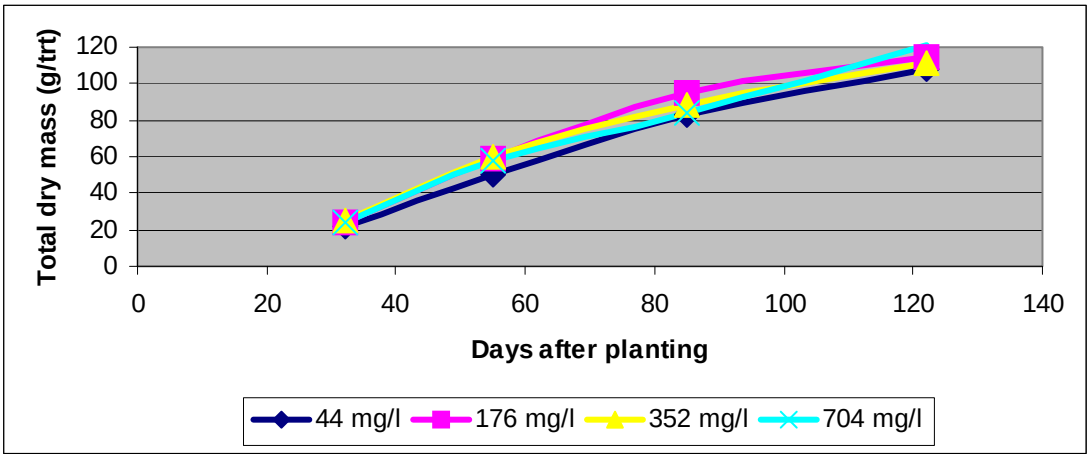


Figure 6.8a: Total dry mass measured at 22/14 ^{o}C controlled temperature at 85 % humidity

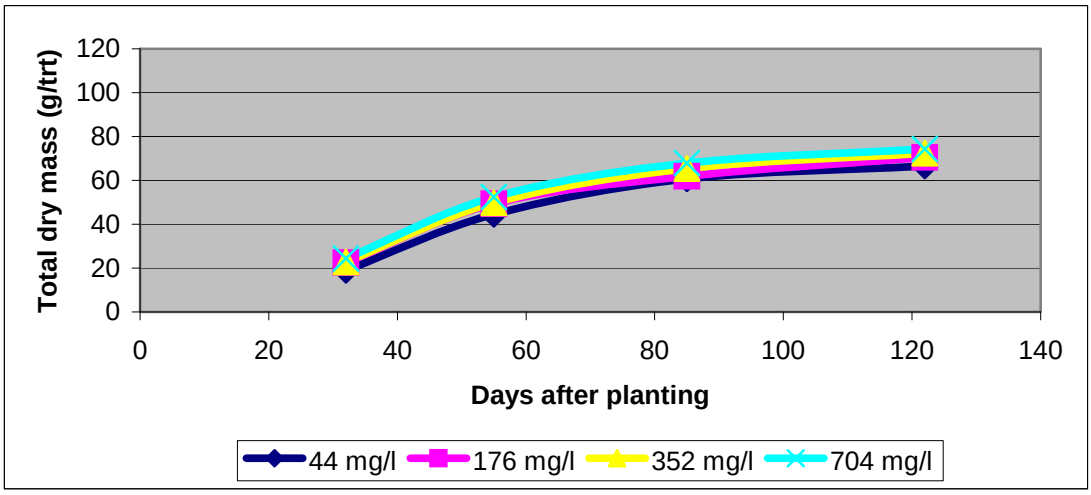


Figure 6.8b: Total dry mass measured at 27/17 ^{o}C controlled temperature at 85 % humidity

Figures 6.8a & 6.8b, indicate that the total dry mass was highest at low controlled temperature (22/14 ^{o}C) compared with the high controlled temperature (27/17 ^{o}C). Similar findings were observed when plants were grown at 35 % humidity (Figures 5.8a & 5.8b). The significant increase in the total dry mass at cool temperatures was evidenced by Manrique (1990).

At 27/17 ^{o}C total dry mass was significantly higher at high calcium levels (Appendix, Table A1.7). Generally potato plants grown at low humidity (35 %) (Figure 5.8a & 5.8b) resulted in higher total dry mass as opposed to high humidity (85 %) (Figures 6.8a & 6.8b). These results contradict the discovery of Wheeler *et al*. (1990) where the increase in total dry mass was favoured by high humidity. Thus, lowering the temperature (22/14 ^{o}C) and relative humidity (35 %) had a detrimental effect on the total dry mass. The least significant difference test did not proceed at 22/14 ^{o}C (Appendix, Table A1.6).

6.3.8 Leaf chemical analysis

Referring to Table 6.1, there was no sign of any nutrient deficiency and all the nutrient levels were within acceptable ranges for potato crops (Bennet, 1993). There was a particular trend of increasing calcium application rates (176 to 352 mg/l) on the calcium content of the leaves. A further increase of the calcium level (704 mg/l Ca) had no positive effect on the calcium content of the leaves. Generally higher calcium contents in the leaves were obtained at 22/14 ^{o}C than at 27/17 ^{o}C. Nitrogen levels

were higher than phosphorus and potassium levels. A similar trend was found when plants were maintained at low humidity (35 %). The results agree with what Walworth & Muniz (1993) discovered. Generally, the leaf nutrient elements were higher at high humidity (85 %) (Table 6.1) as compared to low humidity (35 %) (Table 5.1). Leaf chemical analysis was only done on one replicate and thus the statistical analysis was not done.

Table 6.1: Leaf chemical analysis measured at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity (sampled at 80 DAP)

Trt	**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
mg/lCa	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
22/14 ^{o}C											
44	**4.2**	**0.6**	**1.97**	**4.17**	**0.55**	**0.01**	**1.73**	**12**	**123**	**122**	**41**
176	**4.6**	**0.7**	**2.23**	**4.14**	**0.67**	**0.01**	**1.69**	**15**	**138**	**210**	**51**
352	**4.2**	**0.6**	**2.54**	**3.78**	**0.76**	**0.01**	**1.64**	**14**	**177**	**212**	**42**
704	**4.3**	**0.7**	**2.39**	**3.91**	**0.62**	**0.01**	**1.67**	**14**	**153**	**215**	**60**
27/17 ^{o}C											
44	**5**	**0.7**	**1.2**	**4.82**	**0.58**	**0.01**	**1.73**	**23**	**137**	**114**	**60**
176	**4.7**	**0.6**	**1.89**	**4.36**	**0.65**	**0.01**	**1.7**	**20**	**123**	**135**	**71**
352	**4.5**	**0.6**	**2.09**	**4.38**	**0.71**	**0.01**	**1.65**	**21**	**147**	**99**	**41**
704	**5**	**0.7**	**1.86**	**5.07**	**0.51**	**0.01**	**1.62**	**23**	**141**	**149**	**63**
Norms	>3	>0.25	>0.15	>1.5	>0.1		>0.025	>5	>5	>40	>20

Note: Norms according to Bennet (1993)

6.3.9 Tuber yield

The total tuber yield was determined in 8 pots per treatment at harvest (other plants were harvested for growth analysis). Low controlled (22/14 ^{o}C) temperatures resulted in a higher tuber yield compared to the high (27/17 ^{o}C) controlled temperatures (Figure 6.9). A similar trend was discovered when the plants were exposed to low humidity (35 %) (Figure 5.9). According to Ewing (1981), Khedher and Ewing (1985), and Tadesse (2001), high temperatures reduce tuber production. This is attributed to the reduced allocation of photosynthates to the tubers (El-Beltagy, 2001). Higher tuber yields were produced at low (35 %) humidity (Figure 5.9) compared with high (85 %) humidity (Figure 6.9) at 22/14 ^{o}C controlled temperature. In contrast, at 27/17 ^{o}C high yields were found at high humidity (85 %). Wheeler *et al.*

(1989) discovered the possible benefit of increasing the tuber yields by increasing humidity. It can be concluded that lowering the temperature (22/14 ^{o}C) and humidity (35 %) has a beneficial effect on the tuber yield.

