UNIVERSITY OF NATAL

NUTRIENT STUDIES IN POTATOES
(*Solanum tuberosum*)

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NUTRIENT STUDIES IN POTATOES (*Solanum tuberosum*)

by

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ABSTRACT

One of the biggest problems facing potato *(Solanum tuberosum)* production in Kwazulu-Natal is acidic soils with high a aluminium content. Traditionally, such soils were ameliorated using lime, thus increasing soil pH, Ca and Mg availability, and reducing Al availability. This study aims to determine the extent to which lime could be replaced by Calmag+B (a Ca source with little ameliorative capacity). The Calmag+B fertiliser increases the soil's Ca content appreciably, but does not alter soil pH and Al availability to the same extent as lime. Pot trials were carried out to determine the effects of liming a highly acid soil, resulting in four levels of amelioration. At each level of amelioration, three levels of Calmag+B were applied to determine whether an optimised yield response would be attained through these applications. Plant emergence and subsequent development was shown to be poor, and in extreme cases absent, under highly acidic soil conditions. Soil amelioration using lime greatly improved plant emergence, development and tuber yield, whereas Calmag+B applications were unable to improve plant emergence, development or tuber yield. The effect of both applications of substantial quantities of Calmag+B to a highly acid soil, and of the dipping of mother tubers in a nutrient solution prior to planting was investigated. The Calmag+B soil applications were unable to improve plant emergence and development. The dipping of the mother tubers in nutrient solution, however, resulted in greatly increased seedling emergence and plant development. This was due to increased nutrient uptake from the mother tuber, and not through increased root development and subsequent nutrient uptake.

There were unsubstantiated claims by the manufacturers of Calmag+B that the Mg, NO_3^- and B components of the fertiliser would give rise to increased uptake of the Ca component, thus enhancing the efficacy of the fertiliser. Pot trials using a sand medium were employed to test this claim. The trial consisted of interactions of different levels of Ca^{2+}, Mg^{2+}, NO_3^-, and BO_3^{2-} applied to the sand medium in the form of a nutrient solution. None of the treatments (barring Ca itself) led to increased Ca uptake by the potato tubers. This would indicate that the claim that the Mg, NO_3^- and B components of Calmag+B fertiliser would

enhance the uptake of the Ca component are unfounded.

It has been suggested that one of the main factors limiting potato production in Kwazulu-Natal has been inadequate mineral nutrition. Certain fertiliser distributors claim that fertiliser application over and above the levels recommended by the Kwazulu-Natal Department of Agriculture Fertiliser Advisory (KDAFA) is the solution to the problem of below potential yield and tuber quality in the province. A field trial was carried out in New Hanover (Kwazulu-Natal), using different levels of Calmag+B and Agrifos, as well as one level of application of KNO_3. All treatments were applied after KDAFA fertiliser recommendations had been fulfilled. At the 95% level of significance, the treatments did not give rise to increased yield and tuber quality. At the 80% level of significance, however, the results indicated that applications of 100kg ha^{-1} of Calmag+B and KNO_3 would give rise to increased tuber yield.

DECLARATION

I, Ramtin Ahmadi, certify that the research work reported in this dissertation, unless specifically acknowledged to the contrary, is my own original investigation, and has not been submitted in part, or in whole, to any other university. The research work was carried out at the University of Natal, Pietermaritzburg.

R AHMADI

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LIST OF ABBREVIATIONS AND CONVENTIONS

CV	coefficient of variation
LSD	least significant difference
SIGNIFICANT	statistical significance at the 5 % level
HIGHLY SIGNIFICANT	statistical significance at the 1 % level
NS	statistically non significant
FWC	field water content
GA_3	gibberellic acid
NUTRIENT CONCENTRATION	nutrient concentration of potato tubers measured as g kg^{-1} of dry matter for macro-nutrients and mg kg^{-1} of dry matter for micro-nutrients
NUTRIENT AMOUNT POT^{-1}	total amount of a nutrient present in tubers within each pot
KDAFA	Kwazulu-Natal Department of Agriculture Fertiliser Advisory
BENLATE	benomyl*
BRAVO	chlorothalonil*
PREVICUR	propamocarb hydrochloride*
KOCIDE	copper hydroxide*
ORTHENE	acephate*
DURSBAN	chlorpyrifos*
GAUCHO	imidacloprid*
VYDATE	oxamyl (carbamate)*

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INTRODUCTION

The potato ranks fourth after wheat, rice, and maize, as the most important source of food world-wide (Ulrich, 1993). To produce large tuber yields, as well as high quality tubers, it is essential to supply the required amount of fertiliser to the crop, when it needs it. The plant requires a steady stream of nitrogen, along with adequate supplies of phosphorus, potassium, and the remaining macro and microelements (Ulrich, 1993).

Strong seedling emergence is essential for establishment of a uniform and vigorous crop stand. The unhindered and vigorous development of the plant after seedling emergence, is very important in attaining large tuber yields (Harris, 1990). The application of mineral elements through fertilisers, is crucial in the realisation of seedling emergence and subsequent potato development.

Many of the soils in which potatoes are grown in Natal are acidic. These conditions result in nutrient deficiency – particularly Ca, and the crop may also suffer the effects of Al toxicity. Calcium is associated with plant emergence, vigour and development, tuber formation, yield and size (Beukema and Vander Zaag, 1990), tuber quality, and a reduction in the incidence and severity of certain diseases and physiological disorders afflicting potato tubers (Marschner, 1995). Aluminium toxicity, on the other hand, leads to reduced root development, nutrient and water uptake, and a decrease in tuber yield. A frequently asked question has been whether plant development is hindered by a lack of Ca, or by an excess of Al. One of the main objects of this study was to investigate different methods of overcoming the low pH, low Ca and high Al availability problem, commonly found in Natal soils, such that potato production could take place.

The interaction between mineral elements, and their effect on the plant's uptake of nutrients, is well documented. There have been unsubstantiated claims by the Agrofert fertiliser company that the interaction between the various constituent elements of Calmag+B would lead to the crop's enhanced uptake of the fertiliser's Ca component. Experiments were therefore conducted in order to determine

whether the application of nitrate, magnesium and boron would lead to increase Ca uptake, hence aiding seedling emergence, plant development, and tuber quality.

The major objective with respect to mineral nutrition, subject to economics, environmental and health concerns, is to ensure that tuber yield and quality are not limited by mineral nutrients. The optimal quantity of nutrients to apply would be that which would sustain a closed crop canopy for the duration of the potential growing season, while preventing mutual shading and excessive haulm growth (Harris, 1990).

Another objective of this study was to determine whether the present fertiliser recommendations for Natal represented the thresholds for nutrient application, or alternatively whether additional applications of fertilisers would result in increased tuber yield and quality.

CHAPTER 1

REVIEW OF LITERATURE

1.1 INTRODUCTION

Mineral nutrition plays a substantial and varied role in the production of a healthy and vigorous potato crop. Numerous studies have been carried out detailing the many varied functions, effects and interactions between macro and micro-nutrients in potato crop production. Apart from the effects on plant emergence, growth, development and metabolism, mineral nutrients also affect factors such as tuber dormancy, resistance to insects and diseases, and susceptibility to physiological disorders. The aim of this literature review is, therefore, to cover the functions, effects of, and interactions between the various nutrients that fall within the scope of this study.

1.2 THE ROLE OF ESSENTIAL NUTRIENTS IN THE GROWTH AND DEVELOPMENT OF THE POTATO

1.2.1 Nitrogen

Tuber yield is considered to be mainly a product of three major processes, namely radiation interception, conversion of intercepted radiation to dry matter and the partitioning of dry matter between tubers and the rest of the plant (Harris, 1992).

Nitrogen chiefly increases dry matter yield by increasing the leaf area per plant or leaf area index (L). The increase of photosynthetic efficiency, as measured by net assimilation rate (NAR), is relatively small and erratic (Martin, 1995). The number of leaves on the plant are determined by the number of meristems producing leaf initials, the rate at which new leaves are produced and their longevity. Increased nitrogen causes the lateral buds on the main stem to develop and also causes a slight increase in the rate of leaf production on the main stem. A deficiency in

nitrogen reinforces apical dominance and inhibits the development of lateral buds (Humphries, 1950).

The structure and, more specifically, the function of plant cells are intimately linked to the chemistry of nitrogen. Most of the N in plants is incorporated in carbon containing compounds. These include nucleic acids, some vitamins (e.g. riboflavin), hormones (e.g. Indole Acetic Acid (IAA)), membrane components (e.g. phosphatidycholine), coenzymes (e.g. nicotinamide derivatives) and pigments (e.g. chlorophyll). Nevertheless, by far the most important function of N in terms of agriculture and human nutrition is as an essential constituent of protein (Marschner,1995).

Nitrogen increases the yield of large tubers (Reust, 1995). Porter and Sisson (1991) found that N stimulates haulm growth, and if added in excess may lead to the stimulation of top growth at the expense of the tubers. High levels of nitrogen delay tuber initiation, reduce yields, and delay the maturing of the crop. This delay in maturity may affect tuber quality if the crop is harvested immaturely (Beukema and van der Zaag, 1990), as such tubers have a higher reducing sugar content, are easily damaged and difficult to store. High nitrogen applications favour pigment synthesis, which brings about vascular discolouration. High levels of N may also induce secondary growth (van Ittersum, 1992) which may subsequently affect tuber quality. Certain physiological disorders of tubers, such as translucent end, are a result of stress imposed on the plant by secondary growth (Jefferies and Mackerron, 1986).

Applications of N may be split in order to prevent losses through leaching. In some cases it has been reported that this practice can lead to an increase in yield and N use efficiency (McCann and Stark, 1989). Splitting of N applications, however, may also lead to an increase in physiological disorders such as hollow heart (McCann and Stark, 1989). This will be discussed in greater detail in Chapter 2. Top dressings of N, moreover, give rise to a decrease in dormancy, especially if application takes place during tuber initiation (van Ittersum, 1992).

Nitrogen may be applied in the nitrate form or the ammoniacal form. Different forms of N nutrition may have varying effects on tuber yield (Lorenz and Johnson, 1953), tuber quality (Dahlenburg *et al.*, 1990), the incidence of diseases and the plant's resistance to diseases (e.g. the reduction of potato scab by the application of ammoniacal nitrogen, Keinath and Loria, 1990). The form of N used also affects the availability of N. For example, ammoniacal forms of N leach less readily than nitrate forms, thus making the nutrient available for plant uptake for a longer period of time (Lorenz and Johnson, 1953).

Nitrogen nutrition has an effect on the availability and uptake of other nutrients. For example, application of the nitrate form of nitrogen fertiliser generally increases the total phosphorus absorbed by plants (Hoffman *et. al.,* 1994). Ammoniacal forms of N reduce the pH of the soil and therefore reduce the availability of calcium and molybdenum. This reduction in pH leads to increased availability of Fe, B, Zn and Cu (Haynes and Swift, 1985).

As N is contained in the chlorophyll molecule, a deficiency in N will result in leaf chlorosis. Nitrogen deficiency symptoms normally appear first on older leaves (Nachegowda, 1992). Severe N deficiency causes the leaves at the apex of the plant to become smaller and curl upward (Ulrich, 1993). Other symptoms of N deficiency are indicated when leaf petioles contain less than 500 ppm of nitrate or leaf blades contain less than 400 ppm of nitrate (Ulrich, 1993).

High levels of nitrate cause marginal burn of older leaves followed by interveinal collapse. High levels of ammonia cause blackening around the tips of older leaves. In cases of severe ammonia toxicity leaf necrosis takes place (Fageria *et al.,* 1990). Nitrogen toxicity symptoms are indicated when leaf petioles contain more than 38,000 ppm of nitrate and leaf blades contain more than 11,700 ppm of nitrate (Ulrich, 1993).

1.2.2 Phosphorus

Phosphorus increases both the number of tubers produced per plant (Berryman *et. al.,* 1973) and, to a lesser extent, tuber size (Verma and Grewal, 1978). An increase in P results in an increase in starch percentage (Solle, 1980). Some sources report that it may also reduce viral infections (Skrinskaya *et. al.,* 1976), as well as having the ability to reduce the incidence and severity of diseases such as potato scab (Keinath and Loria, 1990).

The application of phosphorus gives rise to an increase in plant leaf area, as well as causing a small increase in the efficiency of the NAR in the early period of growth (Ivins and Milthorpe, 1963). Phosphorus has a much larger initial effect on plant development than does nitrogen (Beukema and van der Zaag, 1990). It increases the leaf area of the first five leaves but has little effect on subsequent ones (Ivins and Milthorpe, 1963). High concentrations of P are found in the meristematic regions of actively growing plants where prolific cell division is taking place (Marschner, 1995). Phosphorus has a marked effect on leaf number, which it increases by accelerating the production rate and prolonging the life of leaves (Ivins and Milthorpe, 1963). Increased phosphorus supply induces lateral bud growth, and thus an increase in leaf area, however to a lesser extent than is the case with nitrogen.

Phosphorus is a constituent of nucleic acids, phospholipids, the coenzymes NAD and NAPD, and lastly ATP. Phospholipids are important constituents of the cell membrane. The coenzymes NAD and NADP are important in oxidation – reduction reactions in which hydrogen transfer takes place. Photosynthesis and respiration are also dependant on these coenzymes (Hoffman and Schwartz, 1975).

The P deficiency symptoms of potatoes are not easily identifiable. The plants appear somewhat stunted and have a darker green colour. With severe P deficiency leaf roll and the upward cupping of leaves occurs (Ulrich, 1993). A deficiency of the element causes reductions in tuber quality manifested in chip colour (Lintner, 1965). Gross deficiencies in phosphorus give rise to an increase in the phenomenon of

"after cooking blackening " (Beukema and van der Zaag, 1990). Phosphorus deficiency symptoms are indicated by leaf petioles which contain less than 1200 ppm of total P and leaf blades containing less than 1750 ppm of total P (Ulrich, 1993).

Phosphorus toxicity causes interveinal chlorosis in younger leaves and marginal scorch of older leaves (Fageria *et al.*, 1990). These symptoms are indicated when leaf petioles contain more than 11,000 ppm of total P and leaf blades contain more than 12,500 ppm of total P (Ulrich, 1993).

Phosphorus deficiency frequently appears on acid, calcerous or kaolintic soils (Ulrich, 1993). In acid conditions, phosphorus is bound to aluminium (forming aluminium phosphate), while in calcerous soils it is bound to calcium, forming calcium phosphate (calcium phosphate precipitates and hence phosphorus availability is reduced). In soils with a high clay content, phosphorus is readily adsorbed by the soil and is thus not available for plant uptake (Mahmood *et. al.*, 1992).

Application of phosphorus may give rise to deficiencies in other nutrients, or vice-versa. A high phosphorus content in soils can decrease the solubility of Zn as well as causing a reduction in root growth, thus hampering the acquisition of Zn (Tagwira *et. al.*, 1992). Iron associated with phosphorus is much less mobile, as a result excessively high levels of phosphorus appear to interfere with the movement and metabolic functioning of Fe (Haleem *et. al.*, 1992). Boron on the other hand, appears to have a positive effect on the uptake of phosphorus. Research has shown that plants suffering from a boron deficiency experience a reduction in the uptake of phosphorus (Wei and Zuo, 1996).

1.2.3 Potassium

Potassium increases dry matter yield of tubers primarily through increasing the leaf area per plant, especially later in the season (Harris, 1992). The nutrient also delays the senescence of leaves. Potassium has no effect on the number of leaves or on

the growth of lateral buds (Ivins and Milthorpe, 1963). Consequently, potassium mediates its effect on yield through leaf expansion. Potassium increases the yield of large tubers – more so than nitrogen or phosphorus (Singh and Singh, 1995) – but tends to decrease dry matter content at higher levels (Barakat *et. al.,* 1994).

A deficiency of potassium leads to an inhibition of photosynthesis. This is due mainly to the nutrients effect on developing chloroplasts, since the structure of mature chloroplasts appears to be less sensitive to potassium deficiency. The processes of photophosphorylation (Rao *et. al.,* 1989), electron transport and the formation of NADPH are all sensitive to potassium deficiency (Le Pabic *et. al.,* 1990). Potassium is essential in the synthesis of simple sugars and starch as well as in the translocation of carbohydrates (Kaith and Sharma, 1995). The element enhances phloem loading of sucrose through proton-sucrose cotransport. Potassium also causes an increase in the osmotic potential of phloem sap which increases the rate of mass flow in the phloem (Patrick, 1994).

Potassium plays an important part in stomatal regulation, as it is responsible for turgor changes in the guard cells during stomatal movement (Willmer, 1993). An increase in the K concentration of the guard cells (from 100mM in the closed state to between 400 and 800 mM when stomates open) increases their osmotic potential (Marschner, 1995), which results in the uptake of water from adjacent cells. This gives rise to an increase in guard cell turgor, resulting in the opening of stomata (Willmer, 1993).

An increase in potassium appears to reduce the incidence of bruising and blackspot (Workman and Holm, 1984) as well as reducing the tuber's susceptibility to "after cooking blackening" (Swain *et al.,* 1963). This topic will be considered in greater detail in Chapter 2. An increase in potassium increases the reducing sugar content, increases citric acid concentration in the tuber (Rogozinska and Pinska, 1991), increases amino acid and protein content due to enhanced synthesis (Steward and Preston, 1940), as well as improving chip colour (Chapman *et al.,* 1992). If applied

in the sulphate form potassium increases starch content (Lintner, 1965) and total carbohydrate content as well (Latzko, 1955).

Lintner (1965) found that potassium reduces the incidence of early blight (*Alternaria solani*) and stem end rot (*Fusarium* spp.). Pennypacker (1990) found that it increases the plants resistance to Verticillium wilt (*Verticillium dahliae*). Bártz *et* al. (1992) found that potassium reduced bacterial soft rot to a certain degree, but was less effective than calcium. This will be examined in greater detail in Chapter 3.

K deficiency symptoms appear first on young, fully expanded leaf blades. The leaves have a glossy sheen with pronounced crinkling and slightly black pigmentation. A severe deficiency causes marginal leaf scorch, which expands and ultimately causes leaf death (Ulrich, 1993). Potassium deficiency symptoms are indicated in leaf petioles containing less than 1.8% K (dry weight basis) and leaf blades containing less than 0.9% K (dry weight basis) (Ulrich, 1993).

A potassium excess may lead to a deficiency in Ca, Mg, and possibly Mn, Zn and Fe (Fageria *et al.,* 1990). Potassium toxicity symptoms are indicated in leaf petioles containing more than 11.5% K (dry weight basis) and leaf blades containing more than 5.0% K (dry weight basis) (Ulrich, 1993).

Potassium deficiency may occur in plants growing in sandy loam soils with low exchange capacity. Clay loam soils with a high unavailable K fixing power may also occur on peat, muck and other soils which release K too slowly (Ulrich, 1993).

The supply of potassium can affect and be affected by the availability of other nutrients. Competition between K and other cations (e.g. Ca^{2+}, Mg^{2+} and Na^{+}) and affects the element's uptake. The cations compete for the same uptake sites on roots and therefore an increase in one or more of the other cations may give rise to a reduction in the uptake of K (Smith, 1968).

1.2.4 Calcium

Potatoes are relatively tolerant to soil acidity and may not need liming unless the pH is very low. As an essential nutrient, however, the crop may fail due to calcium deficiency (Beukema and van der Zaag, 1990). Sprouts may not emerge and if they do, the plants remain stunted and produce a lot of small tubers. In cases of severe deficiency, tuber formation may not take place at all (Smith and Nash, 1938).

The availability of calcium is also affected by the solubility of the form in which it is applied. Lime, for example, is less soluble than gypsum, resulting in less Ca being available for plant uptake. The solubility of the fertiliser is partially reliant upon particle size. Sieving of lime and gypsum gives rise to finer, more soluble particles (Conway *et al.*, 1992).

Calcium has several functions within the cell, including stabilisation of the plasmalemma, endomembranes and the cell wall (Ferguson, 1984), as well as the secretion of new plasma membrane and cell wall polysaccharides (Steer, 1988). Calcium also forms part of the calmodulin calcium complex. This recently discovered complex is apparently involved in many biochemical reactions in the cell (Marschner, 1995). Calcium is also essential for the functioning of certain enzymes as a co-factor for example. For example, Ca is essential for α-amylase activity, which mobilises starch reserves in germinating seedlings. In the absence of calcium cell separation and organisation is disrupted (Bester and Maree, 1992). Calcium plays an important role in the quality and storage quality of potatoes (Bester and Maree, 1992). Calcium is a vital constituent of the mitotic spindle during cell division (del Vecchio *et. al.*, 1997).

Calcium plays an essential role in the reducing both the incidence, and severity of fungal and bacterial diseases. The application of calcium oxide significantly reduces damping off caused by *Pythium ultimum* (Lewis and Lumsden, 1984). Brown rot (*Pseudomonas solanacearum*) may be reduced as a result of increased resistance to bacterial diseases in the plant, brought about by an increase in the calcium

content of the plant tissues (Kelman *et al.,* 1990). Bartz *et* al.(1992) found that an increase in the tuber's calcium concentration also gives rise to greater control of the incidence and severity of the bacterial soft rot disease, *Erwinia caratovora*. The decrease in these diseases is associated with the effect of calcium on tuber tissue resistance to bacterial maceration, caused by pectolytic enzymes (McGuire and Kelman, 1986), as calcium improves the structural integrity of both cell wall components and cell membranes (Cooper, 1983, cited by Engelhard, 1990). Calcium binds with pectins in the cell wall, resulting in a structure with a bunched configuration, which allows spaces for the insertion of cations. This structure hinders the accessibility to pectolytic enzymes produced by bacteria, fungi and the tuber itself, that cause softening or decay. Calcium increases the periderm thickness and increases resistance to bruising (Kelman *et al.,* 1990). The application and subsequent uptake of Ca also reduce postharvest decay by the crop (Conway *et al.,* 1992).

Supra optimal Ca levels may result in adverse effects on potato yield and quality (Kelman *et al.,* 1990). The application of lime shortly before growing a potato crop can increase the incidence of common scab, and hence it is advisable to lime these soils at some other time (Terman *et al.,* 1948).

Calcium also has an effect on the incidence of physiological disorders in tubers. High levels of calcium in tuber tissue result in reduced internal brown spot (Collier *et al.,* 1980). Calcium also increases resistance to internal rust spot and this effect appears to be associated with a higher antioxidant status in the tuber (Monk and Davies, 1989). Tzeng *et* al (1986) found Ca deficiency in tubers is the primary cause of the physiological disorder "hollow heart". This is, however, in direct conflict with the findings of Hiller and Koller (1987), who found that application of calcium resulted in a higher percentage of tubers with hollow heart. This will be discussed in greater detail in Chapter 2.

A Ca deficiency may cause new leaves to become white (Ulrich, 1993) and may result in the death of the apical bud. The symptoms are caused by an induced

toxicity of NH_3 and urea due to a reduction in the activity of glutamine synthase. A deficiency of Ca may display al toxicity symptoms, indicated by leaf yellowing with white interveinal stripes on older leaves (Fageria *et al.,* 1990). Calcium deficiency symptoms are indicated when leaf petioles and leaf blades contain less than 0.15% Ca (dry weight basis) (Ulrich, 1993).

An excess of Ca may result in a deficiency of Mg and K (Smith, 1968). Calcium toxicity symptoms are indicated when leaf petioles and leaf blades contain more than 2.5% Ca (dry weight basis) (Ulrich, 1993).

The application of some forms of Ca fertiliser, e.g. lime, cause an increase in pH. This rise in pH results in the reduced availability of nutrients such as P, al, Mn, Fe, Zn, Cu and (Mortvedt *et al.,* 1972). all the nutrients mentioned above are more soluble under acid conditions, which explains their reduced availability for plant uptake when a rise in pH occurs (Archer, 1988). Phosphorus is bound by Ca to form calcium phosphate, which then becomes unavailable to plants (Goldstein, 1995). Over and above the problem of reduced solubility in less acid conditions, B also has an antagonistic relationship with Ca, which further reduces its availability to plants (Mehrotra *et. al.,* 1989).

An increase in pH caused by the application of ameliorative forms of Ca brings about an increase in the macronutrient cation concentration of the soil (i.e. Ca, Mg and K). This increase is due primarily to increased solubility (Curtin and Smillie, 1995). The upward shift in pH also increases the availability of Mo. At lower pH values Mo is less soluble, primarily through its reactions with Fe and al (Herbel *et. al.,* 1997).

Lime may be applied as either calcitic or dolomitic lime. Dolomitic lime contains Mg which is an essential element in potato production, which may, however, compete with Ca for uptake sites on plant roots and as a result reduce the uptake of Ca (Archer, 1988).

1.2.5 Magnesium

Potatoes are more sensitive to magnesium deficiency than other crops (Bear *et al.*, 1951, cited by Mondy and Ponnampalam, 1986). Deficiency of the element results in substantial reductions in yield (Smith and Nash, 1937).

Magnesium enhances tuber formation (Krackenberger and Petersen, 1964, cited by Smith, 1968), and is essential for the synthesis and translocation of sugars in potato plants (Lewin and Lewin, 1956, cited by Smith, 1968). The element has no effect on the dry matter production of the plant (Gausman and Estes, 1963, cited by Smith, 1968), but is required in the synthesis of proteins (Gauch, 1972). Magnesium serves as an activator for enzyme systems used in photosynthetic reactions, respiration, and is responsible for the activation of most reactions involving phosphate transfer, lipid metabolism and nitrogen accumulation and protein synthesis (Gauch, 1972). Magnesium also plays a key role in the synthesis of RNA and DNA (Cai *et. al.*, 1991). Magnesium fertilisation increases the yield, total nitrogen, protein (Ponnampalam, 1985), both free and total amino acids, crude lipid and phospholipid content of the tubers (Klein *et al.*, 1981).

