APPLICATION OF SILICON TO IMPROVE YIELD AND QUALITY OF POTATOES (*SOLANUM TUBEROSUM* L.)

By

Daphney Gaafele Seome

Submitted in partial fulfillment of the requirements for the degree
M.INST.AGRAR: LAND-USE PLANNING

Department of Plant Production and Soil Science
Faculty of Natural and Agricultural Sciences
University of Pretoria

Dr Diana Marais
Dr Jacquie Van Der Waals
November 2013

DECLARATION

I declare that the dissertation that I hereby submit for the Masters degree in Land-use planning at the University of Pretoria, have not been submitted in any form to another University.

Signature ………………..

Date ……………………….

ACKNOWLEDGEMENTS

- First and most of all I would like to thank my Heavenly Father for the courage and guidance He provided me with

- I am also thankful to all the people who supported me through my journey:

- Dr Johan van der Waals for the initial encouragement to study further into my master's degree

- The house of Premier, North-West Province, for funding

- My supervisor Dr Diana Marais and co-supervisor Dr Jacquie van der Waals for their support, patience and guidance throughout my study

- The laboratory technicians (Department of Plant Production and Soil Science) and workers at the University of Pretoria's Hatfield Experimental farm for the technical support

- Tsedal Ghebremariam, Andre Swanepoel and Mike van der Linde (STATOMET-University of Pretoria) for their time and helping me with the statistical analysis

- And last, I would like to thank my family without whom I wouldn't be where I am today. My mother and sisters for the emotional and financial support, my brother in-law for providing me with a laptop at the beginning of my masters studies so it can make my journey easier, and my partner Bento Marcos and my son Bento Marcos, Jr. for being there and understanding the pressures of completing my degree.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPLICATION OF SILICON TO IMPROVE YIELD AND QUALITY OF POTATOES (*SOLANUM TUBEROSUM* L.)

BY

DAPHNEY GAAFELE SEOME

SUPERVISOR: DR D MARAIS

CO-SUPERVISOR: DR J VAN DER WAALS

DEPARTMENT OF PLANT PRODUCTION AND SOIL SCIENCE

DEGREE: M.INST.AGRAR: LAND-USE PLANNING

ABSTRACT

The potato (*Solanum tuberosum* L.) crop serves as a staple food worldwide and is capable of reducing the world's food shortages because unlike cereals and other agricultural crops, it is less affected by prices in the international markets. Research on alleviation of food crises suggested root and tuber crops such as potatoes to be the solution to the problem of food shortage. The crop is widely cultivated but is difficult to produce due to susceptibility to numerous pests and pathogenic organisms, as well as abiotic stresses. To control these pests and diseases, strategies to limit susceptibility to factors that interfere with the growth and development of plants, or breeding new varieties that are able to withstand stresses are being researched. Recent studies have shown that non essential nutrients such as Silicon (Si) are beneficial to plants in terms of yield, protection from fungal diseases and improved uptake of phosphorus.

Since very little research has focused on the role of Si in improving potato production, three glasshouse pot trials were conducted at the Hatfield Experimental farm and Department of Plant Pathology glasshouses of the University of Pretoria to evaluate the effect of various soil amendments on potato yield and quality. The effect of these soil amendments on pH was also investigated as P-uptake and development of common scab in potatoes are pH dependent. The soil amendments consisted of different silicon sources and an agricultural lime. The Si sources were Calmasil slag (Middleburg) (30% Si- containing liming material), fly ash (50% Si non-liming material), and Si fume/ash (99% Si non-liming material). Agricultural lime ($CaCO_3$) was included as a control.

The purpose of the first two trials was to identify the most promising silicon-containing source for potato production, while the third trial evaluated the effect of this silicon source on soil pH and potato tuber yield. In all three trials, agricultural lime was used as a control. Due to the high demand for nutrients by the potato crop, other nutrient elements were added to the soil through fertigation every 7 to 14 days, depending on the growth stage of the plants. Plants were irrigated with distilled water when necessary to maintain an adequate moisture level i.e. moist but not too wet. Weekly observations on growth parameters were made. To select the most promising soil amendment, parameters such as leaf chlorophyll content, plant height, tuber number and mass (Fwt), fresh and dry weight (top growth) and change in soil pH were analyzed. Slag treated plants tended to produce tubers with higher mass and better appearance. In this study the highest increase in soil pH was observed in soil mixed with slag, compared to all the other silicon sources. Although there was no significant difference observed among treatments there was a distinct difference in plant growth between trials when soil was amended with lime and slag. Plants treated with slag tended to produce tubers that weigh more, whilst plants treated with lime grew taller and had the highest tuber number. There was a significant rise in soil pH from both lime and slag, which might have in turn influenced vegetative and tuber growth.

CHAPTER 1

INTRODUCTION

The potato (*Solanum tuberosum* L.) crop serves as a staple food worldwide (Dean, 1994) and is capable of reducing the world's food shortages because, unlike cereals and other agricultural crops, it is less affected by prices in the international markets (Food and Agriculture Organization, 2008a). According to the FAO (2004) and the African Union (2006), Africa has undergone more food crises or "hunger situations" than other parts of the developing world. These crises arise from drought, diseases, annual population growth that exceeds food production and civil war in some parts of Africa (AU, 2006). Research on alleviation of food crises suggests that root and tuber crops such as potatoes could be the solution to the problem of food shortages (Alvarez, 1987). According to Thurston (2001) potatoes have become the fourth largest food crop produced in the world, following maize (*Zea mays* L.), wheat (*Triticum spp*.) and rice (*Oryza sativa*). Despite being widely cultivated, potatoes are difficult to produce due to susceptibility to biotic and abiotic factors that reduce tuber yield and quality (Beukema & Van der Zaag, 1990; Agrios, 1997). Further complicating the situation is that the crop is propagated vegetatively from tubers thus making it easy to transfer pests and diseases from propagation material to plants (Okigbo, 1987; Rowe, 1993; Lulai, 2001).

The potato plant can host numerous pests and pathogenic organisms such as bacteria, fungi, viruses, viroids, nematodes and phytoplasmas. These pathogens can occur during plant growth or even storage, making it difficult to achieve and maintain a healthy potato crop (Rowe, 1993; Loria, 2001). Biotic and abiotic factors limit growth and development of potatoes by disrupting the plant's physiological processes. Examples include factors such as: (1) weeds that compete with the crop plant for available resources; (2) insects that damage roots or leaves and by so doing limit processes such as nutrient uptake, water movement and photosynthesis. This may ultimately divert resources from tubers; and (3) diseases that destroy roots or leaves, disrupt plant growth processes, or damage tubers (Rowe, 1993). To control pests and diseases, strategies must be developed to limit factors that interfere with the growth and development of plants, or breed new varieties that are able to withstand stresses. According to Rowe (1993) these strategies should be developed in order to avoid a net financial loss and ensure that precautionary or corrective actions are taken before the economic loss level is reached. General disease management strategies include host resistance, exclusion, eradication or reduction of pathogen populations, and protecting plants from damage by pathogens. According to Loria (2001) this involve the genetic ability of plants to defend against pathogens i.e. host resistance; creating condition that prevent or limit exposure of host plant to the pathogen (exclusion), and elimination or reduction of pathogen populations from propagation material and planting area. Whilst protecting plants from pathogens involve: (1) biological control i.e. introduction of predatory pest or organism to suppress pest insect population or disease (Pal & Gardener, 2006), (2) chemical control i.e. application of fungicides, nematicides or bactericides and (3) cultural practices such as the adjustment of soil pH, row spacing, soil fertility and water management (Rowe, 1993; Loria, 2001).

Silicon is not recognized as an essential nutrient but may also be used as a management strategy due to the beneficial role it plays in a plant's growth and development. It is reported to increase the quality and quantity of some agricultural crops (Ma & Yamaji, 2006). According to Epstein (1999) and several other researchers, silicon has proved its role in protection against abiotic and biotic stresses. Although dicots are reported to be poor Si accumulators, positive results against abiotic and biotic stress following application of silicon have been observed; hence the applications of silicon in the present study to improve quality and yield of a potato.

1.1. LITERATURE REVIEW: POTATO

1.1.1. International and local production of potatoes

Potatoes are the single most important vegetable product in South Africa and an internationally recognized staple food (Potatoes South Africa, 2005; Department of Agriculture Forestry and Fisheries, 2010). Global potato production has changed remarkably through the years. According to FAO (2008a) the demand for potatoes is continuously rising as a result of increasing income levels and the nutritional drive towards more energy dense food and prepared food products. China and South Africa are examples of countries which are experiencing growth in potato consumption with increased demand for processed potatoes as a result of increased income and increased urbanization (FAO, 2008a). According to Alvarez (1987) and FAO (2008a) potatoes are a food security crop that can help shield low-income countries from international food price increases. The Potato crop is not a globally traded commodity; hence, it is less susceptible to fluctuations in international markets since prices are controlled by local supply and demand. The crop is also rapidly growing in terms of its value as source of income especially for small scale producers (FAO, 2008a).

According to FAO (2008c), potato is the number one non-grain food commodity, with production that reached a record of about 325 million tonnes in 2007. Africa produced around 16.7 million tonnes of potatoes in 2007. South Africa showed an increase in potato production from about 1.2 million tonnes in 1990 to about 1.97 million tonnes in 2007, while the farming area for potatoes decreased from 63 000 to 58 000 hectares (FAO, 2008d). According to the Bureau for Food and Agricultural Policy (2010), South Africa experienced an all time record harvest in 2008, producing more than 2 million tonnes. This had a large impact on the market price. Decreased potato prices together with increased fuel and fertilizer prices have lead to a sharp reduction (approximately 10%) in the area under production (BFAP, 2010).

According to Potatoes South Africa (2011) Africa produced about 10t ha^{-1} in 2009, which was the lowest worldwide. The average production in Europe was 20t ha^{-1} with that in North America being 42t ha^{-1}. According to the post seasonal crop report from Potato South Africa (2013), there was a slight change in production for the year 2010. Africa produced 13t ha^{-1} whilst there was a reduction in Europe and North America, with yields of 18t ha^{-1} and 41t ha^{-1}, respectively. South Africa is reported to be amongst the six largest potato producing countries in Africa. The other countries are Egypt, Algeria, Malawi, Rwanda and Morocco. In 2010, South Africa produced about 33 tonnes of potato per hectare. The potato productions (yields) for the same year in Morocco, Egypt, Algeria, Malawi and Rwanda was 28, 26, 25, 19 and 12t ha^{-1}, respectively (Potatoes S.A., 2013).

During the 2010 production year Africa contributed about 7% to the world's total potato yield and about 10% to the total area under potato production, while South Africa contributed about 9% to the total potato crop in Africa (Potatoes S.A., 2013). Recent statistics (2010/2011) indicated that potatoes represented 61% of the gross value of vegetables and 3% to the total value of all agricultural products in South Africa (DAFF, 2012). The three most commonly planted cultivars in the country were Mondial, BP1, and Up-to-Date, contributing about 43, 12 and 9 %, respectively, to the total production in 2010 (Potatoes S.A., 2011). These cultivars represented approximately 83% of the potatoes on the fresh produce markets. According to DAFF (2010) the processing industry for potatoes has grown at a rapid rate over the past 10 years and currently represents about 20% of the total potato crop. Potato is furthermore one of the most widely cultivated crops in the country.

There are 16 production regions in South Africa and these include: Limpopo, North West, Gauteng, Mpumalanga, Northern Cape, Western Free State, Eastern Free State, South Western Free State, KwaZulu-Natal, Sandveld, Ceres, South Western Cape, South Cape, Eastern Cape, Loskop Valley, and North Eastern Cape (Potatoes S.A., 2013). Free State, Limpopo, Western Cape and Mpumalanga were the four major producing regions in 2005, contributing approximately 77% of South Africa's total potato production output, contributing about 30, 18, 19 and 10%, respectively (Potatoes S.A., 2005). In 2009 Limpopo was the leading production region, constituting 19% of the total national hectares under potato production (DAFF, 2010). It was followed by Eastern Free State and Sandveld in which the total hectares cropped were 16 and 14%, respectively. For the crop year 2011 Eastern Free State led by 19% in production area, followed by Limpopo and Sandveld which cropped 18 and 13% of the total hectares, respectively (DAFF, 2012; Potatoes S.A., 2013). According to DAFF (2010) a total of 44 974 hectares were planted during the 2009 production year. This, however, represented a 12% decrease in planted area compared to the 2008 production year (DAFF, 2010). According to DAFF (2012) about 52 563 hectares were cropped in 2010 representing a 3.5% increase as compared to the 2009 production year.

According to FAO (2008d) on average, approximately 34t ha^{-1} over 58 000 ha is harvested. Most of this potato production is under irrigation. Potato crops require large amounts of water to produce good yields. According to Steyn and Du Plessis (2003) more than 95% of the water that is taken up by roots is lost by transpiration, and just a small fraction utilised for growth. The amount of water needed for potato production depends on growth stage. There should not be any shortage or excess of soil water at any growth stage (Steyn and Du Plessis, 2003). The potato crop is known to produce higher yields under a cool climate (optimum between 15 and 20^0C) (Steyn, 2003). Deep, well drained soils of light to medium texture and sufficient amounts of essential nutrients are required for normal growth (Steyn and Du Plessis, 2003). The climate in most of South African production regions limits production of potatoes by creating conditions that favour stresses in the form of pests and diseases. There is a constant need to look at new developments in plant nutrition and crop production in general.

1.1.2. Nutritional value of potato

The potato is high in carbohydrates and has health benefits that contribute to the necessary daily nutritional requirements of a human diet. When freshly harvested, a potato tuber contains about 80% water and 20% dry matter in the form of starch. It has a low fat content (0.1% per 100g), and the protein content is of high biological value (FAO, 2008b). According to Robert *et al.* (2006) the consumption of cooked potatoes enhances antioxidant defenses and improves lipid metabolism, which could be involved in the prevention of cardiovascular diseases. Potatoes are also important sources of minerals, vitamins and fibre. As illustrated in Fig.1.1, potatoes are rich in several micronutrients such as vitamin C. Potatoes are a moderate source of iron and good source of vitamin B1, B3 and B6, potassium, phosphorus and magnesium (United States Department of Agriculture, National Nutrient Database, 2008).

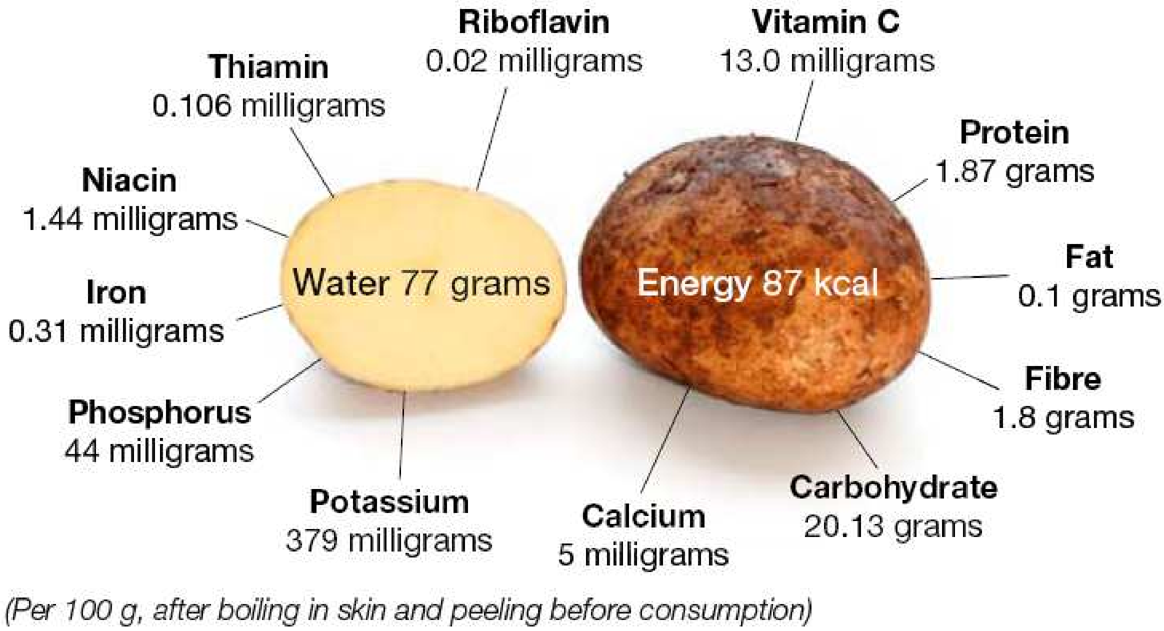


Fig.1.1: Nutrient content of a potato tuber (United States Department of Agriculture, National Nutrient Database, 2008).

1.2. LITERATURE REVIEW: SILICON

1.2.1. Silicon as an essential nutrient for crop growth

Epstein (1999) reported that the beneficial role played by silicon in a plant's growth and development was overlooked until the beginning of the 20th century. Plant physiologists had overlooked the element because deficiencies or toxicities are not noticeable in plants. Today, a deficiency of silicon in the soil is recognized as a limiting factor for crop production (Ma & Yamaji, 2006). Importance of silicon for growth and development of plants is attributed to its role in protection against abiotic and biotic stresses (Epstein, 1999). Silicon is the second most prevalent element in soil after oxygen (Fig. 1.2). Silicon has been reported to be abundant in soil but is depleted in some soils due to repeated cropping and constant application of nitrogen, phosphorus and potassium fertilizers. Silicon is still not recognized as an essential nutrient; however, there have been increasingly evident reports of it being a beneficial nutrient to plants in terms of improved growth, development, yield and disease resistance (Ma & Yamaji, 2006).

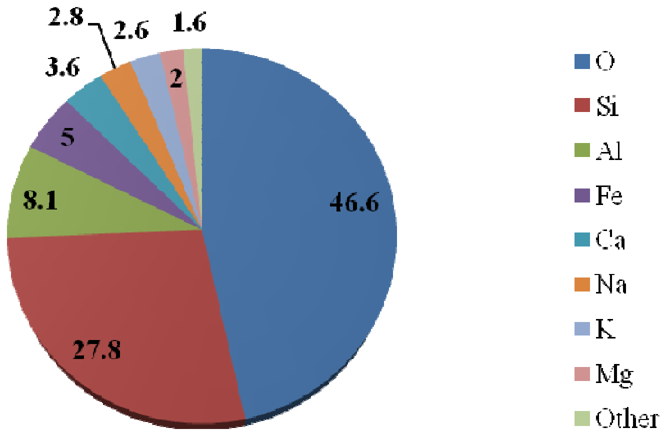


Fig. 1.2: The composition of naturally occurring elements in the earth crust (soil) (volume %) (Reisener, 2010).