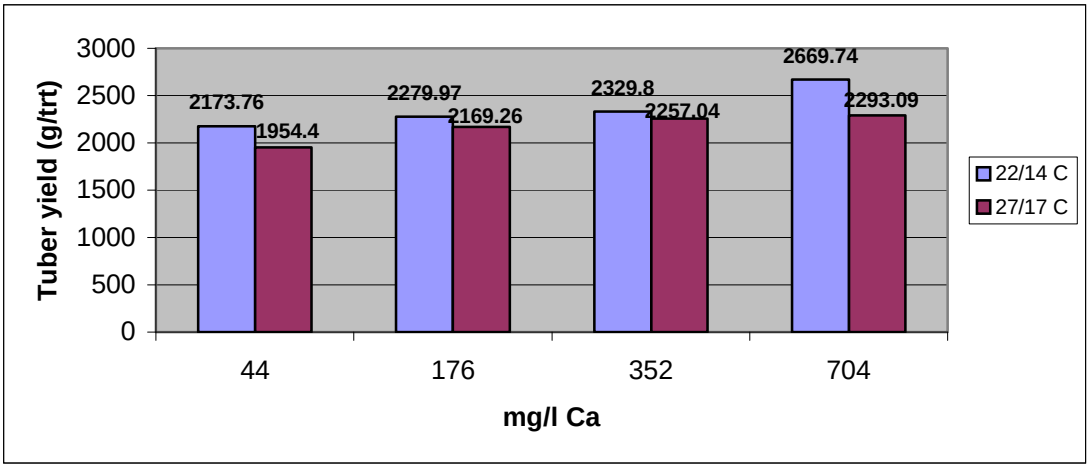


Figure 6.9: Tuber yield determined at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity

At 22/14 ^{o}C the tuber yield was significantly higher at the 704 mg/l calcium application rate (Appendix, Table A1.6). At 27/17 ^{o}C the tuber yield significantly improved compared with the control (Appendix, TableA1.7) when additional calcium was applied. The benefit of increasing the tuber yield by increasing applied calcium rates was also discovered by Locascio *et al.* (1992). However, a reduction in tuber yield with a further increase in calcium levels was reported by El- Beltagy *et al.* (2002).

Figure 6.10: Potato tubers maintained at 22/14 ^{o}C (T1) controlled temperature at 85 % humidity (C1:44, C2:176, C3:352, C4:704 mg/l Ca)

Applying increased levels of calcium seemed to have a positive effect on tuber size when potato plants were irrigated with increasing calcium levels at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures (Figures 6.10 & 6.11).

Figure 6.11: Potato tubers maintained at 27/17 ^{o}C controlled temperature at 85 % humidity (C1:44, C2:176, C3:352, C4:704mg/l Ca)

The temperature treatments have shown the major difference in tuber size as indicated by the small sized tubers at high (27/17 ^{o}C) (Figure 6.11) controlled temperature as opposed to low (22/14 ^{o}C) controlled temperature (Figure 6.10).

6.3.10 Tuber chemical analysis

The tuber chemical analysis was done to determine the impact of calcium on other nutrient levels when increasing levels of calcium in calcium rich water was applied to plants maintained at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures at 85 % humidity. Referring to Figure 6.12, applying higher calcium levels generally resulted in improved tuber calcium content, especially at high controlled temperatures.

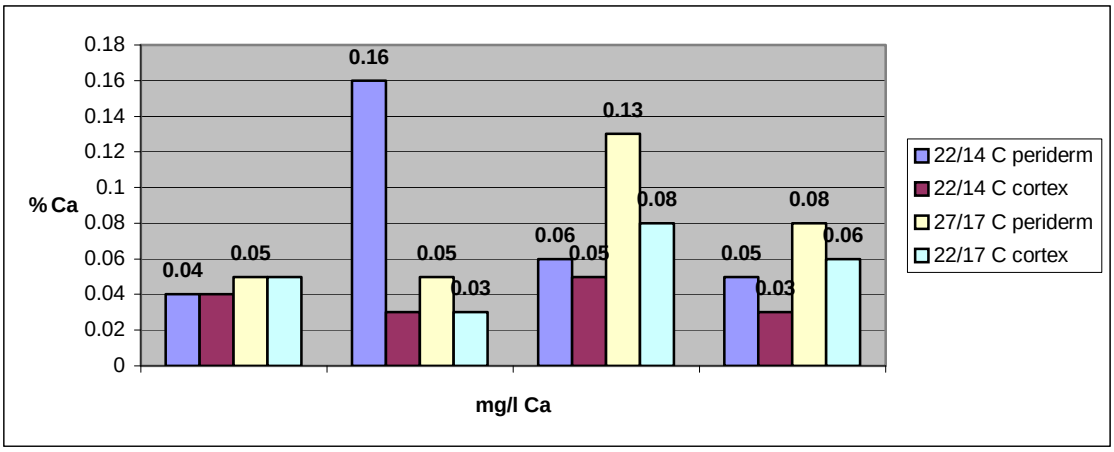


Figure 6.12: Tuber calcium content measured at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity

The tuber chemical analysis was done only on one replicate and thus the statistical analysis was not done. The calcium content of the periderm (A) was higher than that of the cortex (B) except for the control (Figure 6.12). The calcium content of the periderm was also reported to be higher than that of the cortex (Olsen *et al*., 1996). The high calcium content of the periderm can be attributed to the direct availability of calcium in the soil, which suggests that the tubers can absorb calcium directly from the soil solution (Olsen *et al*., 1996; Davies, 1998). Walworth & Muniz (1993) report the calcium content of 0.02 to 0.04 % to be sufficient for the potato tubers, which agrees with the findings of this study. The results have shown that a further increase in the calcium application rate (704 mg/l) has no positive effect on the tuber calcium content. The high calcium content of the tubers was obtained at high humidity (85 %) (Figure 6.12) relative to low humidity (35 %) (Figure 5.9). The highest calcium content at 176 mg/l Ca might be owing to analytical error. Applying higher calcium rates as well as increasing temperature (27/17 ^{o}C) and humidity (85 %) improved calcium uptake by the tubers.

6.3.11 Tuber internal quality tests

Tuber internal quality tests were done to determine how applying increasing levels of calcium (in calcium rich water) at 27/17 ^{o}C and 22/14 ^{o}C controlled temperatures and maintained at high (85 %) humidity, affected the tuber quality.

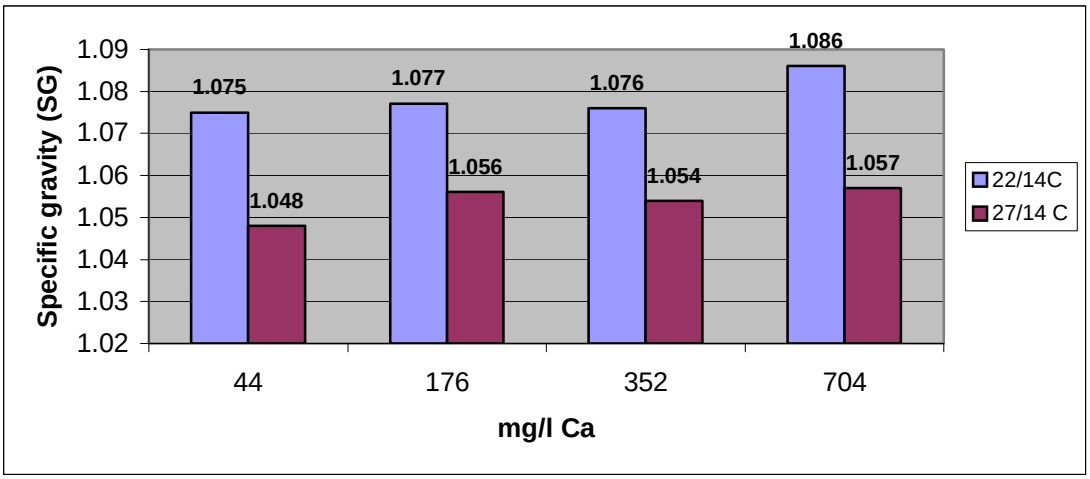


Figure 6.13: Tuber quality determined by specific gravity at 22/14 ^{o}C and 27/17 ^{o}C controlled temperature at 85 % humidity

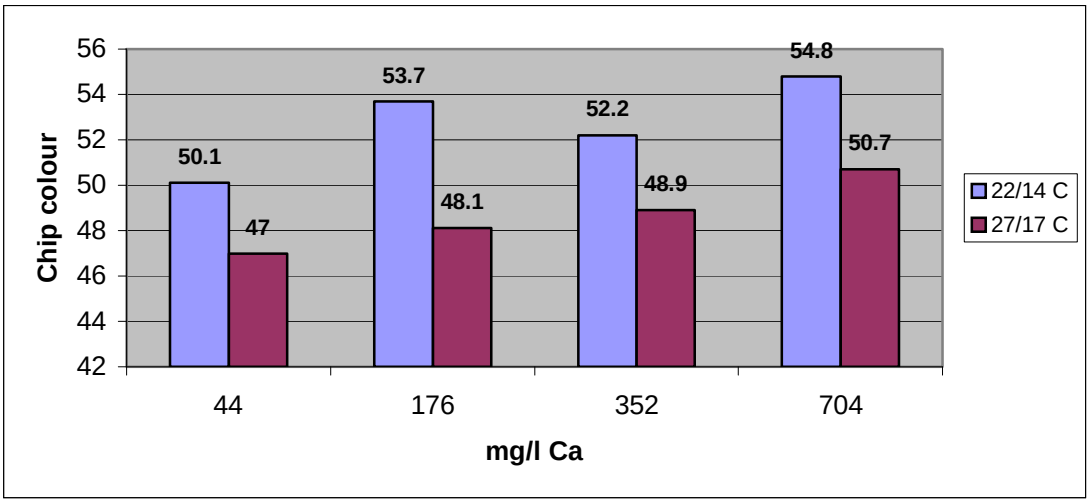


Figure 6.14: Tuber quality determined by chip colour at 22/14 ^{o}C and 27/17 ^{o}C controlled temperatures at 85 % humidity

Referring to Figures 6.13 & 6.14, the tuber quality tests indicate that for both specific gravity (> 1.075) and chip colour (> 45) good quality tubers occurred at a lower (22/14 ^{o}C) temperature and the application of higher levels of calcium. Specific gravity and chip colour values were slightly lower at high (27/17 ^{o}C) controlled temperatures. A similar trend was also observed at low humidity (35 %) (Figures 5.10 & 5.11). The specific gravity (> 1.075) and the chip colour values (> 45) obtained at 22/14 ^{o}C indicated that good quality tubers, acceptable to the chip processing industry were produced. Higher specific gravity and chip colour values were obtained at high controlled humidity (85 %) (Figures 6.13 & 6.14) as opposed to low humidity (35 %) (Figures 5.10 & 5.11). There was a benefit in applying

additional calcium, and lowering the temperature (22/14 ^{o}C) and increasing humidity (85 %) to improve the tuber quality.