A high magnesium to calcium ratio may adversely affect the resistance of plants to diseases such as bacterial soft rot (McGuire and Kelman, 1984). Increasing the levels of Mg increases the cation competition between Mg and Ca as well, resulting in reduced Ca uptake. As Ca increases, tuber tissue resistance to bacterial maceration caused by pectolytic enzymes also increases, whereas a reduction in the element (brought about by cation competition with Mg) gives rise to a reduction in resistance to certain plant diseases (McGuire and Kelman, 1984). Excessively high levels of Mg also cause a reduction in K, brought about by cation competition (Fageria *et al.*, 1990).

The availability of magnesium is reduced in acid soils (Zaini and Abdullah, 1994). As the soil pH drops, the soil H^+ concentration increases, resulting in the impaired movement of H^+ from root cells to the soil. The inhibition of this proton pump

reduces the uptake of Mg^{2+}. Another reason for the reduced availability of Mg in acid soils is the high solubility and availability of al and Mn. Mn^{2+} ions compete with Mg^{2+} for uptake sites, leading to an inhibition of Mg uptake (Marschner,1995).

Magnesium deficiency symptoms first appear on younger mature leaves as a slight chlorosis with green veins and brown spots, which terminate as interveinal scorch. These symptoms are contrast to the marginal scorch indicated with a K deficiency. These symptoms are most severe in the older leaves, while those near the growing points remain green (Ulrich, 1993). Magnesium deficiency symptoms are indicated when leaf petioles contain less than 0.06% Mg (dry weight basis) and leaf blades contain less than 0.09% Mg (dry weight basis) (Ulrich, 1993). Magnesium toxicity symptoms are indicated when leaf petioles and leaf blades contain more than 1.00% Mg (dry weight basis) (Ulrich, 1993).

1.2.6 Sulphur

The application of sulphur gives rise to an increase in tuber yield (Hiller and Koller, 1987). Sulphur is essential for the synthesis of sulphur containing amino acids, namely, cystine, cysteine and methionine. The nutrient is essential for protein synthesis, as well as for activating certain proteolytic enzymes such as ficin (Popovic *et. al.,* 1996). A deficiency in sulphur can lead to an increase in non-protein N such as nitrates and nitrites (Murphy and Quirke, 1997).

Sulphur may be instrumental in the suppression of certain diseases (e.g. common scab of potato - *Streptomyces scabies*), although studies have indicated that the suppression is a consequence of soil pH reduction, which occurs when sulphur is oxidised (Terman *et al.,* 1948).

Sulphur deficiency is similar to N deficiency, with the exception that the entire plant, including the younger leaves, remains light green. Severely deficient leaf blades remain yellowish, and eventually curl upward (Ulrich. 1993). Sulphur deficiencies are seldom apparent due to its presence in superphosphate, gypsum and other

fertilisers. Sulphur deficiency symptoms are indicated when leaf blades contain less than 750 ppm total S (Ulrich, 1993).

An excess of sulphur causes a reduction in growth and leaf size (Fageria *et al.*, 1990). Sulphur toxicity symptoms are indicated when leaf blades contain more than 3,000 ppm total S (Ulrich, 1993).

1.2.7 Manganese

Manganese gives rise to an increase in average tuber mass (Lozek and Fecenko, 1996). The element, however, can become toxic when found at higher concentrations. Toxicity occurs in acid soils, since the element is more soluble under such conditions (Ulrich, 1993). Increased application of Mg, Fe and P (Bolle-Jones, 1955) reduce plant injury caused by Mn toxicity.

Manganese has a large redox potential. It is the only redox system capable of releasing O_2 from water. Mn plays a key role in this process during photosynthesis. Mn is involved in the activation of enzymes in many biochemical reactions in the plant. For example, Mn activates the key enzyme malic acid dehydroginase used in the Krebs Cycle. Apart from its involvement in photosynthesis (Angadi *et. al.*, 1988), manganese plays important roles in respiration, ascorbic acid synthesis and nitrogen metabolism (Dhopte, 1990). Manganese also plays a role in the activation and breakdown of IAA in the plant (Kaur *et. al.*, 1991).

The incidence of common scab of potato is reduced by application of manganese sulphate. High levels of manganese are thought to inhibit the growth of the scab organism (Grzeskiewicz *et. al.*, 1990).

Among vegetable crops, potatoes are relatively tolerant of high manganese levels (Ouellette and Genereux, 1965). When applied in excess, however, it causes a reduction in the plant's growth rate, reduces root size and decreases leaf size (Marsh and Peterson, 1990). Manganese toxicity symptoms include yellowing of the

leaf, beginning at the leaf edge of older leaves. Manganese toxicity symptoms are indicated when leaf blades contain more than 350 ppm Mn (Ulrich, 1993).

A deficiency in the element causes loss of lustre, small size and curling of leaves (Burton, 1948). Mn deficiency symptoms appear as purple-black spots on the veins of leaves (especially on the lower surface). These spots are clumps of secreted MnO_2. Interveinal chlorosis may occur on younger leaves. Affected leaves may cup downward and have necrotic regions (Ulrich, 1993). Manganese deficiency symptoms are indicated when leaf blades contain less than 25 ppm Mn (Ulrich, 1993).

1.2.8 Boron

Boron applications may lead to increased tuber yield (Lozek and Fecenko, 1996). Boron plays an important part in carbohydrate synthesis, and can result in an increase in the starch content of tubers (Dwivedi and Dwivedi, 1992). Hsiao *et al.*, (1959, cited by Smith, 1968) found that boron enhances tuber formation and seed viability.

Soils with a high pH lead to a reduction in B uptake. This may be due to either reduced solubility of B, or the antagonistic relationship between the element and Ca (Mortvedt *et al.*, 1972). Boron deficiency leads to the formation of a bushy plant with droopy leaves, and results in leaf blades crinkling, cupping upward and developing light brown edges. Boron deficiency also affects growing points. Root tips become swollen and dark and the growing point may eventually die (Ulrich, 1993). Smith and Nash (1938) found that boron deficiency brought about a delay in plant emergence. Boron deficiency symptoms are indicated when leaf blades contain less than 20 ppm B (Ulrich, 1993).

Boron toxicity is manifested as interveinal chlorosis (Fageria *et al.*, 1990). Hiller and Koller (1987) found that supra-optimal quantities of boron resulted in a higher

percentage of tubers with hollow heart. Porter *et* al. (1986) found that supra-optimal quantities of B reduced both tuber yield, and the number of tubers per plant.

1.2.9 Other micronutrients

Numerous studies have been carried out detailing the various functions of Fe, Zn, Cl, Cu, and Mo, as well as the possible interactions that exist between them. As these nutrients do not fall within the scope of this study, however, they will not be discussed further. For detailed information regarding these nutrients, see Mortvedt *et. al.,* (1972) and Fageria *et.* al. (1990).

1.2.10 Organic Matter

The potato crop is often grown with the use of both organic and inorganic fertilisers. The importance of such materials has declined with the increased use of inorganic fertilisers. Since the supply of nutrients is not the only function served by organic matter, however, these products still have an essential part to play in improving the physical and chemical properties of soil (Harris, 1992).

1.3 POTATO QUALITY AS AFFECTED BY MINERAL NUTRITION

Quality in potatoes depends upon the varied purpose for which the crop is intended. For example, quality standards for potatoes grown for the home market vary considerably with the more exacting standards required for processing of potatoes into products such as crisps or French fries (Harris, 1992). Potato quality is defined by nutritive value, texture, colour of raw material and processed product, and external and internal tuber morphology and appearance.

1.3.1 Dry Matter Content

Fertiliser applications affect the dry matter (DM) content of potato tubers. DM content is determined using specific gravity. For the production of crisps (chips) and French fries, potato tubers should have a high specific gravity as this reduces the cost involved in the frying process (Dahlenburg *et al.*, 1990).

Increasing rates of nitrogen fertiliser application result in an increase in tuber DM, up to a point. Excessive applications of N result in a decrease in tuber DM (Buniak, 1982). Applications of N early in the season result in a higher specific gravity of tubers (Sawyer and Dallyn, 1958, cited by Smith, 1968). Nitrogen applications around the time of tuber initiation, however, result in a reduction of tuber DM (Smith, 1968).
Sharma and Grewal (1986) found that application of phosphorus and magnesium increased the DM content of potato tubers.

1.3.2 Starch and Protein Content

The starch content of tubers may be increased by fertilisation. Potassium is essential for the synthesis of simple sugars and starch, as well as in the translocation of carbohydrates. The nutrient also results in an increase in carbohydrates in the tuber (Kaith and Sharma, 1995). Excessively high levels of K, however, reduce the starch content of tubers (Singh and Singh, 1996), particularly when the source used is potassium chloride (Smith and Nash, 1938).

The application of S (Pirson, 1955), Mn, B (Dwivedi and Dwivedi, 1992), Zn and Fe (Das and Barooah, 1982) causes an increase in the starch content of potato tubers. The above nutrients each play an essential part in carbohydrate synthesis, the details being beyond the scope of this study.

The protein content of tubers can be increased by fertilisation with nitrogen (Prosba Bialczyk, 1992), with N accumulating in the tubers, predominantly in the form of

proteins and free amino acids. Leszczynski and Lisinska (1988) found that fertiliser nitrogen increased the content of six essential amino acids in the tuber. Negrila *et. al.*, (1994) reported that the amino acid concentration of tubers increases with increasing potassium levels. It has also been shown that P application decreases protein content (Hammet *et. al.*, 1982). Pirson (1955) found that sulphur also plays a part in the synthesis of proteins.

Magnesium is an essential element in the synthesis of proteins (Gauch, 1972). Ponnapalam (1985) observed that magnesium fertilisation increased total non-protein N, as well as protein N. It is important to consider the source of Mg used, as Mondy and Ponnampalam (1986) found that epsom salt causes a greater increase the protein content of tubers than dolomite.

1.3.3 Vitamins

The main vitamin found in potatoes is vitamin C. It is found in both the reduced state (ascorbic acid) which predominates in the tuber (approximately 85-100%) and the oxidised state (dehydroascorbic acid), the two forms being readily interchangeable.

Conflicting results have been reported with regards to the effect of N application on the vitamin C content of the tuber. Mazur and Ciecko (1974) found a drop in vitamin C content with increasing nitrogen, whereas Mondy *et* al. (1979) found the reverse to be true. Maurya and Dhar (1984) found that the application of P and N causes an increase in the vitamin C content, as well as bringing about increases in the content of the vitamins A and B1.

1.3.4 Storage Quality

The storage quality of the crop may be affected by the mineral nutrition of the crop. Increasing the application of nitrogen causes a shorter period of dormancy and leads to earlier sprouting (van Ittersum, 1992). This is important in the case of seed tubers that have to be stored for long periods of time before use or planting. Krauss and

Marschner (1982) observed that a continuous supply of nitrogen to the potato plant led to a relatively low ABA (abscisic acid) level and a high GA (giberellin) level in the shoot, leading to delayed tuberisation, as well as a reduction in dormancy.

For some pathogens, particularly pathogenic bacteria, no practical chemical controls have been developed. Many fungal pathogens have developed resistance to commonly used chemicals. To continue to reduce post-harvest losses and improve the quality of stored produce, natural mechanisms of resistance to pathogens might be exploited to reduce dependency on chemical treatments (Conway *et al.,* 1992). Calcium uptake by potato plants is correlated with a decrease in surface area decay (Conway *et al.,* 1992). Calcium ions bind to pectins in the cell wall resulting in a bunched configuration allowing spaces for the insertion of cations. This hinders pectolytic enzymes produced by the fruit, fungal or bacterial pathogens that cause decay. Thus, the role of calcium in resistance may be one of interfering with the activity of pectolytic enzymes (Conway *et al.,* 1992).

1.3.5 Physiological Disorders

1.3.5.1 Hollow Heart and Brown Centre

Hollow Heart is most commonly characterised by a hole of varying dimensions towards the tuber centre and is more common in large tubers (Silva *et al.,* 1991). There are no external symptoms. Hollow heart may often be preceded by the onset of brown centre, which is characterised by browning due to cell death in the pith area of the tuber. Whether preceded by brown centre or not, it is generally accepted that hollow heart is a result of tissue tension associated with nutritional imbalances or rapid tuber enlargement, leading to reduced specific gravity. Hollow heart usually occurs early in the season at the stem end of the tuber.

High nitrogen applications, particularly around tuber initiation, can induce a higher incidence of hollow heart. Nitrogen is applied at this time in order to promote rapid

tuber growth. The incidence of hollow heart is increased when this application of nitrogen coincides with high soil water content (Harris, 1992).

Potassium appears to lower the incidence of hollow heart (Jackson *et al.,* 1984, cited by Harris, 1992). There is also evidence that an increase in calcium may decrease the severity of hollow heart (Vander Zaag and Ffrench, 1987, cited by Harris, 1992), although work by Hiller and Koller (1987) conflicts with this finding.
It has also been found that higher concentrations of boron increase the incidence of tubers with hollow heart (Hiller and Koller, 1987).

1.3.5.2 Internal Rust Spot

Internal Rust Spot (IRS) is characterised by rust coloured lesions of variable size in the tissues within the vascular ring (Silva *et al.,* 1991). Calcium deficiency in tubers is the primary cause of IRS. A restriction of calcium supply to developing tubers induces the appearance of IRS. Potassium and magnesium also reduce the incidence of IRS. Ca is, however, more efficient at reducing IRS than both K and Mg. It appears that the resistance to IRS is associated with a higher antioxidant status in the tuber in the presence of higher levels of calcium (Monk and Davies, 1989).

1.3.5.3 Blackspot or Internal Bruising

Two independent conditions are necessary for blackspot development - a damaging impact on susceptible tuber tissue and tissue that has the potential to produce the discoloured oxidation products. This phenomenon is induced during rough harvesting, handling, and transportation, and is also influenced by fertility.

Potassium has the greatest and most consistent effect on blackspot. Tubers grown with low levels of potassium are more susceptible to blackspot (Workman and Holm, 1984).

1.3.5.4 Enzymic Browning

This phenomenon causes the discolouration of cut surfaces, external bruising and blackspot (caused by internal bruising). Enzymic browning is reduced when higher levels of potassium are present (Welte and Muller, 1966). Discolouration is more common when the source of potassium used is K_2SO_4, as opposed to KCl^- and K_2O (Joshi *et al.*, 1992).

1.3.5.5 After Cooking Blackening

This is a non-enzymic discolouration of the tuber. The phenomenon is also referred to as stem-end blackening, as it is usually more obvious at the stolon end of the tuber. A high ratio of nitrogen to potassium has been found to predispose tubers to "after-cooking blackening" (Hughes and Evans, 1987). It was shown that potatoes blackened more when grown in soils with high levels of organic matter and low levels of K (Hughes and Evans, 1987).

Iron gives rise to increased blackening. High pH and Ca levels which give rise to reduced iron availability bring about a reduction in after cooking blackening (Griffiths *et. al.*, 1992).

Wallace and Wain (1943, cited by Ivins and Milthorpe, 1963) found that severe deficiencies of P also increased blackening.

1.3.5.6 Smooth Skin

"Smooth skin" is characterised by a smooth skin in the normally russeted skin in Russet Burbank variety. This phenomenon is caused by an excess of N and K, and a corresponding deficiency in P (Ohms, 1962, cited by Li, 1985).

1.3.5.7 Translucent End and Jelly End

Translucent end manifests itself in a water-soaked or glassy appearance at the stem end of affected tubers. The affected tissue becomes soft and spongy and may eventually dry up and crumble. The affected tissue has a lower dry-matter, as well as a higher reducing-sugar level than the unaffected portion of the tuber (Iritani and Weller, 1973, cited by Li, 1985). Jelly end is a progression from translucent-end tubers, which results from stresses on the plant. The incidence of translucent end can be reduced by avoiding excess N applications (Kleinkopf, 1979).

1.4 THE EFFECT OF MINERAL NUTRITION ON PESTS AND DISEASES

1.4.1 Insects

The growth, reproduction and survival of phytophagous insects are positively correlated with the nitrogen content in their food. The variation in plant nitrogen can have either a positive or negative effect, depending on the insect-plant relationship involved (Mattson, 1980). Jansson and Smilowitz (1986) found that an abundance of the Colorado potato beetle (*Leptinotarsa decemlineata*) was positively correlated with foliar nitrogen content. The dry mass gain of larvae are positively correlated with increasing concentration of N applied to potato plants (Zitzman and May, 1989). Increasing levels of plant nitrogen may have beneficial nutritional effects for herbivorous insects, however, this can be countered by nitrogen acting as a plant antifeedant or toxin. Many of the toxic allelochemicals that are found in plants are nitrogen-based (Mattson, 1980). In the case of the Colorado potato beetle, the positive effects of added N on insect nutrition outweigh any beneficial effects on host plant defences (Zitzman and May, 1989).

1.4.2 Bacteria

1.4.2.1 Bacterial Soft Rot

The bacterial soft rot diseases of potato are caused by *Erwinia carotovora* subsp. *atroseptica* and *E. carotovora* subsp. *carotovora* and *E. chrysanthemi*. These diseases have frequently caused serious losses world-wide. At present there are no effective chemical controls or highly resistant cultivars available. Cultural practices and the use of pathogen-free seed have been relatively ineffective.

An increase in the concentration of tuber calcium brings about a decrease in the severity of bacterial soft rot (Bartz *et al.,* 1992). This decrease may be attributed to a reduction in tissue degradation and maceration by pectolytic enzymes, due to an enhanced structural integrity of cell walls and membranes (McGuire and Kelman, 1984). Monovalent ions, such as potassium and sodium also reduce decay, but are not very effective. Magnesium reduces decay to a greater extent than the monovalent ions, but is not as efficient as calcium (Kelman *et al.,* 1990).

An increase in Ca may also result in increased resistance to other bacterial diseases, such as bacterial wilt caused by *Pseudomonas solanacearum* (Kelman, unpublished data., as cited by Kelman *et al.,* 1990), as well as other diseases resulting from pathogens that macerate tissues, primarily with pectolytic enzymes (McGuire and Kelman, 1984). Calcium fertilisation does not provide a means for the complete control of soft rot, but simply reduces the severity of the disease.

1.4.2.2 Brown Rot

This disease, caused by *Pseudomonas solanacearum*, also causes a soft rot of the potato tuber. As with Erwinia soft rot, higher levels of calcium may lead to a reduction in the severity of brown rot (Kelman, unpublished data, cited by Kelman *et al.,* 1990).

The addition of fertilisers such as superphosphate (15% P_2O_5) or potassium sulphate (48-58% K_2S0_4) to potatoes, decreases the incidence and severity of the disease (Fahmy and Mohamed, 1990).

1.4.3 Fungi

1.4.3.1 Potato Wart

The causal agent of this disease is *Synchytrium endobioticum*. It has been shown that two types of nitrogen source exhibited different levels of disease control, urea being much more effective than ammonium nitrate. The application of urea and ammonium nitrate provides partial suppression of the disease, which is manifested in a reduction of disease intensity and severity. It is assumed that the metabolism of ammonia is in some way responsible for this reduction (Hampson, 1985).

1.4.3.2 Verticillium Wilt

This disease, caused by members of the genera *Verticillium*, namely *V. dahliae* and *V. albo-atrum*, is among the most destructive plant diseases, having the potential to limit yield severely (Pennypacker, 1990).

It has been shown that N, in the ammonia form, brings about an increase in resistance to Verticillium wilt (Dutta and Isaac, 1979). It has also been shown that there is an increase in Verticillium wilt with the use of the nitrate form of nitrogen (Davis and Everson, 1986). The uptake of the different ions alters the ion balance in the plant. This affects the expression of resistance that depends on host chemical composition and metabolic activity (Pennypacker, 1990). The two sources of nitrogen also cause differences in the levels of soluble carbohydrates in the root. Under high levels of nitrate fertilisation, levels of root soluble carbohydrate will be higher than they are when the levels of nitrate are low. The high soluble carbohydrate levels promote the disease (Marschner, 1995). The application of organic matter with a high carbon to nitrogen ratio results in the immobilisation of nitrogen during microbial decomposition leading to a reduction in the disease (Barber, 1984).

The effect of potassium on resistance to Verticillium wilt is only evident when the element is deficient in the soil (Marschner, 1995). Increasing the level of potassium increases host resistance. This may be due to improved root growth which reduces the susceptible root tips exposure to the disease. Potassium is involved in a number of metabolic processes in the plant, and thus, a lack of this element affects metabolism, reducing the ability of the plant to respond to pathogen invasion (Pennypacker, 1990).

1.4.3.3 Fusarium Wilt

Fusarium wilt (*Fusarium oxysporum*) can be controlled by the altering of soil pH. The application of calcium in the form of lime causes an increase in pH and a corresponding reduction in the occurrence of wilt. The same researchers showed that the nitrate form of nitrogen decreased disease development as compared with nitrogen in the ammonia form. It has been further demonstrated that the beneficial effects of high pH are negated by the application of ammoniacal nitrogen.

It was found that when using the nitrate form of nitrogen, potassium deficiency favoured disease resistance (Walker and Foster, 1946).

Phosphorus fertilisers favour the formation of glycoalkaloids and phenols in the potato periderm, thus giving rise to reduced infection of tubers by fusarium wilt (Pisarev *et. al.,* 1976).

Applications of copper and manganese reduce growth of the fungus. Liming of soil, and the subsequent increase in pH, makes these micronutrients less available and thus reduces the occurrence of wilt (Langerfield, 1973). The lack of boron, however, results in reduced disease incidence (Keane and Sackston, 1984).

Another disease caused by members of the genera *Fusarium*, is potato stem-end rot. The characteristic symptom being a collapse of the stem just above or below ground level. This leads to the premature death of the plant and the development of

a dry rot of spongy consistency at the stem end of the tuber. The incidence of this disease is reduced by the application of potassium (Lintner, 1965).

1.4.3.4 Watery Wound Rot

This disease is caused by *Fusarium ultimum*. It has been shown that the disease is greatly reduced by the addition of calcium oxide in a large number of host plants (Lewis and Lumsden, 1984).

1.4.3.5 Common Scab

Caused by *Streptomyces scabies*, the disease is affected by changes in soil pH, which then determines the effect of plant nutrients on the disease (Keinath and Loria, 1990). The oxidisation of sulphur and the accompanying drop in pH causes disease suppression (Terman *et al.*, 1948), the effects of which can be reversed by the application of lime (Davis *et. al.*, 1976). The alteration in pH is not the only cause for this reversal. There is also an increase in susceptibility to scab with an increase in tuber Ca levels (Davis *et. al.*, 1976).

The application of copper sulphate provides a certain degree of control for scab, due to the inhibition of calcium uptake, as well as the toxicity of elemental copper to *S. scabies* (Mordtvedt *et al.*, 1963, cited by Keinath and Loria, 1990). Copper is not used commercially, however, due to its negative effects on plant growth and yield when present in supra-optimal levels (Knight, 1941, cited by Keinath and Loria, 1990).

Nitrogen appears to influence potato scab indirectly through its influence on soil pH. Ammoniacal forms of nitrogen and those which produce ammonia can acidify the soil, thus causing a reduction in the incidence of potato scab (Goldberg *et. al.*, 1983).

Phosphorus only indirectly affects scab control and this is dependent on form of P used. Fertilisers with high levels of Ca, even those with no effect on the pH, have little effect on, or may lead to increased potato scab.

The manganese content of potato tubers is increased by manganese treatments, with the result that scab severity is reduced (Grzeskiewics, *et. al.,* 1990). The results of field trials, however, have not been favourable enough to warrant the use of manganese sulphate for scab control. Furthermore, high levels of manganese can be toxic to potatoes.

1.5 TIMING AND PLACEMENT OF FERTILISERS

1.5.1 Timing of Fertiliser Application

The timing of fertiliser application, relative to the stage of growth of the plants, can greatly affect growth and yield of potatoes. In most important potato growing areas, all of the fertiliser is applied through the planter at planting time. The fertiliser is placed in bands at both sides of the row and slightly below the level of the seed pieces (Smith, 1968). In a number of areas, many growers split the application, applying approximately half of the total amount to be used broadcast on unploughed soil and then applying the rest of the fertiliser as side dressings. Ivins and Milthorpe (1963) suggested that yield was increased by the withholding a portion of the N until after tuber initiation, thus increasing the bulking duration. Gunasena and Harris (1971) attributed the increased recovery of the nutrients by the crop with the avoidance of leaching losses associated with delayed fertiliser application. In subsequent experiments conducted on the same sites in the season in which leaching did not occur, delaying the application of all or part of the N fertiliser until after tuber initiation, did not result in any marked effects on the response to N (Ngugi, 1972, cited by Harris, 1992).

High rates of nitrogen application stimulate excessive canopy dry matter production and result in a reduction in early tuber growth (Payton, 1990). Krishnappa and

Sulladmath, 1981) suggested that dividing the application of N into three dressings, might increase tuber yield by increasing tuber size. McCann and Stark (1989), however, found that this practice increased the incidence of the physiological disorders, brown centre and hollow heart, particularly when combined with high irrigation.

Split applications may be useful when large quantities of fertiliser are applied under dry conditions, as this may reduce scorching (Beukema and van der Zaag, 1990). The application of large amounts of fertilisers under dry conditions leads to a concentrated soil solution, which may in turn give rise to the scorching of crop leaves.

Split applications may be useful in the case of phosphorus on soils where it is easily fixed and becomes unavailable. Papadopolous (1991) found that the use of fertigation on a regular basis increased the P content of the soil, compared with a single pre-season treatment. As phosphorus contributes to the early development of the crop, however, the practice of applying split applications of this particular nutrient is not be advisable (Beukema and van der Zaag, 1990).

1.5.2 Fertigation and Foliar Feeding

Fertiliser application can also take place in the form of fertigation (combination of irrigation and fertilisation) and foliar feeding ("non root feeding"). Both fertigation and foliar fertilisation have increased their role in crop production in recent years.

