A COMPARISON OF SOIL EXTRACTION METHODS FOR PREDICTING THE SILICON REQUIREMENTS FOR SUGARCANE

by

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Submitted in partial fulfillment of the academic requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

in the

Discipline of Soil Science

School of Applied Environmental Sciences

Faculty of Science and Agriculture

University of KwaZulu-Natal

Pietermaritzburg

March 2007

DECLARATION

The experimental work described in this thesis was carried out in the South African Sugarcane Research Institute, from April 2003 to December 2005, under the supervision of Professor RJ (Dick) Haynes of the Department of Soil Science, University of KwaZulu-Natal, Faculty of Science and Agriculture, Pietermaritzburg Campus, and JH Meyer of the Plant and Environment Resource Centre, South African Sugarcane Research Institute (SASRI).

These studies represent original work by the author and have not been submitted for degree purposes to another University. Where use was made of the work of others it has been acknowledged in the text.

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ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to the following:

Professor RJ (Dick) Haynes, his supervisor, for his patience and his willing assistance and advice during the period of this study;

Mr JH Meyer, his co-supervisor, for his help and much appreciated guidance, understanding and stimulation through the entire project;

The staff of the Soil Fertility Advisory Service Laboratory of the South African Sugarcane Research Institute who analyzed several soil and plant (leaf) samples;

The staff of the Analytical Chemistry Laboratory of the South African Sugarcane Research Institute who helped in silicon analysis of several soil and plant (leaf) samples;

The families of F. RUTAYISIRE, J. NDAGIJIMANA, D.A. PELSER and R.VAN ANTWERPEN for their help during the period of this study;

The staff of the South African Sugarcane Research Institute who were always helpful and willing to share their experience and wisdom;

The staff of the Soil Science Department at the University of KwaZulu-Natal, as well as fellow students, for their support and advice;

His friends who helped him in so many ways;

His wife Consolee, his son Lionel, his daughter Sarah, and his foster child J Baptist for their encouragement, patience and unfailing support which are gratefully acknowledged;

The National Research Foundation (NRF) for the scholarship.

ABSTRACT

Although silicon (Si) has not yet been recognized as an essential nutrient element, its application to sugarcane (*Saccharum officinarum* L.) has proved to be beneficial. Since optimum crop production depends on the maintenance of adequate plant nutrients in the soil, there is a need in the South African sugar industry for a reliable index for assessing the requirement for supplemental silicon (Si) in soils, particularly in reducing the risk of Eldana saccharina stalk borer infestation in cane. The objective of this study was to assess Si availability in soils, to select a suitable Si extraction method and a critical value for determining when a response is likely. For this purpose, five acid soils (representing some of the most important agricultural soil groups used for sugarcane production in the sugar belt) were used in October 2004, in the JAKE WILSON glasshouse of the South African Sugarcane Research Institute (SASRI) based at Mount Edgecombe.

Except for the *Arcadia* form soil with an initial Si content of 1.2 mmol kg^{-1} as estimated using the 0.01M H_2SO_4 + $(NH_4)_2SO_4$) extractant, soils representing the other five soil forms namely *Cartref, Glenrosa, Longlands* and *Nomanci*; exhibited a sub-optimal Si content of not more than 4.0 mmol kg^{-1}. Sorghum was used as a plant crop and sugarcane as a ratoon crop because of their Si accumulator status. Three different Si sources: calmasil, slagment and wollastonite; with respectively 9.85, 15.20, and 5.25% Si content were applied at increasing rates of 0, 3 and 6 tons ha^{-1} as Si fertilizers. Silicon (Si) was extracted from untreated and treated soils by utilizing six different extractants, (1) 0.01M H_2SO_4 + $(NH_4)_2SO_4$; (2) Distilled water; (3) 0.025M H_2SO_4; (4) 0.5M CH_3COOH; (5) 0.5M CH_3COONH_4 pH 4.8; and (6) 0.01M $CaCl_2.2H_2O$.

The amount of soil Si extracted followed the order: 0.025M H_2SO_4 > 0.5M CH_3COOH > 0.01M H_2SO_4 + $(NH_4)_2SO_4$ > 0.01M $CaCl_2.2H_2O$ > 0.5M CH_3COONH_4 pH 4.8 > distilled water. Soil Si extracted by 0.025M H_2SO_4 was significantly correlated with soil exchangeable cations, CEC, clay content, cane biomass yield, cane Si uptake and increasing rates of applied Si.

Averaged over all soil forms investigated, the increases in dry biomass yield and Si uptake ranged from 18% to 154% for sorghum; and from 23% to 85% for cane respectively. Even though the highest increases (%) in cane biomass yield and Si uptake were obtained on a *Nomanci* form soil with initial poor fertility status, the highest means were obtained on an *Arcadia* form soil with the highest Si initial content. There was no difference between different Si sources in their ability to influence cane biomass yield and Si uptake, and therefore the supply to the soils. Even though the lower and higher Si source rates were not different from each other, they increased cane yield and Si uptake, indicating that Si was undoubtedly beneficial for sugarcane. The Si critical levels for different soils as estimated by 0.025M H_2SO_4 were 6.0 mmol kg^{-1} (168 mg kg^{-1}) for *Arcadia;* 2.6 mmol kg^{-1} (64 mg kg^{-1}) for *Cartref*; 2.5 mmol kg^{-1} (64 mg kg^{-1}) for *Glenrosa*; 1.6 mmol kg^{-1} (45 mg kg^{-1}) for *Longlands*; and 2.4 mmol kg^{-1} (67 mg kg^{-1}) for *Nomanci* form soils.

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LIST OF ABBREVIATIONS

ANOVA:	Analysis of variance
Ar:	Arcadia
BT1:	Burnt Trash Trial
CEC:	Cation Exchange Capacity
Calm H:	Calmasil High (6 tons ha^{-1})
Calm L:	Calmasil Low (3 tons ha^{-1})
Cf:	Cartref
cm:	Centimetre
cmol:	Centimole
FAO:	Food and Agriculture Organization of the United Nations
FAS:	Fertilizer Advisory Services
FMC:	Field Moisture Capacity
g:	gram
Gs:	Glenrosa
kg:	Kilogram
L:	Litre
Lo:	Longlands
LSD:	Least Significant Difference
mg:	Milligram
m:	metre
M:	Molar
meq. %:	Mill-equivalent percent
ml:	Millilitre
mm:	Millimetre
nm:	Nanometre
N:	Normal
N CAT:	Nitrogen mineralisation category (1:low; 2:moderate; 3:high; 4:very high)
No:	Nomanci

NS:	Non-Significant
°C:	Degree Celsius
OM:	organic matter
pH:	Potential hydrogen
ppm:	parts per million
Rep:	Replication
RPM:	Revolutions per minute
SASEX:	South African Sugarcane Association-Experiment Station
SASRI:	South African Sugarcane Research Institute
Slag H:	Slagment High (6 tons ha^{-1})
Slag L:	Slagment Low (3 tons ha^{-1})
t/ha:	Tons per hectare
TO:	Control (Treatment Zero)
USA:	United States of America
USDA:	United States Department of Agriculture
UV:	Ultraviolet
Woll H:	Wollastonite High (6 tons ha^{-1})
Woll L:	Wollastonite Low (3 tons ha^{-1})

CHAPTER 1

GENERAL INTRODUCTION AND STUDY OBJECTIVES.