6.4 CONCLUSIONS

Applying increased levels of calcium at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures maintained at high humidity (85 %) did not have any negative impact on the potato crop growth and quality.

Plants grew taller at high (27/17 ^{o}C) controlled temperature, compared to low (22/14 ^{o}C) controlled temperatures at high (85 %) humidity. However, the plant growth was stunted (85 % humidity) compared to plants grown at 35 % humidity. Lowering humidity (35 %) had a positive effect on the total leaf area compared with high humidity (85 %). The results indicated that the leaf dry mass might be increased by lowering humidity (35 %) and increasing the temperature (27/17 ^{o}C). The stem dry mass was not significantly influenced by temperature treatments. High tuber dry mass was obtained at low humidity (35 %) compared with high humidity (85 %). It can be concluded that lowering the temperature (22/14 ^{o}C) and humidity (35 %) has a beneficial effect on the tuber yield. Applying higher calcium rates as well as increasing temperature (27/17 ^{o}C) and humidity (85 %) improved calcium uptake by the tubers. There was a benefit in applying additional calcium, and lowering the temperature (22/14 ^{o}C) and increasing humidity (85 %) to improve the tuber quality.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

Calcium is important in maintaining cell wall stability (Ilyama *et al*., 1994). Potato (*Solanum tubersolum L*.) tubers have low levels of endogenous calcium compared with other vegetative parts (Davies & Millard, 1985). Low calcium content of the tubers might be due to the immobility of calcium in the phloem and limited calcium transport to the potato tuber because of the tuber's displacement from the main transpiration stream (Kratzke & Palta, 1986; Simmons *et al*., 1988). Low tuber calcium concentrations have been associated with internal brown spot (IBS) of the potato tuber, which is a physiological disorder, causing necrotic cells in the medullary tissue (Olsen *et al*., 1996).

In recent research, various calcium sources have been used to apply additional calcium to plants to determine how it affects the amount of calcium accumulated by the tubers (Simmons *et al*., 1988; Silva *et al*., 1991; Locascio *et al*., 1992). The effluent from coalmines on the Mpumalanga Highveld can possibly be used for irrigation as a source of calcium. For the current study, commercial trials (2001 and 2002) were established at Kleinkopje mines to monitor irrigation with gypsiferous water. This was done to determine the impact of irrigation with gypsiferous mine water as a calcium source on potato yield and quality.

The results indicated that irrigation with gypsiferous mine water as a calcium source seemed not to have a negative impact on the overall potato growth (as shown in Figure 3.2). The leaf dry mass was consistently higher than the stem dry mass (Figures 3.3a & 3.3b). These findings were confirmed by Wheeler *et al*. (1986) and Steyn *et al*. (1992). The leaf area, leaf and stem dry mass obtained in 2001 were higher as compared with the 2002 season (Figure 3.1; Figures 3.3a & 3.3b). Tuber dry mass increased rapidly with the number of days after planting, which was also evidenced by Steyn *et al*. (1992). During the growing season the tuber dry mass was highest in 2001, except for the final harvest. The total dry mass also took the same pattern as the tuber dry mass (Figure 3.4). Irrigation with gypsiferous mine water (high in calcium) did not seem to suppress the uptake of other nutrient elements, as

shown by leaf and tuber chemical analysis results (Tables 3.1a & 3.1b; Table 3.2). There were no signs of nutrient deficiencies during both seasons (Tables 3.1a & 3.1b) and all the nutrients were within the acceptable ranges for potatoes (Bennet, 1993; Walworth & Muniz, 1993).

The calcium content of the leaves was higher than that of the tubers (Table 3.1b; Table 3.2). This agrees with the findings of Davis & Millard (1985); Simmons *et al*. (1988); Olsen *et al*. (1996) and Spillman (2003). The calcium content of the periderm was higher compared to the medullary tissue. Higher calcium content of the periderm could be attributed to the direct availability of calcium in the soil, which suggests that tubers can absorb calcium directly from the soil solution, as reported by Olsen *et al*. (1996) and Davies (1998).

During the growing season, more tubers were formed in the 2001 season as compared with 2002. However, during the final harvest more tubers were obtained in 2002 (Appendix, Tables A1.1 & A1.2). High marketable yields were obtained during the 2002 season (62 t/ha) as compared with the 2001 season (52 t/ha). Lower marketable tuber yields in 2001 could be due to a small percentage of tuber malformation (< 5%) observed at harvest (Figure 3.5). Lower marketable tuber yields during 2001 were attributed to a lack of irrigation during the late tuber bulking phase in December 2001. There was no irrigation for two weeks in December because the electrical cables on the centre pivot had been stolen. However, these yields (62 t/ha) in the 2002 season and (52 t/ha) in the 2001 season can be regarded as very good yields for the Mpumalanga Highveld. This agrees with the findings of Niederwieser *et al*. (1999) that potato tuber yields of 48 t/ha can be expected in this area for a planting date of around the end of August and beginning of September.

Irrigation with gypsiferous mine water resulted in good quality tubers. This was indicated by the high specific gravity [(> 1.075) 1.087 in 2001 and 1.075 in 2002] and chip colour values [(> 45) 50.8 in 2001 and 50.2 in 2002] obtained (Table 3.3). The values indicated that the tubers can be accepted by the chip processing industry. Higher specific gravity values were obtained in 2001 than in 2002. However, the quality results were opposite to the yields obtained in 2001 (52 t/ha) and 2002 (62 t/ha). It was discovered that irrigation with gypsiferous mine water has no negative

effect on potato growth or yield and quality. Irrigation with this water resulted in high tuber yields of good quality. This implies that gypsiferous mine water can possibly be used as a calcium source for the irrigation of potatoes. Unfortunately no control fields (irrigated with normal water) were available for direct comparison. South Africa has limited water resources and there is an increasing demand for water. There is therefore a great opportunity for farmers to use this calcium rich effluent from coal mines on the Mpumalanga Highveld for irrigation.

At Kleinkopje Collieries, there were no control fields for direct comparison. A trial was conducted in Hatfield, where gypsum was applied as a preplant broadcast at four levels (3 (control), 6, 15, 40 t/ha of gypsum). The 40 t/ha gypsum was equivalent to the amount of calcium in gypsiferous mine water at Kleinkopje. The trial was conducted in a different environment (Hatfield) and thus was not a direct comparison. However, it could give an indication of how the application of increasing levels of gypsum could influence the tuber yield and quality.

Applying additional calcium to the plants did not have any positive effect on the number of stems, stolons and tubers formed (Appendix, Table A 1.3). Applying highest gypsum level (40 t/ha) resulted in lower maximum leaf area values (Appendix, Table A1.3; Figure 4.1) as compared with potatoes irrigated with gypsiferous mine water. (54 303 cm^2 in 2002 and 68 296 cm^2 in 2001) (Figure 3.1; Appendix, Tables A1.1 & A1.2). Leaf area was not positively influenced by increasing gypsum application rates.

The leaf dry mass was considerably higher than the stem dry mass (Appendix, Table A1.3). Similar results were obtained when potatoes were irrigated with gypsiferous mine water (Appendix, Tables A1.1 & A1.2). These findings were confirmed by those of Wheeler *et al*. (1986) and Steyn *et al*. (1992). The highest leaf dry mass (402 g/m^2) was obtained when 40 t/ha of gypsum was applied. The value was lower than when potatoes were irrigated with gypsiferous mine water (478 g/m^2 in 2001 and 427 g/m^2 in 2002) (Appendix, Tables A1.1 & A1.2). The highest stem dry mass (251 g/m^2 and 298 g/m^2) obtained in the Hatfield trial was higher compared to the Kleinkopje trial (255 g/m^2 in 2001 and 129 g/m^2 in 2002) (Appendix, Tables A1.1, A1.2 & 1.3). The values obtained by Steyn *et al*. (1992) were slightly lower

compared with these trials. There were indications that applying higher gypsum levels has a positive effect on the leaf and stem dry mass. The total dry mass increased with an increase in days after planting; however, the mass remained almost constant from 80 days after planting (Figure 4.5; Appendix, Table A1.3). For the plants irrigated with gypsiferous water, the total dry mass increased continuously until harvest (Figure 3.4). Steyn *et al*. (1992) also reported a continuous increase in the tuber dry mass during the growing season. There were indications that increased gypsum levels have a positive effect on the tuber dry mass and the total dry mass. Applying increasing gypsum rates (high calcium levels) did not have a negative influence on the uptake of other nutrient elements (Table 4.1). All the nutrient levels were within the acceptable ranges for potatoes (Bennet, 1993). Applying additional calcium had a positive effect on the calcium levels of the leaves.