Some soil fertilisation problems can only be solved by foliar fertiliser application (Eibner, 1985). For example, foliar feeding can be used in cases where the soil is deficient in certain nutrients. Deficiencies occur due to total the absence of the nutrient, removal of the nutrient from the soil by plants, through leaching, or to trace elements and also some macro nutrients being bound due to unfavourable soil conditions. Furthermore, stress situations during growth stages can be readily and effectively overcome with foliar feeding. Supplementary and compensatory foliar

feeding is more economical than root fertilisation due to the greater efficiency of nutrient use (Eibner, 1985).

Millard and Robinson (1990) found that foliar sprays of urea increased both tuber yields and tuber nitrogen contents, when compared to a single application at planting. They also found that a greater proportion of the foliar applied nitrogen was recovered, as opposed to nitrogen broadcast at planting. This was partly due to the prevention of pre-emergence leaching losses of nitrate. The effect of foliar feeding on tuber yield is not certain though, as conflicting evidence has been found.

Fertigation is the application of fertiliser in irrigation water either in surface or overhead irrigation (Tisdale and Nelson, 1975). There are two main advantages of fertigation. Firstly, fertigation allows the regular application of nutrients and carries them to the root zone (Phene and Sanders, 1976). Secondly, the number of field operations are reduced. This may give rise to a reduction in cost and labour use (Tisdale and Nelson, 1975). This is particularly true when split applications are used (Hagin and Tucker, 1982). Water soluble fertilisers at concentrations required by crops are conveyed with every irrigation or at desired intervals, resulting in a reduction of losses through leaching and giving rise to increased fertiliser recovery (Phene and Beale, 1976).

The use of fertigation may give rise to large savings. Hagin and Tucker (1982) found that applications of N as ammonium nitrate in a drip system resulted in 50% savings, when compared with soil applications. In the above case the yields were the same for both fertigation and soil applications. Fertigation has been shown to be a promising means for maintaining nitrogen concentration in potato soils throughout the growing period at desirable levels, without undue losses by leaching (Papadopolous, 1988).

Application of phosphorus through fertigation gives rise to an increase in the yield, specific gravity of tubers, dry matter and starch (Papadopolous, 1991). Phene and Beale (1976) found that fertigation of phosphorus was a viable option as it

substantially increases the phosphorus concentration in the soil solution. With frequent fertigation the use of the soil as a storage reservoir for water and nutrients is minimised (Phene and Beale, 1976).

CHAPTER 2

THE EFFECT OF SOIL ACIDITY ON POTATO GROWTH AND DEVELOPMENT

2.1 INTRODUCTION

Calcium is an essential plant nutrient, and if deficient may lead to a reduction in tuber yield, and in extreme cases, to complete crop failure. The availability of Ca, required for potato growth and development (Beukema and van der Zaag, 1990), is reduced under low pH, high al conditions (Mortvedt *et al.,* 1972). The three experiments in this chapter attempt to investigate the merits involved in different methods of meeting potato Ca requirements in such soils. The experiments also attempt to determine the reasons behind the variations in Ca uptake by the plants, including increases in soil pH and soil Ca content, a reduction in available al in the soil, and an increase in the Ca content of the mother tuber. The addition of lime to acid soils may take place in order to increase the availability of Ca to the potato crop. This, however, is a costly procedure, and an excessive rise in soil pH increases the incidence of diseases such as common scab (Keinath and Loria, 1990). Research aimed at discovering alternative methods of meeting the plants Ca requirements, may lead to a reduction in the expense and time required for the supply of nutrients to the crop. These methods may enable "small farmers" to grow a potato crop in soils that would otherwise be unsuitable for cultivation, and would previously have been beyond their financial means to ameliorate.

The first experiment in this chapter, section 2.2, aimed to determine the extent to which the fertiliser Calmag+B (a soluble fertilizer containing calcium nitrate, magnesium nitrate and boron, with 117 g kg^{-1} Ca, 38 g kg^{-1} Mg, 137 g kg^{-1} N and 2 g kg^{-1} B - Appendix 2), could be used in place of lime. The second experiment (section 2.3), sought to determine the effect of soil "pre-enrichment" (application of large quantities of Ca, Mg, NO_3^- and B, in order to over the soil's deficiency), using

Calmag+B, prior to planting the crop. The experiment was also aimed at determining the effect of "nutrient pre-enrichment" of the mother tuber, prior to planting. This was performed in an attempt to overcome the restrictions imposed by the highly acid and infertile soil. The third experiment (section 2.4), attempted to isolate the factors that led to improved potato emergence, growth and development, among the different treatments used in section 2.3.

2.2 THE EFFECT OF LIME, CALMAG + B AND A COMBINATION OF THE TWO CALCIUM SOURCES ON POTATO DEVELOPMENT

2.2.1 INTRODUCTION

Potatoes are relatively tolerant to acidity and liming may be unnecessary unless the pH is very low (Beukema and van der Zaag, 1990). Calcium, nevertheless, is an essential plant nutrient and if deficient may lead to serious yield reduction and even crop failure (Beukema and van der Zaag, 1990). The object of this experiment was to determine the extent to which Calmag+B could be used in place of lime on an acid, infertile subsoil, to meet the growth and nutrient requirements of the plants. Calmag+B is highly soluble, and hence, there have been unsubstantiated claims that Calmag+B would have greater ease of movement through the soil profile than would lime. Boron was incorporated into the fertilizer since it has a tendency to be deficient under acid conditions, particularly when in the presence of Ca (Mortvedt *et al.*, 1972). There have also been unsubstantiated claims from the producers of Calmag+B, that the presence of B would lead to an increase in plant uptake of Ca.

2.2.2 MATERIALS AND METHODS

Geluksberg subsoil ((Soil Classification Working Group, 1991) Form: Avalon; Series: Normandine; Acid Saturation 84 %; Mineral constituents: 2 mg L^{-1} P; 86.0 mg L^{-1} K; 88.2 mg L^{-1} Ca; 42.5 mg L^{-1} Mg; 4 mg L^{-1} Mn; 0.5 mg L^{-1} Zn - Appendix 3) was ameliorated using $Ca(OH)_2$ (Appendix 4), giving rise to 4 different levels of pH and soil amelioration within the same soil (Table 2.1), the lowest pH level being

unameliorated Geluksberg soil. At each of the four pH levels, there were three levels of Calmag+B applied (each applied on the third, fifth, eighth and tenth weeks after plant emergence), consisting of 0.165, 0.330 and 0.495 g pot^{-1} (approximately equivalent to commercial applications of 50, 100 and 150 kg ha^{-1} respectively). The different levels of Calmag+B application were employed to give an indication of the application of Calmag+B to optimise yield response at the various pH levels presented by the experiment. The experiment was arranged in a 4x3 factorial design with 3 replications. Data was analysed with Genstat 5 (Rothamsted Experimental Station, 1988) and least significant difference (LSD) was used to determine whether differences between means were significant.

Table 2.1 Change in pH, acid saturation and Ca of a Geluksberg series subsoil following amelioration with slaked lime

$Ca(OH)_2$ APPLIED (g $100g^{-1}$ of soil)	pH	ACID SATURATION (%)
0	4.1	84.00
0.170	4.4	23.37
0.235	5.5	0.73
0.280	6.0	0.66

The experimental units used were undrained 250 mm diameter plastic pots lined with blue polyethylene bags. Prior to planting, 2:3:2 (22) fertilizer was applied at a rate of 4.3 g pot^{-1}, approximately equivalent to commercial applications of 1300 kg ha^{-1} (81.9 kg ha^{-1} N; 122.2 kg ha^{-1} P; 81.9 kg ha^{-1} K - Appendix 5). The fertilizer recommendations were based on a target yield of 40 t ha^{-1} and a plant density of 50 000 plants ha^{-1} (Nijland, pers. comm.)[1]. Magnesium was added to each pot (70 mg kg^{-1} of Mg^{++} in the form of $MgSO_4.7H_2O$) in order to raise the magnesium content of the pots with the lowest Mg content to a minimum of 100 mg L^{-1} (Manson *et. al.*, 1995). This was carried out in order to ensure that there was no Mg deficiency. The

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tubers were dipped in a Berelex (10 % GA_3) solution (40g tablet in 200L of water) for a period of ten minutes, and upon removal from the solution were laid out in the sun to dry for twenty minutes. The object of the gibberellic acid treatment was to ensure uniform and vigorous plant emergence. One seed tuber of the cultivar "Up To Date" was planted at a 50mm depth in each pot.

The soil in each pot was brought to Field Water Content (FWC) upon planting, and was maintained at this water level throughout the course of the experiment. To determine the FWC of the soil, water was added to a column of soil in a 1L measuring cylinder, followed by the determination of the quantity of water remaining in the soil after the downward movement of water had ceased. The amount of water added to the soil was measured to prevent the wetting front from reaching the bottom of the cylinder. Insertion of a 9 mm glass tube into the soil permitted the air trapped below the wetting front to escape when displaced by water. To prevent evaporation loss, the top of the cylinder was covered with a thin polyethylene sheet, held in place by a rubber band. Approximately 24 h after the application of water, a sample was taken from the top of the soil surface column so as to determine the moisture content . The soil sample was weighed, and then weighed again after 24 h at 70 °C, thus making it possible to determine of the mass of water in the soil at FWC.

The pots were weighed directly after planting had taken place, with the soil in the pots at FWC. This ensured that any water loss from the pots during the course of the experiment could be measured, and the water mass necessary to achieve FWC again could be calculated. An excess number of pots were planted so that destructive sampling of plants could be undertaken. Plants in these pots were harvested and weighed during the course of the experiment, allowing the mass of the plant to be taken into account when calculating the quantity of water to be added to each pot. Pots were watered on a daily basis.

Fertilizer treatments began 2 weeks after plant emergence (Appendix 5). Mono-ammonium phosphate, in the form of Agrifos (a soluble fertilizer consisting of 120 g

kg^{-1} N and 270 g kg^{-1} P - Appendix 2), was applied to the soil in all of the pots on the second, fourth and sixth weeks after plant emergence, at a rate of 0.165 g pot^{-1} (approximately equivalent to commercial applications of 50 kg ha^{-1}). There were also applications of KNO_3 on the seventh, ninth and eleventh weeks after plant emergence, at a rate of 0.33 g pot^{-1} (approximately equivalent to commercial applications of 100 kgKNO_3 ha^{-1}). As emergence was influenced by soil pH, the application of fertilizer treatments was staggered in accordance with the mean emergence date of each pH treatment. Fertilizer application was staggered to ensure that all plants received the treatments at about the same physiological age.

A Previcur and Benlate mixture (Appendix 1) was used to drench the soil in the pots every 10 days to prevent infection by a*lternaria, Pythium* and *Rhizoctonia*. Bravo (Appendix 1) was sprayed once every seven days in order to prevent early and late blight infections.

The trial was conducted in a polycarbonate growth tunnel. Temperature was controlled by fans at the one end of the tunnel that draw air through a "wet wall" located at the other end. A system of thermostats inside the tunnel was set to switch on the fans when the temperature reached 28°C. Pumps that put water onto the "wet wall" were switched on when the temperature reached 30°C.

Plant harvesting was staggered, taking place precisely 16 weeks after the mean emergence date for each treatment, as the "Up To Date" cultivar has little dormancy and must be harvested as soon as its growing season is over (Naidoo, pers. comm.)[2]. At harvest, the mass and number of tubers per pot were determined, followed by an analysis of the nutrient content of the tubers using the procedures of Farina and Channon, 1988. Tuber N and S were analysed by dry combustion using a LECO CNS 2000 analyser (Smeda *et. al.,* 1997).

Statistical analyses were conducted on the number of plants surviving up to the time of harvest, and on tuber yield, tuber number per pot and mean mass per tuber.

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Statistical analyses were also conducted on the nutrient concentration of tubers (measured as g kg^{-1} of dry matter for macro-nutrients and mg kg^{-1} of dry matter for micro-nutrients) and tuber nutrient amount pot^{-1} between the various treatments (Appendix 6). The purpose of the tuber nutrient amount pot^{-1} analysis was to determine whether a dilution effect had taken place, for example, when a treatment has a low nutrient concentration due to the fact that it has a high yield, indicating a "dilution" of tuber nutrient concentration (Jarrel and Beverly, 1982).

2.2.3 RESULTS

Plants growing in the more acidic soil took longer to emerge than those grown in ameliorated soil. As the pH 4.1 treatment produced only four out of nine pots containing plants that survived up to the time of harvest (with only one of these yielding tubers), only the analyses for yield, tuber number and mean mass per tuber was conducted using all the pH treatments. The analysis for the determination of nutrient concentration and nutrient amount pot^{-1} were carried out using only the pH 4.4, 5.5 and 6.0 treatments. As the data was not normally distributed, power transformations were used in the analyses for the variables tuber number per pot and mean mass per tuber.

2.2.3.1 PLANT SURVIVAL AND YIELD AS AFFECTED BY pH AND CALMAG+B TREATMENTS

There were significantly ($P < 0.01$) fewer surviving plants at the time of harvest in the pH 4.1 treatment, compared with the other three lime treatments (Appendix 7; Figure 2.1).

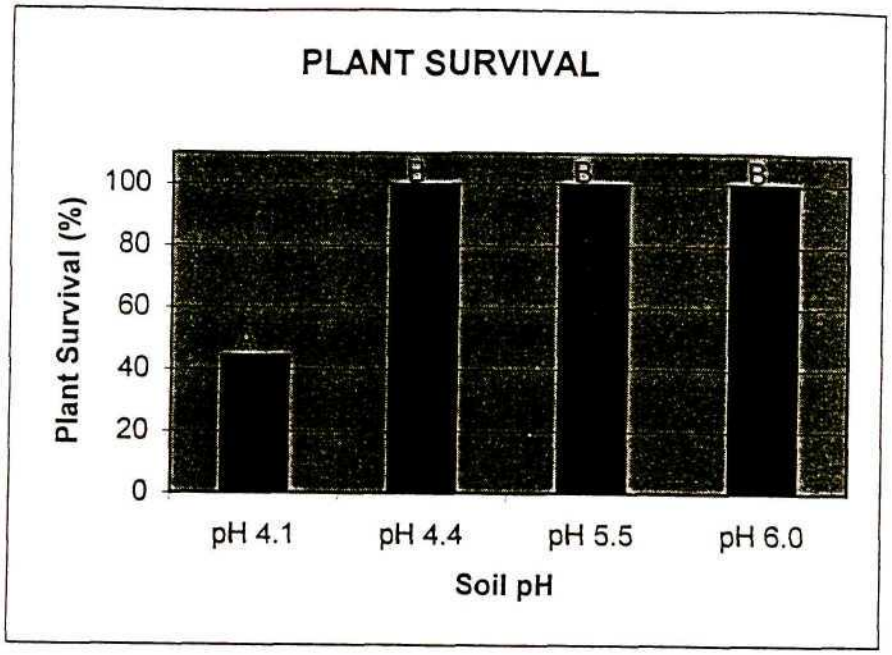

Figure 2.1 Plant survival as affected by different liming levels in Geluksberg soil. Letters above individual bars relate to χ^2 analysis for absolute emergence

There were highly significant differences in tuber yield between the pH 4.1 treatment and the treatments pH 4.4, pH 5.5 and pH 6.0 (Figure 2.2; Table 2.2), the pH 4.1 treatment having a lower yield than the other three treatments. Much of the difference in yield between the pH 4.1 treatment and the other lime treatments is due to the reduction in plant survival, and hence plants producing a tuber yield, in the pH 4.1 treatment at the time of harvest. There were no significant differences for yield between the Calmag+B treatments (Appendix 6).

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	16721	8360	4.10	
pH	3	233544	77848	38.16	<0.001
Calmag+B	2	9206	4603	2.26	0.130
pH.Calmag+B	6	3339	556	0.27	0.944
Residual	21(1)	42838	2040		
Total	34(1)	290253			

Grand mean = 148.9
% CV = 17.7

Figure 2.2 Analysis of variance for yield (g) of potato tubers

2.2.3.2 TUBER NUMBER AND MEAN MASS PER TUBER AS AFFECTED BY pH AND CALMAG+B TREATMENTS

There were highly significant differences in tuber number pot^{-1} and mean mass per tuber between the pH 4.1 treatment and the treatments pH 4.4, pH 5.5 and pH 6.0 (Figure 2.3 and 2.4; Table 2.2), the pH 4.1 treatment having fewer tubers pot^{-1} and a lower mean mass per tuber than the other three treatments. There were no significant differences between Calmag+B treatments for tuber number pot^{-1} or mean mass per tuber (Appendix 6; Table 2.3).

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.06980	0.03490	0.42	
pH	3	11.43664	3.81221	45.60	<.0001
Calmag+B	2	0.32209	0.16104	1.93	0.171
pH.Calmag+B	6	0.39692	0.06615	0.79	0.587
Residual	21(1)	1.75578	0.08361		
Total	34(1)	13.89308			

Grand mean = 1.3 (10)
% CV = 22.2

Figure 2.3 Analysis of variance for tuber number pot^{-1}

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.005400	0.002700	0.72	
pH	3	0.612686	0.204229	54.80	<0.001
Calmag+B	2	0.000991	0.000495	0.13	0.876
pH.Calmag+B	6	0.031898	0.005316	1.43	0.251
Residual	21(1)	0.078264	0.003727		
Total	34(1)	0.715542			

Grand mean = 1.249 (13.7)
% CV = 4.9

Figure 2.4 Analysis of variance for tuber average mass ($g^{0.1}$)

2.2.3.3 Ca RESPONSE TO LIMING TREATMENTS

There was a gradual rise in the Ca concentration of tubers from the pH 4.4 to the pH 6.0 treatment, with a significant difference between the pH 4.4 treatment and the pH 5.5 and 6.0 treatments (Figure 2.5 and 2.7). There is a significant difference in Ca uptake (amount pot^{-1}) between the pH 4.4 and pH 5.5 treatments (the pH 6.0 treatment being mutual to both groups – Figure 2.6 and 2.7). The results indicate a trend in which there is an increase in both Ca concentration and Ca amount pot^{-1} with increasing pH. As these increases in Ca concentration and Ca uptake do not lead to an increase in tuber yield (Table 2.2), tuber number and mean mass per tuber (Table 2.2), it can be assumed that an increase in lime application beyond the pH 4.4 level could only affect tuber quality or the incidence of physiological disorders (e.g. Internal Brown Spot – Monk and Davies, 1989) and certain diseases (eg. Bacterial soft rot - Bartz *et al.*, 1992). Due to the small sample sizes available, tuber quality and the incidence of physiological disorders and diseases could not be determined.

Table 2.2 **The Effect of Lime ($Ca(OH)_2$) Treatments on tuber yield, tuber number, mean mass per tuber, mineral element content and concentration of potato tubers**

TUBER YIELD, TUBER NUMBER PER POT, MEAN MASS PER TUBER AND NUTRIENT ANALYSES	AMELIORATION TREATMENT				LSD (5%)
	pH 4.1	pH 4.4	pH 5.5	pH 6.0	
TUBER YIELD (g)	106.3*	186.2	212.0	178.9	44.3
TUBER NUMBER POT^{-1}($number^{0.2}$)	0.326* (1)**	1.561 (10)**	1.670 (14)**	1.643 (13)**	0.284
MEAN MASS $TUBER^{-1}$ ($g^{0.1}$)	1.026 (0.9)**	1.351 (21.5)**	1.325 (18.2)**	1.295 (14.1)**	0.060
N concentration ($g\ kg^{-1}$)	14.10 *	10.22	10.85	11.36	0.87
N AMOUNT POT^{-1} ($g\ pot^{-1}$)	1.499 *	1.892	2.407	2.045	NS
P concentration ($g\ kg^{-1}$)	4.0*	1.8	2.2	2.4	0.3
P AMOUNT POT^{-1} ($g\ pot^{-1}$)	0.43 *	0.34	0.48	0.40	0.08
K concentration ($g\ kg^{-1}$)	21.6 *	16.9	16.8	18.7	NS
K AMOUNT POT^{-1} ($g\ pot^{-1}$)	2.30 *	3.12	3.68	3.34	NS
Mg concentration ($g\ kg^{-1}$)	1.2 *	0.7	0.7	0.8	NS
Mg AMOUNT POT^{-1} ($g\ pot^{-1}$)	0.13 *	0.13	0.15	0.13	NS
S concentration($g\ kg^{-1}$)	1.73 *	1.36	1.41	1.56	0.13
S AMOUNT POT^{-1} ($g\ pot^{-1}$)	0.184 *	0.253	0.311	0.265	NS
Cu concentration ($mg\ kg^{-1}$)	7 *	3	5	3	2
Cu AMOUNT POT^{-1} ($mg\ pot^{-1}$)	0.7 *	0.6	1.2	0.6	0.5
Zn concentration ($mg\ kg^{-1}$)	29 *	18	16	18	NS
Zn AMOUNT POT^{-1} ($mg\ pot^{-1}$)	3.1 *	3.4	3.6	3.1	NS
B concentration ($mg\ kg^{-1}$)	9 *	6	5	5	NS
B AMOUNT POT^{-1} ($mg\ pot^{-1}$)	1.0 *	1.1	1.1	0.9	NS

* The values displayed under the pH 4.1 treatment in the above table were obtained from one pot - the only pot producing tubers - within the treatment (the treatment originally consisting of nine pots)..

** Figures within brackets depict untransformed means.

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0057266	0.0028633	5.50	
pH	2	0.0061267	0.0030633	5.88	0.013
Calmag+B	2	0.0005086	0.0002543	0.49	0.623
pH.Calmag+B	4	0.0039158	0.0009789	1.88	0.166
Residual	15(1)	0.0078090	0.0005206		
Total	25(1)	0.0240346			

Grand mean = 0.7
% CV = 24.1

Figure 2.5 Analysis of variance for Ca concentration (g Kg^{-1}) of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.017462	0.008731	2.41	
pH	2	0.029535	0.014767	4.07	0.039
Calmag+B	2	0.004903	0.002452	0.68	0.524
pH.Calmag+B	4	0.001846	0.000461	0.13	0.970
Residual	15(1)	0.054451	0.003630		
Total	25(1)	0.102662			

Grand mean = 0.14
% CV = 22.2

Figure 2.6 Analysis of variance for Ca amount pot^{-1} (g pot^{-1})

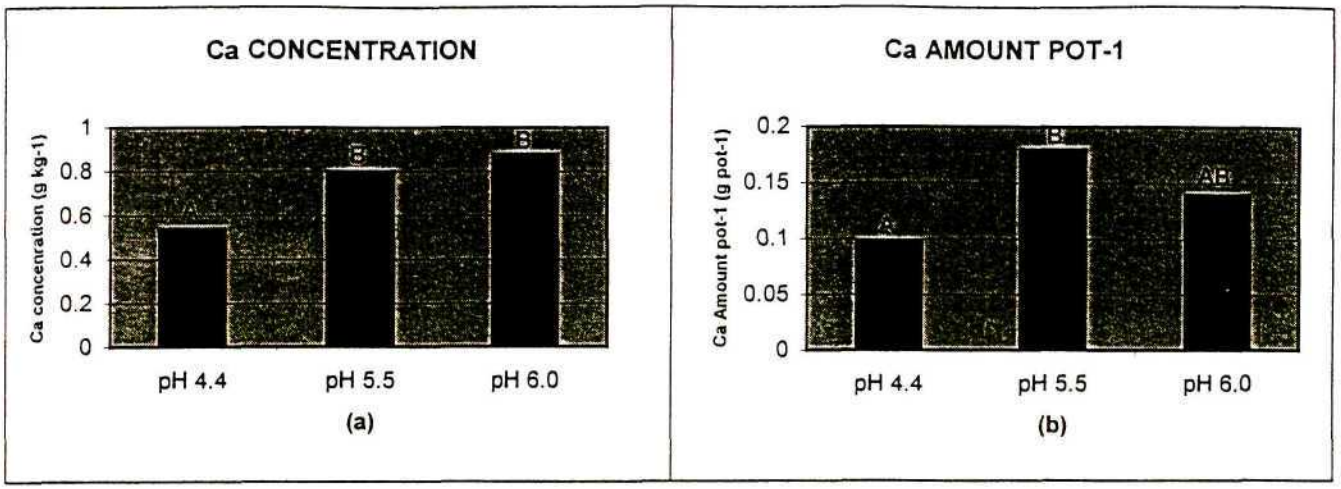

Figure 2.7 **Tuber Ca concentration (a) and Ca amount pot^{-1} (b) as affected by different liming treatments. Letters above individual bars indicate significant differences between liming treatments within each measure factor.**

2.2.3.4 Mn RESPONSE TO LIMING TREATMENTS

There was a gradual reduction in Mn concentration from the pH 4.4 to the pH 6.0 treatment (although there is not a statistically significant difference between the pH 5.5 and pH 6.0 treatment – Figure 2.8 and 2.10), the pH 4.4 treatment having a significantly ($P<0.05$) higher Mn concentration than the pH 5.5 and 6.0 treatments. There was also a gradual reduction in Mn amount pot^{-1} with increasing pH (Figure 2.9 and 2.10). This trend in reduced Mn concentration and Mn amount pot^{-1} with increasing pH, is thought to be related to Mn becoming less available with increasing pH (Fageria *et. al.*, 1990).