Silicon (Si) is the second most abundant element in the earth's crust after oxygen (Bohn *et al.*, 1985; Marschner, 1986; Wild, 1986; Savant *et al.*, 1999; Miller and Gardiner, 1998; Datnoff *et al.*, 2001; Ma and Takahashi, 2002). Because of its abundance in the biosphere, the essentiality of Si as a plant nutrient is very difficult to prove (Marschner, 1986; Epstein, 2001). It was then considered that its addition to soil was unnecessary (Meyer and Keeping, 2000; Gascho, 2001; Ma *et al.*, 2001; Epstein, 2001; Ma and Takahashi, 2002). However, Si is always combined with other elements and most sources are insoluble (Gascho, 2001). Moreover, it was proved from field trials, that soil Si solubility is not high enough to supply Si to rice and sugarcane for healthy growth (Hesse, 1971; Ma and Takahashi, 2002).

In South Africa, silicon deficiency was identified for the first time in 1967 as a potential growth-limiting factor in the highly weathered Oxisol soils of the cane areas of the Natal Midlands (Bishop, 1967). Meyer (1970), du Preez (1970), Moberly (1974) and Moberly and Meyer (1975) have since conducted investigations with positive yield results from applying silicate sources to sugarcane. An experiment was established to compare the relative efficacy of local silicon sources with two forms of slag imported from USA (SASEX, 2002). The local sources performed similarly to the imported slags and silicon uptake by rice from the local silicate sources was superior to that from the two imported sources, which in turn were more efficient silicon suppliers than cement and fly ash.

Sugarcane (*Saccharum officinarum* L.) is a plant of economic importance in many tropical and semitropical countries including South Africa (Ross *et al.*, 1974; Marschner, 1986; Fageira *et al.*, 1991; Hunsigi, 1993; Haynes and Hamilton, 1999; Savant *et al.*, 1999). It is grown on about 400 000ha in the Natal sugar belt under a wide range of climatic and soil conditions (Moberly, 1974; Meyer *et al.*, 1996). When produced under monocropping practice (Qongqo and Antwerpen, 2000), sugarcane makes heavy demands on the soil nutrients (Hunsigi, 1993) and, where fertiliser applications are inadequate, there is a rapid decline in levels of plant nutrients (Haynes and Hamilton, 1999). While much is known about Nitrogen (N), Phosphorus (P) and Potassium (K) requirements for cane (Meyer *et al.*, 1999), relatively little has been published about silicon needs for this crop in South Africa.

Because of the expenses associated with Si fertilisation, Savant *et al.*, (1999) considered the scope for giving proper guidance to sugarcane growers for judicious use of available silicon sources to achieve desired crops. Applying the correct amount of nutrient saves producer's money, helps protect the environment, optimises crop yields, conserves valuable resources and prevents nutrient imbalances (Rice *et al.*, 2002). Estimation of critical levels of an element in soil largely relies on soil testing (Al-Mustafa *et al.*, 2001). Such a level may differ from one soil to another depending on the native prevailing conditions on one hand and the nature of soil extraction on the other hand (Lindsay and Narvell, 1978). Soil and plant tests are used to guide fertilisation in sugarcane growing countries. In South Africa, the Fertiliser Advisory Service (FAS) was established to evaluate, monitor and recommend fertilisation for the whole cane cycle (Wood, 1987).

Several soil Si test methods have been reported by different authors including Fox *et al.* (1967b), Khalid *et al.* (1978a), Barbosa-Filho (1996), Korndörfer *et al.* (1998), Berthelsen *et al.* (1999), Snyder (2001), and Barbosa-Filho *et al.* (2001). However, Si uptake by sugarcane is affected by many factors depending on the soil properties. Therefore, it is very difficult to have an overall method for extraction of Si available for sugarcane (Jones, 2001; Ma and Takahashi, 2002). Furthermore, since the amount of Si solubilized varies with the soil, a local, convenient and rapid rather than a universal method might be necessary for precise diagnosis of soil fertility (Ma and Takahashi, 2002).

The work reported attempts to compare different published soil silicon extraction methods to predict the requirement of silicon for sugarcane. The objectives are (1) to test response of sorghum (*Sorghum bicolor* L.) and sugarcane (*Saccharum officinarum* L.) to applied Si sources, (2) to assess the ability of six different soil extractants to estimate soil available Si, (3) to provide confidence about the Si supplying ability of the candidate Si sources and (4) to define the Si critical level in soil using the tested methods. Glasshouse pot experiments as well as soil and plant testing were used. Five different acid soils were tested for their plant silicon availability. Three candidate Si sources at various rates were applied to supply Si to the soils and therefore to plants in the pots. Sorghum and sugarcane crops were used as test crops because of their Si accumulator status. Dissimilarities among soil extracting methods required a calibration based on the correlation between the obtained soil Si test values and crop response to Si fertilisers. Such calibrations were needed on which to base the recommendations for Si fertilisation.

CHAPTER 2

REVIEW OF LITERATURE

2.1. SILICON AS A BENEFICIAL PLANT NUTRIENT.

The importance of silicon (Si) to plants has been recognised since the days of Liebig (van Reuler and Prins, 1993). All plants growing in soil contain Si to some extent (Hesse, 1971), but it is found in greatest quantities in grasses such as rice and sugarcane (Tan, 1996). The exact roles of Si in plant metabolism are not completely understood (Marschner, 1986; Ma *et al.*, 2001), but a general notion is that Si addition improves plant growth (Jianjun *et al.*, 2002; Ma and Takahashi, 2002). According to (Matichenkov *et al.,* 2001), Si soil amendments influence plant growth in at least two ways. Firstly, the role they play in improved plant Si nutrition must be considered. Secondly, soil treatment with biogeochemically active Si substances optimizes soil fertility through improved water, physical, and chemical soil properties while maintaining nutrients in plant-available form.