An average marketable yield of 52 t/ha was obtained (Figure 4.6), which can be regarded as a good yield for Hatfield, as evidenced by Niederwieser *et al*. (1999). The tuber size and numbers were not positively influenced by the gypsum rates applied (Figure 4.7). These findings were confirmed by Sterrett & Henninger (1991). The findings also indicated that applying higher gypsum levels (15 t/ha) might significantly increase the yield; however, further increase in gypsum (40 t/ha) might not significantly increase the tuber yield. The tuber yields were higher when plants were irrigated with gypsiferous mine water (62 t/ha in 2002). The calcium content of the tubers was lower as compared with the leaves (Table 4.1; Figure 4.8). Similar results were found when the potatoes were irrigated with gypsiferous mine water (Tables 3.1a & 3.1b; Table 3.2). These findings were confirmed by Davis & Millard (1985); Simmons *et al*. (1988); Olsen *et al*. (1996) and Spillman (2003). The calcium content of the periderm was higher than that of the cortex. However, at 3 and 15 t/ha the contents were equal (Figure 4.8). Sufficient tuber calcium levels were obtained, which agree with the norm according to Walworth & Muniz (1993). The results gave indications that applying additional calcium to the potato plants might result in improved calcium content of the tubers. These findings were also evidenced by Kratzke & Palta (1986) and Spillman (2003).

Applying increasing gypsum levels had a positive effect on the tuber specific gravity, whereas the chip colour was not positively influenced by further increase in gypsum

levels (15 t/ha and 40 t/ha) (Figures 4.9 & 4.10). Increasing gypsum levels (6 t/ha, 15 t/ha and 40 t/ha) also had a beneficial effect on the tuber quality.

The general plant growth was not negatively influenced by applying gypsum as a preplant broadcast. Similar findings emerged when potatoes were irrigated with gypsiferous mine water. The leaf area was not positively influenced by applying increasing gypsum levels. However, applying higher gypsum levels had a detrimental effect on the leaf, stem and tuber dry mass and the total dry mass. There were indications that applying additional gypsum might increase the tuber yields; however, further increases in gypsum (40 t/ha) might not have any positive effect. The tuber yields (62 t/ha in 2002) irrigated with gypsiferous mine water (Kleinkopje) out-yielded tubers where gypsum was applied as a preplant broadcast (Hatfield). Applying gypsum as a preplant broadcast (40 t/ha) resulted in higher calcium content of the tubers as compared with irrigation with mine water. There was an opportunity of applying gypsum to potato plants to increase the calcium content of the tubers. Calcium applied to the region of tuber formation has a great impact on improving the tuber calcium content. However, irrigation with mine water improved chip colour and specific gravity (2001 season) more than when gypsum was applied as a preplant broadcast.

Two pot trials were conducted under controlled conditions, because calcium uptake is not affected only by the amount of calcium applied or the location of the calcium application. Factors that affect calcium uptake such as temperature and humidity also play a role. The pot trials were conducted at low (22/14 ^{o}C) and (27/17 ^{o}C) high controlled temperatures at 35 % and 85 % humidities (separate glasshouses).

At both humidities (35 % and 85 %), plants were growing taller at high temperature (27/17 ^{o}C) as compared with low temperature (22/14 ^{o}C) (Figures 5.1 & 6.1). The results agree with the findings of Dawes *et al*. (1983); Khedher & Ewing (1985) and Struik *et al.* (1989), also showed an increase in stem length to be favoured by high temperatures. The plant growth was stunted at 85 % humidity as compared with low humidity (35 %). Similar findings were produced by Wheeler *et al*. (1989), namely that reducing humidity has a positive effect on the stem and foliage growth.

However, an increase in stem length did not show any relation to the increase in calcium levels.

The leaves were narrower at 27/17 ^{o}C and thicker at 22/14 ^{o}C at both humidity levels (Figures 5.2 & 6.2). The results agree with the findings of Khedher & Ewing (1985); Struik *et al*. (1989) and Tadesse *et al*. (2001). Generally the leaf sizes were larger at 85 % humidity compared to 35 % (Figure 6.2; Figure 5.2). However, the application of average calcium rates (176 and 352 mg/l) resulted in a significant increase in the total leaf area. A further increase in calcium level (702 mg/l) had no positive effect (Figures 5.3a & 5.3b; Figures 6.3a & 6.3b). A similar trend was found by El-Beltagy *et al*. (2002). In contrast, applying high calcium levels at high temperatures (27/17 ^{o}C) seemed to have a positive effect on the total leaf area for plants grown at 85 % humidity (Appendix , Table A1.7). The leaves were found to be narrower at 27/17 ^{o}C but the total leaf areas were higher than at low temperatures (22/14 ^{o}C) when plants were grown at 35 % humidity (Figures 5.3a & 5.3b). Manrique (1990) also confirmed these findings. On the contrary, at 85 % humidity the total leaf areas were lower at 27/17 ^{o}C as opposed to 22/14 ^{o}C (Appendix , Tables A1.6 & A1.7). Generally the total leaf areas were significantly higher at 35 % humidity as compared with 85 % humidity (Figures 5.3a & 5.3b; Figures 6.3a & 6.3b).

At 35 % humidity, a relatively higher leaf dry mass was obtained at 27/17 ^{o}C as compared with 22/14 ^{o}C (Appendix , Tables A1.4 & A1.5). This agrees with the findings of Khedher & Ewing (1985) and Wheeler *et al*. (1986). Contradicting results were found at 85 % humidity where the leaf dry mass was relatively higher at 22/14 ^{o}C as opposed to 27/17 ^{o}C (Appendix, Table A1.6 & A1.7). Low relative humidity 35 % had a detrimental effect on the leaf dry mass as compared with high humidity (85 %) (Figures 5.5a & 5.5b; Figures 6.5a & 6.5b). The stem dry mass was not significantly influenced by the temperature treatments at both low and high humidities. Khedher & Ewing (1985) also found the highest stem dry mass at high temperature. Wheeler *et al*. (1986) also confirmed these findings. The stem dry mass was higher at low humidity (35 %) as compared with high humidity (85 %) (Figures 5.6a & 5.6b; Figures 6.6a & 6.6b). The tuber dry mass increased form initiation until harvest at both levels of humidity (Figures 5.7a & 5.7b; Figures 6.7a & 6.7b). A similar pattern was obtained in the field trials at Kleinkopje (Figures 3.3a & 3.3b) and

Hatfield (Figure 4.4). These results were also confirmed by the findings of Steyn *et al*. (1992). A low temperature (22/14 ^{o}C) had a positive effect on the tuber dry mass (Figures 5.6a & 5.6b; Figures 6.6a & 6.6b). These results were confirmed by Khedher & Ewing (1985). At 35 % humidity the tuber dry mass was higher at high calcium levels (704 and 352 mg/l), whereas at 85 % humidity a significant increase in tuber dry mass at high calcium level was only found at 27/17 ^{o}C. In general, the highest tuber dry mass was obtained at low humidity (35 %) (Figures 5.7a & 5.7b) as compared with high humidity (85 %) (Figures 6.7a & 6.7b).

At both humidities (35 % and 85 %) the total dry mass was higher at 22/14 ^{o}C than at 27/17 ^{o}C. (Figures 5.7a & 5.7b; Figures 6.8a & 6.8b). The significant increase in the total dry mass at cool temperature was also evidenced by Manrique (1990). The high total dry mass was due to high calcium application levels (352 and 704 mg/l) when plants were grown at low temperature. To the contrary, at 85 % humidity applying high calcium rates at 27/17 ^{o}C temperature seemed to have a positive effect on the total dry mass (Appendix, Table A1.7). Low humidity (35 %) also had a positive effect on the total dry mass as compared with high humidity (85 %). However, these findings contradicted the discovery of Wheeler *et al*. (1986), where the increase in the total dry mass was favoured by high humidity.

Applying additional calcium to the plants maintained at 22/14 ^{o}C and 27/17 ^{o}C at both 35 % and 85 % humidity did not suppress the uptake of other nutrients in the leaves (Tables 5.1 & 6.1). There were no signs of any nutrient deficiencies and all the nutrients were within the acceptable ranges for the potatoes (Bennet, 1993). There were indications that applying high calcium levels might have a detrimental effect on the calcium content of the leaves, whereas further increase in calcium might not have a positive effect (Table 6.1). The calcium content of the leaves was relatively higher at 22/14 ^{o}C as compared with high temperatures. High humidity resulted in the improved nutrient uptake by the tubers (including calcium), especially at 22/14 ^{o}C. The results indicated the beneficial effect of applying high calcium levels on the tuber yield (Figures 5.9 & 6.9). Locascio *et al*. (1992) also produced similar results. At both levels of humidity (35 % and 85 %), low temperatures (22/14 ^{o}C) seemed to increase the tuber yield as compared with high temperatures (27/17 ^{o}C).