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	25.233	12.616	7.18	
pH	2	29.899	14.950	8.51	0.003
Calmag+B	2	1.399	0.700	0.40	0.678
pH.Calmag+B	4	3.576	0.894	0.51	0.730
Residual	15(1)	26.361	1.757		
Total	25(1)	85.885			

Grand mean = 7
% CV = 17.9

Figure 2.8 Analysis of variance for Mn concentration of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.25776	0.12888	1.81	
pH	2	1.59283	0.79641	11.17	0.001
Calmag+B	2	0.58873	0.29436	4.13	0.037
pH.Calmag+B	4	0.40504	0.10126	1.42	0.275
Residual	15(1)	1.06921	0.07128		
Total	25(1)	3.61493			

Grand mean = 1.3
% CV = 9.5

Figure 2.9 Analysis of variance for Mn amount pot^{-1} (mg pot^{-1})

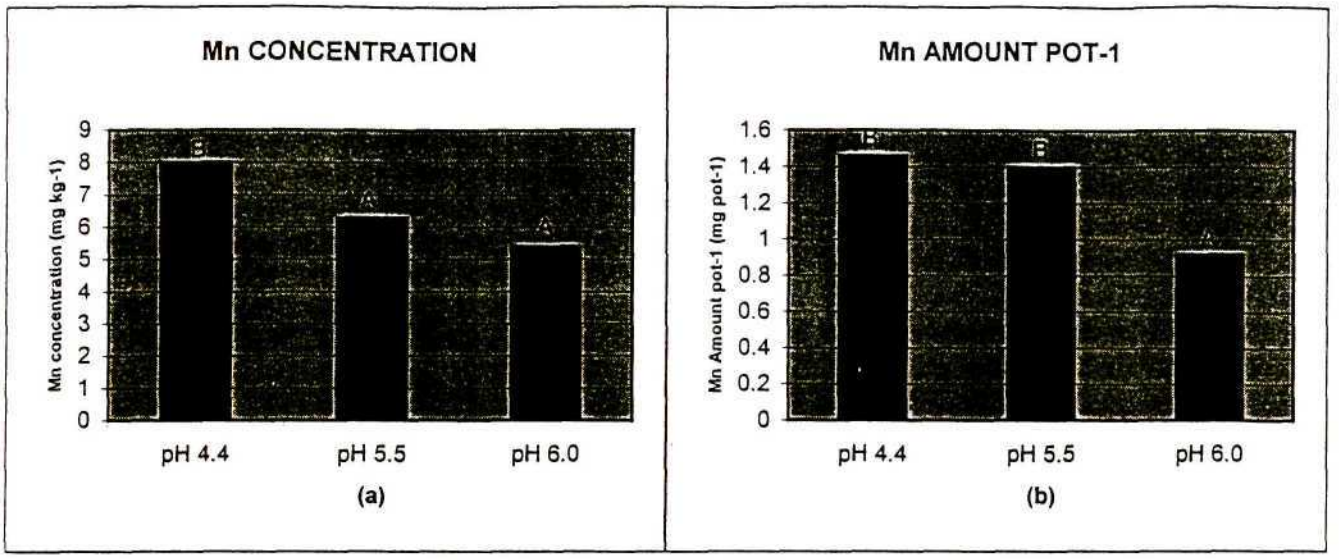

Figure 2.10 Tuber Mn concentration (a) and Mn amount pot^{-1} (b) as affected by different liming treatments. Letters above individual bars indicate significant differences between liming treatments within each measure factor.

2.2.3.5 OTHER NUTRIENT ANALYSES

In the analyses used to determine differences between liming treatments, the analyses for N and S displayed "dilution" effects (Appendix 6; Table 2.2) , i.e. while there was adequate nutrient present for tuber development, development did not take place due to the influence of another factor. A dilution effect was detected when statistically significant differences were present between treatments for the nutrient concentration analyses, while the analyses for nutrient amount pot^{-1} either failed to show any significant differences between treatments, or significant differences that did appear indicated that while enough nutrient was available for development, another factor had been limiting. In the analyses used to determine differences between Calmag+B, the analysis for P (Appendix 6; Table 2.3) also indicated a dilution effect.

Table 2.3 **The Effect of Calmag+B Treatments on tuber yield, tuber number pot^{-1} mean mass per tuber, mineral element content and concentration of potato tubers**

	CALMAG+B (kg ha^{-1})			LSD (5%)
	50	100	150	
YIELD (g)	132.2	170.5	144.0	NS
TUBER NUMBER POT^{-1} (NUMBER $^{0.2}$)	1.208 (8) *	1.430 (12) *	1.262 (9) *	NS
MEAN MASS TUBER^{-1} (g$^{0.1}$)	1.247 (14.4) *	1.256 (13.2) *	1.244 (13.5) *	NS
N concentration (g kg^{-1})	10.51	10.55	11.37	NS
N AMOUNT POT^{-1} (g pot^{-1})	1.837	2.313	2.194	NS
P concentration (g kg^{-1})	2.4	2.0	2.1	0.3
P AMOUNT POT^{-1} (g pot^{-1})	0.39	0.43	0.39	NS
K concentration (g kg^{-1})	18.7	16.6	17.1	NS
K AMOUNT POT^{-1} (g pot^{-1})	3.28	3.63	3.23	NS
Ca concentration (g kg^{-1})	0.8	0.7	0.7	NS
Ca AMOUNT POT^{-1} (g pot^{-1})	0.13	0.16	0.13	NS
Mg concentration (g kg^{-1})	0.8	0.7	0.7	0.1
Mg AMOUNT POT^{-1} (g pot^{-1})	0.13	0.16	0.13	0.03
S concentration (g kg^{-1})	1.51	1.39	1.43	NS
S AMOUNT POT^{-1} (g pot^{-1})	0.253	0.303	0.273	NS
Mn concentration (mg kg^{-1})	6	7	7	1
Mn AMOUNT POT^{-1} (mg pot^{-1})	1.1	1.4	1.3	0.3
Cu concentration (mg kg^{-1})	4	4	4	NS
Cu AMOUNT POT^{-1} (mg pot^{-1})	0.6	1.0	0.8	NS
Zn concentration (mg kg^{-1})	18	18	17	NS
Zn AMOUNT POT^{-1} (mg pot^{-1})	2.9	3.8	3.3	0.7

* Figures within brackets depict untransformed means.

In the analyses used to determine differences between lime treatments, the analysis for P (Appendix 6; Table 2.2) displayed a "yield" effect (i.e. any significance

differences arising between treatments in the nutrient amount pot^{-1} analyses were due to the effect of yield, as the nutrient concentration must be multiplied by the yield in order to obtain the nutrient amount pot^{-1}). In the analyses used to determine differences between Calmag+B treatments, the analysis for Mn (Appendix 6; Table 2.3) displayed a "yield" effect as well.

There were no significant differences for interactions between the lime and Calmag+B treatments (Appendix 6). There were also no significant differences between pH treatments in the analyses of K, Mg, Zn and B (Appendix 6; Table 2.2), or between Calmag+B treatments in the analyses of the nutrients N, K, Ca, Mg, S, Cu and Zn (Appendix 6, Table 2.3). The analysis used to determine differences between pH treatments for the element Cu (Appendix 6; Table 2.2) indicated significant differences between treatments that could not be explained by the conditions present in the experiment. This particular analysis, however, had a great deal of variability in the data (indicated by a high CV%), making the results suspect.

2.2.3.6 B RESPONSE TO CALMAG+B TREATMENTS

The highest level of Calmag+B application (equivalent to commercial applications of 150 kg ha^{-1}) has a significantly ($P<0.05$) higher B concentration than the other two Calmag+B treatments (Figure 2.11 and 2.13). There is also a gradual rise in B amount pot^{-1}, with the highest level of Calmag+B application having significantly ($P<0.05$) greater B amount pot^{-1} than the other two treatments (Figure 2.12 and 2.13). This increase in B concentration and B amount pot^{-1}, however, does not lead to an increase in tuber yield (Appendix 6; Table 2.2), tuber number or mean mass per tuber (Appendix 6). It must, therefore, be assumed that an increase in application of Calmag+B beyond commercial applications of 100 kg ha^{-1} would give rise solely to an increase in tuber quality, e.g. starch content and membrane integrity. Due to restrictive sample sizes, these analyses could not be carried out.

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	13.149	6.575	1.86	
pH	2	2.149	1.075	0.30	0.742
Calmag+B	2	35.899	17.950	5.08	0.021
pH.Calmag+B	4	6.910	1.727	0.49	0.744
Residual	15(1)	53.028	3.535		
Total	25(1)	104.500			

Grand mean = 5
% CV = 15.8

Figure 2.11 Analysis of variance for B concentration (mg kg^{-1}) of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.35810	0.17905	2.01	
pH	2	0.33560	0.16780	1.88	0.186
Calmag+B	2	1.68205	0.84102	9.44	0.002
pH.Calmag+B	4	0.55408	0.13852	1.56	0.237
Residual	15(1)	1.33592	0.08906		
Total	25(1)	4.26044			

Grand mean = 1.0
% CV = 13.9

Figure 2.12 Analysis of variance for B amount pot^{-1} (mg pot^{-1})

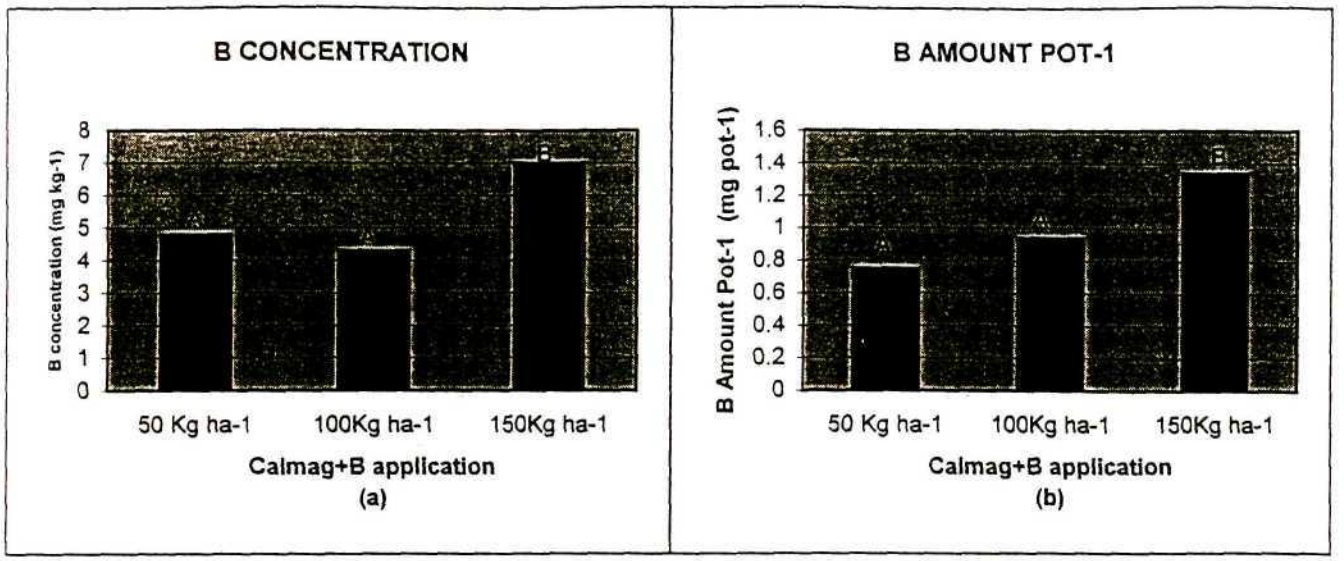

Figure 2.13 Tuber B concentration (a) and B amount pot^{-1} (b) as affected by different liming treatments. Letters above individual bars indicate significant differences between liming treatments within each measure factor.

2.2.4 DISCUSSION AND CONCLUSION

There were no significant differences in tuber yield, tuber number pot^{-1} or mean mass per tuber between treatments where lime was applied. The unameliorated control had a significantly ($P<0.01$) lower tuber yield, tuber number pot^{-1} and mean mass per tuber than the limed treatments, this being due partially to fewer surviving plants at the time of harvest. Whether this reduction in plant survival and yield was due to Ca deficiency or al toxicity is not resolved in this experiment (this concept being addressed in section 2.3). Beyond the lowest level of lime application (pH 4.4) there was an increase in tuber Ca concentration, which may lead to both increased tuber quality, and a reduction in physiological disorders and certain diseases (a noteworthy exception being potato scab disease, which is more common under high pH conditions). The reduction in the Mn concentration of tubers with increasing pH does not result in an increase in yield, tuber number or mean mass per tuber. This reduction in Mn may be beneficial in overcoming Mn toxicity problems, however in

excess, may result in reduced mean mass per tuber and interference in plant physiology (e.g. reduced photosynthesis).

The above results are in accordance with recommendations by the Kwazulu-Natal Department of Agriculture Fertiliser Advisory (KDAFA). The above body recommends liming only where acid saturation is greater than 30% (Manson *et. al.*, 1995). In this experiment, Geluksberg soil at pH 4.4, had an acid saturation of 23% (the pH 5.5 and 6.0 treatments having acid saturations of 0.73% and 0.66% respectively - Appendix 3). Hence, in accordance with the Fertilizer Advisory's recommendations, tuber yield increase was not realised with further lime applications (an increase in tuber Ca may, however, take place).

The experiment also illustrates that the soil application of Calmag+B at the rates used, made no impression on yield, tuber number or mean mass per tuber. The only benefit derived from the application of Calmag+B in this situation was an increase in the B concentration of the tubers. As this effect appeared only at the highest rate of Calmag+B application (equivalent to total commercial applications of 600 kg ha^{-1}), the use of Calmag+B becomes an unjustifiably expensive means of increasing B in the tuber.

No attempt was made to increase Ca availability (using Calmag+B) prior to planting, that is, "pre-enrichment" of the soil. This issue is addressed in section 2.3.

2.3 THE EFFECT OF SOIL AND SEED TUBER TREATMENTS WITH CALMAG+B ON POTATO EMERGENCE AND DEVELOPMENT

2.3.1 INTRODUCTION

The object of this experiment was to determine whether the "pre-enrichment" of Geluksberg subsoil ((Soil Classification Working Group, 1991) Form: Avalon; Series: Normandine; Acid Saturation 84 %; Mineral constituents: 2 mg L^{-1} P; 86.0 mg L^{-1} K; 88.2 mg L^{-1} Ca; 42.5 mg L^{-1} Mg; 4 mg L^{-1} Mn; 0.5 mg L^{-1} Zn - Appendix 8) with Calmag+B (Appendix 2) and the pre-plant treatment of seed tubers with the same fertilizer, would give rise to good potato emergence and development in an acid soil. Section 2.2 dealt with the liming of the highly acid Geluksberg subsoil, however no attempt was made to increase the Ca content of the soil through a "pre-enrichment" treatment of Calmag+B. This experiment sought to determine the extent to which a pre-plant application of Calmag+B to the soil could be used in place of lime. Studies have shown that the application of Ca through a source other than lime (the source of Ca in question being gypsum), may allow for crop growth in soils with a low pH and high al availability (Shainberg *et al.,* 1989). Gypsum has the ability to remove al from the soil profile through leaching, precipitation, and soil pH increase (and hence reduced al solubility), brought about by sulphate adsorption onto soil colloids (Shainberg *et. al.,* 1989). The $Ca(NO_3)_2$ present in Calmag+B cannot remove al from the soil to the same extent as gypsum, as it does so by means of leaching only (Shainberg *et. al.,* 1989). Another objective of this experiment was to establish whether the dipping of seed tubers in a Calmag+B solution prior to planting would give rise to improved plant emergence and development. The purpose behind using the seed tuber dip was to increase the nutrient content of the mother tuber - and thus increase nutrient availability for the developing plant - without having to supply a large quantity of nutrients to the soil. The advantages of this last treatment would be substantial, particularly for the "small" farmer, as it allows for a huge reduction in fertilizer application to the soil, which would have otherwise been required for crop development. There was no literature available to the author pertaining to the

dipping of mother tubers in a "nutrient enriched" solution prior to planting, in an attempt to increase the availability of nutrients for the developing plant.

2.3.2 MATERIALS AND METHODS

Unameliorated Geluksberg subsoil was placed in undrained plastic pots (250 mm diameter) lined with plastic bags. There were 4 main treatments in the experiment, the first being the control, which entailed the planting of seed tubers in untreated Geluksberg soil. The second and third main treatments involved the application of two levels of Calmag+B (with 8.72g Calmag Kg^{-1} of soil being labeled Cal1 and 12.05g Calmag Kg^{-1} of soil being labeled Cal2) to the soil prior to planting (Table 2.4). These two Calmag+B applications were intended to raise the soil Ca availability to that of the pH 4.4 and pH 5.5 liming treatments respectively, used in section 2.2 (Appendix 8). The fourth main treatment involved the dipping of seed tubers in a 1% solution of Calmag+B for a period of 24 hours in an attempt to alleviate the Ca deficiency of the seed tuber prior to planting. The dipped tubers were then planted in untreated Geluksberg soil. There were 3 sub-treatments in the form of different levels of Calmag+B application (on the third, fifth, eighth and tenth weeks after plant emergence), consisting of 0.165, 0.330 and 0.495 g pot^{-1} (approximately equivalent to commercial applications of 50, 100 and 150 kg ha^{-1} respectively). The experiment was arranged as a split plot design with four main treatments and three sub-treatments in three replications. Data was analysed with Genstat 5 (Rothamsted Experimental Station, 1988) and least significant difference (LSD) was used to determine whether differences between means were significant.

Table 2.4 Whole plot treatments used for experiment to determine potato emergence and development

NOTATION	TREATMENT
Control	Unameliorated Geluksberg soil
Cal 1	8.72 g Calmag+B kg^{-1} of soil
Cal 2	12.05 g Calmag+B kg^{-1} of soil
Seed tuber dip	1% Calmag+B solution (24 h)

Prior to planting, 2:3:2 (22) fertilizer was applied at a rate of 4.3 g pot^{-1}, approximately equivalent to commercial applications of 1300 kg ha^{-1} (81.9 kg ha^{-1} N; 122.2 kg ha^{-1} P; 81.9 kg ha^{-1} K). The fertilizer recommendations were based on a target yield of 40 tonnes ha^{-1} and a plant density of 50 000 plants ha^{-1} (Nijland, pers. comm.) [3]. Before planting, tubers were treated with gibberellic acid as described in section 2.2.2. One seed tuber of the cultivar "Up To Date" was planted at a 5 cm depth in each pot. Once planting had taken place, the soil in all the pots was brought to FWC and thus maintained throughout the duration of the experiment. Fertilizer treatments began 2 weeks after plant emergence (Appendix 5). Mono-ammonium phosphate, in the form of Agrifos (a soluble fertilizer consisting of 120 g kg^{-1} N and 270 g kg^{-1} P), was applied to the soil in the pots on the second, fourth and sixth weeks after plant emergence, at a rate of 0.165 g pot^{-1} (approximately equivalent to commercial applications of 50 kg ha^{-1}). There were also applications of KNO_3 on the seventh, ninth and eleventh weeks after plant emergence, at a rate of 0.33 g pot^{-1} (approximately equivalent to commercial applications of 100 kg ha^{-1}).

A mixture of Previcur and Benlate (Appendix 1) was used to drench the soil in the pots every 10 days in order to prevent *Pythium*, *Rhizoctonia* and a*lternaria* infection. Bravo (Appendix 1) was sprayed once every 7 days to prevent early and late blight damage.

[3] I. Nijland, Agrofert (PTY) LTD., Kwazulu-Natal

The plants were harvested 12 weeks after emergence first occurred. This is 4 weeks short of the normal growing season for the "Up To Date" cultivar. The plants were harvested early since the object of the experiment was to determine the effect of the treatments on plant emergence and growth, and not on yield. At harvest, tuber mass and tuber number were recorded. The nutrient content of the tubers was also determined using the procedures of Farina and Channon, 1988. Tuber N and S were analysed by dry combustion using a LECO CNS 2000 analyser (Smeda *et. al.*, 1997).

2.3.3 RESULTS AND DISCUSSION

There was a highly significant difference between tuber dip treatment and the other main treatments (Table 2.5). Of the nine pots which had undergone the Calmag+B dip treatment, eight showed plant emergence and development up to the time of harvest (Table 2.5), with only five of the pots yielding tubers. Out of the twenty seven pots planted under the control, Cal1 and Cal2 treatments, three pots showed plant emergence (all within the Cal1 treatment) with all three plants dying within eight days of emergence. These three plants exhibited tip necrosis, a symptom of Ca deficiency (Plate 2.1).

Table 2.5 The effect of Calmag+B treatments on potato growth

	Percentage of pots surviving up to the time of harvest (%)	Percentage of pots with tubers at the time of harvest (%)	Average tuber yield per pot (g)	Average tuber number per pot
CONTROL	0	0	0	0
TUBER DIP	89	56	27.8	4
CAL 1	0	0	0	0
CAL 2	0	0	0	0

Source of variation	DF	SS	MS	VR	F_{prob}
Replications	2	0.05556	0.02778	1.00	0.381
Main Treatments	3	5.33333	1.77778	64.00	<0.001
Sub Treatments	2	0.05556	0.02778	1.00	0.381
Residual	28	0.77778	0.02778		
Total	35	6.22223			

Figure 2.14 Analysis of variance for survival of potted potato plants between various treatments

At harvest the mass and number of tubers per pot were measured and the nutrient content of the tubers was determined. There was too little data, however (only five pots providing tuber yield, all within the tuber dip treatment), for any meaningful comparison of tuber yield, tuber number and nutrient content to take place between the pots within the tuber dip treatment.

It appears that soil Ca was sufficient for plant development in the Calmag+B soil application treatments (Appendix 8), but that another factor, for example al toxicity, was inhibiting Ca uptake by the plant. It can therefore be assumed that Calmag+B cannot replace lime under the conditions present in the experiment. The experiment also showed that dipping seed tubers in a Calmag+B solution prior to planting - hence increasing the nutrient (Ca, Mg, N and B) content of the mother tuber - would allow for and enhance plant emergence and development in low pH, high al and low Ca availability conditions. This would seem to indicate that the nutrient requirements of the potato crop could be fulfilled - at least to a certain extent - through the process of dipping the tubers in a nutrient enriched solution. This process of supplying nutrients, particularly Ca (as plants not receiving the tuber dip treatment displayed symptoms of Ca deficiency, i.e. tip necrosis), to the mother tuber, appears to overcome the negative influences of high al availability and low soil pH. The above experiment does not determine whether the increase in potato emergence and development, is due to an increase in root development brought about by the tuber dip treatment, or an increase in nutrient uptake from the mother tuber. This issue will

be dealt with in section 2.4. There were no significant differences between Calmag+B treatments (Appendix 6).

2.3.4 CONCLUSION

Soil applied Calmag+B treatments did not reduce the acid saturation of the soil below 30% (the point at which the KDAFA would recommend the application of lime), indicating that amelioration would still benefit plant growth and tuber yield (Appendix 8). Calcium availability was not a restricting factor in the Cal1 and Cal2 soil treatments (potatoes requiring a soil Ca level of 500-600 mg L^{-1} (Manson, *et. al.*, 1995), the treatments having 856.7 and 879.7 mg L^{-1} respectively - Appendix 8). Both treatments had higher levels of Ca than the pH 4.4 limed treatment in section 2.2, which produced good plant growth and tuber yield. It must, therefore, be assumed that the improvement in plant development, tuber yield and tuber nutrient content brought about by an increases in lime application (as seen in section 2.2), is due to a reduction in available al, and not to an increase in the availability of Ca in the soil. The increase in plant survival and yield witnessed in section 2.2 is, therefore, due to the ameliorative effect of lime, as opposed to purely increasing the availability of Ca.

The increased plant emergence and development brought about by the tuber dip treatments may be due to increased nutrient uptake from the mother tuber, or increased root development, and hence nutrient uptake from the soil. The factors leading to increased plant emergence and development in the tuber dip treatment will be addressed in greater detail in section 2.4.

Plate 2.1 Tip necrosis symptom (Ca deficiency) in potatoes. The pot on the left of the photograph is displaying the deficiency symptoms.

Acid Saturation 84%

Acid Saturation 23%

2.4 THE EFFECT OF VARIOUS CALMAG+B TREATMENTS ON POTATO ROOT DEVELOPMENT

2.4.1 INTRODUCTION

The object of this experiment was to determine whether the plant emergence and development observed in the tubers dipped in the Calmag+B (Appendix 2) solution in section 2.3 was due to an increased uptake of nutrients from the soil (i.e. improved root system development) or to an increase in nutrient uptake from the mother tuber. The treatments used in section 2.3 were repeated for this experiment. The trial ran for a period of only seven days, since the potato may develop up to one third of its root system by the time of emergence. This was adjudged to provide adequate time for the development of roots, allowing for comparison between different treatments (Greenfield, pers. comm.)[4].

2.4.2 MATERIALS AND METHODS

Geluksberg subsoil (Appendix 8) was placed into undrained plastic pots (150mm diameter) lined with plastic bags. The experiment consisted of four treatments, the first treatment being the control, which involved the planting of seed tubers in untreated Geluksberg soil. The second and third treatments entailed the application of 2 levels of Calmag+B (labeled Cal1 and Cal2) to the soil prior to planting (the same 2 levels of Calmag+B applied in section 2.3 were used - Table 2.4). The fourth treatment involved the dipping of seed tubers in a 1% solution of Calmag+B for a period of 24 hours, in an attempt to increase the nutrient content (particularly Ca) of the seed tuber prior to planting.

Before planting, tubers were treated with gibberellic acid as described in section 2.2.2. One seed tuber of the cultivar "Up To Date" was planted at a depth of 5 cm in each pot. Once planting had taken place, the soil in the pots was brought to FWC and thus was maintained for the duration of the experiment.

[4] P.L. Greenfield, Department of Agronomy, University of Natal, Pietermaritzburg

At harvest the root mass (if any) of each pot was measured. The experiment was arranged in a randomised block design with 5 replications.

2.4.3 RESULTS AND DISCUSSION

None of the treatments gave rise to root development. The tuber dip treatments both had greater plant emergence (Figure 2.15) and larger plants at the time of harvest than the other three treatments.

All the plants that emerged within the various treatments, survived up to the time of harvest. Plants emerging from tubers having undergone the Calmag+B dip treatments, however, emerged earlier, were larger at the time of harvest, and displayed no signs of nutrient deficiency. The plants emerging in the control and Calmag+B soil application plots were experiencing the initial stages of tip necrosis (Plate 2.1).

One week after emergence there was no root development in any of the treatments. The results clearly show that the enhanced growth and development of the plants arising from dipped tubers (section 2.3) is due to an increase in the uptake of nutrients from the mother tuber, and not an increase in the development of the root system.