Despite the abundance of silicon, it is never found in a free form in soil (Richmond & Sussman, 2003). It is usually combined with other elements in the form of oxides or silicates. According to Ma *et al.* (2001) and Richmond and Sussman (2003) a plant absorbs silicon in the form of uncharged silicic acid (Si (OH_4)), and it is ultimately irreversibly precipitated throughout the plant as amorphous silica (SiO_2-$_nH_2O$). Most sources of silicon are insoluble and thus not readily available to plants. According to Richmond and Sussman (2003) soils with low concentrations of silicon can be amended with silicon compounds to increase the quality and quantity of some agricultural crops such as rice and sugarcane. According to Ma *et al.* (2001) silicon stimulate a plant's resistance against stress conditions. Foliar treatment with silicon appears to improve resistance to pathogens. Foliar-applied Si was found to be successful in the control of powdery mildew in cucumber (*Cucumis sativus*), muskmelon (*Cucumis melo*), zucchini squash (*Cucurbita pepo*) (Menzies *et al.*, 1992) and in grape (*Vitis vinifera*) (Bowen *et al.*, 1992). Results on injuries, if any, have not been reported. Ma *et al*. (2001) indicated Si to be the only element that does not cause damage to plants when applied in excessive dosages.

1.2.2. Silicon in plants

1.2.2.1. Accumulation and uptake of silicon by plants

Silicon has been found to accumulate in plants at similar or higher rates to that of some macronutrients such as Ca, Mg and P. Uptake differs among plant species and Si content ranges from 0.1 to 10% on a dry weight basis (Epstein, 1994; Ma & Takahashi, 2002). According to Snyder *et al.* (2007) plants on average absorb from 50 to 200kg of Si ha^{-1}. They also reported that sugarcane (*Saccharum* spp.) absorbs the highest relative amount of silicon (about 300-700kg Si ha^{-1}), followed by rice (150-300kg of Si ha^{-1}) and wheat (50-150kg of Si ha^{-1}). According to Richmond and Sussman (2003) reports on past theories indicated silicon uptake as a passive event that coincides with the uptake of water or as an active form of nutrient recruitment. General trends have, however, recently been found in terms of silicon accumulation in plants. Monocots tend to be good accumulators and dicots poor accumulators. Takahashi *et al.* (1990) as quoted by Mitani and Ma (2005) reported that there are three types of plants: (1) The Si accumulators - that use an active mode of uptake by the roots. They take up Si at a faster rate than water; (2) The Si intermediate type - that uses a passive mode of uptake by the roots. They take up Si at a similar rate as water; and (3) The Si excluders - that use a rejective mode of uptake by the roots. The excluders' mode of Si uptake is evident by the increased concentrations of Si in the solution surrounding the roots (Mitani & Ma, 2005). Ma and Yamaji (2006) indicated rice (Si accumulator), cucumber (Si passive uptake) and tomato (*Solanum lycopersium*) (Si excluder) as species used to demonstrate different uptake mechanisms. Rice, cucumber and tomato accumulated high, medium and low amounts of Si, respectively.

According to Richmond and Sussman (2003), rice was an early choice as model plant for studying silicon transport. Kim *et al.* (2002) reported rice to have shown the greatest Si uptake in the family Gramineae. Silicon transport and distribution within the plant only takes place via the xylem. Silicon is absorbed into the xylem sap as monosilicic acid and is transported in the outer epidermal cells as amorphous silica. In rice, silicon is mostly deposited in the epidermis of all tissues (Kim *et al*., 2002). According to Kim *et al.* (2002), Si forms a layer in the epidermal cell walls beneath the cuticle and is referred to as the cuticle – silica double layer. Yoshida *et al.* (1962) (quoted by to Kim *et al.*, 2002) suggested that the cuticle-silica double layer controls transpiration and prevents fungal pathogen and insect invasions.

1.2.2.2. Induction of stress resistance by silicon

Silicon can not only protect plants against diseases but can also provide a mechanical barrier in plant tissues to prevent damage from probing and chewing by insects. Savant *et al.* (1999), Richmond and Sussman (2003), Zhu *et al.* (2004) and Ma and Yamaji (2006) indicated other benefits from Si to include alleviation of chemical stresses such as salt, metal toxicity, and physical stress such as lodging, drought, radiation, high temperatures, freezing and UV light amongst many others. A report by Ma and Yamaji (2006) indicated alleviation of metal toxicity to occur through deposition of silicon in roots and ultimately reducing the apoplastic bypass flow and provides binding sites for metals. This was reported to results in reduced uptake and translocation of toxic metals and salts from roots to shoots. According to Savant *et al.* (1999) and Ma and Yamaji (2006), resistance to lodging, low and high temperatures, radiation, UV light and drought stresses is achieved through deposition of Si in culms, leaves and hulls enhancing the strength and rigidity of cell walls and reducing transpiration from the cuticle. According to Ma and Takahashi (2002) the amount of damage from radiation injury depends on the physiological stage of a plant. However, despite the physiological stage, plants treated with silicon after radiation treatment still recovered faster compared to plants without Si. Some of these benefits from applications of Si are discussed in more detail.

i. Disease control

There are numerous past studies that evaluated the effect of Si on enhancing the resistance of plants against fungal and bacterial pathogens. Examples of applications of Si to enhance resistance against diseases include pathogens such as powdery mildew in cucumber (Samuels *et al*., 1991; Menzies *et al*., 1992), powdery mildew in barley (*Hordeum vilgare* L.) (Carver *et al.*, 1987), and blast (*Magnaporthe grisea*) (Kim *et al*., 2002; Seebold *et al.*, 2004) in rice. According to Ma and Yamaji (2006) at least two mechanisms have been proposed for enhanced resistance to pathogens through the application of Si. One of them is the ability of silicon to act as a physical barrier that is formed beneath the cuticle, thereby mechanically interrupting or stopping the penetration of fungi into a host plant; secondly the ability of Si to act as a modulator of host resistance to pathogens.

Reports by Fawe *et al.* (1998), Rodrigues *et al*. (2004) and Remus-Borel *et al.* (2005) are amongst others that indicated silicon to stimulate plants to produce phenolics and phytoalexins in response to fungal infections such as those causing rice blast and powdery mildew. Silicon is reported to induce defense mechanisms.

Kim *et al.* (2002) reported most deposition of silicon in rice to be in the epidermis of all tissues, therefore enhancing the strength and rigidity of the cell walls. This in turn contributes to the improvement of resistance of rice to pests, diseases and lodging (Ma *et al.*, 2004). According to Seebold *et al*. (2000) the severity of the rice blast disease on susceptible and partially resistant cultivars can, in some cases, be reduced to the same levels as those observed for blast-resistant cultivars. Fig. 1.3 demonstrates infection by blast on susceptible plants treated with Si (+ Si) to have been significantly less affected than blast infected susceptible plants that were not treated with Si (- Si). This, however, depends on the application rate of silicon fertilizers.

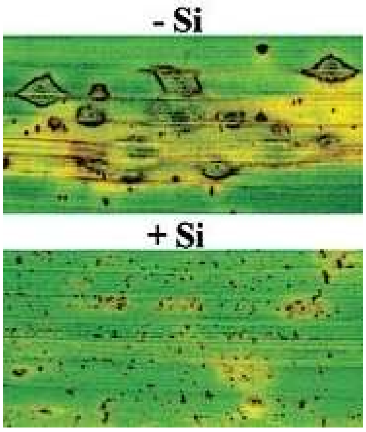


Fig. 1.3: Role of silicon in reducing leaf blast and development of leaf blast symptoms at 96h after inoculation with *Magnaporthe grisea* in rice plants non-amended (-Si) or amended with (+Si) silicon (Datnoff & Rodrigues, 2005).

According to Datnoff and Rodrigues (2005) *M. grisea* infected rice plants that were not treated with silicon, were not efficiently protected against fungal colonization, despite the fact that the plants released antifungal compounds including momilactones. Rice plants treated with Si were able to release high enough levels of momilactones early in the infection process, consequently lowering severity of the disease. Reports by Sitton and West (1975) and Cartwright *et al.* (1977) showed the involvement of momilactones as a defense mechanism in crop resistance against diseases. Therefore the timing of momilactone release might be the key in crop protection. The mechanisms used by the rice plant to resist infection by *M. grisea* when treated with Si are unknown (Datnoff & Rodriques, 2005). Induced resistance in this case was explained by two hypotheses, firstly:

"... it is possible that in certain areas of heavy Si deposition, delayed fungal ingress and colonization provides the rice plant enough time for momilactones synthesis in response to infection by *M. grisea*, to accumulate to considerable levels and express their fungal toxicity within the zone of the infection site..." (quoted from Datnoff & Rodrigues, 2005),

and secondly:

"... as proposed by Fawe *et al.* (2001), the soluble Si present in the plant cells may mediate some defense responses that are functionally similar to systemic acquired resistance..." (quoted from Datnoff &Rodrigues, 2005).

ii. Drought tolerance

Insufficient water supply (drought) is known to be one of the most limiting factors to potato production worldwide. Such stress can result in yield reduction and loss of quality (Van der Zaag & Burton, 1978). According to Van Loon (1986) it is estimated that the average global potato yield could be increased by at least 50% if the water supply to the crop is optimized, taking into account production conditions and present potato yield. Low water supply or drought can affect growth and production of potatoes by reducing amount of foliage, decreasing the rate of photosynthesis per unit of leaf area and shortening the vegetative period. It is also known to affect the tuber quality such as shape, dry matter content and content of reducing sugars

Several studies including that by Agarie *et al.* (1998), Gao *et al.* (2006) (maize), Gong *et al.* (2003) (wheat) and Ma (2004) indicated Si to reduce leaf transpiration of some plant. According to Wong *et al.* (1972) as quoted by Savant *et al.* (1999) the effect of silicon on reduced transpiration rate is the result of a well-thickened layer of silica gel associated with cellulose in the epidermal cell walls. Savant *et al.* (1999) stated the effect of Si on drought tolerance to possibly be due to the reduction in transpiration rate through cuticular layers thickened by silicon deposits. Gao *et al.* (2006) investigated the effect of Si on stomatal transpiration by direct measurement of transpiration rate from leaves and cuticular layers. The results showed reduced transpiration through the stomatal pores and not from cuticular layers. This led to the conclusion that Si influences the stomatal opening but the mechanism is not yet understood.

According to Kaya *et al*. (2006) water stress decreases dry matter, chlorophyll and relative water content. They showed that the introduction of Si into a nutrient solution, improved the water status in water stressed plants. Kaya *et al*. (2006) also suggested that silicon deposited in tissues consequently reduces transpiration and improves light interception by keeping leaf blades erect. They further reported improved tolerance of water stress from application of Si, resulting in partial maintenance of membrane permeability, by enhancing chlorophyll and relative water content, leaf calcium and potassium content, and shoot and total biomass.

Findings by Gong *et al.* (2003) supported reports on the ability of Si to improve plant water status under drought conditions. Water stress affected wheat plant height in untreated plants more than in Si-treated plants, suggesting silicon to have improved plant water status under drought conditions. Plants treated with silicon had an increased leaf weight ratio (LWR) compared to plants not treated with silicon. Greater LWR and lower SLA (specific leaf area) indicated that leaves of stressed plants treated with Si were thicker than those without added Si. Gong *et al*. (2003) concluded that silicon can therefore improve tolerance of crops to drought. This study further concluded that silicon improves tolerance of wheat to drought by maintaining a high leaf area to ensure high assimilation capacity, and thickening of leaves which reduces the transpiration loss of water; thus, making silicon a potential aid for improving crop production in arid or semi arid areas.

iii. Resistance against pest attack

Several studies have indicated that silicon enhances resistance to probing and chewing insects. Investigations conducted to determine the role of silicon on pest suppression discovered that less Si was found in plant parts which were attacked by insects than those which were not attacked. According to Ma and Takahashi (2002) some of the investigations included those by Sasamoto (1958; 1960; 1961) on insect pests such as stem borer, brown planthopper, rice green leafhopper, and whitebacked planthopper, as well as non-insect pests such as leaf spider and mites. According to Savant *et al.* (1999) observations on sugarcane crops were made whereby soil amendments of Si increased resistance to stem borer. The stem borer newly hatched larvae were unable to feed on the epidermal tissues due to presence of Si crystals in tissues (Savant *et al*., 1999). According to Savant *et al.* (1999) crops which are high Si accumulators e.g. rice and sugarcane seem to hamper feeding of insects. This was explained by high level of resistance provided by cuticle double layer leading to the damaged mandibles of the insects.

Report by Kvedaras and Keeping (2007) also provides evidence on Si treatment ability to enhance resistance of plants to insect damage. Kvedaras and Keeping (2007) did a study to evaluate if Si can impede stalk tissue penetration by insects. The research focused on the stem borer (*Eldana saccharum*) which is reported as the most destructive pest of sugarcane in Southern and Eastern Africa (Conlong, 1994; Kvedaras & Keeping, 2007). Kvedaras and Keeping's (2007) report on two sugarcane cultivars i.e. resistant and susceptible to the stem borer, showed an increased percentage in stalk silicon content. According to Kvedaras and Keeping (2007) fewer larvae had penetrated plants treated with Si than those not treated with Si. Rind hardness increased in Si treated plants. This confirmed findings from authors such as Savant *et al.* (1999), Snyder *et al.* (2007) and Hammerschmidt (2005) who reported positive effects of Si against plant pathogens and insect attacks. Kvedaras and Keeping (2007) showed that silicon may have contributed to integrated pest management of *Eldana saccharina* in two ways. First, through a direct effect that includes reduced larval growth (mass gain) and feeding damage to the crop. And secondly, through indirect effects that result from delayed stalk penetration and likely increased exposure time of young larvae to adverse environmental factors or control measures that target such larvae. Gomes *et al.* (2005) also reported that silicon plays a role in activating the plant's endogenous chemical defenses against insect herbivores.

iv. Alleviation of heavy metal toxicity

High concentrations of elements such as aluminium, cadmium and iron can result in reduced crop productivity. According to Kidd *et al.* (2001) components of some silicon deposits were found to be precipitates of silicon and zinc or silicon and aluminium. This suggested that precipitation of heavy metals and silicon can be mechanisms that permit plants to ameliorate heavy metal toxicity. Silicon may play an additional role in improving tolerance to aluminium toxicity. For example, silicon-treated maize plants produced 15 times more phenolics than the untreated maize plants when grown in soils high in aluminium (Richmond & Sussman, 2003).

Methods to alleviate heavy metal toxicity include control of pollution or strict implementation of environmental regulations in terms of waste discharge (Chen *et al*., 2000). Chen *et al*. (2000)

provides an example of studies involving the application of Si to alleviate heavy metal pollution in soils. They conducted trials looking into the application of different silicon sources to alleviate polluted soil contaminated with Cd. According to Chen *et al*. (2000), chemical amendments i.e. silicon sources seemed to have been efficient at reducing Cd uptake. According to Savant *et al.* (1999) increasing rate of applications for silicates can increase water-soluble P and ultimately increasing soil pH. Savant *et al.* (1999) reported calcium silicate to possibly neutralize the acidity in soil with formation of silicic acid and could eventually reduce the solubility of elements such as Mn, Fe and Al. similarly Chen (1988) (quoted by Chen *et al.*, 2000), indicated reduced Cd concentrations to possibly have resulted from an increase in soil pH, Si availability and Cd fixation.

For years lime has been used as a means to increase soil pH thereby reducing Al toxicity (Liang *et al.*, 2001). Other reports, however, have indicated silicon to compensate for lime application by increasing soil pH resulting in reduced rates of application or even eliminating the need for lime. But the mechanisms by which Si alleviates Al toxicity remain poorly understood (Epstein, 1994; 1999; Kidd *et al.*, 2001). However, Si has been found to limit the bioavailability of Al to plants by formation of hydroxyaluminosilicate complexes in solutions. Kidd *et al*. (2001) pointed out reports by Kochian (1995) and Taylor (1995) to have explained the mechanisms by which plants are resistant to Al toxicity to possibly be by either the plant's ability to exclude Al from roots or the ability to detoxify Al within the plants. Ma (2000) showed that organic acids, with Al chelating abilities, play an important role in detoxification of aluminium both externally and internally. Kidd *et al.* (2001) proposed exudation of organic acids to be the potential mechanism of silicon-induced amelioration of Al toxicity in higher plants. In their study Si significantly improved root elongation rate, while in Si-untreated plants Al induced an immediate reduction in root elongation rate.

v. Alleviation of salt stress

Salt affected soils are one of the major problems that restrict crop production (Zhu *et al.*, 2004). Reports by Zhu *et al.* (2004), Zucccarini (2008), Liang (1999) and Wang and Han, (2007) are some of the examples that indicated application of Si to possibly alleviate salt stress. Salt stressed plants treated with silicon had higher plant water content than those not treated with Si. According to Romero-Aranda *et al.* (2006) higher plant water content might explain increased plant growth and could be related to a salt dilution effect in the plant and the consequent mitigation of salt toxicity effects.

According to Savant *et al.* (1999) improved plant water content has been related to a decrease in excessive loss of water by transpiration. Matoh *et al.* (1986) as quoted by Zhu *et al.* (2004) reported silica at 0.89 Mm to have reduced the traslocation of Na^+ to shoots and increased dry matter of salt stressed rice plants as compared the control. According to Zhu *et al.* (2004), cucumber plants, when under salt stress, had lower dry matter content of shoots and roots. A significant improvement was observed when similar plants under the same stress conditions, were treated with Si. According to Zuccarini (2008), the mechanism maybe due to the reduced Na^+ content in shoots. In a study to evaluate the effect of Si on bean plants (*Phaseolus vulgaris*), accumulation of silicon was found in leaves forming a silica-cuticle double layer (Zuccarini, 2008). This was reported to limit transpiration. Salt stressed bean plants when treated with Si showed higher Na^+ content in roots than in shoots. According to Zuccarini (2008) silicon seemed to partially block the apoplastic transport which is responsible for entry of Na^+ through plant root. Reports on rice, *Prosopis juliflora* and barley indicated Si to have induced tolerance to saline conditions by reducing sodium (Na^+) content in shoots. Zuccarini (2008) reported more results on Si's effect on salt stress alleviation to have been observed in rice (Matoh *et al*., 1986), wheat (Ahmad *et al.*, 1992), *Prosopis* (Bradbury & Ahmad, 1990) and barley in hydroponics (Liang et al., 1996; Liang, 1998, 1999; Liang & Ding, 2002).

vi. Alleviation of freezing stress

According to Liang *et al*. (2008), the majority of plants growing in temperate and cold regions are exposed to freezing temperatures during some part of their life cycles. According to Flower and Limin (n.d.) injuries from plants' exposure to cold temperatures include disruption in plant growth and development. Flower and Limin (n.d.) reported freezing stress to result in plants' death at first touch of frost, while some plants as reported by Levitt (1980) can survive extreme low temperatures. Levitt (1980) and Steponkus (1984) (quoted by Liang *et al*., 2008) reported freezing to also result in irreversible damage to plant cells due to mechanical forces generated by formation of extracellular ice crystals, cellular dehydration and increased concentration of intracellular salts.