Plants differ in their capacity to take up silicon (Marschner, 1986). Depending on their stick worth silicon content, Takahashi and Miyake (1977) distinguished plant species into *silicon accumulators* with Si content in the top (mostly leaves) higher than 1.0% and a Si/Ca ratio higher than1.0, and *non-accumulators* with Si content less than 0.5% and a Si/Ca ratio below 1.0. Intermediate plant species are those having 0.5-1.0% of Si or higher than 1.0%, but a Si/Ca ratio below 1.0 (Ma, 2004a). The positive effects of Si are usually observed in those Si accumulator crops including rice (*Oryza sativa* L.), sugarcane (*Saccharum officinarum* L.), wheat (*Triticum sativum* L.), and sorghum (*Sorghum biocolor* L.) (Plucknett, 1972; Takahashi and Miyake, 1977; Cheng, 1982; Elawad *et al.*, 1982a, 1982b; Marschner, 1986; Foy, 1992; Ma, 2004a). Furthermore, the beneficial effects of Si are usually expressed more clearly under stressed conditions (Marschner, 1986; Ma *et al.*, 2001). In addition to physiological and agronomic benefits with increased productivity, Si has the potential to significantly stimulate photosynthesis, enhance tissue strength, reduce plant transpiration, decrease the susceptibility to both abiotic and biotic diseases (Savant *et al.*, 1997b; Husby, 1998; Ma *et al.*, 2001; Ma and Takahashi, 2002). Probably, the function of Si protective agent is one of the most important for plants (Matichenkov *et al.*, 2001).

2.1.1. Possible role of silicon in plant physiology.

Silicon (Si) has been claimed as an 'essential' or 'quasi essential' nutrient element for higher plants (Xu *et al.*, 2001). Besides the rice and wheat (Foy, 1992), sugarcane also accumulates Si from soil by active uptake (Ma, 2004a). Absorption of Si by roots is in the form of silicic acid [Si $(OH)_4$] and is an active process (Hunsigi, 1993; Xu *et al.*, 2001). Three uptake modes have been suggested by Ma *et al.* (2001) and Takahashi *et al.* (1990). These are active, passive and rejective uptake, for which the responsible mechanisms are not understood. Although no biochemical role for Si in the development of plants has been positively identified, enzyme-Si complexes in sugarcane may protect and regulate photosynthesis and enzyme activity, resulting in greater sucrose production (Tisdale *et al.*, 1993).

Under field conditions, a sub-optimal Si content in sugarcane leaves is associated with a drastic reduction in growth and a typical visible deficiency symptom or 'leaf freckling' on leaf blades (Clements, 1967; Elawad *et al.*, 1982b; Fageira *et al.*, 1991). Nevertheless, the requirement for Si as a mineral nutrient for rice vegetative growth seems to be extremely low, and a high Si requirement appears to be confined to the reproductive stage (Table 2.1). The major physiological functions of Si include reduction of evapotranspiration, increasing the root oxygen supply by strengthening air-canal walls, interactions with phosphorus and the amelioration of metal toxicity (Jones and Handreck, 1967). Si deficiency also inhibits the growth of rice; by increasing empty grains that significantly reduces yield (Ma and Takahashi, 2002). Under heavy application of nitrogen fertilizers, the damage due to brown spot and blast was alleviated by Si application (Marschner, 1986; Ma and Takahashi, 2002).

Treatment at vegetative stage Treatment at reproductive stage		- Si - Si	+Si - Si	- Si + Si	+ Si + Si
% SiO_2 (Shoot dry weight)		0.05	2.20	6.90	10.40
Dry weight (g/pot)	Roots	4.00	4.30	4.20	4.70
	Shoots	23.50	26.50	31.00	33.60
	Grain	5.30	6.60	10.30	10.80

Table 2.1. Effect of silicon supplied at different growth stages on growth and grain yield of wetland rice (from Takahashi and Miyake, 1977; Marschner, 1986).

Silicon application can significantly reduce the severity of ring spot by an average of 67%, though the severity of sugarcane rust was not affected by silicate materials application (Raid *et al.*, 1992). Jones and Handreck (1967) associated increased resistance to borer to the promotion of stronger stalks from increased uptake of Si. Takahashi cited by Meyer and Keeping (2000) reported that Si physiologically promotes ammonium assimilation and restrains the increase in soluble nitrogen compounds, including amino-acids and amides that are instrumental for the promotion of hyphae. Xu *et al.* (2001) found that Si deprivation can cause physiological abnormalities in wheat.

2.1.2. Yield increase.

Silicon has been considered an essential nutrient for rice (*Oryza sativa* L.) and sugarcane (*Saccharum officinarum* L.) crops that respond strongly to Si application (Ross *et al.*, 1974; Korndörfer and Lepsch, 2001; Wang *et al.*, 2001). Since D'Hotman de Villiers (1947) obtained improved cane yields due to application of finely ground basalt in Mauritius, a number of studies have been carried out worldwide on the potential agronomic benefits of Si in sugarcane production. Significant responses to silicon treatment in both cane and sugar yields have been reported in several countries (Meyer and Keeping, 2000). Increased yields following silicate applications are attributable to increases in plant size, plant height, stem diameter and the number of millable stalks (Hunsigi, 1993; Korndörfer and Lepsch, 2001).

In Japan, Ma and Takahashi cited by Ma (2004a) obtained 30% increases in shoot dry weight (except the grain) with Si supplied rice plants and a grain dry weight increase more than double that of Si-free plants. A previous study by Ma *et al.* (1989) revealed that the most effective time of Si application for increased rice yield is during the reproductive stage when dry weight production and Si uptake are most vigorous.

In Hawaii, Clements (1965) and Ayres (1966) reported the best yield increases in sugarcane to applied silicate slag in soils with low concentrations of Si (Figure 2.1). Fox *et al.* (1967b) obtained significant increases in yield of cane grown on highly weathered soils with exceptionally low total and soluble Si levels. Long-term yield responses of sugarcane to calcium silicate slag application in Florida (Anderson *et al.*, 1991) were great enough to recommend calcium silicate routinely whenever soil tests indicate the need for Si (Korndörfer and Lepsch, 2001).

In Florida, Gascho and Andreis (1974), Gascho (1979), Anderson *et al.* (1986) and Raid *et al.* (1992), observed significant positive responses of sugarcane to calcium silicate application. In Mauritius, Ross *et al.* (1974) observed a marked increase in sugarcane yield with calcium silicate application.