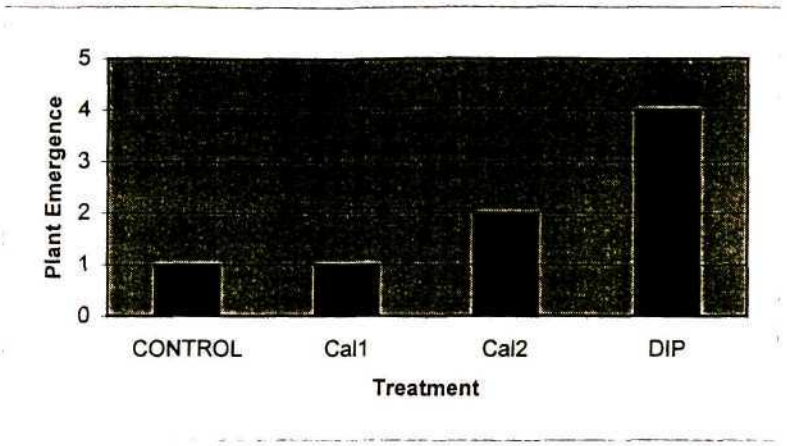

Figure 2.15 The effect of various Calmag+B treatments on potato emergence

2.4.4 CONCLUSION

The experimental results displayed in this chapter illustrate that soil applications of Calmag+B can not replace lime. The dipping of seed tubers in a solution of Calmag+B prior to planting, however, leads to an increase in nutrients available to the developing plant (without the supply of large quantities of nutrients to the soil), bringing about an increase in potato emergence and development. This dipping of seed tubers in a nutrient enriched solution (e.g. 1% Calmag+B), may be able to alleviate or reduce the requirement for lime in soils with low pH and high al availability. As no root development took place, it remains to be shown whether the dipping of tubers gives rise only to increased plant emergence and development, or whether tuber yield and quality can also be improved.

CHAPTER 3

THE EFFECT OF MAGNESIUM, NITRATE AND BORON APPLICATION ON UPTAKE AND RETENTION OF CALCIUM BY POTATO PLANTS AND TUBERS

3.1 INTRODUCTION

Calcium is an essential plant nutrient and if deficient may lead to serious reductions in potential tubers and even crop failure (Beukema and van der Zaag, 1990). In extreme cases of unavailability of soil Ca, sprouts may not emerge, or if they do, the plants remain stunted and produce a lot of small tubers and in some cases a complete lack of tuber formation (Smith and Nash, 1938).

An increase in tuber Ca is associated with a reduction in the incidence and severity of certain fungal and bacterial diseases. The nutrient significantly reduces damping off caused by *Pythium ultimum* (Lewis and Lumsden, 1984), brown rot caused by *Pseudomonas solanacearum* (Kelman *et.* al., 1990) and *Erwinia caratovora* (Bartz *et.* al., 1992). Postharvest decay is also reduced by the uptake of Calcium by the tuber (Conway *et.* al., 1992). Calcium has also been found to cause a reduction in physiological disorders of the tuber such as Internal Brown Spot (Collier *et. al.*, 1980) and Hollow Heart (Vander Zaag and Ffrench, 1987, cited by Harris, 1992).

Studies have shown that excess Mg application to the soil may reduce Ca taken up by the plant (Archer, 1986). Calcium also has an antagonistic relationship with B, in that it reduces the B uptake of plants (Mortvedt *et.* al., 1972). Research has shown that the application of B brings about an increase in the Ca content of apple peel and flesh (Smith *et.* al., 1987). There was, however, no literature available to the author describing the effect of B on Ca uptake in potatoes. Research studies comparing NH_4^+ and NO_3^- sources of N on potato growth show that NH_4^+ reduced Ca^{2+} uptake through cation competition (Shelp, 1987). The use of NO_3^- in place of NH_4^+ resulted

in an increase in Ca uptake (Shelp, 1987). This effect is relative, however, and does not imply that the presence of NO_3^- will give rise to an increase in Ca uptake.

The research in this chapter was aimed at determining whether the application of Mg, NO_3^- and B, individually or in conjunction with each other, would influence uptake of Ca by the plant and tuber. This knowledge would aid in determining whether the Mg, NO_3^- and B components of Calmag+B (a soluble fertiliser containing calcium nitrate, magnesium nitrate and boron, with 117 g kg^{-1} Ca, 38 g kg^{-1} Mg, 137 g kg^{-1} N and 2g kg^{-1} B - Appendix 2) fertiliser would give rise to an increase in plant uptake of Ca. Calcium, also a component of Calmag+B, gives rise to increased tuber yield, disease resistance and the prevention of a number of physiological disorders discussed in Chapter 1.

3.2 MATERIALS AND METHODS

River sand (sieved to obtain a 2mm maximum diameter) was washed a number of times with tap water, and subsequently with distilled water. Acid washed sand was not used in this study due to the very large quantity of potting medium required for the experiment. It was postulated that there would not be enough Ca, Mg, NO^{3-} and B residual in the washed river sand to affect the results of the experiment (Farina, pers. comm.)[1]. The experimental units used were 250mm diameter pots lined with blue polyethylene bags. The bags were punctured in order to allow free drainage. Pots were filled with 3 Kg of sand.

Before planting, tubers were treated with GA_3 as described in section 2.2.2. The object of the GA_3 treatment was to ensure uniform and vigorous plant emergence. One seed tuber of the cultivar "BP 13" was planted at a 50mm depth in each pot.

The trial was conducted in a polycarbonate growth tunnel. Temperature was controlled by fans at the one end of the tunnel that draw air through a "wet wall"

[1] M.P.W. Farina, Grain Crops Institute, Agricultural Research Council, Cedara sub-centre

located at the other end. A system of thermostats inside the tunnel was set to switch on the fans when the temperature reached 28°C. Pumps that put water onto the "wet wall" were switched on when the temperature reached 30°C.

The levels of Ca, N (NO_3^- form), Mg and B were altered within the "standard" nutrient solution (Table 3.1 - modified nutrient solution Venter, 1989) in order to allow for different levels of the four nutrients to be added. Wherever possible, the levels of the other components of the nutrient solution were kept constant. It must be noted that this is not entirely possible as the nutrients can never be completely isolated, and hence with the fluctuation of one nutrient, there must needs be a fluctuation in another nutrient. Two levels of Ca were used in order to determine whether there were variations in the effect of the other 3 treatments with a difference in Ca availability. The lowest level of Mg, NO_3^- and B was present in the "standard" nutrient solution.

The first treatment entailed two separate "standard" solutions, one with the lower level (134mgL^{-1}) and the other with the higher level (268 mg L^{-1}) of Ca^{2+}, designated as Ca1 and Ca2 respectively. These two "standard" solutions were applied to all the pots for five days a week. The other three treatments were applied on the remaining two days of the week. These treatments entailed three levels of Mg (24.25, 48.50 and 72.75 mg L^{-1}) designated as Mg1, Mg2 and Mg3 respectively, three levels of N in the nitrate form (74.9, 102.9 and 130.9mg L^{-1}) designated as NO_3^- 1, NO_3^- 2 and NO_3^- 3 respectively, and three levels of B (0.492, 0.984 and 1.476mg L^{-1}) designated as B1, B2 and B3 respectively.

The experiment was arranged in a 3^3 x 2 factorial design with three replications. Data was analysed with Genstat 5 (Rothamsted Experimental Station, 1988) and least significant difference (LSD) was used to determine whether differences between means were statistically significant.

TABLE 3.1 COMPONENTS OF THE "STANDARD" NUTRIENT SOLUTION

COMPONENT	mg L^{-1}	ELEMENT	mg L^{-1}
NH_4NO_3	236.6	N	82.8
NH_4PO_4	178.1	N	22.1
		P	48.8
KNO_3	241.7	K	93.0
		N	33.5
K_2SO_4	418.5	K	188
		SO_4	231
$MgSO_4.7H_2O$	246.0	Mg	24.25
		SO_4	96.0
$MnSO_4.H_2O$	6.1	Mn	1.98
$CuSO_4.5H_2O$	0.4	Cu	0.102
$ZnSO_4.7H_2O$	1.98	Zn	0.45
$Na_2MoO_4.2H_2O$	0.25	Mo	0.099
EDTA	25.1	Fe	4.39
$Na_2B_4O_7$	4.34	B	0.492
CaCl	371.25	Ca	134
		Cl	237
CaCl	742.5	Ca	268
		Cl	474

A Previcur and Benlate mixture (Appendix 1) was used to drench the soil in the pots every ten days to prevent infection by al*ternaria, Pythium* and *Rhizoctonia*. Bravo (Appendix 1) was sprayed once every seven days in order to prevent early and late blight infections.

Plant harvesting took place 17 weeks after the mean trial emergence date. For seven days prior to harvest no water or nutrient solution was added to the pots. At

harvest the mass and number of tubers per pot were determined. Tubers were then halved and dried in an oven at 70°C for 24h, followed by an analysis of their nutrient content using the procedures of Farina and Channon, 1988. Tuber N and S were analysed by dry combustion using a LECO CNS 2000 analyser (Smeda *et. al.*, 1997).

Statistical analysis were conducted on tuber yield, tuber number pot^{-1}, mean mass per tuber, nutrient concentration of tubers (measured as g kg^{-1} of dry matter for macro-nutrients and mg kg^{-1} of dry matter for micro-nutrients) and tuber nutrient amount pot^{-1} between the various treatments. The purpose of the tuber nutrient amount pot^{-1} analysis was to determine whether a dilution effect had taken place, for example when a treatment has a low nutrient concentration due to the fact that it has a high yield, indicating a "dilution" of tuber nutrient concentration (Jarrel and Beverly, 1982).

3.3 RESULTS AND DISCUSSION

3.3.1 YIELD, TUBER NUMBER PER POT AND MEAN MASS PER TUBER

The only treatment element that significantly affected yield was Ca, where the higher level had a highly significant ($P<0.01$) effect on tuber yield (Figure 3.1; Table 3.2). The significant increase in yield observed for the Ca treatment here, affects many of the results from the nutrient analyses. As the nutrient amount pot^{-1} values are a product of the nutrient concentration and the yield, certain "yield effects" are produced, reflected by statistical significance in the nutrient amount pot^{-1} analyses.

There were no significant treatment effects or their interactions for Tuber Number per Pot and Mean Mass per Tuber (Appendix 9).

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	53888	26944	21.99	
Ca	1	11952	11952	9.76	0.002
Mg	2	4014	2007	1.64	0.199
NO_3	2	762	381	0.31	0.733
B	2	3381	1691	1.38	0.256
Ca. Mg	2	2278	1139	0.93	0.398
Ca. NO_3	2	880	440	0.36	0.699
Mg. NO_3	4	5875	1469	1.20	0.316
Ca. B	2	999	500	0.41	0.666
Mg. B	4	2210	552	0.45	0.772
NO_3. B	4	238	59	0.05	0.996
Ca. Mg. NO_3	4	3413	853	0.70	0.596
Ca. Mg. B	4	3641	910	0.74	0.565
Ca. NO_3. B	4	4322	1081	0.88	0.478
Mg. NO_3. B	8	7768	971	0.79	0.610
Ca. Mg. NO_3. B	8	13361	1670	1.36	0.222
Residual	100(6)	122513	1225		
Total	155(6)	234541			

Grand mean = 177.9
% CV = 12.6

Figure 3.1 Analysis of variance of Yield (g) of potato tubers

Table 3.2 The effect of Ca treatments on tuber yield

	Calcium Application		LSD (5%)
	Ca1 (134mg L^{-1})	Ca2 (268 mg L^{-1})	
TUBER YIELD (g)	169.3	186.5	10.9

3.3.2 CALCIUM

Increasing the level of Ca nutrition to the potatoes significantly increased tuber yield, as well as tuber Ca concentration and amount pot^{-1} (Figure 3.2, 3.3 and 3.4). The above results indicate that the lower level of Ca nutrition was sub-optimal, and that the plant required more Ca in order to achieve its yield potential. As a third level of Ca was not used in the trial, it is impossible to say whether the higher level used met the plant's Ca requirement.

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0098026	0.0049013	21.98	
Ca	1	0.0505663	0.0505663	226.72	<0.001
Mg	2	0.0004810	0.0002405	1.08	0.344
NO_3	2	0.0002445	0.0001222	0.55	0.580
B	2	0.0014146	0.0007073	3.17	0.046
Ca. Mg	2	0.0015094	0.0007547	3.38	0.038
Ca. NO_3	2	0.0005244	0.0002622	1.18	0.313
Mg. NO_3	4	0.0002787	0.0000697	0.31	0.869
Ca. B	2	0.0008867	0.0004434	1.99	0.142
Mg. B	4	0.0005629	0.0001407	0.63	0.642
NO_3. B	4	0.0009702	0.0002426	1.09	0.367
Ca. Mg. NO_3	4	0.0017973	0.0004493	2.01	0.098
Ca. Mg. B	4	0.0016026	0.0004007	1.80	0.135
Ca. NO_3. B	4	0.0007370	0.0001843	0.83	0.512
Mg. NO_3. B	8	0.0018457	0.0002307	1.03	0.416
Ca. Mg. NO_3. B	8	0.0012129	0.0001516	0.68	0.708
Residual	100(6)	0.0223029	0.0002230		
Total	155(6)	0.0941744			

Grand mean = 0.6
% CV = 16.5

Figure 3.2 Analysis of variance for Ca concentration (g kg^{-1}) of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.067668	0.033834	26.36	
Ca	1	0.223577	0.223577	174.19	<0.001
Mg	2	0.004091	0.002046	1.59	0.208
NO_3	2	0.001078	0.000539	0.42	0.658
B	2	0.007522	0.003761	2.93	0.058
Ca. Mg	2	0.003584	0.001792	1.40	0.252
Ca. NO_3	2	0.002683	0.001341	1.05	0.355
Mg. NO_3	4	0.003751	0.000938	0.73	0.573
Ca. B	2	0.003139	0.001570	1.22	0.299
Mg. B	4	0.000796	0.000199	0.15	0.960
NO_3. B	4	0.002734	0.000684	0.53	0.712
Ca. Mg. NO_3	4	0.004413	0.001103	0.86	0.491
Ca. Mg. B	4	0.004656	0.001164	0.91	0.463
Ca. NO_3. B	4	0.005140	0.001285	1.00	0.411
Mg. NO_3. B	8	0.006582	0.000823	0.64	0.742
Ca. Mg. NO_3. B	8	0.008212	0.001027	0.80	0.604
Residual	100(6)	0.128351	0.001284		
Total	155(6)	0.464801			

Grand mean = 0.10
% CV = 24.2

Figure 3.3 Analysis of variance of Ca amount pot^{-1} (g pot^{-1})

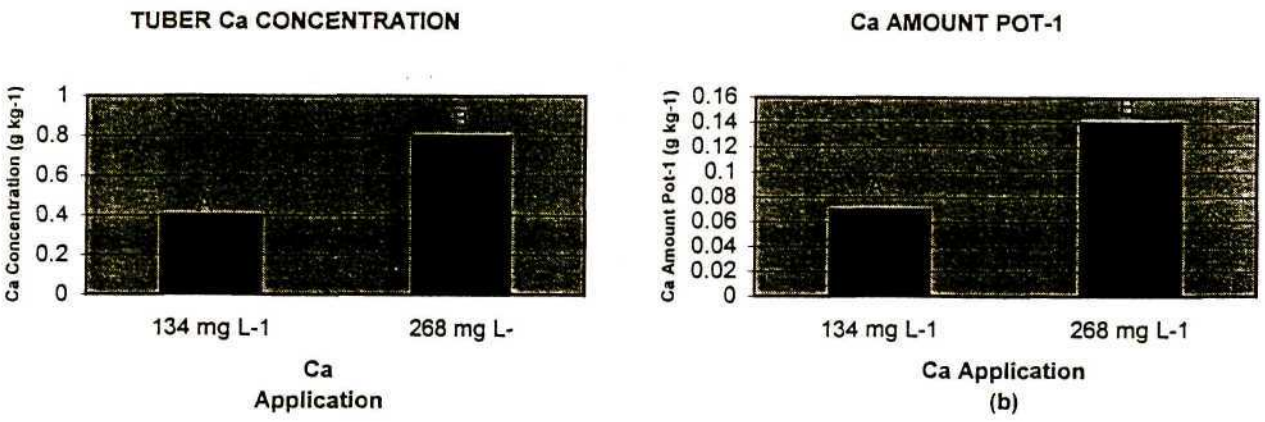

Figure 3.4 Potato tuber Ca concentration (a) and Ca amount pot^{-1} (b) as affected by Ca nutrition. Letters above individual bars indicate significant differences between treatments.

TABLE 3.3 Effect of Ca nutrition on the mineral element content and concentration of potato tubers

NUTRIENT ANALYSES	Calcium Application		LSD (5%)
	Ca1 (134mg L^{-1})	Ca2 (268 mg L^{-1})	
N CONCENTRATION (g kg^{-1})	22.7	22.4	NS
N AMOUNT POT^{-1} (g pot^{-1})	3.80	4.15	0.27
P CONCENTRATION (g kg^{-1})	4.9	4.7	0.1
P AMOUNT POT^{-1} (g pot^{-1})	0.82	0.88	0.05
K CONCENTRATION (g kg^{-1})	26.4	26.4	NS
K AMOUNT POT^{-1} (g pot^{-1})	4.41	4.88	0.32
Mg CONCENTRATION (g kg^{-1})	1.1	1.0	0.1
Mg AMOUNT POT^{-1} (g pot^{-1})	0.18	0.18	NS
S CONCENTRATION (g kg^{-1})	2.4	2.3	0.1
S AMOUNT POT^{-1} (g pot^{-1})	0.40	0.43	0.03
Cu CONCENTRATION (mg kg^{-1})	10	10	NS
Cu AMOUNT POT^{-1} (mg pot^{-1})	1.6	1.9	0.1
Zn CONCENTRATION (mg kg^{-1})	30	31	NS
Zn AMOUNT POT^{-1} (mg pot^{-1})	5.1	5.8	0.4
B CONCENTRATION (mg kg^{-1})	10	9	1
B AMOUNT POT^{-1} (mg pot^{-1})	1.7	1.7	NS

There was a significant difference in Ca concentration between different B treatments (Appendix 9; Table 3.4). It must be noted that in the analysis for Ca amount pot^{-1} (as with some of the other nutrient analyses), the levels of accuracy have been exceeded (i.e. the means displayed in the analyses have a "higher" level of accuracy than the raw data). In this situation, statistical significance is not indicated in the ANOVA table (Appendix 9), but due to rounding-off errors, significant results are reflected in the table of means (Table 3.4). Consequently, the statistical significance mentioned above is not real. The analyses for Mg amount pot^{-1} (Mg and Ca/Mg interaction treatments), S amount pot^{-1} (Ca treatment) and Cu amount pot^{-1}

(Mg/NO_3^- interaction treatment), also experience rounding-off errors, and hence the results from these analyses are not discussed further.

TABLE 3.4 Effect of B nutrition on the mineral element content and concentration of potato tubers

NUTRIENT ANALYSES	Boron Application			LSD (5%)
	B1 (0.492mg L^{-1})	B2 (0.984mg L^{-1})	B3 (1.476mg L^{-1})	
N CONCENTRATION (g kg^{-1})	22.2	22.1	23.4	1.0
N AMOUNT POT^{-1} (g pot^{-1})	4.05	3.88	3.99	NS
Ca CONCENTRATION (g kg^{-1})	0.6	0.5	0.6	0.1
Ca AMOUNT POT^{-1} (g pot^{-1})	0.11	0.10	0.10	0.01
S CONCENTRATION (g kg^{-1})	2.3	2.3	2.4	0.1
S AMOUNT POT^{-1} (g pot^{-1})	0.43	0.41	0.42	NS

There were significant differences in Ca concentration for the Ca/Mg interaction treatment (Appendix 9; Table 3.5). As no significant differences between treatments were indicated in the Ca amount pot^{-1} analysis (Appendix 9; Table 3.5), however, it can be assumed that a dilution effect had occurred. None of the other treatments showed significant differences in the tuber Ca amount pot^{-1} analyses (Appendix 9).

TABLE 3.5 Effect of Ca/Mg interaction on the mineral element content and concentration of potato tubers

NUTRIENT ANALYSES	Ca1 (134mg L^{-1})			Ca2 (268mg L^{-1})			LSD (5%)
	Mg1*	Mg2*	Mg3*	Mg1*	Mg2*	Mg3*	
Ca CONCENTRATION (g kg^{-1})	0.4	0.4	0.4	0.8	0.8	0.7	0.1
Ca AMOUNT POT^{-1} (g pot^{-1})	0.07	0.06	0.07	0.15	0.14	0.13	0.02
Mg CONCENTRATION (g kg^{-1})	1.0	1.0	1.2	0.9	1.0	1.0	0.1
Mg AMOUNT POT^{-1} (g pot^{-1})	0.18	0.16	0.19	0.18	0.18	0.18	0.02

* Mg1, Mg2 and Mg3 were Mg treatments applied at concentrations of 24.25, 48.50 and 72.75 mg L^{-1} respectively.

3.3.3 MANGANESE

There is a highly significant increase in both tuber Mn concentration and Mn amount pot^{-1} with an increase in Ca application (Figure 3.5, 3.6 and 3.7). The above result is difficult to explain, as Ca has a negative effect on Mn uptake from soil (Fageria *et. al.,* 1990). If Ca is taken up by the roots, however, a proton would be extruded, leading to the acidification of the rhizosphere. This could explain the higher uptake of Mn by the plant (Farina, pers. comm.)[1].

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	90.3	45.1	0.39	
Ca	1	1012.4	1012.4	8.76	0.004
Mg	2	1041.9	521.0	4.51	0.013
NO_3	2	3.7	1.8	0.02	0.984
B	2	39.7	19.8	0.17	0.843
Ca. Mg	2	427.5	213.7	1.85	0.163
Ca. NO_3	2	15.0	7.5	0.06	0.937
Mg. NO_3	4	82.7	20.7	0.18	0.949
Ca. B	2	380.0	190.0	1.64	0.199
Mg. B	4	138.6	34.6	0.30	0.878
NO_3. B	4	578.0	144.5	1.25	0.295
Ca. Mg. NO_3	4	207.8	51.9	0.45	0.773
Ca. Mg. B	4	227.2	56.8	0.49	0.742
Ca. NO_3. B	4	126.2	31.5	0.27	0.895
Mg. NO_3. B	8	480.6	60.1	0.52	0.839
Ca. Mg. NO_3. B	8	207.6	25.9	0.22	0.986
Residual	100(6)	11560.9	115.6		
Total	155(6)	16513.7			

Grand mean = 45
% CV = 2.0

Figure 3.5 Analysis of variance of Mn (mg kg^{-1}) concentration of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	143.405	71.702	11.70	
Ca	1	107.813	107.813	17.60	<0.001
Mg	2	52.854	26.427	4.31	0.016
NO_3	2	1.959	0.979	0.16	0.852
B	2	3.881	1.940	0.32	0.729
Ca. Mg	2	1.473	0.736	0.12	0.887
Ca. NO_3	2	4.357	2.179	0.36	0.702
Mg. NO_3	4	21.579	5.395	0.88	0.479
Ca. B	2	5.765	2.882	0.47	0.626
Mg. B	4	6.055	1.514	0.25	0.911
NO_3. B	4	14.629	3.657	0.60	0.666
Ca. Mg. NO_3	4	22.389	5.597	0.91	0.459
Ca. Mg. B	4	3.220	0.805	0.13	0.971
Ca. NO_3. B	4	7.410	1.852	0.30	0.876
Mg. NO_3. B	8	21.582	2.698	0.44	0.894
Ca. Mg. NO_3. B	8	31.063	3.883	0.63	0.748
Residual	100(6)	612.693	6.127		
Total	155(6)	1037.670			

Grand mean = 8.1
% CV = 14.4

Figure 3.6 Analysis of variance of Mn amount pot^{-1} (mg pot^{-1})

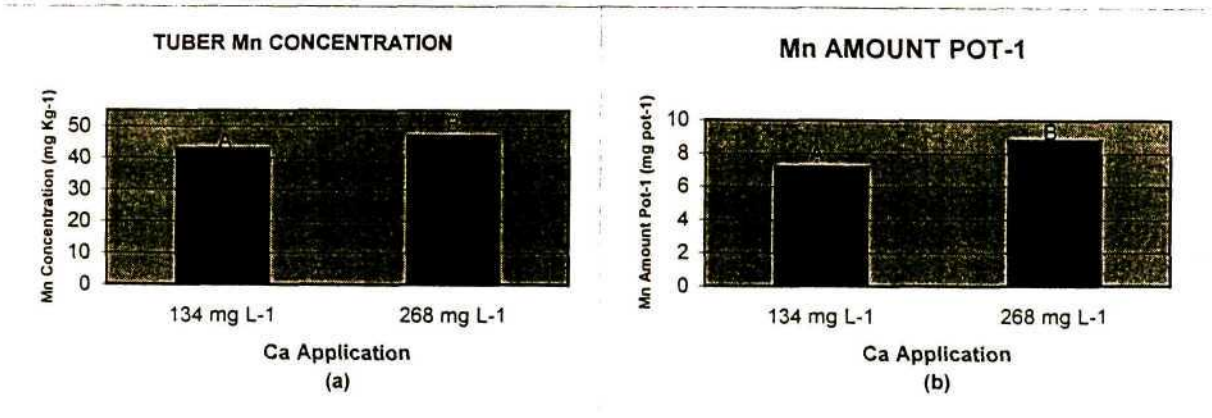

Figure 3.7 Potato tuber Mn concentration (a) and Mn amount pot^{-1} (b) as affected by Ca treatments. Letters above individual bars indicate significant differences between treatments.