According to Liang *et al*. (2008) previous studies such as that by Liang *et al*. (2006), showed characterizing Si uptake and transport in cucumber, rice, maize, sunflower and wax gourd to indicate silicon treated plants exposed hydroponically at low temperatures (0^0-4^0C) to have been more tolerant to cold-induced wilting; while the ability of roots to absorb nutrients was higher. These results motivated Liang *et al*. (2008) to evaluate the role of Si on two wheat cultivars, one tolerant and one susceptible to freezing stress. The study concludes that Si alleviates stress and enhances plant growth under freezing stress. Liang *et al*. (2008) tested the mechanism that enhanced resistance to freezing stress. This was achieved by comparing a susceptible and tolerant wheat cultivar under freezing conditions. The results suggested Si treatment to confer resistance and/or tolerance to chilling/freezing stress (Liang *et al*. 2008). According to Liang *et al*. (2008), a susceptible cultivar experience dehydration and low leaf and shoot dry weight in contrast to a tolerant cultivar. Adding silicon had significantly increased leaf and shoot dry weight. Other reports by Zhu *et al.* (2006) (quoted by Liang *et al*., 2008) showed wheat leaf photosynthesis and water use efficiency to be significantly inhibited under freezing stress but significantly improved when adding silicon to the growth medium. Liang *et al*. (2008) reported the mechanism responsible for enhancing resistance to freezing temperatures to result when Si is added which maintained higher water content in leaf tissue reducing traspirational water loss. This was reported to be achieved through the silica-cuticle double layer.

1.2.3. The effect of silicon on photosynthesis

The positive effect of silicon on photosynthesis was demonstrated in rice, where the deposits of silicon in leaf blade cells of rice seemed to have kept the leaves erect. Therefore, silicon is suspected to stimulate canopy photosynthesis by improving light penetration (Ma & Takahashi, 2002). Results from Takahashi *et al*. (1966), Ma (1990) and Kawamitsu *et al.* (1989) (quoted by Ma and Takahashi, 2002) suggested that the positive effect of Si on photosynthesis is minimal under optimum growth conditions but higher under water stress conditions. Reports from Matoh *et al*. (1991) and Ma and Takahashi (2002), also indicated that the application of silicon caused a decrease in transpiration rate while maintaining photosynthesis.

1.2.4. The effect of silicon and lime on soil pH

For years applications of lime has been used to increase the soil pH. According to Maier *et al.* (2002) applications of lime (in glasshouse experiments) had increased soil pH, which ranged from 4.1 to 5.5 by 0.6 to 3.1 units, depending on the soil type. Maier *et al.* (2002) reported an application of lime to have improved the potato plant height where it was applied together with P. Effect of the lime was greatly noticeable on tuber yield when the number of tubers per plant decreased. This suggests that lime had a negative effect on tuber yield.

Maintenance of a high soil pH by lime can have negative effects on potato growth. According to Lambert and Manzer (1991) and Lacey and Wilson (2001) a more alkaline soil pH can increase the incidence and severity of diseases such as common scab (*Streptomyces scabies*), especially in the pH range of 5.0-8.0.

Authors such as Ma *et al.* (1997, 2001), Epstein (2001) and Owino-Gerroh and Gascho (2004) have reported on the beneficial effects of silicon on low soil pH stress in many crops, particularly in the Gramineae. Owino-Gerroh and Gascho (2004) reported that applications of sodium silicates increase the soil pH. According to Ma and Takahashi (1991), an increase in shoot and root dry weight from application of Si could be attributed to an increase in concentration of silicon in soil solution and soil pH. With Si application, the uptake of phosphorus increased, as did plant growth (Owino-Gerroh & Gascho, 2004).

1.2.5. The effect of silicon on phosphorus uptake

Phosphorus is one of the most important nutrients, especially for potatoes. According to Jenkins and Ali (1999) and Sanchez (2007) it promotes crop growth and serves as a buffer in the maintenance of cellular pH. Rosen and Bierman (2008) reported that potatoes respond to P fertilization on soils testing low in P. According to Sanchez (2007) there has been overwhelming evidence from past researches indicating pre-plant application of P as best. Past reports also report P as a relatively immobile element in soil. According to Abdal and Albaho (2004) its immobility in the soil profile is relatively low because of concentration, activity and continuous fixation with other substances at both low and high soil pH. Application rates for potatoes is reported to can be as high as 100-300 kg P ha^{-1} depending on type of P fertilizer, soil type and residual soil P status (McLaughlin *et al*., 1995; McPharlin, 2000). Among the many benefits from silicon treatments, P availability was reported to improve when adding Si, especially when there is high P sorption (Koski-Vahala *et al.*, 2001; Ma *et al*., 2001).

According to Owino-Gerroh and Gascho (2004), the effects of silicon on phosphorus include partial substitution of Si for P (Ma & Takahashi, 1991), increase of available P in soil (Smyth & Sanchez, 1980), inhibition of Fe, Al and Mn toxicities in such soils and better P utilization. In pot trials conducted by Owino-Gerroh and Gascho (2004), improved plant growth and increased P uptake were evident from silicon treatments. In this study the increase of Si and P content in plant tissue resulted from alleviation of soil acidity through the addition of silicon, consequently enhancing P availability. In studies conducted on rice and barley, silicon application resulted in increased dry weight of shoots. According to Ma and Takahashi (2002), numerous factors could attribute to this, including improvement of P availability in soil and plants, and increased uptake of P by the presence of Si. Improved P availability could possibly be due to displacement of fixed P and/or reduced P fixation by activating Al and Fe (Ma & Takahashi, 2002).

1.2.6. Health risks when applying Si

The agricultural environment can be extremely dusty due to operations such as planting, harvesting, sorting, transportation and storage of the produce. As reported by Donham (1986), agricultural workers are subsequently exposed to high levels of dust (quoted by Berberet *et al.*, 1999). Merchant (1986) also reported soil components such as crystalline silicon (quartz) to have the potential to damage lungs if inhaled. These findings suggest that there is a need to consider the health of workers when working with silicon and to take necessary precautions. Berberet *et al.* (1999) reported that despite the advancement in technology for potato harvesting it has not eliminated the need for manual labour. This implies that individuals still experience exposure to dust during the harvesting operation. The most important step is to educate workers where silicon will be applied about the hazards of working with it and how they can protect themselves against Si exposure. Recommendations to limit exposure include the use of masks, slightly dampening the field prior to harvesting and rotating workers, as this can provide more comfort and prevent any negative effects that could come from working with silicon for long periods of time (Berberet *et al.*, 1999).

1.2.7. Economic impact of silicon application

To evaluate the economic impacts from silicon application on crop production, Alvarez and Datnoff (2001) conducted a research on rice production fileds. Positive economic impacts were observed from the study. Alvarez and Datnoff (2001) reported a study by Wang *et al*. (2000) as an example on reduced input costs. This study indicated a large rice production area in China treated with Si to have resulted in applications of lower fertilizer doses and reduced input costs. According to Alvarez and Datnoff (2001) from production year 1979 to 1999, rice yields had increased from 0 to 400% all over 16 provinces of China. This depended on the severity of Si deficiency. Example of successful reduced disease incidences from application of silicon include studies on rice blast (*M. grisea)* (Datnoff & Rodrigues, 2005) (Aleshin *et al*., 1987) and brown spot in rice (*Cochliobolus miyabeanuts*) (Nanda & Gangopadhyay, 1984). Examples on reduced pest incidence through silicon application include pests such as stem borer (*E. saccharina*) in sugarcane (Kvedaras & Keeping, 2007), and mites (*Tetranychus* spp.) in rice (Savant *et al*., 1997). Reports from Datnoff *et al*. (1997) revealed applications of silicon to areas where there are serious environmental concerns threatening agricultural water and land, as a viable option in reducing fungicide and pesticide use. Acoording to Alvarez and Datnoff (2001) more evidence on Si as beneficial element revealed improved P fertilizer efficiency (IARI, 1988), increasing soil pH and reducing or even eliminating lime application rate (Datnoff & Correa-Victoria, 1999, unpublished data). One may argue that silicon sources are expensive but looking at the beneficial effects on not only the soil properties, but also in terms of pest and disease management as well as the long term beneficial effect for the environment (Alvarez & Datnoff, 2001), application of silicon may seem to be a viable option for potato production.

As pointed out by various reports, beneficial effects from silicon application are more evident when plants are exposed to stress conditions (Richmond and Sussman, 2003; Ma and Yamaji, 2006). According to Ma and Yamaji (2006) this is due to the ability of Si to protect plants from abiotic and biotic stresses. Figure 1.4 summarises the beneficial effects of Si on plant growth in relation to various stresses (Ma & Takahashi, 2002).

FLOW CHART

1.3. OBJECTIVES

Based on the literature review on silicon and potato production it is clear how important it is to evaluate any product that can result in an immediate or long term improvement in potato production. The literature on silicon (Si) suggests that Si has potential benefits for crop production. Since very little research has focussed on the role of Si in improving potato production, a study became necessary to evaluate the effect of various Si containing soil amendments, on soil pH and yield of potato.

Aim

The aim was to use silicon-containing sources in order to:

- Evaluate the effects of silicon on potato quality and yield
- Evaluate the effect of different silicon sources on soil pH

Hypothesis

- Application of silicon to potato plants can improve both quality and yield
- Silicon significantly increases soil pH

1.4. REFERENCES

ABDAL, M.S. & ALBAHO, M.S., 2004. Effect of phosphate rate and splitting on wheat production in Kuwait. *Electron J. Environ. Agric. Food Chem*. 3: 665-669.

AFRICAN UNION (AU), 2006. Status of food security and prospects for agricultural development in Africa. AU ministerial conference of ministers of agriculture. January 31- February 1, 2006. Bamako, Mali.

www.**africa-union**.org/root/AU/Conferences/Past/**2006**/January/REA/JAN...
www.**africa-union**.org/Rural%20Agriculture/MIN%20... · DOC file. ACCESSED IN 2012.

AGARIE, S., UCHIDA, H., QGATA, W., KUBOTA, F. & KAUFMAN, P.B., 1998. Effects of silicon on transpiration and leaf conductance in rice plants (*Oryza sativa* L.). *Jpn. J. Crop Sci.* 1: 89–95.

AGRIOS, G.N., 1997. *Plant Pathology*, 4^{th} Ed. Academic Press. San Diego.

AHMAD, R.R., ZAHEER, H.S. & ISMAIL, S., 1992. Role of silicon in salt tolerance of wheat (*Triticum aestivum* L.). *Plant Sci.* 85: 43–50.

ALESHIN, N.E., AVAKYAN, E.R., DYAKUNCHAK, S.A., ALESHKIN, E.P., BARYSHOK, V.P. & VORONKOV, M.G., 1987. Role of silicon in resistance of rice to blast. *Dokl. Akad. Nauk* SSR 291: 217-219.

ALVAREZ, M.N., 1987. Sweet potato and the African food crisis .Pp. 67-68 In: INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS., Ed. Tropical root crops: root crops and the African food crisis : proceedings of the Third Triennial Symposium of the International Society for Tropical Root Crops--Africa Branch held in Owerri, Nigeria, 17-23 August 1986. Ottawa, Ont., Canada: International Development Research Centre.

ALVAREZ, J. & DATNOFF, L.E., 2001. The economic potential of silicon for integrated management and sustainable rice production. *Crop Prot.* 20: 43-48.

BERBERET, L.J., BUCHAN, R. & BEARD, M., 1999. Respirable dust and crystalline silica (Quartz) exposure resulting from potato harvesting operations. *J. Agric. Safety and Health*. 5: 97-107.

BEUKEMA, H.P. & VAN DER ZAAG, D.E., 1990. *Introduction to potato production.* Pudoc Wageningen. Netherlands.

BOWEN, P., MENZIES, J. & EHRET, D., 1992. Soluble silicon sprays inhibit powdery mildew development on grape leaves. *J. Amer. Soc. Hort. Sci*. 117: 906–912.

BRADBURY, M. & AHMAD, R., 1990. The effect of silicon on the growth of *Prosopis juliflora* growing in saline soil. *Plant Soil* 125: 71–74.

BUREAU FOR FOOD AND AGRICULTURAL POLICY (BFAP), 2010. Potatoes. Pp.41 In: The South African agricultural baseline. www.bpfa.co.za. ACCESSED IN 2012.

CARTWRIGHT, D., LANGCAKE, P., PRYCE, R.J., LEWORTHY, D.P. & RIDE, J.P., 1977. Chemical activation of host defense mechanisms as a basis for crop protection. *Nature* 267: 511-513.

CARVER, T.L.W., ZEYEN, R.J. & AHLSTRAND, G.G., 1987. The relationship between insoluble silicon and success or failure of attempted primary penetration by powdery mildew (*Erysiphe graminis*) germlings on barley. *Physiol. Mol. Plant Pathol.* 31: 133–148.

CHEN, H.M., 1988. Several factors affecting the sorption of cadmium by soils. *Soils* 20: 131-136.

CHEN, H.M., ZHENG, C.R., TU, C. & SHEN, Z.G., 2000. Chemical methods and phytoremediation of soil contaminated with heavy metals. *Chemosphere* 41: 229-234.

CONLONG, D.E., 1994. A review and perspectives for the biological control of the African sugarcane stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Agric. Eco. Environ.* 48: 9–17.

DATNOFF, L.E. & CORREA-VICTORIA, F.J., 1999. Unpublished data.

DATNOFF, L.E., DEREN, C.W. & SNYDER, G.H., 1997. Silicon fertilization for disease management of rice in Florida. *Crop Prot.* 16: 525–531.

DATNOFF, L.E. & RODRIGUES, F.Á., 2005. The role of silicon in suppressing rice diseases. APS net Feature Story February 2005. *Amer. Phytopathol. Soc.*

DEAN, B.B., 1994. *Managing the potato production system*. New York. An Imprint of the Haworth Press, Inc.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF), 2010. A profile of the South African potato market value chain. The department of agriculture, forestry and fisheries, Republic of South Africa. www.daff.co.za. ACCESSED IN 2012.

DEPARTMENT OF AGRICULTURE, FORESTRY AND FISHERIES (DAFF), 2012. A profile of the South African potato market value chain. The department of agriculture, forestry and fisheries, Republic of South Africa. www.daff.co.za. ACCESSED IN 2013.

DONHAM, K.J., 1986. Hazardous agents in agricultural dusts and methods of evaluation. *Amer. J. Ind. Med.* 10: 205-220.

EPSTEIN, E., 1994. The anomaly of silicon in plant biology. *Proc. Natl. Acad. Sci.* 91: 11–17.

EPSTEIN, E.,1999. *Silicon*. Annu. Rev. Plant Physiol. *Plant Mol. Biol*. 50: 641-664.

EPSTEIN, E., 2001. Silicon in plants: facts vs. concepts In: *Silicon in Agriculture*. DATNOFF, L.E., SNYDER, G.H., KORNDORDER, G.H., Eds.; Elsevier, Netherlands. *Studies in Plant Sci.* 8: 1-15.

FAWE, A., ABOU-ZAID, M., MENZIES, J.G., & BÉLANGER, R.R., 1998. Silicon-mediated accumulation of flavonoid phytoalexins in cucumber. *Phytopathol.* 88: 396-401.

FAWE, A., MENZIES, J.G., CHÉRIF, M. & BÉLANGER, R.R., 2001. Silicon and disease resistance in dicotyledons. Pp. 159-169 In: *Silicon in Agriculture*. DATNOFF, L.E., SNYDER, G.H., KORNDORDER, G.H., Eds.; Elsevier Science, New York.

FOOD AND AGRICULTURE ORGANIZATION (FAO), 2004. Monitoring progress towards the world food summit and millennium development state. State of food insecurity in the world. www.fao.org. ACCESSED IN 2012.

FOOD AND AGRICULTURE ORGANIZATION (FAO), 2008(a). The global potato economy In: The United Nations International Year of Potato 2008 (FAO fact sheets). http://www.potato2008.org. ACCESSED IN 2008/2009.

FOOD AND AGRICULTURE ORGANIZATION (FAO), 2008(b). Potatoes, nutrition and diet In: The United Nations International Year of Potato 2008 (FAO fact sheets). http://www.potato2008.org. ACCESSED IN 2008/2009.

FOOD AND AGRICULTURE ORGANIZATION (FAO), 2008(c). Why potato? In: The United Nations International Year of Potato 2008. http://www.potato2008.org. ACCESSED IN 2010.

FOOD AND AGRICULTURE ORGANIZATION (FAO), 2008(d). Potato world- Africa In: The United Nations International Year of Potato 2008. http://www.potato2008.org. ACCESSED IN 2010.

FLOWER, D.B. & LIMIN, A.E., None Dated. Impact of cold tress. Crop development centre. University of Saskatchewan. Saskatoon. Saskatchewan, S7N 5A8 Canada. http://www.plantstress.com/Articles/cold_i/cold_i.htm#Chilling_stress. ACCESSED IN 2013.

GAO, X., ZOU, C., WANG, L. & ZHANG, F., 2006. Silicon decreases transpiration rate and conductance from stomata of maize plants. *J. Plant Nutr.* 29: 1637-1647.

GOMES, F.B., DE MORAES, J.C., DOS SANTOS, C.D. & GOUSSAIN, M.M., 2005. Resistance induction in wheat plants by silicon and aphids. *Scientia Agricola* 62: 547–551.

GONG, H.J., CHEN, K.M., CHEN, G.G., SUO-MIN WANG, S.M. & CHENG-LIE ZHANG, C.L., 2003. Effects of silicon on growth of wheat under drought. *J. Plant Nutr.* 26: 1055-1063.

HAMMERSCHMIDT, R., 2005. Silicon and plant defense: the evidence continues to mount. *Physiol. Mol. Plant Pathol.* 66: 117–118.

INDIAN AGRICULTURE RESEARCH INSTITUTE (IARI), 1988. Annual Report 1987. New Delhi, India.

JENKINS, P.D. & ALI, H., 1999. Growth of potato cultivars in response to application of phosphate fertiliser. *Ann. of Appl. Biol.*135: 431-438.