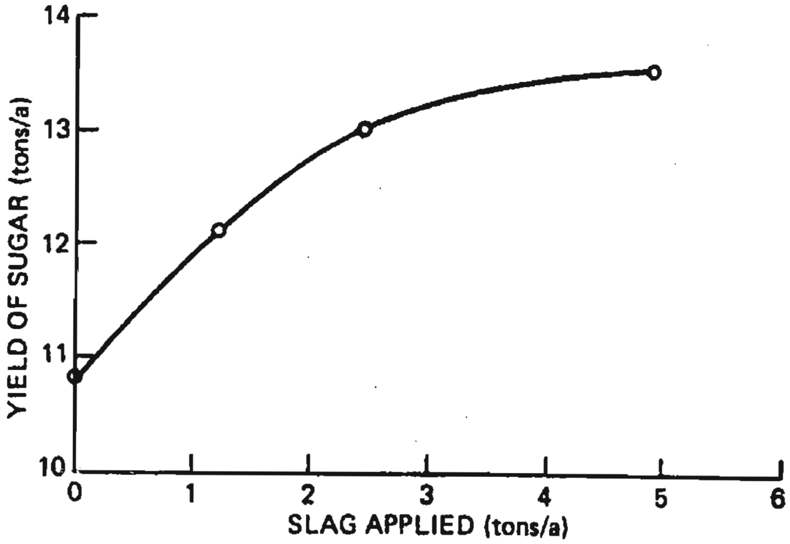

Figure 2.1. Effect of electric furnace slag on yield of sugar from sugarcane grown on an aluminous humic ferruginous latosol in Hawaii. Mean results for plant and ratoon crops combined (from Ayres, 1966; Tisdale *et al.*, 1993).

In South Africa, du Preez (1970) and Moberly (1974) reported yield responses to calcium metasilicate applications that also increased soil Si levels, while Allorerung (1989), indicated increased cane and sugar yields in the plant and ratoon crops using steel slag applied on a fine textured acid soil. In Australia, Hurney (1973) and Haysom and Chapman (1975) obtained positives responses to application of calcium silicate in sugarcane grown on acid soils. Similar results have been reported in Taiwan (Shiue, 1973) and Puerto Rico (Samuels, 1969). Few reports have been published in Indonesia, Malaysia, and Taiwan (Alvarez and Datnoff, 2001).

As for many other nutrient elements (Figure 2.2), the results of the trials to date indicate that there may be a critical level of silicon in the soil below which yields may be limited and hence, some measure of its availability becomes desirable (Ayres, 1966; Clements, 1967; Fox *et al.*, 1967b; Haysom and Chapman, 1975).

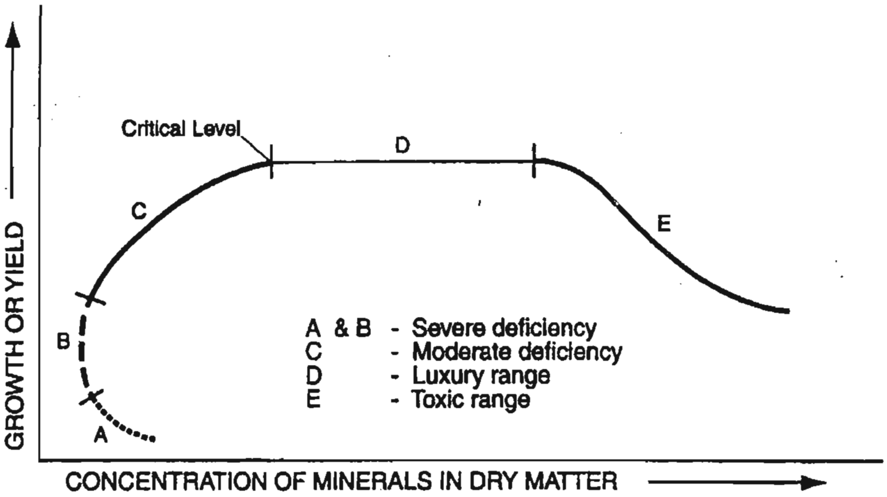

Figure 2.2. General relationship between plant growth or yield and elemental content of the plant (from Fox *et al.*, 1967b; Martin-Prevel *et al.*, 1987; Tisdale *et al.*, 1993; Campbell, 1998; Van Erp and Van Beusichem, 1998; Jones, 2001).

The principle is that as plant nutrient concentration increases towards the critical level, plant yield increases. Above the critical level, the plant contains sufficient levels for normal growth and can continue to absorb the nutrient without increasing yield. Excessive absorption of a nutrient or element can be toxic to the plant and reduce yield or cause plant death.

2.1.3. Stimulation of plant photosynthesis.

The observed responses to Si have been attributed to many factors affecting plant growth, including photosynthesis (Deren, 2001). Under field conditions, Si deposited in the leaf blade keeps the leaf erect. In dense plant stands and when nitrogen fertilizers are heavily applied, Si treatment reduces mutual shading at its minimum and stimulates photosynthesis by improving light interception (Marschner, 1986; Ma and Takahashi, 2002). Anderson *et al.* (1991), reported an improved cane plant photosynthesis through better use of sunlight following calcium silicate slag application on an Everglades' (Florida) histosol. Al-aghabar and Zhu (2002) reported increased photosynthesis parameters and chlorophyll content with Si treatment on plants exposed to salt stress.

Under optimum growth conditions, the effect of Si on photosynthetic rate is small (Ma and Takahashi, 2002), but under water-stress conditions, the photosynthetic rate was reported to be higher in plants supplied with Si probably due to the Si-induced decrease of transpiration rate (Matoh *et al.*, 1991). Kaufman *et al.* (1979) associated the response to Si to increased photosynthesis by facilitating the transmission of light. Freckled plants are considered to be less photosynthetically efficient because freckling reduces the active leaf area for photosynthesis (Meyer and Keeping, 2000).

In Florida, Elawad *et al.* (1982a, 1982b) indicated that application of silicate materials to muck soil (Histosol) increased leaf chlorophyll and corrected cane leaf freckling. There are possibilities that Si might protect photosynthetic mechanisms in plants under extreme changes of moisture stress. Alexander (1973) revealed that pre-treating leaves might prevent the severe disruption of carbon assimilation in plants with aqueous Si solution enabling green foliage and normal sucrose content to be retained.

2.1.4. Increased plant resistance to stress.

Under field conditions, sugarcane plants are subject to a number of biotic and abiotic stresses. Biotic stresses may be factors such as pest and plant diseases, whereas abiotic stresses may be soil water shortage, cold temperature, salinity and heavy metal toxicity (Savant *et al.,* 1999). Some practical solutions to these stress problems may come from Si fertilizers that may improve sugarcane yields by alleviating these stresses (Ma and Takahashi, 2002). Silicon, that is known to be deposited at the external surface of cell walls of plants, forms a mechanical barrier to penetration by pathogens. It is likely that plants with a higher Si content in their tissue will have a higher level of resistance to pests, by interfering in the feeding of larvae by damaging their mandibles (Takahashi, 1996).