High tuber yields were produced at 35 % humidity at low temperature (22/14 ^{o}C). However, at 85 % humidity, yields were higher when plants were maintained at 27/17 ^{o}C temperature. It can be concluded that tuber yields could be improved from lowered temperatures (22/14 ^{o}C) and humidity (35 %). Sufficient tuber calcium content was obtained within the range of 0.02 to 0.045 %, as reported by Walworth & Muniz (1993). However, the calcium contents were lower at high temperature when plants were maintained at low humidity (35 %). Increasing temperature (27/17 ^{o}C) and humidity (85 %) improved calcium uptake by the tubers (Figure 6.12). There were indications that applying high calcium levels might increase the calcium content of the tubers. Lowering the temperature (22/14 ^{o}C) resulted in improved tuber quality as indicated by high specific gravity (> 1.075) and high chip colour values (> 45) (Figures 5.10 & 5.11; Figures 6.13 & 6.14). The results indicated that tubers of good quality were produced which are acceptable to the chip processing industry. Poorer quality tubers resulted owing to high temperatures. However, the results have shown the beneficial effect of maintaining potatoes at high humidity and low temperature as well as applying higher calcium levels on the tuber quality. It can be concluded that calcium translocation in the potato plant is not only affected by the temperature but the transpiration rate as well.

CHAPTER 8

SUMMARY

Two field experiments and two pot experiments were conducted to determine how applying additional calcium to potato crops affect tuber calcium content, yield and quality.

The commercial trials at Kleinkopje Colliery (August 2001 and September 2002) were established under centre pivots for irrigation with gypsiferous mine water. In both seasons, irrigation with gypsiferous mine water as a calcium source had no negative impact on potato crop growth, tuber yield and quality. Irrigating potatoes with gypsiferous mine water did not affect other nutrient element levels, as shown by the leaf and the tuber chemical analysis results. According to Bennet (1993) and Walworth & Muniz (1983) the nutrient levels were within acceptable ranges for potatoes. High tuber yields were produced in both seasons (52 t/ha in 2001 and 62 t/ha in 2002). According to Niederwieser *et al*. (1999) potato tuber yields of about 48t/ha can be expected in this area. Irrigation of potatoes with this mine water also resulted in good quality tubers as indicated by high specific gravity values (>1.075) and chip colours (> 45). Specific gravity and chip colour values were highest during 2001 (SG = 1.087 and chip colour 50.8), compared with the 2002 season (SG = 1.075 and chip colour 50.2), which were in contrast to the yields obtained for these seasons. There were slight variations in yield, tuber quality and crop growth at this two seasons and this could be due to different climatic conditions for each season. The potato crops were successfully irrigated with gypsiferous mine water to produce high tuber yields of good quality, and this mine water can therefore be recommended for the irrigation of potatoes as a calcium source. Unfortunately no control fields (farms nearby irrigated with normal water) were available for comparison at Kleinkopjie mines.

Another field trial was established at the University of Pretoria Experimental Farm where gypsum was applied at four levels (3, 6, 15 and 40t/ha) as a preplant broadcast (including top dressing). The highest gypsum level had a calcium content equivalent to that of gypsiferous mine water from the mines. Applying increasing gypsum rates

did not have a positive effect on the number of stems, stolons, tubers and the total leaf area. However there were indications that applying higher gypsum levels had a positive effect on the stem and leaf dry mass. The higher levels of gypsum seemed to have a detrimental effects on the tuber dry mass and total dry mass. The application of higher gypsum levels was evidenced by leaf and tuber chemical composition not to have any negative impact on the other nutrients levels, hence all the nutrient elements were within the acceptable ranges for potatoes. An average marketable yield of 52 t/ha was obtained, which is regarded as good yield for Hatfield. According to Niederwieser *et al*. (1991) marketable tuber yields around 44 t/ha can be expected in this area. Applying higher gypsum levels resulted in good quality tubers (SG > 1.075 and chip colour > 45). Gypsum can possibly be used as a calcium source to increase the amount of calcium accumulated by the tuber to improve its tuber yield and quality.

The calcium nutrition of the potato crop is not only affected by the amount of calcium applied to the tubers, but also the calcium uptake and distribution within the plant, which are influenced by temperature and humidity. Two pot experiments were established where the potato crops were irrigated with increasing calcium levels in calcium rich water at high (27/17 ^{o}C) and low (22/14 ^{o}C) controlled temperatures maintained either at high (85 %) or low (35 %) humidity.

The plants were more stunted at 85 % humidity and the growth was quite rapid at 35 % humidity. High temperature (27/17 ^{o}C) promoted stem growth at both humidities. The leaves were narrower and lighter in colour at 35 % humidity than at 85 % humidity where leaves were thicker and darker in colour. At both humidities the leaves were thicker at low temperatures (22/14 ^{o}C) and narrower at 27/17 ^{o}C controlled temperature. Lowering humidity (35 %) had a positive effect on the total leaf area as compared to high humidity (85 %). The total leaf areas were high at high temperature (27/17 ^{o}C) when plants were grown at low humidity (35 %). In contrary at high humidity (85 %) leaf area were lower at high temperature (27/17 ^{o}C) as compared to low temperature (22/14 ^{o}C). Applying average calcium rates had a positive effect on the total leaf area. Low relative humidity (35 %) had a detrimental effect on the leaf dry mass compared to high humidity (85 %) (Figures 5.5a & 5.5b; Figures 6.5a & 6.5b). Low humidity also had a positive effect on the stem dry mass (Figures 5.6a & 5.6b; Figures 6.6a & 6.6b). There was a beneficial effect from a

lowered temperature (22/14 ^{o}C) and humidity (35 %) on the increase of the tuber dry mass and the total dry mass.

Applying additional calcium to the plants maintained at low and high controlled temperatures at both 35 % and 85 % humidity, did not affect the leaf and the tuber nutrient levels. All the nutrients were within the acceptable ranges for potatoes. There was a beneficial effect from a lowered temperature (22/14 ^{o}C) and increased humidity (85 %) on the calcium uptake by the leaves. The calcium contents of the leaves were higher than that of the tubers. High humidity (85 %) and temperature (27/17 ^{o}C) improved the calcium uptake by the tubers. Applying higher calcium levels resulted in improved tuber yield. Lowered temperature and humidity (35 %) had a beneficial effect on the tuber yields.

Applying higher calcium rates had a beneficial effect on the tuber quality (SG > 1.075 and chip colour > 45). Low temperature resulted in good quality tubers compared to high temperature. High controlled humidity (85 %) also resulted in better tuber quality than 35 % humidity. Maintaining potato plants at low temperature and high humidity could improve the tuber quality. Applying additional calcium to the potato plants can increase calcium accumulation in the tubers and result in improved tuber quality.

APPENDIX A

Table A1.1: Growth analysis results (Kleinkopje 2001)

Sample no.	DAP	Number of				Fresh mass (g/m^2)		Dry mass (g/m^2)			TDM(g/m^2)
		Plants	Stems	Stolons	Tubers	Leaf area (cm^2)	Tuber	Tuber	Leaf	Stem	
1	47	8	17	52		6960.72			63.51	11.8	
2		7	24	56		9701.32			118.4	27.14	
3		5	20	63		11874.61			100.87	26.35	
AVE		7	20	57		9512.22			94.26	21.76	116.02
1	62	8	24	50	9	24248.39	56.23	8.27	240.99	71.12	
2		6	32	54	20	27776.38	87.1	10.86	168.35	108.56	
3		6	27	58	22	24248.39	96.11	14.09	246.35	81.46	
AVE		7	28	54	17	25424.39	78.81	11.07	218.56	87.05	316.68
1	76	6	28	62	48	35518.88	631.66	144.36	384.72	94.36	
2		6	32	68	52	51789.88	598.37	136.89	496.33	149.81	
3		7	30	66	46	46918.88	695.33	154.8	414.56	138.87	
AVE		6	30	65	49	44742.55	461.79	145.35	431.87	127.68	704.9
1	89	7	30	72	74	72132.69	2001.61	511.33	512.34	223.45	
2		7	35	66	66	67207.29	1894.23	446.96	489.36	293.46	
3		8	32	68	62	65550.97	1778.42	396.73	432.86	250.25	
AVE		7	33	69	67	68296.98	1891.4	451.67	478.19	255.72	1185.58
1	130	5	26	86	78	17031.22	5974.9	1461.95	393.26	164.5	
2		6	24	92	90	18988.26	6646.7	1577.48	417.04	244.28	
3		5	29	44	38	11549.62	4516	1176.88	179.77	164	
AVE		5	26	74	68	15845.37	5712.53	1405.47	330.02	190.93	1926.42

Table A1.2: Growth analysis results (Kleinkopje 2002)