KAWAMITSU, M., KAWAMITSU, Y., AGATA, W. & KAUFMAN, P.B., 1989. Effect of SiO_2 on CO_2 assimilation rate, transpiration rate, leaf conductance and dry matter production in the rice plants. *Sci. Bull. Fac*. Kyushu Univ. 43: 161-169.

KAYA, C., TUNA, L. & HIGGS, D., 2006. Effect of silicon on plant growth and mineral nutrition of maize under water-stress conditions. *J. Plant Nutr*. 29: 1469-1480.

KIDD, P.S., LLUGANY, M., POSCHENRIEDER, C., GUNSÉ, B. & BARCELÓ, J., 2001. The role of root exudates in aluminium resistance and silicon-induced amelioration of aluminium toxicity in three varieties of maize (*Zea mays* L.). *J. Exp. Bot.* 52: 1339-1352.

KIM, S.G., KIM, K.W., PARK, E.W. & CHOI, D., 2002. Silicon-induced cell wall fortification of rice leaves: A possible mechanism of enhanced host resistance to blast. *Amer. Phytopathol. Soc.* 92:1095-1103.

KOCHIAN, L.V., 1995. Cellular mechanisms of aluminium toxicity and resistance in plants. *Annul. Rev. Plant Physiol. Plant Mol. Biol.* 46: 237-260.

KOSKI-VAHALA, J., HARTIKAINEN, H. & TALLBERG, P., 2001. Phosphorus mobilization from various sediment pool in response to increase pH and silicate concentration. *J. Environ. Qual*. 30: 546-552.

KVEDARAS, O.L. & KEEPING, M.G., 2007. Silicon impedes stalk penetration by the borer *Eldana saccharina* in sugarcane. *Ent. Exp. et Appl.* 125: 103–110.

LACEY, M.J. & WILSON, C.R., 2001. Relationship of common scab incidence of potatoes grown in Tasmanian Ferrosol soils with pH, exchangeable cations and other chemical properties of those soils. *J. Phytopathol.* 149: 679-683.

LAMBERT, D.H. & MANZER, F.E., 1991.Relationship of calcium to potato scab. *Phytopathol.* 81: 632-636.

LEVITT, J., 1980. *Responses of plants to environmental stresses.* Chilling, freezing, and high temperature stresses, Vol. 1., 2nd Ed. Academic Press, New York, Pp. 102-106.

LIANG, Y.C., 1998. Effects of silicon on leaf ultrastructure, chlorophyll content and photosynthetic activity in barley under salt stress. *Pedosphere* 8: 289–96.

LIANG, Y.C., 1999. Effects of silicone on enzyme activity and sodium, potassium and calcium concentration in barley under salt stress. *Plant Soil* 29: 217–224.

LIANG, Y.C. & DING, R. X., 2002. Influence of silicon on micro distribution of mineral ions in roots of salt-stressed barley as associated with salt tolerance in plants. *Sci*. *China* (Ser. C) 45: 298-308.

LIANG, Y.C., HUA, H.X., ZHU, Y.G., ZHANG, J., CHENG, C.M. & RÖMHELD, V., 2006. Importance of plant species and external silicon concentration to active silicon uptake and transport. *New Phytol*. 172: 63-72.

LIANG, Y.C., SHEN, Q.R., SHEN, Z.G. & MA, T.S., 1996. Effects of silicon on salinity tolerance of two barley cultivars. *J. Plant Nutr*. 19: 173–83.

LIANG, Y., YANG, C. & SHI, H., 2001. Effects of silicon on growth and mineral composition of barley grown under toxic levels of aluminium. *J. Plant Nutr*. 24: 229-243.

LIANG, Y., ZHU, J., LI, Z., CHU, G., DING, Y., ZHANG, J. & SUN, W., 2008. Role of silicon in enhancing resistance to freezing stress in two contrasting winter cultivars. *Environ. Exp. Bot*. 64: 286-294.

LORIA, R., 2001. Potato disease management strategies. Pp. 7 In: STEVENSON, R., LORIA, R., FRANC, D.G. & WENGARTNER, D.P., Ed. *Compendium of potato diseases*. 2nd Ed. *Amer. Phytopathol. Soc.*. APS Press

LULAI, E.C., 2001. Development and anatomy of the potato plant. Pp. 2 In: STEVENSON, R., LORIA, R., FRANC, D.G. & WENGARTNER, D.P., Ed. *Compendium of potato diseases.* 2nd Ed. *Amer*. *Phytopathol. Soc.*. APS Press

MA, J.F., 1990. Studies on beneficial effects of silicon in rice plants. Master thesis, Kyoto University.

MA, J.F., 2000. Role of organic acids in detoxification of aluminium in higher plants. *Plant Cell Physiol.* 41: 383-390.

MA, J.F., 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Sci Plant Nutr*. 50: 11–18.

MA, J.F., MITANI, N., NAGAO, S., KONISHI, S., TAMAI, K. , IWASHITA, T. & YANO, M., 2004. Characterization of the silicon uptake system molecular mapping of the silicon transporter gene in rice. *Plant Physiol.* 136: 3284-3289.

MA, J.F., MIYAKE, Y. & TAKAHASHI, E., 2001. Silicon as a beneficial element for crop plants In: *Silicon in Agriculture*; DATNOFF, L.E., SNYDER, G.H., Eds.; Elsevier: Netherlands. *Studies in Plant Sci.* 8: 17-39.

MA, J.F., SASAKI, M. & MATSUMOTO, H., 1997. Al-induced inhibition of root elongation in corn (*Zea mays* L.), is overcome by Si addition. *Plant Soil* 188: 171-176.

MA, J.F. & TAKAHASHI, E., 1991. Effect of silicate phosphate availability for rice in a P-deficient soil. *Plant Soil* 133: 151-155.

MA, J.F. & TAKAHASHI, E., 2002. *Soil, fertilizer, and plant silicon research in Japan.* Elsevier Science. The Netherlands.

MA, J.F. & YAMAJI, N., 2006. Silicon uptake and accumulation in higher plants. *Trends in Plant Sci. Rev.* 1: 392-397.

MAIER, N.A., MCLAUGHLIN, M.J., HEAP, M., BUTT, M. & SMART, M.K., 2002. Effect of current-season application of calcitic lime and phosphorus fertilization on soil pH, potato growth, yield, dry matter content, and cadmium concentration. *Commun. Soil. Sci. Plant Anal.* 33: 2145-2165.

MATOH, T., KAIRUSMEE, P. & TAKAHASHI, E., 1986. Salt-induced damage to rice plants and alleviation effect of silicate. *Soil Sci. Plant Nutr*. 32: 295–304.

MATOH, T., MURATA, S. & TAKAHASHI, E., 1991. Effect of silicate application on photosynthesis on rice plants. *Jpn. J. Soil Sci. Plant Nutr*. 62: 248-251.

McLAUGHLIN, M.J., MAIER, N., FREEMAN, A.K., TILLER, K.G., WILLIAM, C.M.J. & SMART, M.K., 1995. Effect of potassic and phosphatic fertilizer type, fertilizer Cd concentration and zinc rate on cadmium uptake by potatoes. *Fertil. Res*. 40: 63-70.

McPHARLIN, I., 2000. Phosphorus management of potatoes on coarse sands In: Potatoes linking research to practice, Australian potato research, development and technology transfer conference, 31 July to 3 August, 2000, Adelaide, South Australia, 2000.

MENZIES, J., BOWEN, P., EHRET, D. & GLASS, D.M., 1992. Foliar application of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon, and zucchini squash. *J. Amer. Soc. Hort. Sci*. 117: 902-905.

MERCHANT, J.A., ed. 1986. *Occupational Respiratory Diseases.* DHHS (NIOSH) Pub. No.86-102. Washington, D.C.: GPO.

MITANI, N. & MA, J.F., 2005. Uptake system of silicon in different plant species. *Exp. Bot. J.* 56: 1255-1261.

NANDA, H.P. & GANGOPADHYAY, S., 1984. Role of silicated cells in rice leaf on brown spot disease incidence by *Bipolaris oryzae*. *Int. J. Trop. Plant Dis.* 2: 89-98.

OKIGBO, B.N., 1987. Roots and tubers in the African food crisis. Pp. 9 In*:* INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS., Ed. Tropical root crops: root crops and the African food crisis: proceedings of the Third Triennial Symposium of the International Society for Tropical Root Crops- International institute of tropical Agriculture. Ibadan, Nigeria.

OWINO-GERROH, C. & GASCHO, G.J., 2004. Effect of silicon on low pH soil phosphorus sorption and on uptake and growth of maize. *Commun. Soil sci. Plant Anal.* 35: 2369-2378.

PAL, K.K. & GARDENER, B.M., 2006. Biological Control of Plant Pathogens. *The Plant Health Instruc.*Pg. 1-25. www.apsnet.org. ACCESSED IN 2013.

POTATOES SOUTH AFRICA, 2005. Potato industry statistics. Unpublished Report, Potatoes South Africa, Pretoria.

POTATOES SOUTH AFRICA, 2011. Potatoes S.A. annual report. www.PotatoesSA.co.za. ACCESSED IN 2011.

POTATOES SOUTH AFRICA, 2013. Potatoes S.A. Post seasonal annual report. www.PotatoesSA.co.za. ACCESSED IN 2013.

REISENER, R., 2010. The occurrence of elements and minerals in the earth's crust- Abundance of elements in earth's crust (volume %) In: From atoms to minerals.

http://www.indiana.edu/~geol116/week2/earthcomp.jpg. ACCESSED IN 2010**.**

REMUS-BOREL, W., MENZIES, J.G. & BÉLANGER, R.R., 2005. Silicon induces antifungal compounds in powdery mildew-infected wheat. *Physiol. Mol. Plant Pathol.* 66: 108-115.

RICHMOND, K.E. & SUSSMAN, M., 2003. Got silicon? The non-essential beneficial plant nutrient. *Curr. Opin. Plant Biol.* 6: 268–272.

ROBERT, L., NARCY, A., ROCK, E., DEMIGNE, C., MAZUR, A. & RÉMÉSY, C., 2006. Entire potato consumption improves lipid metabolism and antioxidant status in cholesterol-fed rat. *Eur. J. Nutr.* 45: 267-274.

RODRIGUES, F.A., MCNALLY, D.J., DATNOFF, L.E., JONES, J.B., LABBE, C.,BENHAMOU, N., MENZIES, J.G. & BÉLANGER, R.R., 2004. Silicon enhances the accumulation of diterpenoid phytoalexins in rice: a potential mechanism for blast resistance. *Phytopathol.* 94: 177–183.

ROMERO-ARANDA, M.R., JURADO, O. & CUARTERO, J., 2006. Silicon alleviates the deleterious salt effect on tomato plant growth by improving plant water status. *J. Plant Physiol.* 163: 847-855.

ROSEN, C.J. & BIERMAN, P.M., 2008. Potato yield and tuber set as affected by phosphorus fertilization. *Amer. J. Pot. Res*. 85: 110-120.

ROWE, R.C., 1993. *Potato health management*.APS Press. *Amer. Phytopathol. Soc.* USA.

SAMUELS, A.L., GLASS, A.D.M., EHRET, D.L. & MENZIES, J.A., 1991. Distribution of silicon in cucumber leaves during infection by powdery mildew fungus (*Sphaerotheca fuliginea*). *Can. J. Bot.* 69: 140-146.

SANCHEZ, C.A., 2007. Phosphorus. Pp. 51-83 In: BARKER, A.V. & PILBEAN, D.J. (Ed.). *Handbook of plant nutrition*. Publisher Boca Raton, FL. Crc/Taylor & Francis.

SASAMOTO, K., 1958. Studies on the relation between the silica content in the rice plant and insect pests VI. On the injury of silicated rice plant caused by the rice stem borer and its feeding behaviour. *Jpn. J. Appl. Entomology and Zoology*. 2: 82-92.

SASAMOTO, K., 1960. Studies on the relation between the silica content in the rice plant and insect pests VIII. Feeding preference of the rice stem borer larvae for the rice plants cultured in soil of different nitrogen levels. *Jpn. J. Appl. Entomology and Zoology*. 4: 115-118.

SASAMOTO, K., 1961. Resistance of the rice plant applied with silicate and nitrogenous fertilizers to the stem borer *Chilo suppressalic* Walker. Proceedings of the Faculty of Liberal Arts and Education. Yamanashi Univ. No3 1-73.

SAVANT, N.K., KORNDORFER, G.H., DATNOFF, L.E. & SNYDER, G.H., 1999. Silicon nutrition and sugarcane production. A review. *J. Plant Nutr.* 22: 1853–1903.

SEEBOLD, K.W., JR., DATNOFF, L.E., CORREA-VICTORIA, F.J., KUCHAREK, T.A. & SNYDER, G.H., 2004. Effects of silicon and fungicides on the control of leaf and neck blast in upland rice. *Plant Dis.* 88:253-258.

SEEBOLD, K.W, DATNOFF, L.E., CORREA-VICTORIA, F.J., KUCHAREK, T.A. & SNYDER, G.H., 2000. Effect of silicon rate host resistance on blast, scald, and yield of upland rice. *Plant Dis.* 84:874-876.

SITTON, D. & WEST, C.A., 1975.Casbene: an anti-fungal diterpene produced in cell-free extracts of *Ricinus communis* seedlings. *Phytochemistry* 14:1921-1925.

SMYTH, T.J. & SANCHEZ, P., 1980. Effect of lime, silicate, and phosphate application to an Oxisol on phosphorus sorption and ion retention. *Soil Sci. Soc. Amer. J.* 44: 500-505.

SNYDER, G.H., MATICHENKOV, V.V. & DATNOFF, L.E., 2007. Silicon. Pp. 551-568 In: BARKER, A.V. & PILBEAN, D.J. (Ed.). *Handbook of plant nutrition*. Publisher Boca Raton, FL. Crc/Taylor & Francis.

STEPONKUS, P.L., 1984. Role of the plasma membrane in freezing injury and cold acclimation. *Ann. Rev. Plant Physiol.* 35: 543-584.

STEYN, P.J., 2003. The origin and growth stages of the potato plant. Pp. 7-10 In: NIEDERWIESER, J.G., Ed. *Guide to potato production in South Africa*. ARC-Roodeplaat Vegetable and Ornamental Plant Institute.

STEYN, J.M. & DU PLESSIS, H.F., 2003. Soil, water and irrigation requirements. Pp. 25 In: NIEDERWIESER, J.G., Ed. *Guide to potato production in South Africa*. ARC-Roodeplaat Vegetable and Ornamental Plant Institute. Potatoes SA. http://www.nbsystems.co.za. ACCESSED IN 2011/2012.

TAKAHASHI, E., ARAI, K. & KASHIDA, Y., 1966. Studies on physiological role of silicon in crop plant. Part 14 effect of silicon on the assimilation and translocation of CO_2 supplied at the various growth stages of rice. *J. Sci. Soil and manure, Jpn*. 37: 594-598.

TAKAHASHI, E., MA, J.F. & MIYAKE, Y., 1990. The possibility of silicon as an essential element for higher plants. *Comments Agric. Food Chem.* 2: 99–122.

TAYLOR, G.J., 1995. Overcoming barriers to understanding the cellular basis of aluminium resistance. *Plant and Soil* 171: 89-103.

THURSTON, H.D., 2001. Origin, history and importance of the potato. Pp. 1-2 In: STEVENSON, R., LORIA, R., FRANC, D.G. & WENGARTNER, D.P., Ed. *Compendium of potato diseases*. 2nd Ed. *Amer. Phytopathol. Soc*. APS Press.

UNITED STATES DEPARTMENT OF AGRICULTURE, NATIONAL NUTRIENT DATABASE, 2008. Nutrient content of potatoes. The United Nations International Year of Potato 2008 (FAO fact sheets). FAO. http://www.potato2008.org. ACCESSED IN 2008/2009.

VAN DER ZAAG, D.E. & BURTON, W.G., 1978. Potential yield of the potato crop and its limitations. Pp. 7-22 In: Survey papers 7th Triennial Conference EAPR, Warsaw, Poland.

VAN LOON, C.D., 1986. Drought, a major constraint in potato production and possibilities for screening for drought resistance. Pp. 5-16 In: BEEKMAN, A.G.B., LOUWES, K.M., DELLAERT, L.M.W. & NEELE, A.E.F., Ed. (Organizing committee). *Potato research of tomorrow: Drought tolerance, virus resistance and analytic breeding methods.* Proceedings of an international seminar, Wageningen, Netherlands, 30-31 October 1985. Pudoc Wageningen.

WANG, X.S. & HAN, J.G., 2007. Effect of NaCl and silicon on ion distribution in the roots, shoots and leaves of two alfafa cultivars with different salt tolerance. *Soil Sci. and Plant Nutr.* 53: 278-285.

WANG, H., LI, C. & LIANG, Y., 2000. Agricultural utilization of silicon in China In: DATNOFF, L.E., SNYDER, G.H., KORNDORFER, G.H. Eds., *Silicon in Agriculture.* Elsevier Science, The Netherlands, in press.

WONG YOU CHEONG, Y., HEITS, A., & DE VILLE, J., 1972. Foliar symptoms of silicon deficiency in the sugarcane plant In: Cong. Intern. Soc. Sugarcane Techno. 14, New Orleans, 1971, Proceedings. Baton Rouge, LA 14: 766-776.

YOSHIDA, S., OHNISHI, Y. & KITAGISHI, K., 1962. Histo-chemistry of silicon in rice plant. III. The presence of cuticle-silica double layer in the epidermal tissue. *Soil Sci. Plant Nutr.* 8: 1-5.

ZHU, J., LIANG, Y.C., DING, Y.F. & LI, Z.J., 2006. Effects of silicon on photosynthesis and its related physiological parameters in two winter wheat cultivars under cold stress. *Sci. Agric. Sinica* 39: 1780-1788.

ZHU, Z., WEI, G., LI, J., QIAN, Q. & YU, J., 2004. Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). *Plant Sci.* 167: 527-533.

ZUCCARINI, P., 2008. Effects of silicon on photosynthesis, water relation and nutrient uptake of *Phaseolus vulgaris* under NaCl stress. *Biologia Plantarum* 52: 157-160.