An adequate silica content may increase the resistance of some cereals to powdery mildew (*Erysiphe graminis*) and of rice to blast (*Pyricularia oryzae*), and to some stem borers such as *Chilo suppressalis*, of sorghum to central shoot fly (*Atherigone indica*) and wheat to Hessian fly (*Mayetiola destructor*) (Wild, 1986). Elawad *et al.* (1985) observed an increased resistance of sugarcane to stem borer (*Diatraea saccharalis F.*) with Si nutrition. Ayres (1966), Fox *et al.* (1967b) and Elawad *et al.* (1982b) observed that leaf freckling symptoms in sugarcane disappeared following Si treatment.

Foliar application of Si has been reported to be effective in inhibiting powdery mildew development on leaves from cucumber and grape plants (Ma, 2004a). Si applied on leaves may deposit on their surface and play a similar role as Si taken up by roots. This approach may be useful for crops with a passive or rejective Si uptake mode. Datnoff and Rutherford (2003) found that when soils low in plant available Si were amended with soluble sources of Si, the resistance of bermuda grass against leaf spot caused by *B. cyanodontis* could be enhanced. This also suggests that fungicides might be better managed if used in combination with Si for controlling diseases in turfs.

It has been shown that calcium silicate may neutralise soil acidity with the formation of silicic acid that could diminish the solubility of potentially toxic elements such as Mn, Fe and Al (Savant *et al.*, 1999). The Mn/SiO_2 ratio in plant tissue is an important indicator of Mn toxicity (Halais and Parish, 1964). The lower the ratio the better plants will grow (Liang *et al.*, 2001). According to Marschner (1986), Si does not appear to affect Mn uptake, but rather the distribution of Mn in plant tissues. When Si levels in tissues are low, Mn tends to be distributed non-homogeneously with accumulation to toxic levels as dark neurotic spots in leaves. Husby (1998) and Ma (2004a) also agreed and pointed out that sufficient levels of Si caused Mn to be more evenly distributed in plant tissues, thereby preventing areas of toxic accumulation in leaves.

Freeze damage during the winter in certain subtropical areas (Florida, and South of Brazil) is considered to be a major constraint to sugarcane production (Savant *et al.,* 1999). In addition to cultivation of cold tolerant varieties, increased tolerance to freeze damage of sugarcane has been noted in areas treated with calcium silicate (Ulloa and Anderson cited by Savant *et al.*, 1999). Under field conditions, Si deficient plants may be subjected to water stress as a result of excessive leaf transpiration (Savant *et al.*, 1999).

Si nutrition may reduce excessive leaf transpiration, playing then an important role in the water economy for the plant (Ma *et al.*, 2001). Another effect of increased plant Si content reported in literature, is the increased mechanical strength of plant tissue. In dense stands of sugarcane, Si may improve leaf erectness and then decrease mutual shading and susceptibility to lodging (Marschner, 1986; Hesse, 1971; Hunsigi, 1993; Savant *et al.*, 1999).

2.1.5. Increased phosphorus (P) nutrition in plants.

In phosphate-poor soils, the availability of phosphorus (P) is controlled by the levels of Mn and Fe in plants, due to P affinity with metals such as Fe and Mn (Ma and Takahashi, 2002; Ma, 2004a, 2004b). In such soils, plants become very susceptible to disease, and take up excessive amounts of Fe and Mn (Hesse, 1971). Under field conditions, the addition of Si is reported to increase soil P availability, and this can result in improved plant growth and increased crop yields (Hesse, 1971; Prasad and Power, 1997). According to Savant *et al.*, (1997a), Ma *et al.* (2001), Ma and Takahashi (2002) and Ma (2004a, 2004b), the greatest beneficial effect of Si on plant growth under P-deficiency stress may be attributed to the enhanced availability of internal P through higher P/Fe and P/Mn ratios in the shoots due to decreased Fe and Mn uptake. Thus, there is indirectly improved P utilisation within the plant.

Experiments at Rothamsted Experimental Station in England as reported by Berthelsen (2002), showed enhanced yield of barley following the addition of sodium silicate to nitrogenous fertilizers. Such beneficial effects of Si were previously explained as a potential substitute of Si for P or an improvement of P availability in soil. However, later experiments showed that Si is unable to affect P availability in soil (Ma, 2004a, 2004b). In the soil solution, silicon is present in the form of silicic acid or molecular form of silica (SiO_2), which does not undergo dissociation at a pH of less than 8.5 to 9.0 (Figure 2.3) (Tan, 1994; Ma, 2004a, 2004b). Therefore, it is unlikely that interaction between silicic acid and phosphate (anionic form) occurs in soil. Accordingly, Si is unable to affect P availability in the soil.

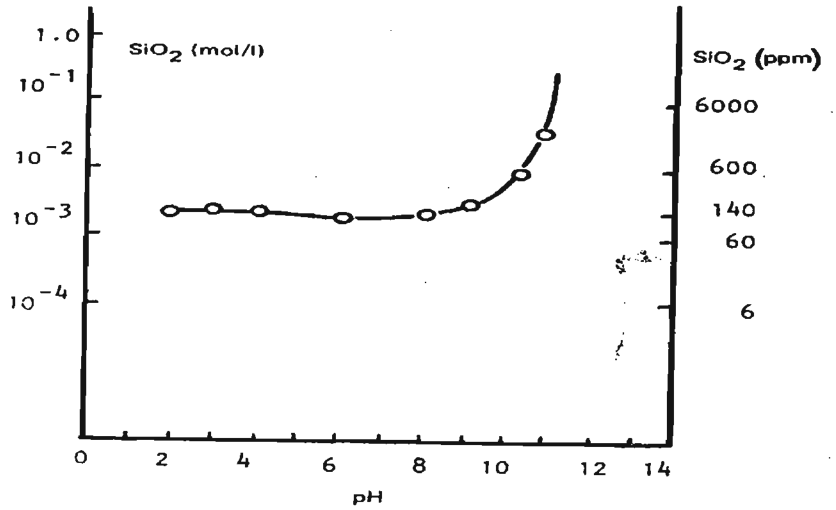

Figure 2.3. Solubility of silica as related to pH (from Tan, 1994).