3.3.4 BORON

There is a highly significant increase in tuber B concentration, and a significant increase in B amount pot^{-1} with each successive increase in B application (Figure 3.8, 3.9 and 3.10). The increase in tuber B concentration and B amount pot^{-1} with increasing B application would indicate that the lower two levels of B application were sub-optimal with regards to tuber B content, but that an increase in B application from the lowest level of application would still not result in an increase in yield (Appendix 9). An increase in tuber B content, however, may give rise to an increase in tuber quality, e.g. improved starch content and membrane integrity (Dwivedi and Dwivedi, 1992). The B treatments had no effect on the uptake of Ca by the tuber.

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	491.210	245.605	31.74	
Ca	1	48.995	48.995	6.33	0.013
Mg	2	9.299	4.649	0.60	0.550
NO_3	2	13.693	6.847	0.88	0.416
B	2	193.457	96.728	12.50	<0.001
Ca. Mg	2	13.981	6.991	0.90	0.408
Ca. NO_3	2	4.448	2.224	0.29	0.751
Mg. NO_3	4	25.757	6.439	0.83	0.508
Ca. B	2	10.999	5.500	0.71	0.494
Mg. B	4	38.441	9.610	1.24	0.298
NO_3. B	4	18.729	4.682	0.61	0.660
Ca. Mg. NO_3	4	21.971	5.493	0.71	0.587
Ca. Mg. B	4	14.288	3.572	0.46	0.764
Ca. NO_3. B	4	7.109	1.777	0.23	0.921
Mg. NO_3. B	8	72.414	9.052	1.17	0.325
Ca. Mg. NO_3. B	8	28.659	3.582	0.46	0.879
Residual	100(6)	773.689	7.737		
Total	155(6)	1766.224			

Grand mean = 10
% CV = 21.9

Figure 3.8 Analysis of variance of B concentration (mg kg^{-1}) of potato tubers

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	6.9115	3.4558	9.61	
Ca	1	0.0207	0.0207	0.06	0.811
Mg	2	0.0959	0.0480	0.13	0.875
NO_3	2	0.2159	0.1080	0.30	0.741
B	2	3.1064	1.5532	4.32	0.016
Ca. Mg	2	0.3093	0.1547	0.43	0.652
Ca. NO_3	2	0.4195	0.2098	0.58	0.560
Mg. NO_3	4	1.6494	0.4124	1.15	0.339
Ca. B	2	0.2133	0.1066	0.30	0.744
Mg. B	4	0.6304	0.1576	0.44	0.781
NO_3. B	4	0.5503	0.1376	0.38	0.821
Ca. Mg. NO_3	4	0.4632	0.1158	0.32	0.863
Ca. Mg. B	4	0.1187	0.0297	0.08	0.988
Ca. NO_3. B	4	0.2235	0.0559	0.16	0.960
Mg. NO_3. B	8	1.4359	0.1795	0.50	0.854
Ca. Mg. NO_3. B	8	2.3673	0.2959	0.82	0.584
Residual	100(6)	35.9537	0.3595		
Total	155(6)	54.0279			

Grand mean = 1.7
% CV = 15.1

Figure 3.9 Analysis of variance of B amount pot^{-1} (mg pot^{-1})

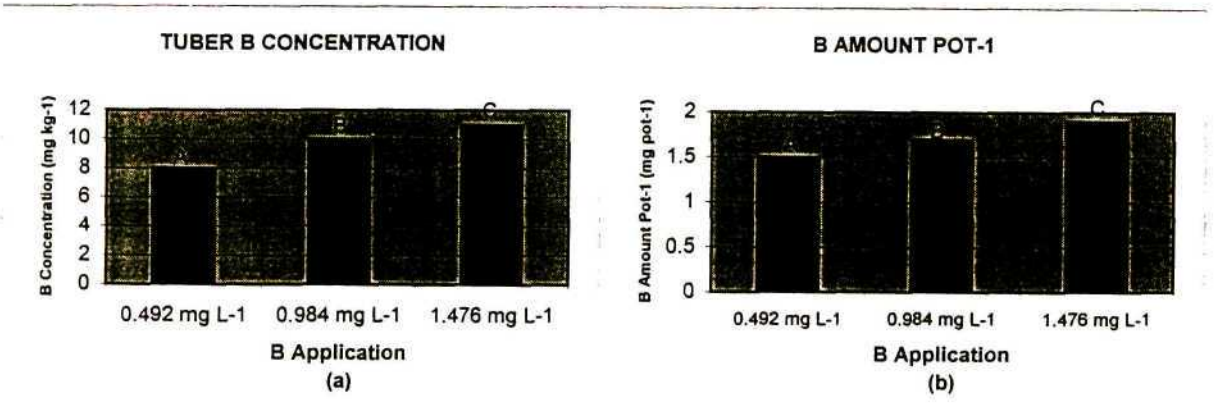

Figure 3.10 Potato tuber B concentration (a) and B amount pot^{-1} (b) as affected by B treatments. Letters above individual bars indicate significant differences between treatments.

3.3.5 OTHER NUTRIENT ANALYSES

Most of the significant results indicated for the nutrient concentration analyses were due to a dilution effect (Appendix 9; Figure 3.11).

NUTRIENT	TREATMENT	TABLE
Nitrogen	Mg	3.6
Nitrogen	NO_3^-	3.7
Nitrogen	B	3.4
Nitrogen	Mg/ NO_3^- Interaction	3.8
Phosphorus	Ca	3.3
Phosphorus	Mg	3.6
Phosphorus	Mg/ NO_3^- Interaction	3.8
Magnesium	Ca	3.3
Magnesium	Mg	3.6
Magnesium	Mg/ NO_3^- Interaction	3.8
Sulphur	Ca	3.3
Sulphur	B	3.4
Sulphur	Mg/ NO_3^- Interaction	3.8
Manganese	Mg	3.6
Copper	Mg/ NO_3^- Interaction	3.8
Zinc	NO_3^-	3.7
Boron	Ca	3.3

Figure 3.11 List of nutrients and treatments involved in dilution effects

Many of the significant differences indicated in the nutrient amount pot^{-1} analyses were due to "yield effects" (section 3.3.4). These yield effects are observed for the Ca treatment in the analyses for the mineral nutrients N, K, Cu and Zn (Appendix 9; Table 3.3).

TABLE 3.6 Effect of Mg nutrition on the mineral element content and concentration of potato tubers

NUTRIENT ANALYSES	Mg Application			LSD (5%)
	24.25 mg L^{-1}	48.50 mg L^{-1}	72.75 mg L^{-1}	
N CONCENTRATION (g kg^{-1})	21.9	23.1	22.8	1.0
N AMOUNT POT^{-1} (g pot^{-1})	4.03	3.97	3.92	NS
P CONCENTRATION (g kg^{-1})	4.7	4.9	4.9	0.2
P AMOUNT POT^{-1} (g pot^{-1})	0.86	0.84	0.85	NS
Mg CONCENTRATION (g kg^{-1})	1.0	1.0	1.1	0.1
Mg AMOUNT POT^{-1} (g pot^{-1})	0.18	0.17	0.19	0.02
Mn CONCENTRATION (mg kg^{-1})	46	41	47	4
Mn AMOUNT POT^{-1} (mg pot^{-1})	8.5	7.2	8.3	1.0

TABLE 3.7 Effect of NO_3^- nutrition on the mineral element content and concentration of potato tubers

NUTRIENT ANALYSES	NO_3^- Application			LSD (5%)
	74.9 mg L^{-1}	102.9 mg L^{-1}	130.9mg L^{-1}	
N CONCENTRATION (g kg^{-1})	22.3	22.0	23.4	1.0
N AMOUNT POT^{-1} (g pot^{-1})	4.00	3.83	4.09	NS
Zn CONCENTRATION (mg kg^{-1})	30	30	32	2
Zn AMOUNT POT^{-1} (mg pot^{-1})	5.4	5.3	5.6	NS

TABLE 3.8 **Effect of Mg/NO_3^- interaction on the mineral element content and concentration of potato tubers**

NUTRIENT ANALYSES	NO_3^- (74.9 mg L^{-1})			NO_3^- (102.9 mg L^{-1})			NO_3^- (130.9mg L^{-1})			LSD (5%)
	Mg1*	Mg2*	Mg3*	Mg1*	Mg2*	Mg3*	Mg1*	Mg2*	Mg3*	
N CONCENTRATION (g kg^{-1})	22.5	22.0	22.4	21.1	22.1	22.8	22.1	25.0	23.1	1.7
N AMOUNT POT^{-1} (g pot^{-1})	3.97	4.07	3.95	3.95	3.77	3.78	4.18	4.06	4.03	0.57
P CONCENTRATION (g kg^{-1})	4.8	4.7	4.8	4.7	4.7	5.0	4.6	5.2	4.9	0.3
P AMOUNT POT^{-1} (g pot^{-1})	0.85	0.87	0.84	0.87	0.81	0.82	0.86	0.84	0.88	0.11
S CONCENTRATION (g kg^{-1})	2.3	2.4	2.3	2.3	2.3	2.5	2.3	2.5	2.4	0.1
S AMOUNT POT^{-1} (g pot^{-1})	0.42	0.42	0.41	0.43	0.39	0.41	0.43	0.42	0.42	0.06
Cu CONCENTRATION (mg kg^{-1})	10	10	9	10	10	10	10	11	10	1
Cu AMOUNT POT^{-1} (mg pot^{-1})	1.8	1.8	1.6	1.8	1.7	1.7	1.8	1.8	1.8	0.2

* Mg1, Mg2 and Mg3 represent Mg^{2+} application levels of 24.25, 48.50 and 72.75 mg L^{-1} respectively.

3.4 CONCLUSION

A number of significant differences between treatments are observed, however most of these were attributed to either "dilution effects" or "yield effects".

The results illustrate that none of the nutrient treatments, namely different levels of Mg^{2+}, NO_3^- or BO_3^{2-} application, alone or in interaction with each other, brought about a significant increase (or decrease, as expected in the case of Mg - Archer, 1986) in the tuber Ca concentration or Ca amount pot^{-1}. This would indicate that the Mg^{2+}, NO_3^- or BO_3^{2-} components of the Calmag+B fertiliser do not enhance the uptake of the Ca component of the fertiliser. The results show that the antagonistic effect of Ca on B uptake is not reciprocated.

The importance of Ca nutrition on tuber yield and the mineral element content of tubers (and hence, tuber quality) is again highlighted, with significant losses in both of the above-mentioned factors becoming apparent with sub-optimal Ca nutrition.

CHAPTER 4

THE RESPONSE OF FIELD GROWN POTATOES TO APPLICATIONS OF DIFFERENT LEVELS OF CALMAG+B, AGRIFOS AND KNO_3 ON AN ACIDIC HUTTON SOIL

4.1 INTRODUCTION

The objective of this experiment was to determine whether the application of the fertilisers Calmag+B (a soluble fertiliser containing calcium nitrate, magnesium nitrate and boron, with 117 g kg^{-1} Ca, 38 g kg^{-1} Mg, 137 g kg^{-1} N and 2 g kg^{-1} B - Appendix 2), Agrifios (a soluble fertiliser consisting of 120 g kg^{-1} N and 270 g kg^{-1} P - Appendix 2) and KNO_3 (a soluble fertiliser consisting of 380 g kg^{-1} K and 130 g kg^{-1} N), over and above the application rates recommended by the KDAFA (Manson *et. al.,* 1995), would have a superior effect on the potato crop grown in the field. The nutrients provided by these fertilisers have the ability to alter tuber yield, tuber quality and size, as well as the incidence and severity of certain diseases and physiological disorders.

Nitrogenous fertilisers give rise to increased tuber yield. Excessive application of the nutrient, however, brings about a reduction in both tuber yield and quality (Porter and Sisson, 1991). It has been shown that split applications of N prevent losses through leaching, as well as increased yield and N use efficiency (McCann and Stark, 1989). This practice may, however, give rise to an increase in the incidence of physiological disorders such as "hollow heart" (McCann and Stark, 1989).

Phosphorus increases both the number of tubers produced per plant (Berryman *et. al.,* 1973) and, to a lesser extent, tuber size (Verma and Grewal, 1978). An increase in P results in an increase in starch percentage (Solle, 1980). Some sources report that it may also reduce viral infections (Skrinskaya *et. al.,* 1976), as well as having

the ability to reduce the incidence and severity of diseases such as potato scab (Keinath and Loria, 1990).

Potassium gives rise to an increase in tuber yield, mainly through a marked increase in the number of large tubers (Singh and Singh, 1995). It has been shown that an increase in soil available K lowers the incidence of physiological disorders, among which is "hollow heart" (Jackson *et. al.,* 1984, cited by Harris, 1992). It has also been found that K improves chip colour (Chapman *et. al.,* 1992).

Calcium improves plant emergence and brings about an increase in tuber size (Smith and Nash, 1938). An increase in tuber Ca leads to a reduction in both the incidence and severity of certain fungal (e.g. *Pythium ultimum* - Lewis and Lumsden, 1984) and bacterial (e.g. *Erwinia caratovora* - Bartz *et. al.,* 1992) diseases. The nutrient has also been found to cause a reduction in physiological disorders of the tuber, such as Internal Brown Spot (Collier *et. al.,* 1980).

Magnesium enhances tuber formation (Krackenberger and Petersen, 1964, cited by Smith, 1968), and if deficient, may result in substantial reductions in tuber yield (Smith and Nash, 1937). The nutrient also plays an essential role in plant physiology, influencing sugar synthesis and translocation, and serving as an activator for enzyme systems used in photosynthetic reactions and respiration, to name but a few (Ponnampalam, 1985). Increasing Mg levels brings about an increase in cation competition and may result in a reduction in Ca and K uptake, thus leading to the increased incidence of certain diseases, e.g. bacterial soft rot (McGuire and Kelman, 1984).

Research has shown that B application may increase tuber yield (Lozek and Fecenko, 1996). Applications of supra-optimal quantities of B have been shown to reduce both tuber yield as well as the number of tubers per plant (Porter *et. al.,* 1986). An increase in tuber B content may lead to an increase in tuber quality e.g. starch content and membrane integrity (Dwivedi and Dwivedi, 1992). Research has

also shown, however, that higher concentrations of B increase the incidence of "Hollow Heart" in tubers (Hiller and Koller, 1987).

4.2 MATERIALS AND METHODS

Prior to planting the crop, lime was applied to the soil at a rate of 400 kg ha^{-1}. There was also a fertiliser application in the form of 1.4 t ha^{-1} of 2:3:4 (24)+Zn. The potato crop was planted in a Hutton soil ((Soil Classification Working Group, 1991) Hutton form and series; Acid Saturation: 42 %; Mineral constituents: 39 mg P L^{-1}; 203 mg K L^{-1}; 595 mg Ca L^{-1}; 128 mg Mg L^{-1}; 11 mg Mn L^{-1}; 10.8 mg Zn L^{-1} - Appendix 12), previously used for potato and maize crops, at a farm in New Hanover ($29^0$23'S $30^0$28'E; 750m), Kwazulu-Natal. Seed potato of the cultivar "BP1" was planted in double rows on the 10^{th} of July 1995. Rows were 0.5 m apart within the double row, and 1.2 m apart between double rows. Each plot consisted of a double row of 6m length.

Four weeks after planting, a side dressing of KNO_3 (400 kg ha^{-1}) was applied. Soil samples were taken one week after the application of KNO_3, and analyzed for nutrient content and acidity by laboratories at the Kwazulu-Natal Department of Agriculture (Smeda *et. al.,* 1997). The soil analyses indicated that there was 595 mg Ca L^{-1} and 128 mg Mg L^{-1} in the soil (the KDAFA assessing threshold levels of 500-600 mg Ca L^{-1}, and over 100 mg Mg L^{-1} for potatoes (Manson, *et. al.,* 1995)). The soil analysis indicates that the KDAFA would not recommend any further application of Ca and Mg to this soil for potato production.

Recommendations for the application of N, P and K by the above-mentioned Advisory, and the actual amounts of the three nutrients applied to the soil (in the form of 2:3:4(24)+Zn and KNO_3) prior to the commencement of the experiment treatments, are displayed in Table 4.1.

Table 4.1 KDAFA recommendations for application of N, P and K, and actual levels of N, P and K used for the experiment

Nutrient	KDAFA recommendations for application of N, P and K (Kg ha^{-1})	Actual applications of N, P and K prior to treatments (Kg ha^{-1})
N	240* 300**	127
P	80†	112
K	120* 200**	302

* Recommended application in order to achieve a tuber yield of 60 t ha^{-1}

** Recommended application in order to achieve a tuber yield of 80 t ha^{-1}

† This value represents the minimum application of P recommended for a potato crop by the KDAFA (Manson *et. al.*, 1995).

The figures in the above table illustrate that fertiliser applications - prior to the commencement of treatment applications - comfortably met the P and K requirements of the crop, perhaps even providing them in excess (according to the recommendations of the above-mentioned advisory). The only nutrient that could be considered deficient in the soil was N, and this only if it is assumed that the soil provided no N at all (Manson, pers. comm.)[1].

The first of five treatments commenced eight weeks after planting, with the fertilisers being applied in the form of an overhead spray at a volume of 300 L ha^{-1}. Three levels of Calmag+B (0, 50 and 100 Kg ha^{-1}) were combined with three levels of Agrifos (0, 50 and 100 Kg ha^{-1}) in a 3^2 factorial. An additional treatment of 100 Kg ha^{-1} of Calmag+B, Agrifos and KNO_3 was inserted.

[1] A.D. Manson, Kwazulu-Natal Department of Agriculture

The experiment was arranged in a 3^2+1 randomised block design with 3 replications. Data was analysed using Genstat 5 (Rothamsted Experimental Station,1988), and least significant difference (LSD) was used to determine whether differences between means were significant.

The field was irrigated once every seven days, with 50 mm of water being applied at each irrigation. Irrigation took place 24h after treatments were applied, in order to allow for the foliar absorption of nutrients by the plant, while preventing leaf burn from fertiliser standing on the leaf surface for extended periods of time.

Bravo (Appendix 1) was sprayed to prevent early and late blight diseases from infecting the plants.

One week subsequent to the completion of the treatments, leaf samples were taken from each plot and sent to the Agrofert laboratories for nutrient analysis. Due to successive irregularities and discrepancies in the analyses performed by this laboratory, these results were deemed to be unreliable, and were discarded.

The crop was harvested 23 weeks after planting had taken place. At harvest the tubers from each plot were weighed, and tuber size determined (Extra small: 15-50g; Small: 40-100g; Medium: 80-250g; Large: 200+ g (Van Zyl, pers. comm.)[2]). Samples of tubers (each sample weighing 10Kg and being proportionally representative of the different size categories mentioned above) from each plot were used in order to determine the mineral nutrient content of the tubers using the procedures of Farina and Channon, 1988. Tuber N and S were analysed by dry combustion using a LECO CNS 2000 analyser (Smeda *et. al.*, 1997). The specific gravity (using a hydrometer), colour quality (using a Hunter Lab spectrophotometer) and total quality (fried potato inspection procedure using green colour, other undesirable colours, internal defects and external defects) of the tubers were also determined. all of the above factors were determined through in-house procedures used by Simba (PTY) LTD.

[2] P. Van Zyl, South African Potato Board

4.3 RESULTS AND DISCUSSION

Statistical analyses were conducted on tuber yield and tuber size (Appendix 10), tuber specific gravity, colour quality and total quality (Appendix 11), nutrient concentration of tubers (measured as g kg^{-1} of dry matter for macro-nutrients and mg kg^{-1} of dry matter for micro-nutrients) as well as nutrient amount $plot^{-1}$ (Kg $plot^{-1}$), between the various treatments (Appendix 10). The purpose of the tuber nutrient amount $plot^{-1}$ analysis was to determine whether a dilution effect had taken place, for example, when a treatment has a low nutrient concentration due to the fact that it has a high yield, indicating a "dilution" of tuber nutrient concentration (Jarrel and Beverly, 1982).

4.3.1 TUBER YIELD, SPECIFIC GRAVITY, TUBER COLOUR AND TOTAL QUALITY

There were no significant differences between treatments for tuber yield (Appendix 10; Table 4.2), or any of the quality factors mentioned above (Appendix 10 and 11). It must be noted, however, that if the level of significance is dropped from 95% to 80% (a figure that may be of greater interest to potato producers), significant differences in yield between treatments become apparent (Table 4.2). Treatments five, six, nine and ten (Table 4.2) all have significantly ($P<0.20$) higher yield than treatment four (with a yield increase of up to 4.7 t tubers ha^{-1} in some cases). Treatments six and ten also have significantly ($P<0.20$) higher yields than treatment one. The general trends (at the 80% level of significance) involve increased yield with applications of Calmag+B and KNO_3. The two lowest yields arose from treatments which had no Calmag+B applied (treatment 4, however, received 50 Kg Agrifos ha^{-1}, and had the lowest yield out of all the treatments). Three out of the four treatments that had a statistically significant yield increase (namely treatments six, nine and ten) received the highest application of Calmag+B (100 Kg ha^{-1}), with the fourth treatment receiving 50 Kg Calmag+B ha^{-1} (Table 4.2). The results would indicate, therefore, that at the 80% level of significance, the crop would have benefited from applications of 100 Kg ha^{-1} of Calmag+B and KNO_3.

Table 4.2 Tuber yield (Kg ha^{-1}) of potatoes in response to fertiliser treatments on a Hutton soil at New Hanover, Kwazulu-Natal

TREATMENT NUMBER	TREATMENT	YIELD (Kg ha^{-1}) (LSD(5%)=5800) (LSD(20%)=3684)
1	0 Kg Agrifos ha^{-1} and 0 Kg Calmag+B ha^{-1}	45 294
2	0 Kg Agrifos ha^{-1} and 50 Kg Calmag+B ha^{-1}	45 882
3	0 Kg Agrifos ha^{-1} and 100 Kg Calmag+B ha^{-1}	46 078
4	50 Kg Agrifos ha^{-1} and 0 Kg Calmag+B ha^{-1}	44 804
5	50 Kg Agrifos ha^{-1} and 50 Kg Calmag+B ha^{-1}	48 725
6	50 Kg Agrifos ha^{-1} and 100 Kg Calmag+B ha^{-1}	49 510
7	100 Kg Agrifos ha^{-1} and 0 Kg Calmag+B ha^{-1}	48 333
8	100 Kg Agrifos ha^{-1} and 50 Kg Calmag+B ha^{-1}	47 353
9	100 Kg Agrifos ha^{-1} and 100 Kg Calmag+B ha^{-1}	48 529
10	100 Kg Agrifos ha^{-1}, 100 Kg Calmag+B ha^{-1} and 100 Kg KNO_3 ha^{-1}	49 216

4.3.2 TUBER SIZE

The analysis for "small" tubers (40-100g) indicated that the 50 kg ha^{-1} Calmag+B application had significantly ($P<0.05$) more small tubers than the 100 kg ha^{-1} Calmag+B treatment (the control being mutual to both groups- Appendix 10; Table 4.3). A Ca deficiency may lead to an overabundance of small tubers (Smith and Nash, 1938), hence one would expect the control (0 kg ha^{-1}) to have more small tubers than the other two treatments. As Ca was not considered to be deficient, even where no Calmag+B was applied, it may be assumed that this result is an anomaly.

Table 4.3 The Effect of Calmag+B Treatments on the number of "small" tubers per 10 Kg sample

TUBER SIZE	CALMAG+B APPLICATION RATE ($Kg\ ha^{-1}$)			LSD (5%)
	0	50	100	
SMALL	19	24	16	6

4.3.3 Cu ANALYSES

There were significant differences between the Agrifos treatments in the Cu concentration analysis (Appendix 10; Table 4.4). As this trend in statistical significance was not reflected in the Cu amount $plot^{-1}$ (Appendix 10; Table 4.4) analysis, it can be assumed that a "dilution" effect had taken place (Jarrel and Beverly, 1982). This means that there was enough nutrient available for plant development, and that another factor was limiting development

4.3.4 OTHER NUTRIENT ANALYSES

There were no significant differences between treatments in any of the other nutrient analyses (Appendix 10).

4.4 CONCLUSION

As the soil had an acid saturation value of 42%, the crop may have benefited from further liming prior to planting (The KDAFA recommends the application of lime where a soil's acid saturation is above 30% - Manson *et. al.,* 1995). This was not possible unfortunately, as the crop had been planted prior to the field being made available for this particular experiment.

The lack of significant differences between treatments (at the 95% level of significance) for almost all of the variables, would indicate that there was adequate nutrient available for plant uptake prior to the application of treatments (it must be noted, however, that at the 80% level of significance, the results indicate that the crop may have benefited from further applications of Calmag+B and KNO_3, over and above the KDAFA recommendations). The experiment shows, therefore, that a nutrient "threshold" is attained, beyond which any additional fertiliser application will not bring about an increase in tuber yield, tuber size, or in the mineral nutrient content or quality of potato tubers. From this it can be understood that excessive applications of fertiliser, as recommended in certain circles, does not lead to any benefit for the grower, but may lead to the leaching of nutrients bringing about damage to the environment in the form of eutrophication.

The field in which the trial was carried out had previously yielded in the order of 45 t ha^{-1} with soil applications of granular fertilisers. The range of yields obtained in this trial (with an average tuber yield of 47.7 t ha^{-1}) were very similar to those previously obtained under "regular" farming practices. As nutrient deficiency was shown not to be a yield limiting factor, it can be assumed that the relatively low yields obtained on this field are be due to other factors. These limiting factors may include inadequate soil amelioration with lime, or sub-optimal water application.

GENERAL CONCLUSION

The research work undertaken for this thesis had multiple aims. A substantial portion of the research was concerned with the availability of Ca, and the effect of this nutrient on seedling emergence, potato development, and tuber yield and quality.