Sample no.	DAP	Number of				Fresh mass (g/m^2)			Leaf area(cm^2)	Dry mass (g/m^2)			TDM (g/m^2)
		Plants	Stems	Stolons	Tubers	Tuber	Leaf	Stem		Tuber	Leaf	Stem	
1	46	6	7	30			276.85	91.66	4754.51		46.28	8.38	
2		5	8	24			234.32	87.02	3336.26		34.73	6.89	
3		7	8	21			184.44	66.84	3305.18		29.23	5.84	
AVE		6	8	25			231.87	81.77	3798.65		36.75	7.04	43.79
1	64	7	7	47	2	7.68	1260.64	929.65	17476.3	1.09	134.24	56.24	
2		8	8	56	2	7.22	1257.74	903.62	17355.02	1.06	133.79	55.4	
3		8	9	54	3	16.02	1375.51	1039.84	17626.68	2.24	149.79	63.97	
AVE		8	8	52	2	10.31	1297.96	957.7	17486	1.46	139.27	58.54	199.27
1	86	6	16	49	34	1183.74	1593.19	1756.29	54489	185.51	263.33	143.9	
2		7	14	44	29	663.14	1193.3	1185.5	54030	125.22	172.58	102.19	
3		7	15	52	17	558.78	1793.16	1775.71	56390	103.43	306.78	141.03	
AVE		7	15	48	27	827.63	1508.55	1572.31	54303	138.05	427.56	129.04	694.65
1	135	5	12	38	64	2794.9	1411.66	1400.11	17321.11	558.92	211.32	128.39	
2		6	10	41	78	2399.6	1034.2	980.11	18113.22	485.13	169.67	100.31	
3		5	14	44	72	3190.25	1701.32	1689.31	20011.66	632.7	284.11	122.37	
AVE		6	12	41	71	8384.75	1382.39	1356.51	18481.99	1676.75	211.6	117.02	2015.37

Table A1.3: Growth analysis results (Hatfield field experiment)

Treatment	DAP	Number of				Fresh mass (g/m^2)			Leaf area(cm^2)	Dry mass (g/m^2)			
		Plants	Stems	Stolons	Tubers	Tuber	Leaf	Stem		Tuber	Leaf	Stem	TDM(g/m^2)
3t/ha	43	6	16	23			163.21	134.21	9193.34		95.18	25.98	121.2
6t/ha		6	16	30			218.32	214.06	7752.01		72.17	20.31	92.48
15t/ha		7	18	10			194.17	232.24	8716.48		69.01	18.92	87.93
40t/ha		7	16	8			174.31	200.11	8782.18		86.74	25.88	112.6
3t/ha	61	7	24	27	16	85.69	244.65	147.58	20635.74	12.08	128.94	48.32	189.3
6t/ha		7	22	34	26	87.89	307.41	250.85	19040.33	12.46	136.33	54.93	203.7
15t/ha		7	22	12	8	28.45	280.35	277.41	17449.89	13.55	142.61	59.33	215.5
40t/ha		7	24	8	3	22.04	248.86	247.14	17346.33	13.87	151.12	63.11	228.1
3t/ha	78	6	30	42	32	626.63	276.09	246.58	34396.65	269.91	345.11	251.11	1866.1
6t/ha		6	30	42	35	651.15	365.45	382.99	32658.98	346.68	362.86	294.89	1004
15t/ha		6	31	34	22	990.98	319.96	209.19	32172.38	318.39	373.71	282.42	974.5
40t/ha		6	30	38	18	732.77	276.03	233.34	34972.88	305.41	402.31	298.15	1006
3/ha	121	7	30	43	38	936.29	264.32	210.11	22372.31	396.53	287.34	156.77	840.9
6t/ha		7	31	43	39	1026.39	341.62	317.32	20321.78	461.31	279.91	160.33	901.6
15t/ha		6	30	37	29	1030.76	284.37	194.32	20005.99	488.73	311.27	168.14	968.1
40t/ha		6	30	33	23	1032.26	266.32	214.32	22944.73	572.37	331.32	206.42	1110

	Fresh mass				**Dry mass**			
	Leaf area	Leaf	Stem	Tuber	**Leaf**	**Stem**	**Tuber**	TDM
SEM	509.4	4.86	23.4	60.1	7.04	6.54	24.4	33.4
CV%	50.0	3.7	20.2	17.2	6.3	9.8	16.0	8.2
$LSD_{(p=0.05)}$	-	15.55	74.8	-	22.52	-	-	-
Fpr	0.063	<0.001	0.060	0.501	0.049	0.084	0.318	0.096

Table A 1.4: Growth analysis (Hatfield pot experiment, plants maintained at 22/14 ^{o}C at 35 % humidity)

Treatment mg/l Ca		Number of				Fresh mass (g/trt)				Dry mass (g/trt)			
	DAP	Plants	Stems	Stolons	Tubers	Tuber	Leaf	Stem	Leaf area(cm^2)	Tuber	Leaf	Stem	TDM(g/trt)
44	33	1	1	23			163.21	134.21	1140.31		16.12	18.37	34.49
176		1	1	30			218.32	214.06	1314.31		21.99	24.35	46.34
352		1	1	10			194.17	232.24	1234.69		20.06	26.31	46.37
704		1	1	10			174.31	200.11	1020.22		18.62	20.14	38.76
44	57	1	1	27	16	85.69	244.65	147.58	5211.9	13.02	32.2	21.74	66.96
176		1	1	34	16	87.89	307.41	250.85	6362.7	13.45	50.04	25.86	89.35
352		1	1	12	18	88.45	280.35	277.41	6549.8	15.76	34.32	28.79	78.87
704		1	1	10	13	82.04	248.86	247.14	5177.75	14.79	41.76	21.48	78.03
44	89	1	1	42	32	626.63	276.09	246.58	7836.38	106.58	47.19	63.39	217.2
176		1	1	42	35	651.15	365.45	382.99	10149.45	116.68	62.59	73.29	252.5
352		1	1	34	22	990.98	319.96	209.19	8870.81	222.35	47.93	72.7	343
704		1	1	38	18	732.77	276.03	233.34	8524.46	147.71	47.45	78.71	345.2
44	121	1	1	43	38	936.29	264.32	210.11	4879.32	210.31	36.31	57.33	304
176		1	1	43	39	1026.39	341.62	317.32	7943.32	237.28	58.61	62.33	358.2
352		1	1	37	29	1030.76	284.37	194.32	6011.31	266.32	43.08	64.32	374.4
704		1	1	33	23	1032.26	266.32	214.32	4877.99	243.21	42.87	70.14	355.2

	Fresh mass				**Dry mass**			
	Leaf area	Leaf	Stem	Tuber	**Leaf**	**Stem**	**Tuber**	TDM
SEM	313.9	4.86	22.9	53.5	1.875	1.854	15.25	19.19
CV%	11.5	3.7	19.7	15.1	9.7	8.1	19.7	13.9
$LSD_{(p=0.05)}$	1004.3	15.55	-	-	6.000	5.931	-	-
Fpr	0.015	<0.001	0.055	0.310	0.001	0.050	0.140	0.138

Table A1.5: Growth analysis (Hatfield pot experiment, plants maintained at 27/17^{o}C at 35% humidity)

Treatment mg/l Ca		**Number of**				Fresh mass (g/trt)				**Dry mass (g/trt)**			
	DAP	**Plants**	**Stems**	**Stolons**	**Tubers**	Tuber	Leaf	Stem	**Leaf area(cm^2)**	**Tuber**	**Leaf**	**Stem**	**TDM(g/trt)**
44	33	1	1	8			110.29	106.32	3787.26	22.83	19.05	41.88	
176		1	1	9			278.96	273.33	5567.93	43.82	35.36	79.16	
352		1	1	8			145.39	193.57	5697.52	21.28	21.98	43.26	
704		1	1	17			227.52	295.89	4525.51	35.76	18.08	53.84	
44	57	1	1	14	4	52.32	163.24	281.37	5588.31	8.88	34.21	22.21	64.31
176		1	1	12	7	70.18	186.31	307.32	5843.87	10.8	53.21	37.36	101.3
352		1	1	12	8	79.85	294.74	387.22	7004.32	13.01	38.62	38.36	89.9
704		1	1	11	8	72.32	240.1	324.29	6774.31	9.87	41.71	32.31	83.8
44	89	1	1	16	10	148.95	363.64	626.2	10349.98	18.38	56.44	65.07	139.8
176		1	1	12	12	163.28	435.93	735.98	12009.99	25.33	67.67	90.96	183.9
352		1	1	14	13	191.29	420.69	568.85	12961.49	32.45	66.11	70.54	169
704		1	1	15	11	187.57	374.85	591.65	11363.29	30.01	56.68	67.43	154
44	121	1	1	17	11	216.55	321.23	583.75	8148.39	58.08	52.31	61.04	171.4
176		1	1	12	10	217.28	416.93	661.37	11413.32	59.35	62.31	68.31	189.9
352		1	1	15	13	311.75	401.12	541.85	11637.32	72.14	60.82	62.31	195
704		1	1	15	11	456.07	360.85	563.81	10937.67	80.75	52.38	64.33	197

	Fresh mass				**Dry mass**			
	Leaf area	Leaf	Stem	Tuber	**Leaf**	**Stem**	**Tuber**	TDM
SEM	307.2	22.6	30.3	34.5	2.62	2.60	3.19	4.62
CV%	7.4	15.2	13.8	33.0	11.0	10.7	19.7	5.5
$LSD_{(p=0.05)}$	982.8	-	-	-	8.40	8.30	-	15.98
Fpr	0.003	0.083	0.220	0.258	0.016	0.009	0.105	0.010