Even though excess P stress hardly occurs in natural soils, when P fertilizers are heavily applied or when high P concentration is supplied in nutrient solution culture, excess P may cause chlorosis or necrosis in leaves probably due to decreased availability of essential metals such as Fe and Zn. Silicon can alleviate P excess induced damage by decreasing excessive P uptake, resulting in a decreased internal inorganic P concentration (Ma and Takahashi, 1990). Applied Si fertilizers usually exhibit very good adsorption ability and the deposition of Si in the roots may be responsible for the decreased uptake of P in the medium containing a high concentration of P (Ma *et al.*, 2001; Ma and Takahashi, 2002; Ma, 2004a). Lindsay (1979) and Matichenkov and Ammosova (1996) showed that the reaction of displacing phosphate-anion by silicate-anion from slightly soluble phosphate and formation of corresponding silicates is possible. The process starts with an increase in concentration of monosilicic acid in the soil solution, along with its adsorption on slightly soluble phosphates of Ca, Al, Fe and Mn. There is then an exchange of phosphate-anion by silicate-anion as follows:

$CaHPO_4 + Si(OH)_4 \rightarrow CaSiO_3 + H_2O + H_3PO_4$

$2Al(H_2PO_4)_3 + 2Si(OH)_4 \rightarrow Al_2Si_2O_7 + 6H_3PO_4 + H_2O$

$2FePO_4 + Si(OH)_4 + 2H^+ \rightarrow Fe_2SiO_4 + 2H_3PO_4$

These reactions are followed by desorption of phosphate-anion leading to an increasing content of phosphorus in the soil solution (Matichenkov and Bocharnikova, 2001).

Reports on the effects of Si on P availability in plants are encouraging, but explanations for this effect vary. All the facts suggest that Si-rich materials can be used for reducing P leaching (Matichenkov and Ammosova, 1996; Matichenkov and Bocharnikova, 2001) and for keeping applied plant nutrients in plant-available forms (Savant *et al.*, 1997b). In greenhouse experiments, Matichenkov *et al.* (2002) reported greater plant growth responses from Si slag-treated soil than from P fertilization. Savant *et al.* (1997b) and Savant *et al.* (1999) reported increased water-soluble P with increasing application rate of silicates to soils low in soluble Si. In Florida, Elawad *et al.* (1982b), found that silicate materials do not solubilize P from soil, but that only materials that contain Si increase available soil P and plant P. The increased P content was attributed to better availability of soil P and/or enhanced mobility of P from the roots to the stems. The suggestion is that Si might not reduce the formation of insoluble calcium phosphates, but rather the adsorption of P by freshly precipitated Al and Fe hydroxides that are effective in Si sorption.

2.1.6. Other silicon benefit effects.

Under field conditions, there are numerous other benefits of Si nutrition in sugarcane that have been put forward (Savant *et al.*, 1999). One of these benefits is a possible increased resistance to UV-B radiation that is higher near the tropics where sugarcane is largely produced. Si may play an important role in protecting sugarcane plant leaves from ultraviolet radiation damage by filtering out the harmful ultraviolet rays (Savant *et al.*, 1999; Husby, 1998; Ma and Takahashi, 2002).

Miller and Gardiner (1998), in an attempt to reduce the amount of plant damage from soluble salts, by adding soluble silica, suggested that Si causes reduction in membrane permeability, thus reducing sodium uptake. Some other studies have observed increased plant's tolerance to salt due to added silica, but they have not suggested any possible reasons (Bohn *et al.*, 1985; Tamdan, 1994). Al-aghabar and Zhu (2002) reported increased plant growth in areas of high soil salinity due to addition of Si to soils.

2.2. SILICON SUPPLY TO RICE AND SUGARCANE SOILS.

The natural sources of silicon for plants are irrigation water and soil (Ma and Takahashi, 2002). According to Epstein (2001), under the influence of chemical and biological weathering, all soil minerals release Si that becomes a "solute" in the soil solution. The amount of Si released varies with the soil parent material and the geology of the river basin (Ma and Takahashi, 2002). A negligible quantity of Si comes from precipitation, rainfall, snow, capillary ascension from water table, or by aeolian, alluvial or any other deposition of silicate material at the soil surface. Silicon can also be supplied to plants through organic and inorganic fertilizer application.

2.2.1. Silicon supplies from soil.

As related by Bohn *et al.* (1985) and Tan (1994), soluble silicon taken up from the soil solution originates from weathering of primary and secondary silicate minerals under the influence of climate and biological activity. Many of the materials released during weathering are elements that can serve as plant nutrients (Ca, K, Mg, Fe and P) and can, therefore, improve soil fertility (Tan, 1994).

One of the chemical reactions important in breakdown of primary minerals is hydrolysis. It involves the splitting of water-molecules with other substances to form hydroxides and other new substances that usually are more soluble than the original material (Miller and Donahue, 1990; Tan, 1994; Sparks, 1995). According to Bohn *et al.* (1985); Wild (1993) and Tan (1994), hydrolysis of feldspars forms illitic types of clays as follow:

$$3KAlSi_3O_8 + 2H^+ + 12H_2O \leftrightarrow KAl_3Si_3O_{10}(OH)_2 + 6H_4SiO_4 + 2K^+$$

However, in the subtropics and tropical regions, hydrolysis of orthoclase produces kaolinitic types of clays (Trudgil, 1988).

$$2KAlSi_3O_8 + 2H^+ + 9H_2O \leftrightarrow H_4Al_2Si_2O_9 + 4H_4SiO_4 + 2K^+$$

The second example of chemical reaction that releases silicic acid in the soil solution is by hydration. By definition, hydration is an adsorption of water molecules to a solid mineral or a salt. The following example illustrates the hydration of quartz to form silicic acid (Bohn *et al.*, 1985; Miller and Donahue, 1990).

$$SiO_2 + 2H_2O \rightarrow Si(OH)_4$$

The hydration of quartz above appears to be the simplest source of silicic acid in soils (Epstein, 2001).

2.2.2. Silicon supplies from irrigation water.

Silicon (Si) is present in natural waters as suspended particles of silica (SiO_2), in colloidal and polymeric forms, and as soluble SiO_2 (Rayment and Higginson, 1992). Soluble silica comprises orthosilicic acid [$Si(OH)_4$]. The concentration of dissolved silica in natural water is usually very small, ranging from 1 to 30 mg SiO_2 L^{-1}, although higher levels (> 100mg L^{-1}) may occur. Seawater is usually low in silicon content because of its use by marine organisms in the formation of their skeletons and shells (Tan, 1994). Irrigation water could be a potential source of Si for sugarcane, because the following forms of Si may occur in natural waters: ionic and molecular Si, aggregate Si (as colloid, solid and/or gel), Si adsorbed onto sesquioxides, organic Si-complexes (humites), metal-Si complexes and in living organisms, plankton and detritus, etc. The monomeric form of Si (H_4SiO_4), has been recognized to be the main form (Tan, 1994; Savant *et al.*, 1999). Soluble Si may also be introduced in the soil solution by runoff and capillary rise from the water table (Marshall, 1977; Tan, 1993).