In Chapter 2, the effects of severe Ca deficiency under highly acid soil conditions was investigated, resulting in greatly reduced seedling emergence, plant development and tuber yield. This problem was rectified through the application of lime ($Ca(OH)_2$) to the soil, which led to increased soil pH, Ca availability, and reduced al availability. The supply of Ca to the soil through a source with little ameliorative qualities (Calmag+B), failed to lead to increased seedling emergence, plant development, or tuber yield. although it is unlikely that a potato crop will ever be grown in a soil with such unfavourable characteristics, this research is useful in illustrating that a Ca source with strong ameliorative qualities will be required, should a grower plant under such conditions. Hence, one can conclude that a Ca source with little ameliorative effect (such as Calmag+B), would be inadequate in overcoming the adverse conditions of severely low pH and Ca availability, and high al availability. The results obtained here are in accordance with the recommendations of the KDAFA, where it is suggested that acid soils should be ameliorated in order to achieve an acid saturation of 30% (or less). The results further confirm that soil amelioration beyond this point is ineffectual in creating increased tuber yield, although it may give rise to increased tuber Ca content.

The problem of seedling emergence and plant development under highly acid soil conditions was also overcome by the "pre-enrichment" of the mother tuber with calcium, magnesium, nitrate and boron. The enhanced seedling emergence and plant development observed here, was due to increased feeding from the mother tuber, and not due to increased root development. The effect of this practice on tuber yield was not investigated. As literature covering this topic was unavailable to the

author, it would appear that further research is necessary to determine the full effects, and possible benefits, from "nutrient pre-enrichment" of the mother tuber.

The research reported on in Chapter 3, was successful in determining the effects on plant uptake, of interactions between different levels of Mg^{2+}, NO_3^-, BO_3^{2-}, and Ca^{2+}. Agrofert's assumptions that their Calmag+B fertiliser increases Ca uptake - due to the presence of the three other nutrients in the above-mentioned fertiliser - appear to be unfounded. all of these three elements (namely, Mg^{2+}, NO_3^- and BO_3^{2-}) were ineffectual in giving rise to increased Ca^{2+} uptake.

The effects of "supra-optimal" fertiliser applications on tuber yield and quality were discussed in Chapter 4. The results of these trials showed that no improvement in tuber yield or quality (at the 95% level of significance) was achieved with application of N, P, K, Ca, Mg and B fertilisers, over and above the rate recommended by the KDAFA. It must be noted, however, that at the 80% level of significance, the results indicate that the crop may have benefited from further applications of Calmag+B and KNO_3, over and above the KDAFA recommendations. The research conducted for this study investigated the effects of increased fertiliser application rates on both tuber yield and quality. Further research is required to determine whether the application time of these "supra-optimal" rates of fertiliser has any effect on the above-mentioned factors. This may foster future research, and hence evidence, pointing to a "window" period for fertiliser application, which may lead to improved crop performance.

The research topics covered in this thesis have addressed some key issues for potato fertilisation and production in South Africa, and more specifically, in Natal. In carrying out this research, however, many new questions deserving further scrutiny and in-depth research were raised.

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APPENDIX 1

Crop protection chemicals used in experiments

1.	**Common name:**	Benomyl
	Chemical name:	methyl 1-(butylcarbamoyl)-2-benzimidazole carbamate (IUPAC)
	Formulation used:	500 g Kg^{-1} (Benlate)
	Dosage:	2 g L^{-1}
2.	**Common name:**	Chlorothalonil
	Chemical name:	Tetrachloroisophthalonitrile (IUPAC)
	Formulation used:	500 g L^{-1} (Bravo)
	Dosage:	2.75 ml L^{-1}
3.	**Common name:**	Propamocarb hydrochloride
	Chemical name:	*S*-ethyl *N*-(3-dimethylaminopropyl) thiocarbamate hydrochloride (IUPAC)
	Formulation used:	722 g Kg^{-1} (Previcur)
	Dosage:	1.2 ml L^{-1}
4.	**Common name:**	Copper hydroxide
	Chemical name:	Copper hydroxide (IUPAC)
	Formulation used:	770 g Kg^{-1} (Kocide)
	Dosage:	2 g L^{-1}
5.	**Common name:**	Acephate
	Chemical name:	*O,S*-dimethyl acetylphosphoramidothioate (IUPAC)
	Formulation used:	750 g Kg^{-1} (Orthene)
	Dosage:	2 g L^{-1}

6. **Common name:** Chlorpyrifos

Chemical name: *O,O*-diethyl *O*-3,5,6-trichloro-2-pyridyl phosphorothioate (IUPAC)

Formulation used: 480 g L^{-1} (Dursban)

Dosage: 1 ml L^{-1}

7. **Common name:** Imidacloprid

Chemical name: 1-(6-chloro-3-pyridylmethyl)-*N*-nitroimidazolidin-2-ylideneamine (IUPAC)

Formulation used: 700 g Kg^{-1} (Gaucho)

Dosage: 1.1 g L-1

8. **Common name:** Oxamyl (carbamate)

Chemical name: *S*-methyl *N',N'*-dimethyl-*N*-(methylcarbamoyloxy)-1-thio-oxamimidate(I) (IUPAC)

Formulation used: 310 g L^{-1} (Vydate)

Dosage: 5 ml L^{-1}

APPENDIX 2

Characteristics and Contents of Agrofert Fertilisers used in experiments

Calmag+B

Calmag+B is a soluble fertiliser used in fertigation and foliar feeding of crops. The product is a mixture of calcium nitrate and magnesium nitrate with added soluble boron.

Element	Content (g kg^{-1} of fertiliser)
Ca	117
Mg	38
N	137
B	2

Agrifos

Agrifos is a soluble fertiliser used in fertigation and foliar feeding of crops. The product consists of pure, soluble ammonium phosphate.

Element	Content (g kg^{-1} of fertiliser)
N	120
P	270

APPENDIX 3

Soil test results for Geluksberg soil (ameliorated to 4 pH values) used in the experiment to determine the "effect of soil acidity on potato development". The pH 4.1 level is unameliorated Geluksberg soil.

	Ca mg L^{-1}	Mg mg L^{-1}	K mg L^{-1}	Acid Sat. (%)	pH (KCl)	Zn mg L^{-1}	Mn mg L^{-1}	P mg L^{-1}
pH 4.1	88.2	42.5	86.0	84.00	4.05	0.5	4	2
pH 4.4	827.6	69.3	86.0	23.37	4.35	0.5	6	1.1
pH 5.5	1234.4	45.0	101.7	0.73	5.46	0.6	3	1.1
pH 6.0	1398.7	30.4	97.7	0.66	6.01	0.5	3	1.2

APPENDIX 4

The determination of quantities of $Ca(OH)_2$ required to ameliorate Geluksberg subsoil to desired pH levels

A range of quantities of $Ca(OH)_2$ (0.148, 0.296, 0.444, 0.592, 0.740 and 0.888 g) were added to 100g samples of Geluksberg subsoil in beakers, followed by an application of water to each sample in order to raise the water level of the soil to FWC. The samples were then incubated at a temperature of 20 °C for a period of 14 days.

The value obtained from each quantity of $Ca(OH)_2$ was plotted on a graph (Figure 5.1). This graph was then used to determine the quantities of $Ca(OH)_2$ required to ameliorate the Geluksberg subsoil to the desired pH levels.

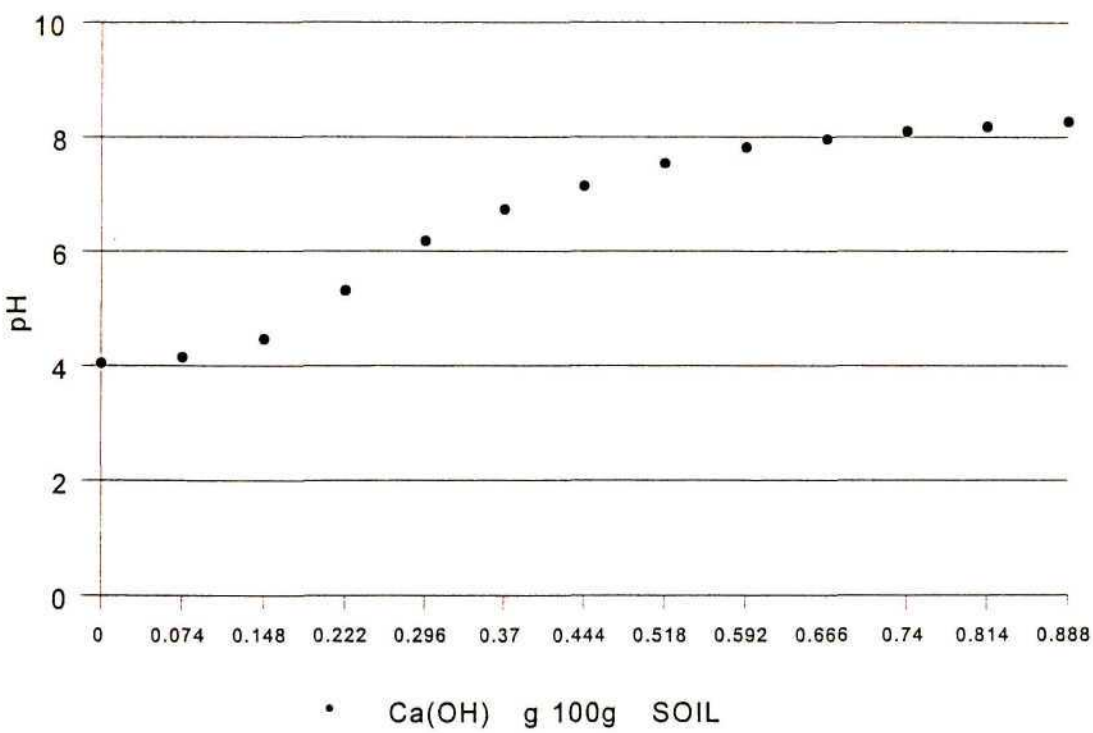

Figure 5.1 Geluksberg subsoil pH as affected by the application of different quantities of $Ca(OH)_2$ (pH determination using KCl).

APPENDIX 5

Fertilizer program used in experiments to determine the "effect of soil acidity on potato development"

WEEK (after emergence)	FERTILIZER	RATE(kg ha^{-1})
PRE-PLANT	2:3:2 (22)	1300
2	AGRIFOS	50
4	AGRIFOS	50
6	AGRIFOS	50
7	KNO_3	100
9	KNO_3	100
11	KNO_3	100

APPENDIX 6

Analyses of variance for the trial dealing with "the effect of lime, Calmag+B and a combination of the two calcium sources on potato development"

Analysis of variance for N concentration of potato tubers

Variate: N concentration (g Kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.000463	0.000232	0.03	
pH	2	0.058664	0.029332	3.93	0.042
Calmag+B	2	0.042158	0.021079	2.83	0.091
pH.Calmag+B	4	0.025129	0.006282	0.84	0.520
Residual	15(1)	0.111839	0.007456		
Total	25(1)	0.238253			

Grand mean = 10.81
% CV = 0.5

Analysis of variance for N amount pot^{-1}

Variate: N amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	3.7188	1.8594	8.23	
pH	2	1.2565	0.6282	2.78	0.094
Calmag+B	2	1.1064	0.5532	2.45	0.120
pH.Calmag+B	4	0.6147	0.1537	0.68	0.616
Residual	15(1)	3.3888	0.2259		
Total	25(1)	8.8352			

Grand mean = 2.115
% CV = 21.5

Analysis of variance for P concentration of potato tubers

Variate: P concentration (g Kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.021622	0.010811	10.68	
pH	2	0.014156	0.007078	6.99	0.007
Calmag+B	2	0.008600	0.004300	4.25	0.034
pH.Calmag+B	4	0.001511	0.000378	0.37	0.824
Residual	15(1)	0.015178	0.001012		
Total	25(1)	0.057862			

Grand mean = 2.2
% CV = 16.1

Analysis of variance for P amount pot^{-1}
Variate: P amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.020073	0.010037	1.51	
pH	2	0.092499	0.046249	6.95	0.007
Calmag+B	2	0.006369	0.003184	0.48	0.629
pH.Calmag+B	4	0.027450	0.006863	1.03	0.423
Residual	15(1)	0.099758	0.006651		
Total	25(1)	0.230661			

Grand mean = 0.41
% CV = 8.2

Analysis of variance for K concentration of potato tubers
Variate: K concentration (g Kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.02235	0.01117	0.21	
pH	2	0.21882	0.10941	2.10	0.157
Calmag+B	2	0.22603	0.11302	2.17	0.149
pH.Calmag+B	4	0.27198	0.06799	1.30	0.313
Residual	15(1)	0.78248	0.05217		
Total	25(1)	1.50011			

Grand mean = 17.5
% CV = 2.0

Analysis of variance for K amount pot^{-1}
Variate: K amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	8.843	4.422	4.00	
pH	2	1.416	0.708	0.64	0.541
Calmag+B	2	0.825	0.413	0.37	0.695
pH.Calmag+B	4	0.327	0.082	0.07	0.989
Residual	15(1)	16.578	1.105		
Total	25(1)	25.583			

Grand mean = 3.38
% CV = 20.7

Analysis of variance for Mg concentration of potato tubers
Variate: Mg concentration (g Kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.00023993	0.00011997	1.74	
pH	2	0.00032604	.000016302	2.36	0.128
Calmag+B	2	0.00045104	0.00022552	3.26	0.067
pH.Calmag+B	4	0.00016042	0.00004010	0.58	0.681
Residual	15(1)	0.00103611	0.00006907		
Total	25(1)	0.00220385			

Grand mean = 0.7
% CV = 5.1

Analysis of variance for Mg amount pot^{-1}
Variate: Mg amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0091022	0.0045511	4.56	
pH	2	0.0031234	0.0015617	1.56	0.242
Calmag+B	2	0.0049048	0.0024524	2.45	0.120
pH.Calmag+B	4	0.0033829	0.0008457	0.85	0.517
Residual	15(1)	0.0149856	0.0009990		
Total	25(1)	0.0306019			

Grand mean = 0.14
% CV = 16.3

Analysis of variance for S concentration of potato tubers
Variate: S concentration (g Kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0014529	0.0007264	4.27	
pH	2	0.0018956	0.0009478	5.57	0.016
Calmag+B	2	0.0006557	0.0003279	1.93	0.180
pH.Calmag+B	4	0.0010317	0.0002579	1.51	0.248
Residual	15(1)	0.0025538	0.0001703		
Total	25(1)	0.0071420			

Grand mean = 1.44
% CV = 6.2

Analysis of variance for S amount pot^{-1}
Variate: S amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.038613	0.019307	5.49	
pH	2	0.016914	0.008457	2.41	0.124
Calmag+B	2	0.011578	0.005789	1.65	0.226
pH.Calmag+B	4	0.004270	0.001067	0.30	0.871
Residual	15(1)	0.052718	0.003515		
Total	25(1)	0.111147			

Grand mean = 0.276
% CV = 16.8

Analysis of variance for Cu concentration of potato tubers
Variate: Cu concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	17.662	8.831	2.53	
pH	2	26.621	13.310	3.82	0.046
Calmag+B	2	2.537	1.269	0.36	0.701
pH.Calmag+B	4	3.769	0.942	0.27	0.892
Residual	15(1)	52.257	3.484		
Total	25(1)	100.962			

Grand mean = 4
% = 24.2

Analysis of variance for Cu amount pot^{-1}
Variate: Cu amount pot^{-1} (mg pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.7126	0.3563	1.69	
pH	2	2.4241	1.2121	5.76	0.014
Calmag+B	2	0.5089	0.2545	1.21	0.326
pH.Calmag+B	4	0.3338	0.0835	0.40	0.808
Residual	15(1)	3.1559	0.2104		
Total	25(1)	6.5980			

Grand mean = 0.8
% CV = 24.4

Analysis of variance for Zn concentration of potato tubers
Variate: Zn concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	67.836	33.918	3.72	
pH	2	20.211	10.105	1.11	0.355
Calmag+B	2	1.516	0.758	0.08	0.921
pH.Calmag+B	4	20.450	5.112	0.56	0.694
Residual	15(1)	136.646	9.110		
Total	25(1)	234.038			

Grand mean = 18
% CV = 11.0

Analysis of variance for Zn amount pot^{-1}
Variate: Zn amount pot^{-1} (mg pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	2.5735	1.2868	2.42	
pH	2	1.4066	0.7033	1.32	0.296
Calmag+B	2	3.6343	1.8172	3.41	0.060
pH.Calmag+B	4	1.6173	0.4043	0.76	0.568
Residual	15(1)	7.9904	0.5327		
Total	25(1)	15.8208			

Grand mean = 3.4
% CV = 11.3

APPENDIX 7

"Corrected χ^2" analysis for survival of potted potato plants between liming treatments

Variate: Plant survival

	NO PLANT SURVIVAL	PLANT SURVIVAL	TOTAL
pH 4.1	8	1	9
pH 4.4, 5.5 and 6.0	0	27	27
TOTAL	8	28	36

"Corrected c^2" (1df) $= \frac{\{(8x27)-(0x1)-(0.5)(36)\}^2 \times 36}{8x28x9x27}$

$= 25.93^{**}$

95% Confidence limit (1df) = 3.84
99% Confidence limit (1df) = 6.63

APPENDIX 8

Soil test results for Geluksberg soil with the application of two levels of Calmag+B fertilizer, used in the experiments to determine the effect of Calmag+B soil and seed tuber treatments on potato emergence and development. The control is unameliorated Geluksberg soil.

	Ca mg L^{-1}	Mg mg L^{-1}	K mg L^{-1}	Acid Sat. (%)	pH (KCl)	Zn mg L^{-1}	Mn mg L^{-1}	P mg L^{-1}
Control	88.2	42.5	86.0	84	4.05	0.5	4	2
Cal 1	856.7	271.0	86.0	37	3.80	2.5	8	0.5
Cal 2	879.7	337.8	82.1	31	3.76	2.6	7	0.3

There is a large increase in Ca availability and a corresponding drop in the acid saturation with the addition of the first level of Calmag+B. The addition of the second (and higher) level of Calmag+B application, however, produces only a slight increase in Ca availability, as well as a small reduction in acid saturation. The reason for this phenomenon is that the increase in Calmag+B application brings about an increase in the ionic strength of the soil solution, thus making Al available from originally non-available sources.

APPENDIX 9

Analyses of variance for yield, tuber number, average tuber mass, nutrient concentration of tubers, and nutrient amount pot^{-1} for the trial aimed at determining factors influencing the uptake of Ca.

Analysis of variance of tuber number per pot
Variate: Tuber number (tuber number pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	111.13	55.56	3.97	
Ca	1	27.30	27.30	1.95	0.071
Mg	2	14.90	7.45	0.53	0.589
NO_3	2	50.72	25.36	1.81	0.169
B	2	15.75	7.88	0.56	0.572
Ca. Mg	2	15.41	7.71	0.55	0.578
Ca. NO_3	2	6.20	3.10	0.22	0.802
Mg. NO_3	4	15.69	3.92	0.28	0.890
Ca. B	2	5.95	2.97	0.21	0.809
Mg. B	4	36.27	9.07	0.65	0.630
NO_3. B	4	12.83	3.21	0.23	0.921
Ca. Mg. NO_3	4	47.16	11.79	0.84	0.502
Ca. Mg. B	4	22.99	5.75	0.41	0.801
Ca. NO_3. B	4	22.02	5.50	0.39	0.813
Mg. NO_3. B	8	46.26	5.78	0.41	0.911
Ca. Mg. NO_3. B	8	119.12	14.89	1.06	0.395
Residual	100(6)	1400.22	14.00		
Total	155(6)	1911.61			

Grand mean = 11
% CV = 9.1

Analysis of variance for tuber average mass
Variate: Tuber average mass (g)

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	1305.36	652.68	11.90	
Ca	1	103.14	103.14	1.88	0.073
Mg	2	248.59	124.29	2.27	0.109
NO_3	2	258.94	129.47	2.36	0.100
B	2	0.90	0.45	0.01	0.992
Ca. Mg	2	0.82	0.41	0.01	0.993
Ca. NO_3	2	34.67	17.34	0.32	0.730
Mg. NO_3	4	40.95	10.24	0.19	0.945
Ca. B	2	55.62	27.81	0.51	0.604
Mg. B	4	193.71	48.43	0.88	0.477
NO_3. B	4	193.67	48.42	0.88	0.477
Ca. Mg. NO_3	4	206.66	51.66	0.94	0.443
Ca. Mg. B	4	233.88	58.47	1.07	0.377
Ca. NO_3. B	4	321.14	80.29	1.46	0.219
Mg. NO_3. B	8	255.66	31.96	0.58	0.790
Ca. Mg. NO_3. B	8	430.30	53.79	0.98	0.456
Residual	100(6)	5484.77	54.85		
Total	155(6)	9176.77			

Grand mean = 17.7
% CV = 19.6

Analysis of variance of N concentration of potato tubers
Variate: N concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.55242	0.27621	4.35	
Ca	1	0.05172	0.05172	0.81	0.369
Mg	2	0.41664	0.20832	3.28	0.042
NO_3	2	0.56908	0.28454	4.48	0.014
B	2	0.58767	0.29384	4.63	0.012
Ca. Mg	2	0.27687	0.13843	2.18	0.118
Ca. NO_3	2	0.07889	0.03944	0.62	0.539
Mg. NO_3	4	0.70445	0.17611	2.77	0.031
Ca. B	2	0.12576	0.06288	0.99	0.375
Mg. B	4	0.33162	0.08290	1.31	0.273
NO_3. B	4	0.04249	0.01062	0.17	0.955
Ca. Mg. NO_3	4	0.11173	0.02705	0.43	0.790
Ca. NO_3. B	4	0.26084	0.06521	1.03	0.397
Mg. NO_3. B	8	0.86538	0.10817	1.70	0.107
Ca. Mg. NO_3. B	8	0.23760	0.02970	0.47	0.876
Residual	100(6)	6.34853	0.06349		
Total	155(6)	11.54741			

Grand mean = 22.6
% CV = 3.2

Analysis of variance of N amount pot^{-1}
Variate: N amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	22.7598	11.3799	15.61	
Ca	1	4.9005	4.9005	6.72	0.011
Mg	2	0.3643	0.1822	0.25	0.779
NO_3	2	1.8291	0.9146	1.25	0.290
B	2	0.8432	0.4216	0.58	0.563
Ca. Mg	2	0.0582	0.0291	0.04	0.961
Ca. NO_3	2	1.1374	0.5687	0.78	0.461
Mg. NO_3	4	0.3998	0.1000	0.14	0.968
Ca. B	2	1.1177	0.5588	0.77	0.467
Mg. B	4	1.2915	0.3229	0.44	0.777
NO_3. B	4	0.5412	0.1353	0.19	0.945
Ca. Mg. NO_3	4	1.2195	0.3049	0.42	0.795
Ca. Mg. B	4	2.2826	0.5707	0.78	0.539
Ca. NO_3. B	4	4.8453	1.2113	1.66	0.165
Mg. NO_3. B	8	1.5188	0.1899	0.26	0.977
Ca. Mg. NO_3. B	8	9.7805	1.2226	1.68	0.113
Residual	100(6)	72.9135	0.7291		
Total	155(6)	124.3331			

Grand mean = 3.97
% CV = 11.6

Analysis of variance of P concentration of potato tubers
Variate: P concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.079944	0.039972	22.34	
Ca	1	0.011865	0.011865	6.63	0.011
Mg	2	0.013812	0.006906	3.86	0.024
NO_3	2	0.004253	0.002126	1.19	0.309
B	2	0.003543	0.001771	0.99	0.375
Ca. Mg	2	0.003717	0.001858	1.04	0.358
Ca. NO_3	2	0.010153	0.005076	2.84	0.063
Mg. NO_3	4	0.034634	0.008658	4.84	0.001
Ca. B	2	0.003326	0.001663	0.93	0.398
Mg. B	4	0.007093	0.001773	0.99	0.416
NO_3. B	4	0.005509	0.001377	0.77	0.547
Ca. Mg. NO_3	4	0.012250	0.003063	1.71	0.153
Ca. Mg. B	4	0.000605	0.000151	0.08	0.987
Ca. NO_3. B	4	0.011348	0.002837	1.59	0.184
Mg. NO_3. B	8	0.013537	0.001692	0.95	0.483
Ca. Mg. NO_3. B	8	0.007720	0.000965	0.54	0.824
Residual	100(6)	0.178935	0.001789		
Total	155(6)	0.394569			

Grand mean = 4.8
% CV = 5.6

Analysis of variance of P amount pot^{-1}
Variate: P amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.73916	0.36958	12.35	
Ca	1	0.12415	0.12415	4.15	0.044
Mg	2	0.01730	0.00865	0.29	0.750
NO_3	2	0.02134	0.01067	0.36	0.701
B	2	0.05196	0.02598	0.87	0.423
Ca. Mg	2	0.03978	0.01989	0.66	0.517
Ca. NO_3	2	0.07769	0.03884	1.30	0.278
Mg. NO_3	4	0.04635	0.01159	0.39	0.817
Ca. B	2	0.00450	0.00225	0.08	0.928
Mg. B	4	0.05990	0.01498	0.50	0.736
NO_3. B	4	0.03099	0.00775	0.26	0.904
Ca. Mg. NO_3	4	0.02647	0.00662	0.22	0.926
Ca. Mg. B	4	0.08026	0.02006	0.67	0.614
Ca. NO_3. B	4	0.15976	0.03994	1.33	0.262
Mg. NO_3. B	8	0.13217	0.01652	0.55	0.815
Ca. Mg. NO_3. B	8	0.31385	0.03923	1.31	0.247
Residual	100(6)	2.99332	0.02993		
Total	155(6)	4.82075			