Table A1.6: Growth analysis (Hatfield pot experiment, plants maintained at 22/14^{o}C at 85% humidity)

Treatment mg/l Ca		**Number of**				Fresh mass (g/trt)				**Dry mass (g/trt)**			
	DAP	**Plants**	**Stems**	**Stolons**	**Tubers**	Tuber	Leaf	Stem	**Leaf area(cm^2)**	**Tuber**	**Leaf**	**Stem**	**TDM(g/trt)**
44	32	1	1	13			23.78	16.61	620.34		12.61	8.71	21.32
176		1	1	15			26.31	18.31	694.33		14.62	9.32	23.94
352		1	1	15			27.32	19.71	732.23		14.89	10.31	25.2
704		1	1	15			28.16	15.88	711.67		15.78	8	23.78
44	55	1	1	16	9	87.34	39.64	22.38	1098.78	27.32	18.61	14.61	50.54
176		1	1	18	10	72.99	42.16	21.66	1100.84	22.18	20.44	16.11	58.73
352		1	1	17	10	82.14	40.96	20.89	1182.61	26.14	19.01	15.14	60.29
704		1	1	17	10	74.34	40.01	18.32	1148.64	24.31	20.31	12.81	57.43
44	85	1	1	18	12	138.71	60.01	29.65	1228.65	42.31	22.54	16.85	82.7
176		1	1	20	12	160.2	63.88	28.03	1232.82	54.61	23.15	17	94.76
352		1	1	19	10	142.2	62.95	27.76	1315.64	49.36	22.69	16.23	88.28
704		1	1	18	12	140.85	56.13	22.85	1235.92	48.52	21.35	13.74	83.61
44	122	1	1	23	24	271.72	37.82	13.93	609.49	86.87	13.71	5.37	108
176		1	1	28	36	285	57.72	16.49	916.65	94.34	14.5	5.42	114.3
352		1	1	32	31	282.13	43.3	14.99	968.98	92.94	13.37	5.39	117.7
704		1	1	23	34	333.72	29.27	12.94	940.83	102.81	13.41	5.35	121.6

		Fresh mass			**Dry mass**			
	Leaf area	Leaf	Stem	Tuber	**Leaf**	**Stem**	**Tuber**	TDM
SEM	35.7	2.82	0.678	11.12	0.439	0.403	2.92	2.29
CV%	7.3	13.3	6.8	11.2	5.0	7.1	9.0	4.6
$LSD_{(p=0.05)}$	982.8	-	2.168	-	-	1.289	-	-
Fpr	0.057	0.183	0.014	0.727	0.271	0.027	0.507	0.102

Table A1.7: Growth analysis (Hatfield pot experiment, plants maintained at 27/17^{o}C at 85% humidity)

Treatment mg/l Ca		**Number of**				Fresh mass (g/trt)				**Dry mass (g/trt)**			
	DAP	**Plants**	**Stems**	**Stolons**	**Tubers**	Tuber	Leaf	Stem	**Leaf area(cm^2)**	**Tuber**	**Leaf**	**Stem**	**TDM(g/trt)**
44	32	1	1	12			20.61	16.01	514.62		10.67	8.32	18.99
176		1	1	14			22.68	20.38	589.31		11.88	10.36	22.4
352		1	1	14			23.94	20.18	689.76		12.79	10.01	22.8
704		1	1	13			21.14	18.69	642.39		13.14	11.37	24.41
44	55	1	1	14	7	36.37	32.61	22.22	874.31	13.31	16.32	14.84	44.47
176		1	1	16	9	39.33	40.61	26.32	833.41	14.88	18.11	16.39	49.38
352		1	1	16	9	40.86	39.01	26.01	882.66	16.32	17.14	16.38	49.84
704		1	1	15	10	43.77	38.32	20.32	992.31	18.32	19.71	14.41	54.45
44	85	1	1	15	9	62.08	54.9	25.74	1191.7	23.65	19.82	17.31	60.78
176		1	1	19	12	68.77	48.28	29.48	1060.86	24.99	19.55	17.33	61.87
352		1	1	16	10	77.57	52.97	29.88	1076.63	26.99	21.24	17.1	65.33
704		1	1	15	11	78.41	59.35	30.04	1164.68	27.86	22.48	17.52	67.46
44	122	1	1	16	14	175.78	32.92	17.67	589.34	48.37	10.98	6.35	66.56
176		1	1	14	19	216.93	37.77	15.38	783.58	52.82	11.8a	5.85	70.51
352		1	1	14	20	255.7	38.31	19.61	868.84	53.75	12.32	6.32	72.39
704		1	1	14	20	229.31	41.42	16.32	884.4	55.56	12.8b	5.93	74.36

		Fresh mass			**Dry mass**			
	Leaf area	Leaf	Stem	Tuber	**Leaf**	**Stem**	**Tuber**	TDM
SEM	39.9	1.490	0.932	9.68	0.303	0.432	0.466	0.507
CV%	9.4	7.8	8.4	15.2	3.9	7.1	2.6	1.4
$LSD_{(p=0.05)}$	-	-	-	-	0.968	-	1.613	1.755
Fpr	0.163	0.133	0.078	0.190	0.001	0.573	<0.001	<0.001

Table A1.8: Tuber chemical analysis (Kleinkopje 2002)

	%							mg/kg			
Sample	**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
KK1A	1.33	0.18	0.03	2.36	0.04	0	0.33	8	51	12	27
KK2A	1.45	0.23	0.03	2.74	0.04	0	0.31	11	39	12	30
KK3A	0.97	0.19	0.03	2.68	0.04	0.01	0.4	9	29	12	38
AVE	**1.25**	**0.2**	**0.03**	**2.59**	**0.04**	**0.03**	**0.35**	**9.33**	**39.7**	**12**	**31.2**
KK1B	1.08	0.19	0.02	2.64	0.04	0	0.52	6	18	12	26
KK2B	1.55	0.26	0.02	2.95	0.05	0	0.78	8	33	11	36
KK3B	1.43	0.22	0.02	2.79	0.04	0	0.49	8	24	11	44
AVE	**4.06**	**0.22**	**0.02**	**2.99**	**0.04**	**0**	**0.6**	**7.33**	**21.7**	**11.3**	**35.31**

Tuber chemical analysis was done on three samples (A-peridem, B-Medullary tissue)

Table A1.9: Tuber chemical analysis (Hatfield field experiment 2002)

(t/hagypsum)	%							Mg/kg			
Treatment	**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
3t/haA	1.56	0.33	0.02	2.44	0.04	0	0.28	8	28	8.5	28
3t/haB	1.33	0.37	0.02	2.59	0.04	0	0.6	8.5	24	12.5	31
6t/haA	1.77	0.29	0.03	2.37	0.03	0	0.44	11.5	70.5	11.5	28.5
6t/haB	1.24	0.34	0.02	2.45	0.04	0	0.53	8.5	11	14	27
15t/haA	0.97	0.19	0.03	2.68	0.04	0.01	0.4	9	29	12	38
15t/haB	0.97	0.19	0.03	2.68	0.04	0.01	0.4	9	29	12	38
40t/haA	1.53	1.39	0.04	2.22	0.03	0	0.52	8	26	6	28
40t/haB	1.48	0.32	0.03	2.27	0.04	0	0.48	7	7.5	7.5	26

A-peridem, B-Medullary tissue

Table A1.10: Tuber chemical analysis (Hatfield pot experiment, plants maintained at 22/14^{o}C and 27/17^{o}C at 35% humidity)

(mg/lCa)		%							Mg/kg			
Treatment		**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
22/14^{o}C	44(A)	0.23	0.24	0.02	2.62	0.04	0.01	0.24	9	11	8	32
	44(B)	1.2	0.16	0.02	2.22	0.04	0.01	0.82	12	32	8	174
	176(A)	2.69	0.16	0.01	1.98	0.04	0.01	0.43	9	21	6	21
	176(B)	1.28	0.19	0.02	1.96	0.04	0.01	0.69	11	20	6	51
	352(A)	3.07	0.25	0.01	1.71	0.03	0.01	0.52	8	12	5	41
	352(B)	1.29	0.39	0.01	1.81	0.04	0.01	0.68	9	44	6	59
	704(A)	2.24	0.22	0.02	2.11	0.04	0	0.5	12	14	5	17
	704(B)	1.34	0.34	0.01	2.34	0.04	0.01	0.45	11	6	6	21
27/17^{o}C	44(A)	1.52	0.43	0.03	3.03	0.05	0.02	0.71	17	48	11	38
	44(B)	2.1	0.52	0.03	3.41	0.06	0.02	1.09	14	29	12	41
	176(A)	1.51	0.57	0.04	3.45	0.05	0.01	1.03	20	47	12	44
	176(B)	3.16	0.58	0.03	3.13	0.05	0.01	1.03	17	20	9	59
	352(A)	1.82	0.36	0.02	2.63	0.04	0.01	0.39	17	20	6	36
	352(B)	1.9	0.48	0.03	2.52	0.04	0.01	0.83	14	14	8	29
	704(A)	1.61	0.41	0.03	2.86	0.04	0.01	0.71	17	59	5	33
	704(B)	1.58	0.44	0.02	2.68	0.05	0.01	0.68	14	29	6	38