The mean dissolved Si in concentration of most river waters seem to vary from 4.7 to 16,4 ppm Si (McKeague and Cline, 1993a, 1963b). Fox *et al.*, (1967a) and Savant *et al.* (1999) found that rainwater contained less than 0.2 mg dm^{-3} Si that was considered not enough to be of agronomic importance. In Hawaii, mountain water at about 300m contains only 2.5mg dm^{-3} Si, whereas irrigation water pumped from wells near sea level contained 30mg dm^{-3} of Si. Savant *et al.* (1997a) found that the Si supply through irrigation water at times may be substantial and may influence Si management of irrigated rice. The increase of irrigated rice crop yields in Japan was partly attributed higher Si/Al ratio in soil colloids. The soluble Si content of river water tends to be high in catchment areas and, when used for irrigation, such water may benefit the rice crop supplying Si and eventually increasing and/or sustaining yields.

2.2.3. Silicon supplies from compost and plant recycling.

Before the introduction of silicate fertilizers for rice and sugarcane soils, the main source of silicon supply was compost that on average contained about 5% SiO_2 (Ma and Takahashi, 2002). Composting is defined in general terms as the practice of employing biological mineralisation of organic wastes to humus or humus-like substances used as soil amendments or fertilizers (Rechcigl, 1995). According to the same author, the beneficial effects of compost application to crops are due to improved physico-chemical properties of soil and nutrient enhancement that result in increased crop quality and yield. From 1955, slag containing about 25% SiO_2 was introduced as a silicate fertilizer and reliance on compost as a Si source gradually decreased. The slow release of Si from compost was replaced by the fast release of Si from inorganic Si fertilizers (Ma and Takahashi, 2002). However, Kang and Jung (2002) reported that in Japan, rice straw is still returned to paddy soil as compost for the supply of nutrients.

Plant recycling is another option available for supplying Si to rice and sugarcane soils (Savant *et al.*, 1997b; Savant *et al.*, 1999). Positive effects on the growth and yield of rice and sugarcane have been reported following the application of trash, bagasse, ash, filter-press cake, furnace bagasse and rice hulls. These plant materials are generally applied as sources of organic carbon, increase the availability of N, P, and K in soils and improve soil physical and/or chemical properties. However, some of the effects observed could be also due to Si supplied through these plant materials (Savant *et al.*, 1997b, Savant *et al.*, 1999; Viator *et al.*, 2002).

For many years, in cane growing areas such as South Africa and Australia, more growers were burning rather than trashing their cane fields before harvesting, focusing on ease of cane removal from the field and greater tonnage output per cutter (Robertson and Thorburn, 2001; van Antwerpen *et al.*, 2001). Surveys conducted in South Africa by Schroeder *et al.* (1994), Meyer *et al.* (1996) and van Antwerpen and Meyer (1996) linked soil acidification and salinisation to reduced soil organic matter due to trash burning. Follow up investigations of this phenomenon in South Africa by Meyer *et al.* (1996), van Antwerpen *et al.* (2001) and Graham *et al.* (2002), and in Australia by Robertson and Thorburn (2001) recommended green cane harvesting to replenish soil organic matter levels. Where trash is retained on the soil surface, cultivation is greatly reduced, allowing nutrients and organic matter to accumulate in the soil. This means that nitrogen fertilizer application can probably be reduced, the soil surface stabilized, infiltration of water increased, while run off and erosion are reduced.

2.2.4. Silicon supplies from silicate fertilizers.

Silicate fertilizers are generally Si-rich inorganic substances that increase the content of plant-available Si compounds (monosilicic acid) in the soil (Matichenkov and Bocharnikova, 2001). In most rice and sugarcane producing regions of the world, application of silicate materials has entered experimental and commercial practices for Si fertilization of rice and sugarcane (Berthelsen *et al.*, 2001b; Snyder, 2001). Matichenkov and Bocharnikova (2001) believe that Si fertilization is needed on all soils, except for unique soils with an abnormally high level of Si, such as recent volcanic soils. Studies conducted in Australia by Berthelsen *et al.* (2001b) have highlighted the fact that Si is an important component of the production system and should be included in any fertilizer strategy associated with cane production. Certain characteristics such as a high content of soluble silicon, physical properties that are conducive to mechanized application, ready availability and low cost are some of the factors that characterise an acceptable Si source for agriculture (Gascho, 2001).

Si fertilization mostly with by-products is generally extremely expensive (Alvarez and Datnoff, 2001) for soil applications at rates suitable for supplying Si nutrition (Gascho, 2001). Despite the high cost of Si material, it is obvious that applying a calcium silicate source to sugarcane does pay since the returns outweigh the cost of the material (Alvarez and Datnoff, 2001).

For research purposes, a number of silicon sources have been evaluated for use in agriculture as silicate fertilizers: calcium silicate (Ayres, 1966; Khalid *et al.*, 1978b; Keeping and Meyer, 2002); TVA slag and Portland cement (Fox *et al.*, 1967b; Elawad *et al.*, 1982a, 1982b); filter cake (Bishop, 1967); silene F (pure calcium silicate $CaSiO_3$), amcor slag (a blast furnace slag), sodium metasilicate (Na_2SiO_3), Hawaiian slag (a metasilicate slag) and Portland cement (Du Preez, 1970; Moberly, 1974; Elawad *et al.*, 1982a, 1982b); calcium metasilicate, slagment and Hulsar lime (Moberly, 1974); Florida slag (Elawad *et al.*, 1982a, 1982b); mill ash, mud ash, cement, rock dust and calcium silicate slag (Snyder *et al.*, 1986; Anderson *et al.*, 1991; Berthelsen *et al.*, 2001a; SASEX, 2002); fly ash and cement (SASEX, 2002). Savant *et al.* (1997b) and Savant *et al.* (1999) have also published reviews on silicon sources as fertilizers respectively for rice and sugarcane.

These silicon sources vary in their composition (Table 2.2) and their silicon supplying value depends on relative amounts of their soluble basic constituents such as dicalcium silicate, monocalcium silicate, and sodium silicate (Tisdale *et al.*, 1993; Gascho, 2001).

Silicon sources	**Formula**	**Silicon content (%)**
Calcium silicate slag	$CaAl_2Si_2O_8$	18 to 21
Calcium metasilicate	$Ca(SiO_3)_2$	31
Sodium metasilicate	$NaSiO_3$	23
Wollastonite	$CaSiO_3$	23.1

Table 2.2. The common Si fertilizers with their silicon content (from Hunsigi, 1993; Tisdale *et al.*, 1993; Husby, 1998; Savant *et al.*, 1999 and Gascho, 2001).