Grand mean = 0.85
% CV = 9.7

Analysis of variance of K concentration
Variate: K concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	6.24505	3.12252	32.60	
Ca	1	0.00002	0.00002	0.01	0.999
Mg	2	0.03090	0.01545	0.16	0.851
NO_3	2	0.16576	0.08288	0.87	0.424
B	2	0.00277	0.00138	0.01	0.986
Ca. Mg	2	0.28106	0.14053	1.47	0.235
Ca. NO_3	2	0.39852	0.19926	2.08	0.130
Mg. NO_3	4	0.92648	0.23162	2.42	0.053
Ca. B	2	0.37618	0.18809	1.96	0.146
Mg. B	4	0.22780	0.05695	0.59	0.667
NO_3. B	4	0.25993	0.06498	0.68	0.608
Ca. Mg. NO_3	4	0.32053	0.08013	0.84	0.505
Ca. Mg. B	4	0.15899	0.03975	0.42	0.797
Ca. NO_3. B	4	0.66460	0.16615	1.73	0.148
Mg. NO_3. B	8	0.34480	0.04310	0.45	0.888
Ca. Mg. NO_3. B	8	0.35939	0.04492	0.47	0.875
Residual	100(6)	9.57682	0.09577		
Total	155(6)	19.84674			

Grand mean = 26.4
% CV = 9.1

Analysis of variance of K amount pot^{-1} of potato tubers
Variate: K amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	25.583	12.792	12.24	
Ca	1	8.713	8.713	8.34	0.005
Mg	2	2.615	1.307	1.25	0.291
NO_3	2	1.859	0.930	0.89	0.414
B	2	2.554	1.277	1.22	0.299
Ca. Mg	2	0.526	0.263	0.25	0.778
Ca. NO_3	2	1.744	0.872	0.83	0.437
Mg. NO_3	4	2.518	0.630	0.60	0.662
Ca. B	2	0.669	0.335	0.32	0.727
Mg. B	4	1.183	0.296	0.28	0.888
NO_3. B	4	1.566	0.391	0.37	0.826
Ca. Mg. NO_3	4	1.450	0.362	0.35	0.846
Ca. Mg. B	4	2.536	0.634	0.61	0.659
Ca. NO_3. B	4	2.630	0.657	0.63	0.643
Mg. NO_3. B	8	7.719	0.965	0.92	0.501
Ca. Mg. NO_3. B	8	12.454	1.557	1.49	0.170
Residual	100(6)	104.515	1.045		
Total	155(6)	177.990			

Grand mean = 4.65
% CV = 10.5

Analysis of variance of Mg concentration of potato tubers

Variate: Mg concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0059671	0.0029835	13.21	
Ca	1	0.0025844	0.0025844	11.44	0.001
Mg	2	0.0039307	0.0019653	8.70	<0.001
NO_3	2	0.0006361	0.0003180	1.41	0.249
B	2	0.0002375	0.0001187	0.53	0.593
Ca. Mg	2	0.0038067	0.0019034	8.43	<0.001
Ca. NO_3	2	0.0004808	0.0002404	1.06	0.349
Mg. NO_3	4	0.0018056	0.0004514	2.00	0.100
Ca. B	2	0.0006368	0.0003184	1.41	0.249
Mg. B	4	0.0011373	0.0002843	1.26	0.291
NO_3. B	4	0.0006408	0.0001602	0.71	0.587
Ca. Mg. NO_3	4	0.0012574	0.0003144	1.39	0.242
Ca. Mg. B	4	0.0002008	0.0000502	0.22	0.925
Ca. NO_3. B	4	0.0003676	0.0000919	0.41	0.803
Mg. NO_3. B	8	0.0007177	0.0000897	0.40	0.920
Ca. Mg. NO_3. B	8	0.0007275	0.0000909	0.40	0.917
Residual	100(6)	0.0225826	0.0002258		
Total	155(6)	0.0472359			

Grand mean = 1.0
% CV = 7.4

Analysis of variance of Mg amount pot^{-1}
Variate: Mg amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.070143	0.035071	17.59	
Ca	1	0.000490	0.000490	0.25	0.621
Mg	2	0.004825	0.002412	1.21	0.303
NO_3	2	0.003175	0.001587	0.80	0.454
B	2	0.005696	0.002848	1.43	0.245
Ca. Mg	2	0.004041	0.002021	1.01	0.367
Ca. NO_3	2	0.002441	0.001221	0.61	0.544
Mg. NO_3	4	0.001615	0.000404	0.20	0.936
Ca. B	2	0.000579	0.000290	0.15	0.865
Mg. B	4	0.003959	0.000990	0.50	0.738
NO_3. B	4	0.002396	0.000599	0.30	0.877
Ca. Mg. NO_3	4	0.002755	0.000689	0.35	0.847
Ca. Mg. B	4	0.004537	0.001134	0.57	0.686
Ca. NO_3. B	4	0.005442	0.001360	0.68	0.606
Mg. NO_3. B	8	0.013444	0.001680	0.84	0.567
Ca. Mg. NO_3. B	8	0.019275	0.002409	1.21	0.302
Residual	100(6)	0.199373	0.001994		
Total	155(6)	0.336854			

Grand mean = 0.18
% CV = 14.3

Analysis of variance of S concentration of potato tubers
Variate: S concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.0021315	0.0010657	2.21	
Ca	1	0.0034927	0.0034927	7.25	0.008
Mg	2	0.0013043	0.0006521	1.35	0.263
NO_3	2	0.0025613	0.0012807	2.66	0.075
B	2	0.0047750	0.0023875	4.96	0.009
Ca. Mg	2	0.0011082	0.0005541	1.15	0.321
Ca. NO_3	2	0.0013161	0.0006581	1.37	0.260
Mg. NO_3	4	0.0079234	0.0019809	4.11	0.004
Ca. B	2	0.0003536	0.0001768	0.37	0.694
Mg. B	4	0.0032934	0.0008233	1.71	0.154
NO_3. B	4	0.0003780	0.0000945	0.20	0.940
Ca. Mg. NO_3	4	0.0007855	0.0001964	0.41	0.803
Ca. Mg. B	4	0.0001179	0.0000295	0.06	0.993
Ca. NO_3. B	4	0.0018887	0.0004722	0.98	0.422
Mg. NO_3. B	8	0.0038611	0.0004826	1.00	0.439
Ca. Mg. NO_3. B	8	0.0033266	0.0004158	0.86	0.550
Residual	100(6)	0.0481599	0.0004816		
Total	155(6)	0.0864077			

Grand mean = 2.4
% CV = 1.9

Analysis of variance of S amount pot^{-1}
Variate: S amount pot^{-1} (g pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	0.305269	0.152635	18.21	
Ca	1	0.024733	0.024733	2.95	0.089
Mg	2	0.009526	0.004763	0.57	0.568
NO_3	2	0.006094	0.003047	0.36	0.696
B	2	0.013110	0.006555	0.78	0.460
Ca. Mg	2	0.003523	0.001761	0.21	0.811
Ca. NO_3	2	0.013218	0.006609	0.79	0.457
Mg. NO_3	4	0.011266	0.002816	0.34	0.853
Ca. B	2	0.006891	0.003445	0.41	0.664
Mg. B	4	0.007115	0.001779	0.21	0.931
NO_3. B	4	0.003548	0.000887	0.11	0.980
Ca. Mg. NO_3	4	0.019463	0.004866	0.58	0.677
Ca. Mg. B	4	0.020727	0.005182	0.62	0.650
Ca. NO_3. B	4	0.036508	0.009127	1.09	0.366
Mg. NO_3. B	8	0.027169	0.003396	0.41	0.915
Ca. Mg. NO_3. B	8	0.136188	0.017023	2.02	0.060
Residual	100(6)	0.838090	0.008381		
Total	155(6)	1.446757			

Grand mean = 0.42
% CV = 12.7

Analysis of variance of Cu concentration of potato tubers
Variate: Cu concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	55.066	27.533	13.26	
Ca	1	2.658	2.658	1.28	0.260
Mg	2	6.533	3.266	1.57	0.212
NO_3	2	9.091	4.546	2.19	0.117
B	2	12.366	6.183	2.98	0.055
Ca. Mg	2	1.069	0.534	0.26	0.774
Ca. NO_3	2	4.576	2.288	1.10	0.336
Mg. NO_3	4	30.803	7.701	3.71	0.007
Ca. B	2	1.211	0.606	0.29	0.748
Mg. B	4	17.355	4.339	2.09	0.088
NO_3. B	4	10.285	2.571	1.24	0.299
Ca. Mg. NO_3	4	14.339	3.585	1.73	0.150
Ca. Mg. B	4	9.790	2.448	1.18	0.325
Ca. NO_3. B	4	4.067	1.017	0.49	0.743
Mg. NO_3. B	8	11.233	1.404	0.68	0.711
Ca. Mg. NO_3. B	8	7.932	0.992	0.48	0.869
Residual	100(6)	207.596	2.076		
Total	155(6)	399.769			

Grand mean = 10
% CV = 7.2

Analysis of variance of Cu amount pot^{-1}
Variate: Cu amount pot^{-1} (mg pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	4.7991	2.3996	18.44	
Ca	1	2.0062	2.0062	15.42	<0.001
Mg	2	0.2830	0.1415	1.09	0.341
NO_3	2	0.1852	0.0926	0.71	0.493
B	2	0.1056	0.0528	0.41	0.668
Ca. Mg	2	0.1117	0.0559	0.43	0.652
Ca. NO_3	2	0.4940	0.2470	1.90	0.155
Mg. NO_3	4	0.4738	0.1185	0.91	0.461
Ca. B	2	0.1546	0.0773	0.59	0.554
Mg. B	4	0.6136	0.1534	1.18	0.325
NO_3. B	4	0.2900	0.0725	0.56	0.694
Ca. Mg. NO_3	4	0.0903	0.0226	0.17	0.952
Ca. Mg. B	4	0.4602	0.1150	0.88	0.476
Ca. NO_3. B	4	0.4981	0.1245	0.96	0.435
Mg. NO_3. B	8	0.7658	0.0957	0.74	0.660
Ca. Mg. NO_3. B	8	1.4200	0.1775	1.36	0.222
Residual	100(6)	13.0138	0.1301		
Total	155(6)	24.9793			

Grand mean = 1.7
% CV = 12.1

Analysis of variance of Zn concentration of potato tubers

Variate: Zn concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	363.16	181.58	7.95	
Ca	1	35.61	35.61	1.56	0.215
Mg	2	41.08	20.54	0.90	0.410
NO_3	2	162.61	81.31	3.56	0.032
B	2	25.30	12.65	0.55	0.577
Ca. Mg	2	7.02	3.51	0.15	0.858
Ca. NO_3	2	8.44	4.22	0.18	0.832
Mg. NO_3	4	43.32	10.83	0.47	0.755
Ca. B	2	86.69	43.34	1.90	0.155
Mg. B	4	60.69	15.17	0.66	0.619
NO_3. B	4	57.58	14.40	0.63	0.642
Ca. Mg. NO_3	4	95.10	23.77	1.04	0.390
Ca. Mg. B	4	117.06	29.26	1.28	0.283
Ca. NO_3. B	4	34.41	8.60	0.38	0.825
Mg. NO_3. B	8	277.05	34.63	1.52	0.161
Ca. Mg. NO_3. B	8	83.19	10.40	0.46	0.885
Residual	100(6)	2285.21	22.85		
Total	155(6)	3756.69			

Grand mean = 31
% CV = 6.0

Analysis of variance of Zn amount pot^{-1}
Variate: Zn amount pot^{-1} (mg pot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
Reps	2	44.161	22.081	13.41	
Ca	1	19.089	19.089	11.59	<0.001
Mg	2	3.577	1.788	1.09	0.342
NO_3	2	3.374	1.687	1.02	0.363
B	2	1.992	0.996	0.60	0.548
Ca. Mg	2	1.029	0.515	0.31	0.732
Ca. NO_3	2	0.309	0.155	0.09	0.910
Mg. NO_3	4	8.858	2.215	1.34	0.259
Ca. B	2	0.772	0.386	0.23	0.792
Mg. B	4	1.793	0.448	0.27	0.895
NO_3. B	4	1.069	0.267	0.16	0.957
Ca. Mg. NO_3	4	6.893	1.723	1.05	0.387
Ca. Mg. B	4	2.059	0.515	0.31	0.869
Ca. NO_3. B	4	5.974	1.493	0.91	0.463
Mg. NO_3. B	8	4.521	0.565	0.34	0.947
Ca. Mg. NO_3. B	8	22.443	2.805	1.70	0.107
Residual	100(6)	164.698	1.647		
Total	155(6)	282.978			

Grand mean = 5.4
% CV = 11.8

APPENDIX 10

Analyses of variance for yield, tuber size, nutrient concentration of tubers, and nutrient amount plot^{-1} for field trial.

Treatment plots 10.2m^2 in area, with a 3^2+1 randomised block design with 3 replicates.

Analysis of variance for Yield of potato tubers per plot
Variate: Yield (kg)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	7.17	7.17	0.20	0.660
Agrifos	2	50.35	25.18	0.70	0.508
Calmag+B	2	29.10	14.55	0.41	0.569
Agrifos.Calmag+B	4	2.37	0.59	0.02	0.999
Residual	20	718.50	35.92		
Total	29	807.49			

Grand mean = 48.7
% CV = 12.3

Analysis of variance for Tuber size in field trial
Variate: Tuber size - Extra Small (number 10Kg^{-1} sample)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	1.34	1.34	0.04	0.837
Agrifos	2	83.19	41.59	1.34	0.284
Calmag+B	2	161.41	80.70	2.61	0.099
Agrifos.Calmag+B	4	47.70	11.93	0.39	0.817
Residual	20	619.33	30.97		
Total	29	912.97			

Grand mean = 12
% CV = 11.1

Variate: Tuber size – Small (number $10Kg^{-1}$ sample)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	19.20	19.20	0.56	0.463
Agrifos	2	14.00	7.00	0.20	0.817
Calmag+B	2	278.22	139.11	4.06	0.033
Agrifos.Calmag+B	4	148.44	37.11	1.08	0.392
Residual	20	686.00	34.30		
Total	29	1145.87			

Grand mean = 20
% CV = 8.5

Variate: Tuber size – Medium (number $10Kg^{-1}$ sample)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	13.78	13.78	1.37	0.256
Agrifos	2	5.63	2.81	0.28	0.759
Calmag+B	2	0.30	0.15	0.01	0.985
Agrifos.Calmag+B	4	93.93	23.48	2.33	0.091
Residual	20	201.33	10.07		
Total	29	314.97			

Grand mean = 16
% CV = 7.4

Variate: Tuber size – Large (number $10Kg^{-1}$ sample)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	27.393	27.393	2.78	0.111
Agrifos	2	9.185	4.593	0.47	0.634
Calmag+B	2	2.296	1.148	0.12	0.891
Agrifos.Calmag+B	4	15.259	3.815	0.39	0.816
Residual	20	197.333	9.867		
Total	29	251.467			

Grand mean = 9
% CV = 15.2

Analysis of variance for N concentration of potato tubers for field trial
Variate: N concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00545	0.00545	0.17	0.687
Agrifos	2	0.02407	0.01203	0.37	0.695
Calmag+B	2	0.00537	0.00268	0.08	0.921
Agrifos.Calmag+B	4	0.11694	0.02923	0.90	0.483
Residual	20	0.64988	0.03249		
Total	29	0.80170			

Grand mean = 17.37
% CV = 10.4

Analysis of variance for N Amount $plot^{-1}$ for field trial
Variate: N Amount $plot^{-1}$ (kg $plot^{-1}$)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00004	0.00004	0.00	0.969
Agrifos	2	0.01261	0.00630	0.25	0.784
Calmag+B	2	0.00044	0.00022	0.01	0.991
Agrifos.Calmag+B	4	0.02531	0.00633	0.25	0.908
Residual	20	0.51177	0.02559		
Total	29	0.55016			

Grand mean = 0.848
% CV = 18.9

Analysis of variance for P concentration of potato tubers for field trial
Variate: P concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.001424	0.001424	0.96	0.339
Agrifos	2	0.000119	0.000059	0.04	0.961
Calmag+B	2	0.003519	0.001759	1.18	0.327
Agrifos.Calmag+B	4	0.010126	0.002531	1.70	0.189
Residual	20	0.029733	0.001487		
Total	29	0.044920			

Grand mean = 2.6
% CV = 14.6

Analysis of variance for P Amount plot^{-1} for field trial
Variate: P Amount plot^{-1} (kg plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0002058	0.0002058	0.31	0.586
Agrifos	2	0.0005771	0.0002885	0.43	0.657
Calmag+B	2	0.0006204	0.0003102	0.46	0.637
Agrifos.Calmag+B	4	0.0023057	0.0005764	0.86	0.506
Residual	20	0.0134455	0.0006723		
Total	29	0.0171545			

Grand mean = 0.13
% CV = 20.2

Analysis of variance for K concentration of potato tubers for field trial
Variate: K concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.02151	0.02151	0.22	0.644
Agrifos	2	0.14005	0.07003	0.71	0.501
Calmag+B	2	0.09436	0.04718	0.48	0.625
Agrifos.Calmag+B	4	0.30877	0.07719	0.79	0.547
Residual	20	1.95960	0.09798		
Total	29	2.52430			

Grand mean = 27
% CV = 11.7

Analysis of variance for K Amount plot^{-1} for field trial

Variate: K Amount plot^{-1} (kg plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00084	0.00084	0.01	0.906
Agrifos	2	0.03407	0.01703	0.29	0.753
Calmag+B	2	0.01022	0.00511	0.09	0.918
Agrifos.Calmag+B	4	0.08190	0.02048	0.35	0.844
Residual	20	1.18483	0.05924		
Total	29	1.31186			

Grand mean = 1.30
% CV = 18.7

Analysis of variance for Ca concentration of potato tubers for field trial
Variate: Ca concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00008333	0.00008333	0.89	0.356
Agrifos	2	0.00000001	0.00000001	0.01	0.999
Calmag+B	2	0.00028889	0.00014444	1.55	0.237
Agrifos.Calmag+B	4	0.00017778	0.00004444	0.48	0.753
Residual	20	0.00186667	0.00009333		
Total	29	0.00241667			

Grand mean = 0.3
% CV = 15.6

Analysis of variance for Ca Amount $plot^{-1}$ for field trial
Variate: Ca Amount $plot^{-1}$ (kg $plot^{-1}$)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00001792	0.00001792	0.82	0.375
Agrifos	2	0.00000452	0.00000226	0.10	0.902
Calmag+B	2	0.00007683	0.00003842	1.76	0.197
Agrifos.Calmag+B	4	0.00003969	0.00000992	0.46	0.767
Residual	20	0.00043570	0.00002179		
Total	29	0.00057466			

Grand mean = 0.02
% CV = 16.8

Analysis of variance for Mg concentration of potato tubers for field trial
Variate: Mg concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0001959	0.0001959	1.05	0.318
Agrifos	2	0.0000963	0.0000481	0.26	0.775
Calmag+B	2	0.0005630	0.0002815	1.51	0.245
Agrifos.Calmag+B	4	0.0010815	0.0002704	1.45	0.255
Residual	20	0.0037333	0.0001867		
Total	29	0.0056700			

Grand mean = 1.3
% CV = 10.4

Analysis of variance for Mg Amount plot^{-1} for field trial
Variate: Mg Amount plot^{-1} (kg plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0000232	0.0000232	0.16	0.696
Agrifos	2	0.0001868	0.0000934	0.63	0.542
Calmag+B	2	0.0001866	0.0000933	0.63	0.543
Agrifos.Calmag+B	4	0.0002210	0.0000535	0.37	0.825
Residual	20	0.0029605	0.0001480		
Total	29	0.0035781			

Grand mean = 0.06
% CV = 19.0

Analysis of variance for S concentration of potato tubers for field trial
Variate: S concentration (g kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0005348	0.0005348	1.57	0.224
Agrifos	2	0.0005316	0.0002658	0.78	0.471
Calmag+B	2	0.0001765	0.0000883	0.26	0.774
Agrifos.Calmag+B	4	0.0019550	0.0004888	1.44	0.258
Residual	20	0.0067967	0.0003398		
Total	29	0.0099947			

Grand mean = 1.99
% CV = 9.3

Analysis of variance for S Amount plot^{-1} for field trial
Variate: S Amount plot^{-1} (kg plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0000558	0.0000558	0.19	0.671
Agrifos	2	0.0000379	0.0000189	0.06	0.939
Calmag+B	2	0.0000571	0.0000285	0.09	0.910
Agrifos.Calmag+B	4	0.0003862	0.0000965	0.32	0.860
Residual	20	0.0060085	0.0003004		
Total	29	0.0065454			

Grand mean = 0.097
% CV = 17.9

Analysis of variance for Mn concentration of potato tubers for field trial
Variate: Mn concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	10.80	10.80	0.27	0.608
Agrifos	2	149.56	74.78	1.88	0.179
Calmag+B	2	14.00	7.00	0.18	0.840
Agrifos.Calmag+B	4	156.44	39.11	0.98	0.440
Residual	20	796.67	39.83		
Total	29	1127.47			

Grand mean = 28
% CV = 20.9

Analysis of variance for Mn Amount $plot^{-1}$ for field trial
Variate: Mn Amount $plot^{-1}$ (g $plot^{-1}$)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.0429	0.0429	0.30	0.592
Agrifos	2	0.2108	0.1054	0.73	0.495
Calmag+B	2	0.0216	0.0108	0.07	0.928
Agrifos.Calmag+B	4	0.3482	0.0870	0.60	0.665
Residual	20	2.8911	0.1446		
Total	29	3.5146			

Grand mean = 1.3
% CV = 24.3

Analysis of variance for Cu concentration of potato tubers for field trial
Variate: Cu concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	2.504	2.504	1.47	0.239
Agrifos	2	18.074	9.037	5.32	0.014
Calmag+B	2	2.074	1.037	0.61	0.553
Agrifos.Calmag+B	4	12.815	3.204	1.88	0.153
Residual	20	34.000	1.700		
Total	29	69.467			

Grand mean = 7
% CV = 20.0

Analysis of variance for Cu Amount plot^{-1} for field trial
Variate: Cu Amount plot^{-1} (g plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.003987	0.003987	0.63	0.437
Agrifos	2	0.026604	0.013302	2.09	0.149
Calmag+B	2	0.007368	0.003684	0.58	0.569
Agrifos.Calmag+B	4	0.030701	0.007675	1.21	0.338
Residual	20	0.127012	0.006351		
Total	29	0.195673			

Grand mean = 0.3
% CV = 22.1

Analysis of variance for Zn concentration of potato tubers for field trial
Variate: Zn concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	30.00	30.00	1.55	0.228
Agrifos	2	12.67	6.33	0.33	0.725
Calmag+B	2	32.67	16.33	0.84	0.445
Agrifos.Calmag+B	4	100.00	25.00	1.29	0.307
Residual	20	387.33	19.37		
Total	29	562.67			

Grand mean = 32
% CV = 13.9

Analysis of variance for Zn Amount plot^{-1} for field trial
Variate: Zn Amount plot^{-1} (g plot^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.04988	0.04988	0.51	0.485
Agrifos	2	0.00805	0.00402	0.04	0.960
Calmag+B	2	0.10019	0.05010	0.60	0.609
Agrifos.Calmag+B	4	0.23496	0.05874	0.60	0.669
Residual	20	1.96845	0.09842		
Total	29	2.36153			

Grand mean = 1.5
% CV = 20.3

Analysis of variance for B concentration of potato tubers for field trial
Variate: B concentration (mg kg^{-1})

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.833	0.833	0.76	0.394
Agrifos	2	0.222	0.111	0.10	0.904
Calmag+B	2	0.222	0.111	0.10	0.904
Agrifos.Calmag+B	4	8.889	2.222	2.02	0.130
Residual	20	22.000	1.100		
Total	29	32.166			

Grand mean = 2
% CV = 22.0

Analysis of variance for B Amount $plot^{-1}$ for field trial
Variate: B Amount $plot^{-1}$ (g $plot^{-1}$)

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.001987	0.001987	0.60	0.447
Agrifos	2	0.001661	0.000831	0.25	0.780
Calmag+B	2	0.000795	0.000397	0.12	0.887
Agrifos.Calmag+B	4	0.022203	0.005551	1.68	0.194
Residual	20	0.066138	0.003307		
Total	29	0.092784			

Grand mean = 0.1
% CV = 24.7

APPENDIX 11

Analyses of variance for Specific Gravity, Colour Average and Total Quality for field trial.

Analysis of variance for Specific Gravity of potato tubers in field trial
Variate: Specific Gravity

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.00001974	0.00001974	1.40	0.250
Agrifos	2	0.00001474	0.00000737	0.53	0.599
Calmag+B	2	0.00001096	0.00000548	0.39	0.683
Agrifos.Calmag+B	4	0.00010859	0.00002715	1.93	0.145
Residual	20	0.00028133	0.00001407		
Total	29	0.00043537			

Grand mean = 1.068
% CV = 0.2

Analysis of variance for Colour Average of potato tubers in field trial
Variate: Colour Average

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	0.082	0.82	0.02	0.903
Agrifos	2	1.334	0.667	0.12	0.884
Calmag+B	2	0.723	0.361	0.07	0.935
Agrifos.Calmag+B	4	42.415	10.604	1.98	0.137
Residual	20	107.133	5.357		
Total	29	151.687			

Grand mean = 58.4
% CV = 1.3

Analysis of variance for Total Quality of potato tubers in field trial
Variate: Total Quality

Source of variation	DF	SS	MS	VR	F_{prob}
KNO_3	1	4.31	4.31	0.38	0.546
Agrifos	2	2.22	1.11	0.10	0.908
Calmag+B	2	0.15	0.07	0.01	0.993
Agrifos.Calmag+B	4	25.65	6.41	0.56	0.693
Residual	20	228.38	11.42		
Total	29	260.71			

Grand mean = 2.89
% CV = 25.0

APPENDIX 12

Soil test results for Hutton soil used in field trial (New Hanover). Soil tests were performed after the application of 1400 kg ha^{-1} of 2:3:4 (24) and 400 kg ha^{-1} of KNO_3.

Ca mg L^{-1}	Mg mg L^{-1}	K mg L^{-1}	Acid Sat. (%)	pH (KCl)	Zn mg L^{-1}	Mn mg L^{-1}	P mg L^{-1}
595	127.6	203.3	42	3.86	10.8	11	39