CHAPTER 2

THE EFFECT OF LIME AND SELECTED SILICON AMENDMENTS ON GROWTH AND YIELD OF POTATOES

2.1. INTRODUCTION

Potatoes are one of the widely cultivated crops. Producers of this crop face challenges such as the crop's susceptibility to a wide range of pathogens, insects as well as other adverse environmental conditions. These pathogens can infect during the time of plant growth or even storage, making it difficult to produce a healthy potato crop (Rowe, 1993; Loria, 2001). According to Robert and Cartwright (2007) reduced yields can also result from high temperatures, insufficient moisture availability and incorrect pH. Potatoes are reported to grow well at a range of soil pH levels, which can be as low as 5.0, while soil pH of about 5.0-6.0 is reported to be the best (Robert & Cartwright, 2007). Soil pH not only affects the growth of the potato plant, but also the incidence of common of scab, a serious disease affecting the yield and quality of potato tubers in South Africa and worldwide. According to Robert and Cartwright (2007), potato plants are less susceptible to scab when soil pH is between 5.0 – 5.5. To avoid the incidence of scab or other biotic and/or abiotic conditions, there is a need to examine ways in which production can be improved. The desired goal is to produce crops with better yield and good quality.

Traditionally lime is used to correct soil pH. However, in recent years other ameliorating compounds such as slags, fume and fly ash have been used. All of these ameliorants contain some silicon. Silicon is well documented to have played an important role in reducing susceptibility of some plants e.g. cucumber (*Cucumis sativus*) and rice (*Oryza sativa*) to fungal diseases (Husby, 1998). Husby (1998) also indicated that Si fertilization may even increase growth and yield in addition to reducing susceptibility to both biotic and abiotic stresses. Since the available Si sources affects the soil pH, this study was conducted to compare the effect of Si sources versus lime in a quest to improve growth conditions for the potato plant.

In investigating the effects of silicon sources and lime on the potato crop, it was hypothesized (chapter 1) that:

- Application of silicon to potato plants can improve both quality and yield
- Silicon significantly increases soil pH

2.2. MATERIALS AND METHODS

2.2.1. Cultivar selection

BP1 being one of the popularly cultivated potato cultivars in South Africa, was chosen for use in the trials.

2.2.2. Experimental site and trial establishment

Two glasshouse experiments (Trial 1 and Trial 2) were conducted on the University of Pretoria's Hatfield Experimental Farm. Trial 1 was conducted from November 2007 to January 2008 and Trial 2 from December 2007 to March 2008. The soil amendments used were Calmasil slag (Middleburg) (containing liming material); fly ash (containing non liming material), Si fume/ash (containing non liming material) and lime ($CaCO_3$) as a control. Each of the Si sources i.e. slag, fly ash and Si fume/ash contained about 30, 50 and 99% of Si, respectively. There were three rates per treatment: 0t ha^{-1} as negative control (without any silicon containing source or lime), 2t $ha^{-1}$and 4t ha^{-1} for each silicon amendment and lime. For Trial 1, plastic pots with a 4 litre capacity were filled with 4kg of sandy soil, low in P (Table 2.1.). Phosphorus in the form of superphosphate (10.5% of P) was incorporated into the soil pre-plant (0.9g superphosphate per 4kg pot soil) to prevent any P deficiencies. No K was added for Trial 1 or Trial 2. Slag, fly ash and lime were added to pots at a rate of 1.8g (2t ha^{-1}) or 3.6g (4t ha^{-1}) per pot, respectively while

Si fume/ash was applied as 0.45g (2t ha^{-1}) or 0.9g (4t ha^{-1}) per pot, respectively. Each treatment was replicated four times which totaled 36 pots. All soil amendments (silicon containing sources, lime and superphosphate) were incorporated into the potted soil before planting the potato tubers. Similar procedures were used in Trial 2, except that plastic pots with a 10kg capacity were used. Amendments were 4.5g (2t ha^{-1}) or 9g (4t ha^{-1}) per pot for slag, fly ash and lime, and Si fume/ash as 1.12g (2t ha^{-1}) or 2.24g (4t ha^{-1}) per pot. In trial 2, P was also incorporated into the soil as superphosphate at 2.25g per 10kg pot soil.

Table 2.1: Soil analysis of the sandy soil used in the glasshouse pot trials, taken before planting.

Coarse sand- 79.4 %	**pH (H_2O)** = 6.3	**K mg/kg** = 91
Silt = 7.9%	**P Bray I mg/kg** = 9.1	**Mg mg/kg** = 98
Clay =12.1 %	**Ca mg/kg** = 336	**Na mg/kg** = 14

The pots were watered with 450ml (1000ml for 10kg pots) of distilled water in preparation for planting. Well sprouted seed tubers (BP1 cultivar) were planted 24 hours after adding the distilled water, while the soil was still moist. Wet conditions had to be avoided to prevent tuber rot.

A complete balanced nutrient feed (Supafeed) (Table 2.2) was used to prevent any nutrient deficiencies in the trials. Supafeed was added by means of fertigation every 7 to 14 days. For every 6 litres of distilled water needed for fertigation, 3g of Supafeed was applied. About 450ml of this solution was applied to each pot.

Plants were irrigated with distilled water when necessary to maintain an adequate moisture level i.e. moist but not too wet. Weekly observations on growth parameters were made. During the run of the trials, plants were irrigated every two days on average.

Table 2.2: The mineral composition of nutrient solution (Supafeed) used for fertigation during all the trials

N -19.0%	Zn – 350 ppm	B - 100 ppm
P - 8.2%	Mn – 300 ppm	Cn – 75 ppm
K – 15.8%	Fe – 750 ppm	Mo- 70 ppm
Mg- 900 ppm		

2.2.3. Parameters assessed

2.2.3.1. Measurements taken during the growth period:

i. Height and canopy size

The plant height was measured with a tape measure at two week intervals while a total fresh and dry mass of stems and leaves were measured to determine canopy size. To evaluate plant height as influenced by soil amendments, only the last measurement (at harvest) of the main stem was taken into consideration. Plants were uprooted and length (height in cm) measured.

ii. Chlorophyll content

When testing for chlorophyll content a portable chlorophyll meter (SPAD 502) is positioned onto the leafy tissue for a short time, to obtain an index of relative chlorophyll content (0.00 to 99.9). The leaf colour was observed using a similar procedure as that used by Costa *et al.* (2003) on maize, adapted to get readings on potato crop leaves, using a Minolta portable chlorophyll meter [Soil Plant Analysis Development (SPAD)]. Samples were taken from the top, middle and bottom parts of the plant. This was conducted every two weeks during the growing season.

2.2.3.2. Measurements taken at harvest

i. Fresh and dry weight of the vegetative parts (Haulm)

After harvest, loose soil was removed from plants. Plants were rinsed with distilled water and blotted dry with a paper towel. Plant material (stem and leaves) was then put in a brown paper bag and weighed to determine the fresh weight. The plant material was then put in a drying oven set at 60-70^{0}C for 72 hours to dry. After 72 hours the plant material was again weighed to determine the dry weight.

ii. Tubers

Tuber size, number and mass were determined at harvesting. The total mass and number of tubers per pot were determined and the results grouped per treatment for further analysis.

2.2.4. Experimental design

The experimental layout was a completely randomized design (CRD). Pots were rearranged from time to time to limit glasshouse orientation effect. Data was analyzed statistically and least significant differences (LSD) at 5% probability were determined, with help from STATOMET (University of Pretoria). Significant differences between treatment means were determined at $P \leq 0.05$.

2.3. RESULTS AND DISCUSSION

2.3.1. Chlorophyll content

As demonstrated in Table 2.3, no significant differences in chlorophyll content of the crop leaves between treatments in both the first and second trials was established ($P \leq 0.05$). Although there was no significant difference in chlorophyll content, plants treated with fly ash tended to give the lowest values. On the other hand plants receiving fly ash at 4t ha^{-1} appeared greener giving the impression of being the healthiest. In plants treated at 4t ha^{-1} rather than 2t ha^{-1} of Si sources and lime, there were no consistent observations between trial 1 and 2. At first (Trial 1) it was thought that random reading and low number of sample points for each treatment might have affected the determination of chlorophyll level, indicating that it may not be a true reflection on how each treatment influence the chlorophyll content. This motivated increased number of sampling points for chlorophyll content analysis. Sample readings therefore increased from three leaves to ten leaves per plant.

Despite the insignificance in treatments, it was further noted that the chlorophyll content of the plants in Trial 2 was on average higher than that of Trial 1. Contributing factors could have been a longer growing season for Trial 2 (73 days for Trial 1 versus 91 days for Trial 2) or the bigger pots used in Trial 2 providing better growing conditions. However, even with increased number of sample points, no treatment significantly enhanced the amount of chlorophyll when comparing different treatments in Trial 2. Neither Trial 1 nor Trial 2 indicated any significant role played by soil amendments to chlorophyll content. The results were in contrast with past reports that pointed out Si sources to stimulate canopy photosynthesis by improving light interception. The two trials did not give evidence on the ability of Si to enhance chlorophyll levels in potato plants.

Table 2.3: Mean chlorophyll content in plants as influenced by lime and three different silicon amendments (treatment 1=2t ha^{-1} & 2= 4t ha^{-1}) at P ≤ 0.05.

Chlorophyll levels (SPAD 502 meter)		
Treatments	**Trial 1**	**Trial 2**
Control	32.358**a**	32.975**a**
Lime 1	33.44**a**	33.66**a**
Lime 2	27.093**a**	36.698**a**
Slag 1	28.935**a**	39**a**
Slag 2	31.398**a**	37.11**a**
Fly ash 1	28.768**a**	33.483**a**
Fly ash 2	28.418**a**	37.457**a**
Si fume 1	29.625**a**	31.565**a**
Si fume 2	30.54**a**	35.198**a**

* Values with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

2.3.2. Potato plant height

During the growth period, photos of the potato plants were taken to non-destructively compare the canopy size and height as affected by the different treatments. At most except in the case of the control and lime 2 treatments (Trial 1), there was no significant difference detected among the treatments. The plants in Trial 2 were taller than those in Trial 1. Despite the difference in height between the two trials (Table 2.4), on average plants treated with lime (both rates) in trials 1 and 2, grew taller than the rest of the plants (Fig. 2.1), as measured 73 and 91 days after planting, respectively. From the visual observations (Fig. 2.1) it confirms the effect of lime at 4t ha^{-1} (Fig. 2.1(b)); while it also shows that fly ash at 2t ha^{-1} (Fig. 2.1(a)) could have more effect on potato plant height.

A.

Control Lime Si fume Fly ash Slag (Trial 1 at 2t ha^{-1})

B.

Control Lime Si fume Fly ash Slag (Trial 1 at 4t ha^{-1})

Fig. 2.1: Visual assessment of plants (Trial 1- A & B) treated with lime and three different silicon amendments, 73 days after planting.

The plants in Trial 2 were significantly taller than those in Trial 1; however, there was no significant difference in plant height among treatments from the same Trial (Table 2.4). The reason for the taller plants in Trial 2 can be attributed to longer and better growing conditions as compared to Trial 1. Both lime and silicon treated plants were consistently taller than the control plants. This was true for both trials (Table 2.4).

Table 2.4: The effect of lime and silicon amendments on potato plant height (cm) (treatment 1=2t ha^{-1} & 2= 4t ha^{-1}) at P ≤ 0.05.

	Plant height (cm)	
Treatments	**Trial 1**	**Trial 2**
Control	28.25**b**	93.25**a**
Lime 1	38.25**ab**	109.125**a**
Lime 2	47.25**a**	99.25**a**
Slag 1	34.75**ab**	106.25**a**
Slag 2	34.75**ab**	96.75**a**
Fly ash 1	39**ab**	97.5**a**
Fly ash 2	34.25**ab**	102**a**
Si fume 1	34.75**ab**	102.375**a**
Si fume 2	38**ab**	101.5**a**

* Values with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

2.3.3. Potato tuber number and mass

Similarly to the assessment on chlorophyll content and plant height, none of the soil amendments indicated any significant involvement in potato tubers (Table 2.5.a). There was no significant difference at the 5% probability level established between treatments.

In Trial 1

Although there wasn't any significant difference among treatments, tubers produced from the control and lime 1 (at 2t ha^{-1}) and Si fume 2 (at 4t ha^{-1}) treatments tended to be the highest in number; whilst tubers from lime 2 and Si fume 1 were the lowest. More noticeable is that the difference in terms of tuber number between the two rates of each treatment was less in Trial 2 than in Trial 1, but it was not reflected in the tuber mass.

In Trial 2

Slag treated plants tended to produce the highest number of tubers followed by the control treated plants and the lowest in tuber number was from lime 1 treatment.

Table 2.5.a: Effect of lime and different silicon soil amendments (1 = 2t ha^{-1} & 2 = 4 t ha^{-1}) on potato tuber number and mass per plant at $P \leq 0.05$.

	Trial 1	**Trial 2**	**Trial 1**	**Trial 2**
Treatments	**Tuber number**		**Tuber mass (g)**	
Control	5 **a**	4 **a**	81.3 **a**	31.5 **a**
Lime 1	5 **a**	2.8 **a**	64.8 **a**	21.1 **a**
Lime 2	2.5 **a**	3.3 **a**	61.9 **a**	27.2 **a**
Slag 1	3.5 **a**	5 **a**	89.1 **a**	40.9 **a**
Slag 2	3.5 **a**	4.5 **a**	92.8 **a**	68.4 **a**
Fly ash 1	4.3 **a**	3.3 **a**	73.9 **a**	39.1 **a**
Fly ash 2	3 **a**	3 **a**	82.3 **a**	38.4 **a**
Si fume 1	2.8 **a**	3.3 **a**	67.5 **a**	35.3 **a**
Si fume 2	5 **a**	3.5 **a**	75.7 **a**	44.2 **a**

* Values with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

The difference in total tuber mass per treatment between the two trials was much more noticeable than the tuber number (Table 2.5.a) with the average weight in Trial 1 almost twice that of Trial 2. There was no significant difference at the 5% probability level between treatments. In both trial 1 and 2, slag 2 (at 4t ha^{-1}) treatments indicated the tendency of producing the highest tuber mass. The higher rate of 4t ha^{-1} of Si fume and slag treatments seemed to have improved tuber mass in comparison to the first rate (2t ha^{-1}) within same treatment.

With regard to the mean tuber mass (Table 2.5.b), treatments within trial 1 and 2 seemed to have the same trend. In both trials lime 1 had the lowest mean tuber mass. Another similarity with both trials is that of the second rate of treatments i.e. 4t ha^{-1} tended to be higher than the first rate at 2t ha^{-1}, except in Trial 1 in the case of Si fume whereby the first rate was higher than the second one. In Trial 1 there was a big gap between fly ash 1 and fly ash 2, with fly ash 2 being the highest mean tuber mass. On average i.e. in Trial 1, slag treatment tended to be the highest followed by fly ash. The control and lime treatments results in the lowest mean tuber mass.

There was inconsistency between the two trials. In Trial 2 the big difference was observed in slag treatments. Fly ash had the highest mean tuber mass followed by slag treatment. Similarly to Trial 1, both the control and lime treatment showed the tendency of producing the lowest mean tuber mass.

Mean tuber mass = average tuber mass/average tuber number

Table 2.5.b: Mean tuber mass (g) as observed from lime and Si treatments.

	Trial 1	**Trial 2**
Control	16.26	7.88
Lime 1	12.96	7.54
Lime 2	24.76	8.24
Slag 1	25.46	8.18
Slag 2	26.51	15.2
Fly ash 1	17.19	11.85
Fly ash 2	27.43	12.8
Si fume 1	24.11	10.7
Si fume 2	15.14	12.63

*Data not statistically analyzed.

2.3.4. Fresh and dry mass of haulms

Fresh and dry weight as a measure for the above ground-growth i.e. stems and leaves was also used as an indication of canopy size and how plants responded to each treatment. The aim of these two trials was to select the best silicon source of the three. From Table 2.6 the observations were made in terms of the different silicon sources.

In Trial 1

The insignificant differences in treatments seemed to be a trend with lime and the silicon sources assessed in this particular study. However, even though there was no evidence of any significance, slag treatment same as in other growth parameters tended to give higher values. On average the fresh mass of haulms from slag 1 were 17.19g and 17.15g more than fly ash 1 (at 2t ha^{-1}) and Si fume 1 (at 2t ha^{-1}), respectively (Table 2.6). Similar comparisons can be made from the double rate treatment (4t ha^{-1}) where fly ash 2 plants and Si fume 2 plants were 25.85 g and 28.19 g, respectively, less than slag 2 amended plants on a fresh mass basis (Table 2.6). The dry mass of haulms followed similar trends. The only significant difference was observed between lime 1 and slag 2.

In Trial 2

In comparison to Trial 1, the yield (both fresh and dry) was almost two and a half times more in Trial 2 than in Trial 1 (Table 2.6). Except for lime 2 (at 4t ha^{-1}), all the weights (fresh and dry) of the other treatments were higher than that of the control. Plant material (haulm) (both fresh and dry mass) from the lower rate of application (at 2t ha^{-1}) of lime, fly ash and Si fume was the highest (Table 2.6). In Trial 2 the lower rate of application (at 2t ha^{-1}) of all the treatments tended to give higher mass than the higher rate of application (at 4t ha^{-1}). In Trial 1 the opposite was true (Table 2.6) except in the case of Si fume where weights (fresh and dry) from lower (2t ha^{-1}) and higher (4t ha^{-1}) rates were not much different.

Table 2.6: Fresh and dry weight for above-ground growth of potato plants treated with lime and different silicon sources at P ≤ 0.05.

	Trial 1	Trial 2	Trial 1	Trial 2
Treatments	**Fresh weight (g)**		**Dry weight (g)**	
Control	93.088**a**	189.075**a**	10.225**ab**	21.3**a**
Lime 1	68.97**a**	240.6**a**	9.12**b**	30.525**a**
Lime 2	79.268**a**	177.35**a**	10.485**ab**	20.23**a**
Slag 1	93.578**a**	214.35**a**	12.458**ab**	26.722**a**
Slag 2	105.54**a**	200.3**a**	14.6275**a**	23.12**a**
Fly ash 1	76.393**a**	240.6**a**	10.848**ab**	29.476**a**
Fly ash 2	79.69**a**	211.667**a**	11.688**ab**	25.222**a**
Si fume 1	76.425**a**	241.45**a**	11.115**ab**	30.27**a**
Si fume 2	77.348**a**	197.8**a**	11.405**ab**	24.121**a**

* Values with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

At most the statistical analysis results did not indicate any significant difference among treatment. Although there were no significant differences established, in finding a Si source that influenced plants the most, slag treatment showed the tendencies of producing higher values in certain measurements. These results agree with report by Ma *et al.* (2001) suggesting that neither lime nor Si sources play a significant role in the physiological process of plant growth. Ma and Takahashi (2002) reported Si to play a role in healthy plant growth. According to Ma and Takahashi (2002), functions of Si deposited in plants are more mechanical than physiological. This suggests the effects on plants to be more evident under stress conditions. They further explained evidence of Si involvement in plant metabolism to still lack. On the other hand Savant *et al.* (1999) reported applications of calcium silicate slag to have played a nutrient beneficial role in sugarcane, whereby it was able to improve height, number of millable stalks and stem diameter. They suggested a Si source to have improved photosynthesis efficiency.