A-peridem, B-Medullary tissue

Table A1.11: Tuber chemical analysis (Hatfield pot experiment, plants maintained at 22/14 ^{o}C and 27/17^{o}C at 85% humidity)

(mg/lCa)		%							Mg/kg			
Treatment		**N**	**P**	**Ca**	**K**	**Mg**	**Na**	**SO_4**	**Cu**	**Fe**	**Mn**	**Zn**
22/14^{o}C	44(A)	1.7	0.45	0.04	2.73	0.14	0.02	0.63	11	86	11	29
	44(B)	1.9	0.3	0.04	2.37	0.16	0.02	0.66	9	47	8	56
	176(A)	1.5	0.3	0.16	2.57	0.14	0.02	0.77	11	45	6	33
	176(B)	1.7	0.34	0.03	2.11	0.16	0.01	0.74	9	45	8	29
	352(A)	1.4	0.2	0.06	2.2	0.11	0.02	0.42	9	59	6	30
	352(B)	1.5	0.3	0.05	2.04	0.13	0.01	0.53	9	53	14	41
	704(A)	1.6	0.3	0.05	2.42	0.13	0.01	0.6	11	80	9	21
	704(B)	1.9	0.3	0.03	2.04	0.13	0.01	0.7	15	42	8	51
27/17^{o}C	44(A)	2	0.4	0.05	2.83	0.15	0.03	0.82	14	75	9	33
	44(B)	2	0.4	0.05	2.37	0.14	0.02	0.7	12	126	12	65
	176(A)	2	0.4	0.05	2.57	0.13	0.02	0.84	15	60	8	42
	176(B)	2.1	0.4	0.03	2.3	0.14	0.02	0.72	15	102	8	60
	352(A)	2.1	0.41	0.13	2.23	0.13	0.01	0.86	15	60	9	89
	352(B)	1.8	0.4	0.08	2.35	0.13	0.01	0.76	14	56	8	50
	704(A)	1.7	0.3	0.08	2.03	0.14	0.1	0.73	11	53	9	35
	704(B)	2	0.4	0.06	2.5	0.14	0.02	0.73	17	57	8	29

APPENDIX B

Table B1.1: Soil analysis results (Kleinkopje 2001, before planting)

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g	
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4	Cl
0-30	5.4	441	498.2	0.914	0.361	1.008	0.139	2.396	0.907	1.229	0.148	1.276	0.66
30-60	6.4	110	11.3	0.52	0.029	0.398	0.06	1.587	0.239	1.057	0.114	0.719	0.07
60-90	5.7	88.2	1.2	0.389	0.003	0.294	0.044	0.82	0.066	0.873	0.109	0.471	0.03
90-120	6	95	11.3	0.437	0.05	0.343	0.048	0.992	0.05	0.89	0.113	0.606	0.02
0-30				183.16	141.18	122.49	31.95	479.95	354.72	149.35	34.02	612.70	234
30-60				104.20	11.34	48.36	13.79	318.03	93.47	128.45	26.20	345.24	24.82
60-90				77.95	1.17	35.72	10.11	164.32	25.81	106.09	25.05	266.16	10.64
90-120				87.57	0.782	41.68	11.03	198.79	19.55	108.15	25.97	290.98	7.091

Table B1.2: Soil analysis results (Kleinkopje 2002, before planting)

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
0-20	4.6	304	22.53	0.544	0.082	0.249	0.023	6.067	0.32	0.509	0.161	0.891
20-40	4.6	213	3.83	0.374	0.015	0.096	0.006	4.366	0.127	0.327	0.13	0.568
40-60	4.3	181	2.34	0.28	0.018	0.186	0.01	2.205	0.11	0.541	0.139	0.685
60-80	4.3	219	2.67	0.349	0.012	0.311	0.026	2.89	0.097	1.004	0.184	0.983
80-100	4.5	268	1.94	0.376	0.02	0.412	0.059	3.052	0.134	1.643	0.216	1.062

Table B1.3a: Soil analysis results (Kleinkopje 2002, after harvesting)

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
0-20	3.6	160	46.26	0.147	0.073	0.081	0.016	0.145	2.188	2.421	0.48	0.025
20-40	3.6	89	2.43	0.11	0.033	0.041	0.008	3.092	0.944	1.177	0.235	0.009
40-60	3.9	74	1.37	0.146	0.013	0.051	0.009	4.059	0.361	1.445	0.26	0.003
60-80	4.3	39	0.22	0.081	0.005	0.045	0.008	2.113	0.122	1.206	0.206	0.006
80-100	4.4	16	0.42	0.018	0.003	0.009	0.01	0.38	0.069	0.233	0.26	0

The soil samples were taken out of the piviot.

Table B1.3b: Soil analysis results (Kleinkopje 2002, after harvesting)

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
A0-20	4.6	257	13.63	1.067	0.031	0.304	0.031	30.149	0.874	8.61	0.865	1.091
A20-40	4.1	236	2.19	1.031	0.012	0.278	0.033	29.686	0.361	8.034	0.954	1.044
A40-60	4.1	228	1.28	0.901	0.008	0.292	0.053	25.375	0.223	8.251	1.483	1.03
A60-80	4.3	277	1.26	0.8	0.012	0.685	0.076	24.129	0.366	20.714	2.295	1.034
A80-100	4.4	273	1.51	0.602	0.026	0.828	0.074	16.543	0.731	22.875	2.053	1.129
B0-20	5.1	227	5.59	0.989	0.018	0.275	0.033	28.58	0.534	7.98	0.946	1.049
B20-40	4.9	230	1.63	0.946	0.029	0.356	0.036	27.87	0.866	10.509	1.069	1.019
B40-60	4.5	228	1.42	0.836	0.046	0.378	0.045	24.043	1.318	10.898	1.286	1.019
B60-80	4.8	216	2.24	0.774	0.013	0.361	0.041	23.306	0.379	10.914	1.25	0.964
B80-100	4.9	115	1.04	3.52	0.003	0.177	0.031	11.403	0.095	5.766	1.026	0.376

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
C0-20	4.9	258	13.73	0.865	0.029	0.436	0.05	25.66	0.871	12.979	1.473	0.967
C20-40	4.8	252	8.93	0.946	0.03	0.396	0.042	27.127	0.86	11.374	1.198	1.03
C40-60	4.4	215	1.63	0.689	0.023	0.446	0.041	19.949	0.668	12.969	1.19	0.953
C60-80	4.7	236	1.32	0.568	0.028	0.634	0.075	15.877	0.793	17.802	2.096	1.045
C80-100	4.3	200	1.71	0.714	0.024	0.251	0.031	21.669	0.723	7.626	0.943	0.839

The soil samples were taken at three points (A.B and C) within the pivot.

Table B1.4: Soil analysis results (Hatfield field experiment 2002, before planting)

				Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)** me/100g				
Depth (cm)	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
A0-20	5	21	10.491	0.035	0.004	0.026	0.013	1.838	0.107	0.813	0.196	0.017
A20-40	5.5	18	1.693	0.034	0.001	0.008	0.004	0.852	0.023	0.3	0.119	0.002
B40-60	5.4	64	16.819	0.111	0.004	0.03	0.015	3.414	0.112	2.306	0.229	0.022
B60-80	5.7	25	3.046	0.059	0.001	0.038	0.008	1.565	0.019	0.924	0.004	0.021
C60-80	5.3	58	19.156	0.109	0.009	0.036	0.019	2.937	0.234	2.037	0.311	0.019
C80-100	5.5	29	12.495	0.06	0.002	0.1	0.009	1.774	0.058	0.911	0.056	0.012

Table B1.5: Soil analysis results (Hatfield field experiment 2002, after harvesting)

					Soluble cations(cmol(c)/kg)				**Exchangeable cations (cmol(c)/kg)**				me/100g
Depth (cm)	**TRT**	**pH(water)**	**Ec(mS/m)**	**P(mg/kg)**	Ca	K	Mg	Na	**Ca**	**K**	**Mg**	**Na**	SO_4
0-20	3t/ha	5.7	33	25.115	0.061	0.004	0.046	0.01	1.903	0.125	1.015	0.103	0.03
20-40	3t/ha	5.8	39	1.678	0.093	0.001	0.039	0.011	2.235	0.013	1.491	0.067	0.097
0-20	6t/ha	5.1	44	275.939	0.058	0.031	0.029	0.01	1.811	1.006	0.991	0.103	0.076
20-40	6t/ha	5.3	32	4.554	0.084	0.013	0.086	0.019	1.899	0.295	0.868	0.208	0.1
0-20	15t/ha	5.1	201	12.418	1.053	0.004	0.231	0.016	28.335	0.088	2.855	0.219	0.963
20-40	15t/ha	5.5	132	2.76	0.513	0.02	0.088	0.017	11.81	0.03	6.347	0.166	0.683
0-20	40t/ha	5	204	116.674	1.021	0.015	0.102	0.011	30.713	0.449	2.012	0.098	0.881
20-40	40t/ha	5.3	109	1.964	0.445	0.045	0.129	0.016	10.031	1.005	3.837	0.145	0.446

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