Reports as mentioned above might possibly explain the response observed from plants treated with slag as compared to other Si sources, despite the insignificance. Some differences were observed under stress conditions during the run of trials especially Trial 2.

The glasshouse used for Trial 2 was poorly equipped in terms of ventilation and cooling, resulting in the occurrence of very high temperatures within the glasshouse, which could have resulted in taller plants. The high temperatures possibly had a negative effect on plant height, tuber number and mass. For example, some of the replicates in Trial 2, such as that of lime at 4t ha^{-1} did not produce any tubers. The tubers from Trial 2 were furthermore very small in comparison to that of the other trials. These observations could be explained by work done by Thornton (2002) who investigated the effect of heat on potatoes with similar results.

Thornton (2002) pointed out that potatoes are likely to experience some heat stress even during seasons when temperatures are more “normal”. Heat stress for extended periods at the time of tuber initiation can result in big and healthy vines but very few tubers. This phenomenon has been reported by several authors including Thornton (2002) and Tekalign & Hammes (2004). The glasshouse from Trial 1 received the same incoming radiation; but fortunately there was a cooling system available. Therefore the plants from Trial 1 were not exposed to these extreme temperatures. According to Ginzberg *et al*. (2005) heat can also affect the appearance of tubers by inducing russetting of the skin. They also reported that tubers with poor skin-set or quality to be more susceptible to pathogens and/or more susceptible to wounding during the harvest process.

Another stress condition induced by high temperatures (during Trial 2) was the presence of high numbers of red spider mite (*Tetranychus urticae).* Red spider mites are known to disseminate by wind, irrigation water and field workers (through clothes and tools) (Anon., 2004). During Trial 2, a neighbouring glasshouse was highly infested with red spider mites that then spread to the potato plants via the worker’s clothes and tools. This led to reduced canopy cover, less photosynthesis and ultimately fewer tubers. Martin (2000) and Wikipedia (2010) reported hot, dry conditions and favourable host plants to encourage development of red spider mite numbers.

According to Gillespie (n.d.), these are the most destructive or worst greenhouse pests. They feed on leaves and living plant tissues causing damage by sucking the sap (Gillespie, n.d.; Martin, 2000). This eventually causes whitening or yellowing and silver or brown lesions on leaves (Visser, 2005). The red spider mites are reported to have a wide host range as they can attack almost all plant species (both indoor and outdoor plants). To detect the existence of two spotted mites on plants, one needs to check underneath the leaves. In figures 2.2-2.4 the damage on potato plants after being under attack by red spider mites (as indicated by the Royal Horticultural Society, 2009) is illustrated namely:

1) A pale mottling or localized yellow speckling that develops on the upper leaf surface (Fig. 2.2),
2) When severely infested, leaves turn brown or bronze (Fig. 2.2 & 2.3),
3) Discolouration is followed by premature defoliation (Fig. 2.4) and if severely infected it can even lead to complete die-back of the plants.
4) From heavy infestation there is also the occurrence of a fine silky web over the plants (Fig. 2.3).

Fig. 2.2: A pale mottling developing on the upper surface of potato leaves in response to red spider mite attacks.

Fig. 2.3: A highly infested potato plant covered by red spider mite webs

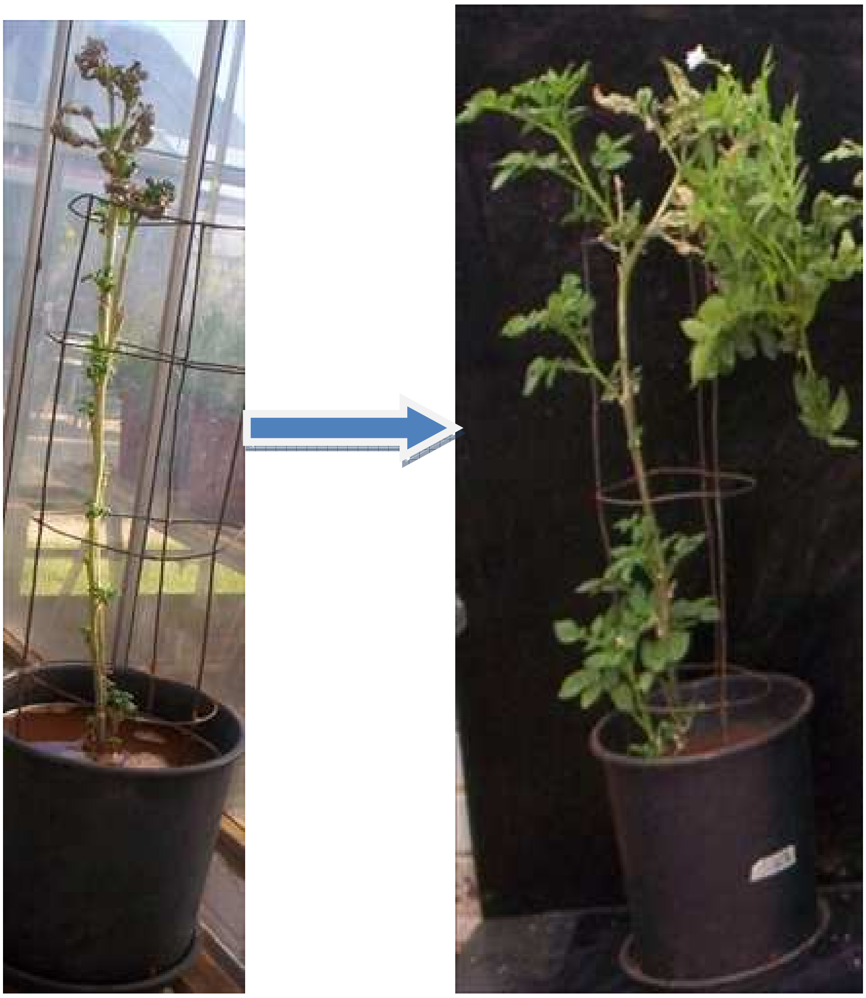


Fig. 2.4: A potato plant with premature defoliation after being attacked by red spider mites (left) and same plant on the right showing recovery four weeks later (17 February to 18 March).

Two plants treated with lime (especially at 4t ha $^{-1}$ (Fig. 2.4)) were more severely attacked than the other treatments. They were on the border (at the time of attack) with the highly spider mite infested neighbouring glasshouse, possibly making them the first set of plants to be attacked by red spider mites. To control and prevent further spider mite attacks, all plants were sprayed with Agrimec. From the eradication of red spider mites, plants were able to recover without any boost from other chemicals.

According to Epstein (2009), silicon is a very complex element that is greatly misunderstood. More reports on Si suggest that more work is yet to be done to fully understand the mechanism and functions of Si on plant growth.

2.4. CONCLUSIONS

Overall, no statistically significant effects of the lime and different silicon treatments on the growth and yield parameters of the potato plants were evident. The only significant difference detected was in Trial 1 between the control and lime 1 for plant height and between lime 1 and slag 2 for haulm dry mass. None of the other variables i.e. chlorophyll content, tuber size and haulm fresh mass, treatments were significantly different in either of the trials. The aim of the trials discussed in this chapter was to identify the silicon source(s) which give the best yield and quality. These silicon sources would then be used in further studies together with lime (pH control amendment). Although there was no significant evidence that indicated one Si source to be better than the other, slag treatment seemed to be more promising with tendencies to produce tubers that weighed more, better tuber appearance and response as observed under stress conditions. Under heat stress slag treated plants had the tendencies to respond better, resulting in lower plant height and more tubers, as compared to the other Si sources under the same conditions. Even though conclusion cannot be reported on one Si treatment to be best for potato growth and quality in comparison to others, slag seemed to be a more promising silicon source.

2.5. REFERENCES

ANONYMOUS, 2004. *Tetranychus evansi* (Acari: Tetranychidae) – red spider mite. Eppo.org. http://www.eppo.org/QUARANTINE/Alert_List/deleted%20files/insects/Tetranychus_evansi.doc. ACCESSED IN 2009.

COSTA, C., FRIGON, D., DUTELLEU, P., DWYER, L.M., PILLAR, V.D., STEWART, D.W. & SMITH, D.L., 2003.Sample size determination for chlorophyll meter reading on maize hybrids with a broad range of canopy types. *J. Plant Nutr*. 26: 1117-1130.

EPSTEIN, E., 2009. Silicon: its manifold roles in plants. *Ann. Appl. Biol.*: 155-160.

GILLESPIE, D., None dated. How to control red spider mite. http://www.eporchids.org.za/Documents/Control%20red%20spider%20mite.pdf. ACCESSED IN 2009/2010

MA, J.F., MIYAKE, Y. & TAKAHASHI, E., 2001. Silicon as a beneficial element for crop plants In: *Silicon in Agriculture*; DATNOFF, L.E., SNYDER, G.H., Eds.; Elsevier: Netherlands. *Studies in Plant Sci.* 8: 17-39.

MA, J.F. & TAKAHASHI, E., 2002. *Soil, fertilizer, and plant silicon research in Japan*. Elsevier Science. The Netherlands.

GINZBERG, I., GERCHIKOV, N., ZIV, E., FOGELMAN, E., TANAMI, Z. & WARSHAVSKY, S., 2005. Potato tuber skin development: the effect of hot climate and plant desiccation In: *Proc. Meeting Physiol. Section EAPR*. CASA, R. & VIOLA, R., Eds. *Acta Hort.* 684: 93-98.

HUSBY, C., 1998. The role of silicon in plant susceptibility to disease In: Paper for plant disease course. http://www2.fiu.edu/~chusb001/GiantEquisetum/Silicon_and_Plant_Health.html. ACCESSED IN 2010.

LORIA, R., 2001. Potato disease management strategies. Pp. 7 In: STEVENSON, R., LORIA, R., FRANC, D. G. & WENGARTNER, D. P., Ed. *Compendium of potato diseases*. 2nd Ed. *Amer. Phytopathol. Soc.*. APS Press

MARTIN, N.A. (Ed), 2000. Two-spotted mite: Biology, identification and life cycle. New Zealand Institute for Crop & Food Research Ltd. Broad sheet Number 112, November 2000. http://www.crop.cri.nz/home/products-services/publications/broadsheets/112-Mite.pdf.

ACCESSED IN 2010.

ROBERT, W. & CARTWRIGHT, B., 2007. Potato production In: Oklahoma Cooperative Extension Fact Sheets. http://osufacts.okstate.edu. ACCESSED IN 2008.

ROWE, R.C., 1993. *Potato health management*. APS Press. *Amer. Phytopathol. Soc.* USA.

SAVANT, N.K., KORNDORFER, G.H., DATNOFF, L.E. & SNYDER, G.H., 1999. Silicon nutrition and sugarcane production. A review. *J. Plant Nutr.* 22: 1853–1903.

TEKALIGN, T. & HAMMES, P.S., 2004. Response of potato grown under non-inductive condition to paclobutrazol: shoot growth, chlorophyll content, net photosynthesis, assimilate partitioning, tuber yield, quality and dormancy. *Plant Growth Regul*. 43: 227-236.

THE ROYAL HORTICULTURAL SOCIETY, 2009.Glasshouse red spider mite.

http://apps.rhs.org.uk/advicesearch/Profile.aspx?pid=190. ACCESSED IN 2010.

THORNTON, M.K., 2002. Effects of heat and water stress on the physiology of potatoes. Idaho Potato Conference (January 23).

VISSER, D., 2005. *Guide to potato pests and their natural enemies in South Africa*. Agricultural Research Council (ARC)—Roodeplaat Vegetable and Ornamental Plant Institute.

WIKIPEDIA, 2010. Spider mite. http://en.wikipedia.org/wiki/Spider_mite. ACCESSED IN 2010.

CHAPTER 3

SOIL PH AND POTATO GROWTH AS INFLUENCED BY APPLICATIONS OF LIME AND SLAG

3.1. INTRODUCTION

According to Ma and Yamaji (2006) the mounting evidence on silicon being an important nutrient element for crop production includes its ability to improve plant growth and development, and protection against diseases and insects. There are also some Si sources that contain liming material which increases soil pH. Correct soil pH and provision of adequate nutrition are important elements for producing healthy potato vines. Potato is a crop that prefers slightly acidic conditions for optimum growth and to minimize the incidence of common scab. Potatoes are also known to require very high quantities of nutrients. Some researchers have shown the availability of phosphorus and other nutrients to increase as soil pH increases (Horneck *et al*, 2007). According to Haverkort *et al.* (1993) soil pH not only influences the availability of nutrients but also the activity of the flora and fauna of the soil. The potato crop can, however, grow in a wide range of soil pH values i.e. 5.0-8.3 but the lower the soil pH (pH of 5.5-6.3) the better. High soil pH, above pH 7.0 has been reported to limit nutrient supply and plant growth. Iron chlorosis and reduced availability of P are among the problems caused by high soil pH. According to Horneck *et al.* (2007) low Fe availability is a result of decreased Fe solubility; a similar phenomenon is seen with P when soil pH is above 7.0. On the other hand soil pH should not be too acidic as this will also limit the availability of plant nutrients. Soil pH can also influence tuber quality and yield. According to Loria (1991) a low soil pH is good for controlling scab but the disadvantage is that most nutrients are more available at a soil pH near 6.5, at which scab can become problematic. During the study in evaluating the effect of Si on potato plants, influences on soil pH were also evaluated. One of the effects of raised soil pH on potatoes is increased incidence of common scab caused by *Streptomyces scabies*, which is present throughout the potato cultivating regions of the world. According to Lacey and Wilson (2001) this disease affects the economic value of potatoes by causing downgrading of tubers from fresh market to processing quality. Scab results in poor skin quality in the fresh produce market, requiring deep peeling and therefore increasing processing costs.

Even though scab was not part of this particular study; it is important to be aware of environmental conditions that favour the disease. It is therefore important to create unfavourable environmental conditions for this disease and one way in which it can be done is by lowering the soil pH.

In Chapter 2 silicon sources were evaluated with the aim of finding the best silicon source for plant growth. No significant difference was found between the Si treatments, however slag treated plants tended to produce tubers that weighed more and had better appearance. In terms of soil pH, slag had raised soil pH more while pH values from fly ash and Si fume remained similar or closer to that of the control treatment. Despite none of Si sources being significantly outstanding as compared to the control, slag treatment tended to produce tubers that weighed more and improve tuber appearance and soil pH, and thus identified as the treatment with possibly the best potential. It was chosen to be evaluated further in comparison to lime. It was hypothesized that slag have a similar effect on soil pH as lime and that it could possibly enhance potato yield and quality.

3.2. MATERIALS AND METHODS

3.2.1. Cultivar selection

The cultivar BP1 was chosen for use in these trials as it is a popular cultivar in South Africa.

3.2.2. Experimental site and trial establishment

A glasshouse experiment (Trial 3) was conducted on the University of Pretoria in the glasshouses of the Department of Microbiology and Plant Pathology. The trial was run from April to August 2008. The Si treatment was Calmasil slag (Middleburg) (30% Si- containing liming material), the lime treatment was $CaCO_3$ (a pH control). There were three rates per treatment: 0t ha^{-1} as negative control (no slag or lime), 2t $ha^{-1}$and 4t ha^{-1} for both slag and lime. This resulted in application of 1.8g (2t ha^{-1}) or 3.6g (4t ha^{-1}) of slag and lime to the soil per 4kg pot, respectively. Slag and lime were incorporated into the soil before potato tubers were planted.

The sandy soil in this and the previous trials was low in P (Table 2.1). Phosphorus in the form of superphosphate (8.3% P) was incorporated pre-plant (1.2g superphosphate per 4kg soil) to prevent any P deficiencies.

Following the same method as in Chapter 2, the pots were watered with 450ml distilled water in preparation for planting. Well sprouted seed tubers were planted 24 hours after adding the distilled water, while the soil was still moist. Wet conditions had to be avoided to prevent soft rot.

A complete balanced nutrient feed (Supafeed) (Table 2.2) was used to prevent any nutrient deficiencies in the trial. Supafeed was added by means of fertigation every 7 to 14 days. For every 6 litres of distilled water needed for fertigation, 3g of Supafeed was applied. About 450ml of this solution was applied to each pot.

Plants were irrigated with distilled water when necessary to maintain an adequate moisture level i.e. moist but not too wet. Weekly observations on growth parameters were made. During the run of the trials, plants were irrigated every two days on average.

3.2.3. Parameters assessed

3.2.3.1. Measurements taken during the growth period

i. Height and canopy size

The plant height was measured with a tape measure at two week intervals while a total fresh and dry mass of stems and leaves were measured to determine canopy size. To evaluate plant height as influenced by soil amendments, only the last measurement (at harvest) of the main stem was taken into consideration. Plants were uprooted and length (height in cm) measured.

ii. Chlorophyll content

When testing for chlorophyll content a portable chlorophyll meter (SPAD 502) is positioned onto the leafy tissue for a short time, to obtain an index of relative chlorophyll content (0.00 to 99.9). The leaf colour was observed using a similar procedure as that used by Costa *et al.* (2003) on maize, adapted to get readings on potato crop leaves, using a Minolta portable chlorophyll meter [Soil Plant Analysis Development (SPAD)]. Initially readings were made on fewer leaves per plant. Due to absence in variation between the treatments, the number was raised to at least ten leaves per plant. Samples were taken from the top, middle and bottom parts of the plant. This was conducted every two weeks during the growing season.

3.2.3.2. Measurements taken at harvest

i. Fresh and dry weight of the vegetative parts (Haulm)

After harvest soil was removed from the plants. Plants were rinsed with distilled water and blotted dry with a paper towel. Plant material (stems and leaves) was then put in a brown paper bag and weighed to determine the fresh weight. The plant material was then put in a drying oven at 60-70^{0}C for 72 hours to dry. After 72 hours the plant material was again weighed to determine the dry weight.

ii. Tubers

Tuber size, number and mass were determined at harvesting. The total mass and number of tubers per pot were determined and the results grouped per treatment for further analysis.

iii. Skin appearance

Photos were taken to illustrate the difference in appearance of tubers from different treatments. This was with reference to Merchant (1955) and Ginzberg *et al*. (2005) on consumer preference in the fresh produce market i.e. light skinned tubers with few or no dark spots or other blemishes being more preferable.

Although the same parameters (i.e. chlorophyll content, plant height, tuber yield (number and mass), and fresh and dry plant weight) as in trial 1 and 2 were assessed, the focus was more on how slag and lime could influence soil pH, tuber yield and quality.

iv. Soil pH

The soil used in these experiments was a reddish sandy soil suitable for potato production. A soil sample was collected and analyzed for both nutrient content and pH (H_2O). Soil pH readings were again taken from each pot after harvest. The analysis for soil pH was done by placing 20g of soil in 100ml glass beaker, mixing it with 50ml of distilled water. After an hour it was stirred and the pH reading taken.

3.2.4. Experimental design

The experimental layout was a completely randomized design (CRD). Pots were rearranged from time to time to limit glasshouse orientation effect. Data was analyzed statistically and least significant differences (LSD) at 5% probability were determined, with help from STATOMET (University of Pretoria). Significant differences between treatment means were determined at $P \leq 0.05$.

3.3. RESULTS AND DISCUSSION

Throughout the three trials non-significant differences amongst treatments consistently occurred. There was no significant difference from any soil amendment on plant growth parameters in Trial 3. Though the effect of lime and slag were insignificant on plant growth parameters, there were some trends similar to that of Trial 1. Such included the tendency of the lime treatment to produce more tubers than slag, while slag treatment tended to increase tuber weight more (Table 3.1). The control plants tended to have the lowest chlorophyll level, followed by lime, slag 1 and slag 2 respectively, while the lime 2 treatment induced somewhat higher chlorophyll levels.

Observations on plant height indicated the control plants to have been the shortest and lime 2 the tallest. More tubers per treatment, as demonstrated in Table 3.1, tended to be present in the control treatment, followed by that of lime 1. Slag tended to give the lowest tuber number whilst lime 2 and slag 2 were more or less the same.

Table 3.1: The effect of lime and slag treatment on growth parameters

(1 = 2t ha^{-1} & 2= 4t ha^{-1}).

	Chlorophyll level (SPAD 502 meter)	**Plant height(cm)**	**Tuber number**	**Tuber mass (g)**	****Mean tuber mass (g)**	**Haulm fresh mass (g)**	**Haulm dry mass (g)**
Treatment				**Trial 3**			
Control	33.58 **a**	43.88 **a**	6.8 **a**	74.55 **a**	10.963	57.050 **a**	4.875 **a**
Lime 1	34.47 **a**	50.25 **a**	6 **a**	101.40 **a**	16.9	52.475 **a**	3.650 **a**
Lime 2	37.89 **a**	55.88 **a**	5 **a**	97.88 **a**	19.576	41.225 **a**	3.175 **a**
Slag 1	35.35 **a**	47.75 **a**	4.8 **a**	104.05 **a**	21.677	37.175 **a**	3.025 **a**
Slag 2	36 **a**	52.25 **a**	5.5 **a**	103.23 **a**	18.763	41.4 **a**	3.8 **a**

*Values with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

** Data on mean tuber mass was not statistically analyzed.

The mean tuber weight tended to be opposite to tuber number. The relation had tendency of being opposite in most cases i.e. high tuber number = less mean tuber mass and vice versa. This was especially detected in the case of the control and slag treatment. Slag mean tuber mass was significantly higher than that of the control. Plants treated with slag1 produced about 21.68 per tuber, followed by lime 2 with 19.58g per tuber. The control treatment gave the lowest mean tuber mass of about 10.96g. The highest rate of lime (4t ha^{-1}) had increased the mean tuber mass and the opposite was observed on slag whereby the mean tuber mass decreased as rate went up.

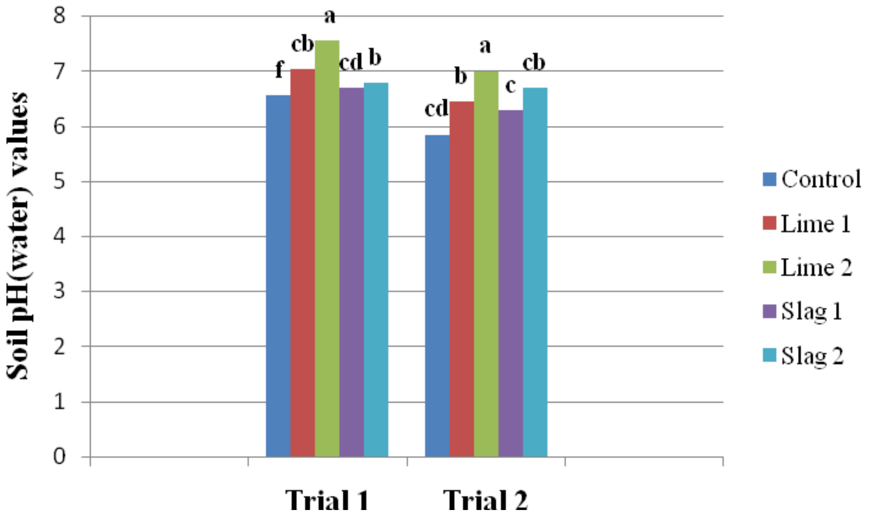
Evaluation on canopy size (haulm fresh mass) indicated slag treated plants to have the smallest haulm fresh mass, while control and lime tended to result in the largest haulm fresh mass. This could possibly mean that plants spent more energy on canopy growth at the expense of tuber growth.

Correlations between mean tuber weight (MTW) and other plant growth parameters from slag and lime treatments indicated:

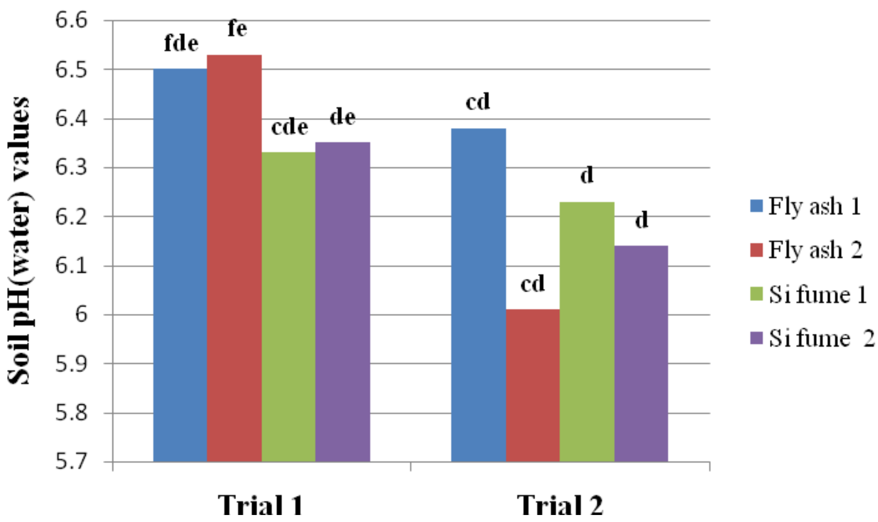
- MTW was negatively correlated to plant height (the taller plants produced the lowest MTW and vice versa)
- MTW was negatively correlated to tuber number
- MTW was positively correlated to tuber yield (higher yields were associated with larger tubers)
- MTW was negatively correlated to fresh weight of the haulms (more top growth was associated with lower tuber yields)

In all three trials, both slag and lime soil amendments significantly increased the soil pH. The pre-experiment pH for trial 1, 2 and 3 were 6.3, 6.18 and 5.95, respectively. Even though the same soil from the same source was used it seemed as though the soil pH for some unknown reason decreased with time. There was not much of a difference in soil pH from soils amended with fly ash and Si fume. They were closer to that of the control treatment (Fig. 3.1.A and B). The soil pH's of the fly ash and control treatments was around the same level, whilst Si fume did not affect the soil pH. In all the trials (Fig. 3.1) lime at either 2t or 4t ha^{-1} increased soil pH more than slag at the same rates.

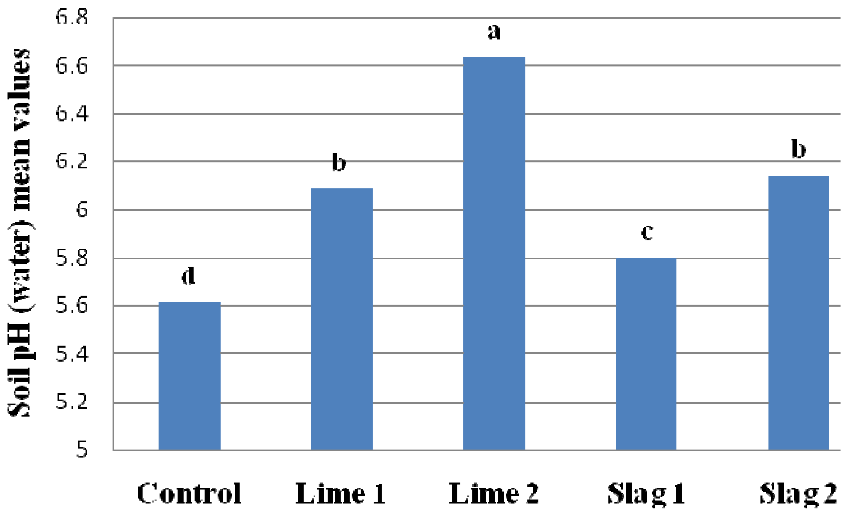
A.


Soil pH(water) values
8
7
6
5
4
3
2
1
0
f
cb
a
cd
b
cd
b
a
c
cb
Trial 1
Trial 2
Control
Lime 1
Lime 2
Slag 1
Slag 2

B.


Soil pH(water) values
6.6
6.5
6.4
6.3
6.2
6.1
6
5.9
5.8
5.7
fde
fe
cde
de
cd
cd
d
d
Trial 1
Trial 2
Fly ash 1
Fly ash 2
Si fume 1
Si fume 2

C.

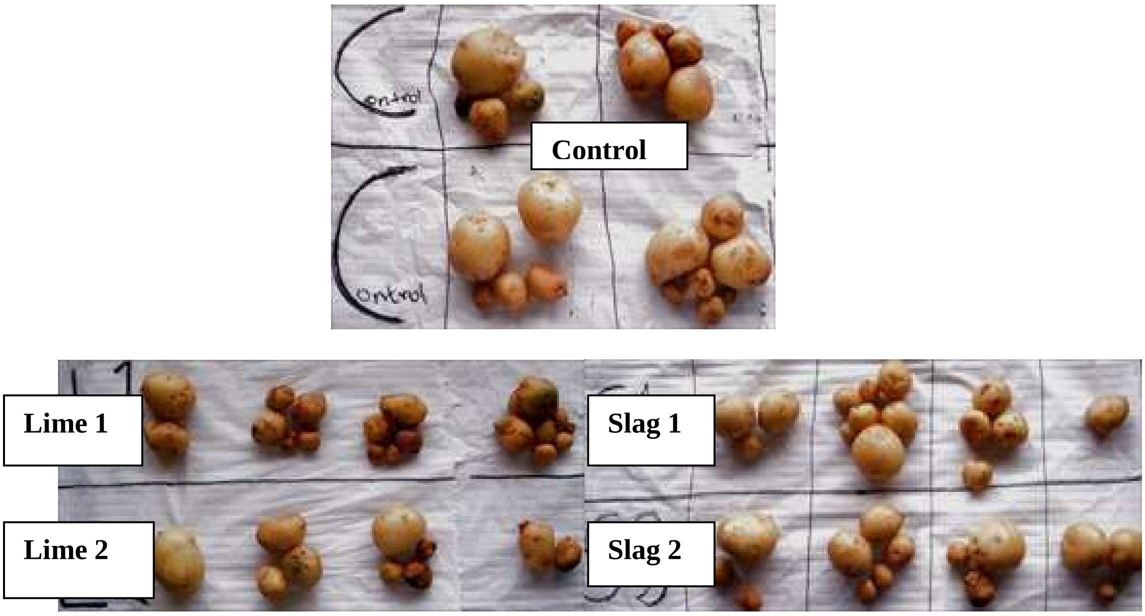


* Bars with the same letter, in a trial do not differ significantly from each other at the 5% level of probability.

Fig. 3.1: Soil pH as affected by soil applications of fly ash and Si fume (A), lime and slag (B & C) at two levels (1 = 2t ha^{-1} & 2= 4t ha^{-1}).

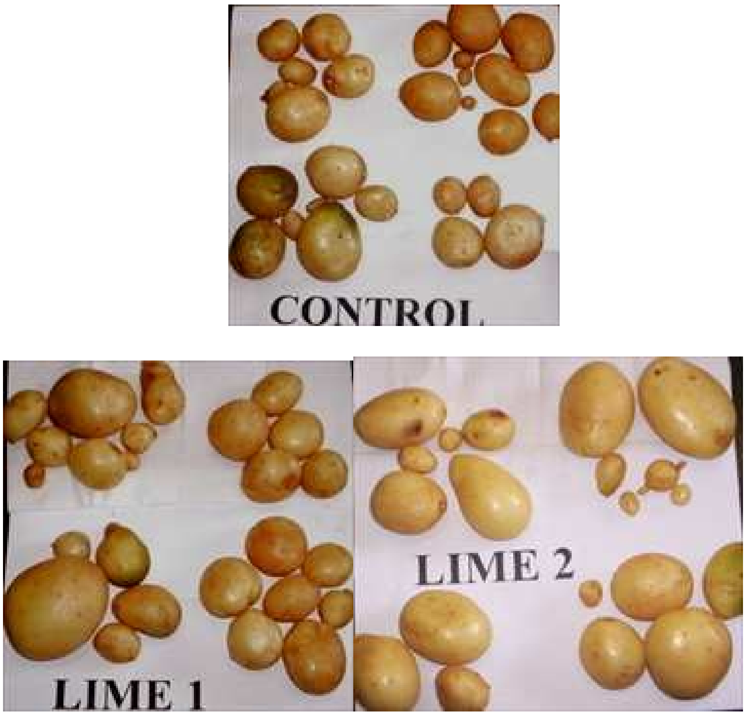
The differences in tuber size from slag and lime applications might have been due to the different pH levels. Slag tended to have promoted bigger tubers, even under constrained circumstances (Fig. 3.2). The constrained circumstances were exposure to high temperatures (Trial 2).

A.



B.

C.



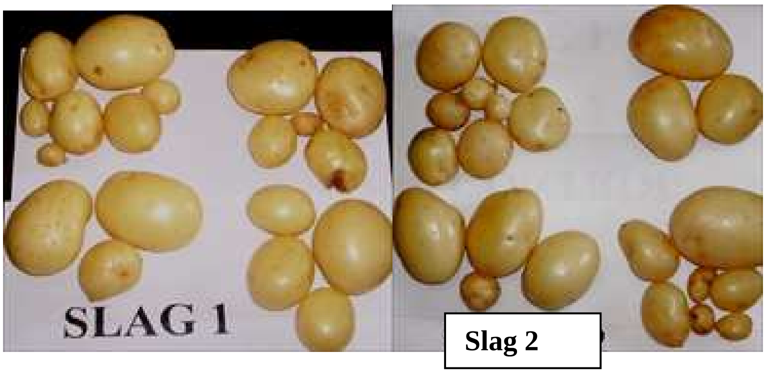


Fig. 3.2: The effects of lime and slag on tuber size and appearance (A. Trial 1, B. Trial 2, C. Trial 3).

The high levels of soil pH may possibly have provided the conditions for plants to grow taller and consequently affected tuber growth. According to Maier *et al.* (2002), lime was reported to have increased plant height, had no significant effect on potato yield and reduced number of tubers per plant especially in glasshouse experiments. The availability of P was also reported to decrease as soil pH increase above 7.0. This poses a negative effect on potato production since P is very important for potato growth. According to Kaya *et al.* (2006) Si sources can improve tuber yield and quality by improving the availability of calcium to plants. Calcium was reported to have the tendency to reduce tuber number and increase tuber size (Ozgen & Palta, 2004). This may explain the trial results on the tendency of slag treatment to increase tuber size but decrease tuber numbers. According to Kaya *et al.* (2006) applications of Si also promoted Ca levels in leaves and roots, which can ultimately help with coping with stress conditions. According to Lambert and Manzer (1991) the more alkaline the soil pH the more favourable the conditions would be for common scab to occur.

Correlations amongst the growth parameters, plant height and tuber size and soil pH were analyzed for the control, lime and slag treatments of all three trials. Data from all three trials were combined for correlation analysis. There was no significant correlation between plant height, soil pH and tuber number (Table 3.2), while plant height and tuber weight were negatively correlated. The negative correlation between plant height and tuber weight implied that as plants grew taller, the tuber weight decreased. Tuber number was only slightly negatively correlated with plant height. The only positive correlations with plant height were that of the haulm fresh and dry mass. Thus the taller the plants the higher the fresh and dry weights of the above ground parts. Correlations between the soil pH and all other parameters were very weak, with soil pH being negatively correlated with plant height and tuber number and mass. Increased soil pH in these trials may have negatively influenced the plant height, which consequently affected the tuber number. The correlation between tuber number and mass was not positive. Slag resulted in plants having fewer tubers that weighed more, while lime resulted in plants having more, but smaller tubers.

Table 3.2: Correlations between growth parameters in potato plants as affected by lime and slag (in all 3 trials).

	Plant height	Haulm fresh mass	Haulm dry mass	Tuber number	Tuber mass	Soil pH
Plant height	1.00000	0.83076 < .0001	0.75705 < .0001	-0.18117 0.1659	-0.61632 < .0001	-0.08208 0.5330
Haulm fresh mass	0.83076 < .0001	1.00000	0.94558 < .0001	-0.21128 0.1051	-0.68112 < .0001	0.06954 0.5975
Haulm dry mass	0.75705 < .0001	0.94558 < .0001	1.00000	-0.28265 0.0287	-0.65707 < .0001	0.16046 0.2207
Tuber number	-0.18117 0.1659	-0.21128 0.1051	-0.28265 0.0287	1.00000	0.400690 0.0015	-0.35067 0.0060
Tuber mass	-0.61632 < .0001	-0.68112 < .0001	-0.65707 < .0001	0.400690 0.0015	1.00000	-0.13165 0.3160
Soil pH	-0.08208 0.5330	0.06954 0.5975	0.16046 0.2207	-0.35067 0.0060	-0.13165 0.3160	1.00000

3.4. CONCLUSIONS

Overall, the reaction of all growth parameters on the application of lime and slag did not follow the same trend in the 3 trials. From these results there were no significant effects on growth parameters indicating that neither of the treatments was better than the other. Consistency of results was seen for tuber mass and plant height. Plants treated with slag tended to produce tubers that weighed more, while plants were taller when treated with lime. Even though the uses of slag tended to give greater tuber mass, there were no significant differences among the treatments for tuber mass or number. Tubers from slag-amended soil appeared to be smooth, with light coloured skin without rusetting, as preferred by consumers (Ginzberg *et al*., 2005).

The soil pH increased after applying lime and slag, and according to reports from Lopes (1977) (as quoted by Savant *et al*., 1999), Si uptake in plants is pH dependent. This suggests that slag which contains a liming material to have the ability to increase soil pH. Furthermore according to Lopes (1977) an increase in silicon adsorption enhances the availability of phosphorus, resulting from a rise in pH.

Overall none of the treatments proved to be better than the other. Significant differences were only observed in soil pH. There was insignificant difference on potato growth parameters whilst there was a clear effect on soil pH, making the study on lime versus slag to be inconclusive. Reports from Maier *et al.* (2002) indicated applications of lime and superphosphate to increase plant height. In my trials there was no significant effect on plant height, though plants treated with lime had the tendency to grow taller. Rosen and Bierman (2008) reported on the inverse relation between tuber number and mass i.e. increase in tuber number resulted to decrease in tuber weight. This was seen especially from P fertilization. The results were inconclusive to how either lime or slag could better potato production. Due to proven role of Si on alleviation of diseases and ability to correct soil pH, silicon may possibly play a significant role on disease control, such as common scab, when applied under acidic conditions. More research on slag versus lime with regard to tuber quality and nutrient availability or uptake is required.

3.5. REFERENCES

COSTA, C., FRIGON, D., DUTELLEU, P., DWYER, L.M., PILLAR, V.D., STEWART, D.W. & SMITH, D.L., 2003.Sample size determination for chlorophyll meter reading on maize hybrids with a broad range of canopy types. *J. Plant Nutr*. 26: 1117-1130.

GINZBERG, I., GERCHIKOV, N., ZIV, E., FOGELMAN, E., TANAMI, Z. & WARSHAVSKY, S., 2005. Potato tuber skin development: the effect of hot climate and plant desiccation. In: *Proc. Meeting Physiol. Section EAPR*. CASA, R. & VIOLA, R., Eds. *Acta Hort.* 684: 93-98.

HAVERKORT, A.J., MULDER, A. & VAN DE WAART, M., 1993. The effect of soil pH on yield losses caused by the potato cyst nematode *Globodera pallid*. *Potato Res.* 36:219-226.

HORNECK, D., WYSOCKI, D., HOPKINS, B., HART, J. & STEVENS, R., 2007. Acidifying soil for crop production: Inland Pacific Northwest. A Pacific Northwest Extension publication.

http://extension.oregonstate.edu. ACCESSED IN 2010

KAYA, C., TUNA, L. & HIGGS, D., 2006. Effect of silicon on plant growth and mineral nutrition of maize under water-stress conditions. *J. Plant Nutr*. 29: 1469-1480.

LACEY, M.J. & WILSON, C.R., 2001. Relationship of common scab incidences of potatoes grown in Tasmanian Ferrosol soils with pH, exchangeable cations and other chemical properties of those soils. *J. Phytopathol*. 149: 679-683.

LAMBERT, D.H. & MANZER, F.E., 1991.Relationship of calcium to potato scab. *Phytopathol.* 81: 632-636.

LOPES, M.S., 1977. Relationships between pH and adsorption of phosphorus and silicon in soils. M.Sc. Thesis. Agricultural School-Federal University of RionGrande do Sul. Porto Alegre, Brazil. (Quoted by Savant *et al*., 1999)

LORIA, R., 1991. Potato Scab (Fact Sheet Page 725.80 Date 10-1991).Cooperative extension. New York state. Department of Plant Pathology. Cornell University.

http://vegetablemdonline.ppath.cornell.edu/factsheets/Potato_Scab.htm. ACCESSED IN 2009.

MA, J.F. & YAMAJI, N., 2006. Silicon uptake and accumulation in higher plants. *Trends in Plant Sci. Rev.* 1: 392-397.

MAIER, N.A., MCLAUGHLIN, M.J., HEAP, M., BUTT, M. & SMART, M.K., 2002. Effect of current-season application of calcitic lime and phosphorus fertilization on soil pH, potato growth, yield, dry matter content, and cadmium concentration. *Commun. Soil. Sci. Plant Anal*. 33: 2145-2165.

MERCHANT, C.H., 1955. News and Reviews: Consumer acceptance of potatoes of various qualities. The Sixth National Potato Utilization Conference, Cornell University, Ithaca, N.Y., November, 1954.

OZGEN, S. & PALTA, J., 2004. Supplemental calcium application influences potato tuber number and size. *Hort. Sci.* 40(1): 102-105.

ROSEN, C.J. & BIERMAN, P.M., 2008. Potato yield and tuber set as affected by phosphorus fertilization. *Amer. J. Pot. Res*. 85: 110-120.

SAVANT, N.K., KORNDORFER, G.H., DATNOFF, L.E. & SNYDER, G.H., 1999. Silicon nutrition and sugarcane production. A review. *J. Plant Nutr.* 22: 1853–1903.

CHAPTER 4

GENERAL CONCLUSIONS AND RECOMMENDATIONS

4.1. GENERAL CONCLUSIONS

Numerous reports have alluded to the benefits of silicon in crop production but very little research has focussed on the role of Si in improving potato production. Since the potato crop is highly important to the global economy, a study was conducted to evaluate the effect of various Si-containing soil amendments on soil pH and yield of potatoes in order to improve production. The selected Si sources for the study were used in comparison to lime which is normally used to correct low soil pH. Since a potato crop is sensitive to low soil pH and is susceptible to a wide range of pathogens, these sources were evaluated in order to distinguish a soil amendment that played a more beneficial role or create favourable conditions to potato plants.

The study concentrated on the role of silicon sources compared to lime in improving the quality and productivity of potatoes. Silicon-containing sources used included Calmasil slag (Middleburg) (30% Si- containing liming material), fly ash (50% Si-containing non liming material), Si fume/ash (99% Si-containing non liming material) and a lime control ($CaCO_3$). All the soil amendments including lime were applied at three rates i.e. 0t ha^{-1} as negative control, 2t ha^{-1} and 4t ha^{-1}. The soil amendments were incorporated into the soil and each replicated four times. The trial was repeated three times.

The first two trials i.e. Trial 1 (with use of 4kg pots) and Trial 2 (with the use of 10kg pots) were conducted with the concentration of finding a silicon containing source that could significantly stimulate best potato production, while the third trial was to evaluate the effect of the best silicon source on soil pH in comparison to lime. In selecting the best Si containing soil amendment, parameters such as chlorophyll content, plant height, tuber number and mass (Fwt), fresh and dry mass (haulms) and change in soil pH were analysed. There was no significant difference detected between the silicon treatments. Although there wasn't any significant difference with most of the parameters assessed, slag treated plants had a tendency to produce tubers with greater average mass per pot and better appearance. Merchant (1955) indicated potatoes that are better sized and have less external defects to have been initially used to express real satisfaction to consumers, but with repeated purchase potato satisfaction depended on acceptance and use of potato cultivar in home use. The greatest rise in soil pH amongst Si sources was also read in soil amended with slag. This was despite slag having the lowest Si content i.e. 30% Si. The higher soil pH could thus be due to the liming element in slag.

In Trial 3 soils amended with slag 2 and lime 2 resulted in soil pH's that were highly significant from each other. Plants treated with slag tended to be shorter and with higher tuber mass as compared to lime. Results from all three trials agree with a study by Ma *et al.* (2001) who reported Si not to have given evidence that proved it to have a physiological role in plant metabolism. According to Ma *et al.* (2001) Si is a typical beneficial element that show effects clearly when plants are under stress conditions. They further more pointed out Si to can ultimately result in increased productivity through alleviation of stresses. Silicon sources did not show any significant effect on plant growth, but in relation to report by Ma *et al.* (2001) tended to respond differently when under stress condition.

To further understand the effects of slag vs. lime, advantages and disadvantages of using lime or slag in potato production were assessed. The use of lime which ultimately leads to increased pH level can possibly result in adverse conditions for potato growth such as increased incidence of common scab. On the other hand applications of slag is said to be potentially hazardous to the environment due to its heavy metal content. Some recent studies revealed that contamination of heavy metals in slag can potentially cause more harm than good to plants. According to Van der Waals (2001) slags contain impurities derived from ore processing which include heavy metals.

In contrast to the findings mentioned above, amending soil with slag was found not to pose as much of a threat to the environment compared to metals applied in other materials e.g. sewage sludge, due to its liming effect on acid soils which reduces the solubility or availability of many heavy metals (van der Waals, 2001). According to van der Waals (2001), guidelines in terms of recommended maximum levels of heavy metals application to soil accepted for South Africa are based on the use of sewage sludge and not slag.

There were no significant differences among treatments showing one treatment to be better than the other, therefore cannot suggest slag as a more viable source for potato production. The results led to the conclusions that neither slag nor lime treatment is better than the other. The inconclusive results suggest the need for more research to be conducted to further understand the effects that slag and lime treatments pose on plants.

4.2. RECOMMENDATIONS

As in many past reports on silicon there might be a potential from applications of Si on stimulating resistance to stress conditions rather than a role in plant metabolism. More researches on the effect of Si on potato production have to be assessed, during which use an alternative Si source has to be considered. Si sources such as potassium silicate and calcium silicate have been used in previous projects. Past reports on these sources have verified them to stimulate similar benefits without causing hazardous effects. For an even deeper understanding of the effect of a Si source in contrast to the lime on plants, it would be more practical to conduct experiments on open field; look at how the Si source influences root growth and size, how much and where (peels or inner flesh) it accumulates in tubers, the influence on nutrient uptake and even include tests on the flavour and cooking quality of tubers.

4.3. REFERENCES

MA, J.F., MIYAKE, Y. & TAKAHASHI, E., 2001. Silicon as a beneficial element for crop plants In: *Silicon in Agriculture*; DATNOFF, L.E., SNYDER, G.H., Eds.; Elsevier: Netherlands. *Studies in Plant Sci.* 8: 17-39.

MERCHANT, C.H., 1955. News and Reviews: Consumer acceptance of potatoes of various qualities. The Sixth National Potato Utilization Conference, Cornell University, Ithaca, N.Y., November, 1954.

VAN DER WAALS, J.H., 2001. Slags as agricultural limes: reactivity and heavy metal and phosphorus bio-availability. M.Sc. (Soil science). Thesis. Faculty of Natural and Agricultural Sciences. University of Pretoria. Pretoria.

CHAPTER 5

SUMMARY

From worldwide reports it is evident that the potato crop serves as a staple diet food crop worldwide and is capable of reducing the world's food shortage. However, production of this crop is reported to be difficult due to exposure and susceptibility to biotic and abiotic factors. These biotic and abiotic factors limit growth and development of potatoes by greatly disrupting the plant's physiological processes. To improve growth conditions for potato production strategies must be devised to limit factors that interfere with the growth and development of plants or breeding new varieties that are able to withstand stresses. As indicated by Rowe (1993) the aim is to avoid a net financial loss and to ensure that precautionary or corrective actions are taken before the economic loss level is reached.

Several researchers, silicon have proved its role in protection against abiotic and biotic stresses. Although dicots are reported to be poor accumulators, positive results against abiotic and biotic stresses from application of silicon have been detected. The literature on silicon (Si) suggests that Si has both economical and agronomical benefits for crop production. Since very little research has focussed on the role of Si in improving potato production, a study became necessary to evaluate the effect of various Si containing soil amendments, on soil pH and yield of potato. The present study is a presentation of research conducted on the evaluation of silicon sources namely slag, fly ash and Si fume, in comparison to lime.

The research focused on the effects, both beneficial and non-beneficial, of soil applications of these sources (Si and lime) on potato growth. Beneficial roles played by silicon in a plant's growth and development have been revealed in numerous past reports. Si has been reported as being abundant in soil but is still not recognized as an essential nutrient element. However, evidence of Si being a beneficial element to plants in terms of improved yield, growth, development, and disease resistance has been observed (Ma & Yamaji, 2006). The effect, benefits and absorption of silicon were reported to vary with plant species and three types of plants have been identified. There are Si accumulators- that use an active mode of uptake mechanism by roots. They take up Si at a faster rate than water, while the Si intermediate type uses a passive mode of uptake mechanism by roots and therefore Si uptake is at a similar rate as water. The third type is the Si excluders that use a rejective mode of uptake by roots. The excluders' mode of Si uptake is evident by the increased concentrations of Si in the solution surrounding the roots.

Si might have the ability to bring both economical and agronomical benefits to crop production. A literature review on Si and potato production has revealed very little research focused on the role of Si in improving potato production. Therefore a study was conducted to evaluate the effect of various soil amendments on soil pH and yield of potatoes.

Parameters assessed included chlorophyll levels, plant height, Fwt and Dwt (haulms), tuber number, and tuber mass (Fwt) and soil pH. Neither slag nor lime showed any significant effect on potato plants. Slag tended to respond better under constrained conditions. Overall data from parameters analysed with the exclusion of soil pH were significantly indifferent. Plants treated with slag tended to produce tubers with better appearance and higher tuber mass per pot compared to other Si sources and lime.

Since there were no significant differences among treatments, neither slag nor lime can be reported as a more viable source for potato production as compared to the other.

APPENDIX A

CALCULATIONS INCLUDED IN ESTABLISHMENT OF TRIALS

The following calculations were done for both 4 kg and 10 kg pot soils. The density of soil was assumed to be 1.5t m^{-3} and calculations to determine how much of each treatment to apply to the soil were done as follows:

Soil density = 1.5t m^{-3}

= 100m (L) x 100m (b) x 03m (depth)

= 3000m^3

1.5t m^{-3} x 3000m^3 = 4 500t ha^{-1}

2t ha^{-1} was added ⟶ 2/ 4 500 = 1/ 2 250

⟶ 1.8g of slag, fly ash and lime was added per 4kg pot soil; and 4.5g per 10kg pot soil for all the treatments.

With Si fume/ash 0.5t ha^{-1} was added ⟶ 0.45g per 4kg pot soil and 1.12g for 10kg pot soil.

According to the recommendations for potato production, at least 110kg of P ha^{-1} had to be supplemented (Steyn & Prinsloo, 2003). Superphosphate in use contained about 10.5 % of P.

$$\longrightarrow \frac{110\text{kg P}}{\text{ha}} \times \frac{100\ P_2O_5}{10.5\ \text{P}} \times \frac{1\text{ha}}{4\ 500\ 000\text{kg}} \times 4\text{kg}$$

= 0.000931216kg = 0.9g superphosphate per 4kg pot soil

Similar calculations for 10kg pots gave 2.25g superphosphate per pot soil.

$$\longrightarrow \frac{110\text{kg P}}{\text{ha}} \times \frac{100\ P_2O_5}{8.3\ P} \times \frac{1\text{ha}}{4\ 500\ 000\text{kg}} \times 4\text{kg}$$

= 0.00116627kg = 1.2g superphosphate per 4kg pot soil

APPENDIX B

ANOVAS

Table B1. ANOVA data of Trial 1: The effect of lime and Si containing sources on growth of potatoes (from 4kg pots).

Variable	R-square	Coefficient of variance	Root MSE*	Mean	Source	LSD**
Chlorophyll content	0.336417	10.38418	3.121858	30.06361	**treatment**	**NS*** **
Plant height	0.460481	16.47877	6.028482	36.58333	**treatment**	**NS*** **
Fresh plant mass	0.389620	18.82372	15.69265	83.36639	**treatment**	**NS*** **
Dry plant mass	0.349274	20.41128	2.312598	11.33000	**treatment**	**NS*** **
Number of tubers	0.373563	37.06293	1.420746	3.833333	**treatment**	**NS*** **
Fresh tuber mass	0.178378	32.66228	25.01096	76.57444	**treatment**	**NS*** **

***Root MSE= Root Mean Squared Error**

****LSD=Least significant difference**

*****NS= Non significant**

Table B2. ANOVA data of Trial 2: The effect of lime and Si containing sources on growth of potatoes (from 10kg pots).

Variable	R-square	Coefficient of variance	Root MSE*	Mean	Source	LSD**
Chlorophyll content	0.288552	12.08398	4.250524	35.17486	**treatment**	**NS*** **
Plant height	0.210616	10.37051	10.45940	100.8571	**treatment**	**NS*** **
Fresh plant mass	0.459477	13.52770	28.76029	212.6029	**treatment**	**NS*** **
Dry plant mass	0.473819	17.49153	4.491416	25.67766	**treatment**	**NS*** **
Number of tubers	0.158743	51.55827	1.870829	3.628571	**treatment**	**NS*** **
Fresh tuber mass	0.265884	63.95919	24.58823	38.44363	**treatment**	**NS*** **

***Root MSE= Root Mean Squared Error**

****LSD=Least significant difference**

*****NS= Non significant**

Table B3. ANOVA data of Trial 3: The effect of lime and slag on soil pH, and growth of potatoes.

Variable	R-square	Coefficient of variance	Root MSE*	Mean	Source	LSD**
Chlorophyll content	0.337037	6.677930	2.367293	35.44950	**treatment**	**NS*** **
Plant height	0.182354	19.83011	9.915056	50.00000	**treatment**	**NS*** **
Fresh plant mass	0.318320	27.85327	12.77490	45.86500	**treatment**	**NS*** **
Dry plant mass	0.296792	31.26907	1.158519	3.705000	**treatment**	**NS*** **
Number of tubers	0.158951	34.03804	1.906130	5.600000	**treatment**	**NS*** **
Fresh tuber mass	0.387883	16.64513	16.01594	96.22000	**treatment**	**NS*** **
Soil pH	0.963747	1.284091	0.077739	6.054000	**treatment**	**S*** **

***Root MSE= Root Mean Squared Error**

****LSD=Least significant difference**

*****NS= Non significant**

*****S= Significant**

Table B4. Combined ANOVA data for all 3 trials (trial 1, 2 and 3): The effect of lime and slag on soil pH, and growth of potatoes.

Variable	R-square	Coefficient of variance	Root MSE*	Mean	Source	LSD**
Chlorophyll content	0.019225	13.69444	4.655312	33.99417	**treatment**	**NS*** **
Plant height	0.021176	48.74366	30.47697	62.52500	**treatment**	**NS*** **
Fresh plant mass	0.010194	65.64398	74.02201	112.7628	**treatment**	**NS*** **
Dry plant mass	0.017074	73.49569	9.668897	13.15573	**treatment**	**NS*** **
Number of tubers	0.072696	44.36720	1.981735	4.466667	**treatment**	**NS*** **
Fresh tuber mass	0.098734	47.43519	33.51755	70.65967	**treatment**	**NS*** **
Soil pH	0.465575	6.078602	0.393367	6.471333	**treatment**	**S*** **

***Root MSE= Root Mean Squared Error**

****LSD=Least significant difference**

*****NS= Non significant**

*****S= Significant**