Of all these sources, calcium silicate slags have been shown as the most effective silicon fertilizers (Snyder *et al.*, 1986) because of their high silicon content (211 g kg^{-1}) (Savant *et *al.,* 1999). However, as by-products of industry, slags are too costly for general use (Savant *et al.,* 1999), and may not be the silicon source of choice everywhere (Gascho, 2001).

In Australia, an assessment of silicate products in trials conducted by Berthelsen (2001b) suggested that there were some locally available products that were suitable as sources of Si. Results from a similar assessment in South Africa (SASEX, 2002) confirmed that some of the local sources were as effective as the imported sources in supplying silicon to the plant. The challenge is then to find the best source for a given situation, location and soil type (Savant *et al.*, 1997b; Gascho, 2001).

2.3. SOIL EFFECTS OF SILICON.

Although the element Si is second to oxygen amongst the most abundant elements known (Matichenkov *et al.*, 1999; Husby, 1998; Ma, 2004b), soluble and available Si in soil is continuously lost through leaching and plant uptake (Savant *et al.*, 1997a; Savant *et al.*, 1999; Bohn *et al.*, 2001). Under high leaching environments that are characteristic of tropical regions, soils undergo significant weathering that result in stripping of bases and declining charge capacity (Berthelsen *et al.*, 2001a). The consequences of natural weathering are acidification and 'desilication' of soils.

According to Berthelsen *et al.* (2001a), 'desilication' is a natural process of soil pedogenesis favoured in humid tropical environments as a direct consequence of the high rainfall and temperature associated with those regions. Easton (1969) associated 'desilication' with alumination and ferration where aluminium and iron compounds accumulate after the removal of silica from the soil profile under conditions of acid weathering and free drainage. Consequently, soils that have undergone significant weathering may have sub-optimal Si levels for sugarcane production.

The properties of Si-deficient soils include low total Si, high exchangeable Al, low base saturation and low pH (Tisdale *et al.*, 1993). Accordingly, Easton (1969), Tisdale *et al.* (1993) and Husby (1998) reported that tropical soils consist largely of Al and Fe oxides that remain after Si is leached, leading to a high phosphate fixing potential. The beneficial effects of Si added to these soils may be attributed to several factors including correction of soil toxicities arising from high levels of available Mn, Fe and active Al. Easton (1969) and Ma and

Takahashi (2002) reported that the role of silica applied to soils that have undergone desilication, include the displacement of phosphates from soil colloids, thereby enhancing the availability of phosphorus in the soil solution.

According to Savant *et al.* (1997b) and Matichenkov *et al.* (1999), most of the highly weathered soils such as Entisols, Alfisols and Spodosols are characterized by extremely low contents of plant-available Si. Quartz (SiO_2) is the main mineral component in these soils. However, this inert form of Si has a poor adsorption capacity, low water holding capacity and very low solubility and, hence, does not contribute significantly to the labile pool of soluble Si (Tan, 1994). Matichenkov *et al.* (1999) reported increased water holding capacity and raised adsorption capacity of sandy soils following silicon fertilizer application, and that was attributed to silicon fertilizers which usually possess a very large surface area.

Multiple laboratory and field experiments have shown that the use of silicon fertilizers is effective in reducing aluminium toxicity. Lindsay (1979), Matichenkov *et al.* (1999), and Matichenkov and Bocharnikova (2001) postulated five different mechanisms for Al toxicity reduction in which Si-rich compounds are involved. Firstly, silicate materials may increase the pH level of acid soils. Secondly, monosilicic acids can be adsorbed by aluminium hydroxides impairing their mobility. Thirdly, soluble monosilicic acid can react with ions of aluminium to form slightly soluble substances. Fourthly, Si-rich compounds have a strong adsorption capacity for mobile aluminium on silicate surfaces. Fifthly, mobile silicon compounds can increase plant tolerance to aluminium. All these mechanisms can work simultaneously, but usually one mechanism will be the most prevalent.

A "heavy metal-contaminated" soil is a common phrase in the environmental literature (Bohn *et al.*, 2001). Heavy metal ions may be toxic to plants at concentrations higher than those in native soils. Heavy metals can occur to some extent in most soil types that have a large capacity for assimilating such toxic constituents. Heavy metals may be transmitted to the food chain and because of their toxicity, they present a threat to crop production, and to animal and human health (Korentajer, 1991; Logan, 1992; Ginster, 1993). According to Lindsay (1979), Matichenkov and Bocharnikova (2001), and Sangster *et al.* (2001), silicon compounds can act as a powerful ameliorator of some of the deleterious effects of aluminium and a number of heavy metals on the growth of higher plants such as sorghum, barley, corn, wheat and rice. Monosilicic acids are able to combine with heavy metals (Cd, Pb, Zn, Hg, and others) in soluble complex compounds and weakly or slightly soluble heavy metal silicates. As a result, a low concentration of monosilicic acid in the solution leads to formation of complexes of a heavy metal with a silicic acid anion (Matichenkov and Bocharnikova, 2001):

$$H_4SiO_4 + Zn^{2+} = ZnSiO_4^{2-} + 4H^+$$

$$H_4SiO_4 + Pb^{2+} = PbSiO_4^{2-} + 4H^+$$

A high concentration of monosilicic acids may then cause complete precipitation of heavy metals with weak formation of soluble silicates.

2.4. IMPORTANCE OF MEASURING SOIL SILICON.

Silicon plays an important role in the growth of plants that take it up in different amounts depending on the soil and on the plant species (Marschner, 1986). Silicon has been found necessary for the normal growth of rice and sugarcane (Fox *et al.*, 1967b) and other plants such as wheat, barley, sorghum, beet and sunflower (Foy, 1992). With the exception of potassium, sugarcane is known to take up more Si than any other mineral nutrient (Meyer and Keeping, 2000; Matichenkov *et al.*, 2002). A 100 tonnes ha^{-1} crop of cane can remove up to 300 kg ha^{-1} of Si (Meyer and Keeping, 2000). Samuels (1969) gave an amount of 379kg ha^{-1}, whereas Ross *et al.* (1974) estimated it at 408kg ha^{-1} of Si. Anderson *et al.* (1991), Savant *et al.* (1997a) and Savant *et al.* (1999) reported that the removal of Si from soil could be more important (500kg ha^{-1}) in intensively cultivated areas. In an irrigated cane crop, Si accumulation was estimated at up to 400kg ha^{-1} in a 12-month crop cycle (Meyer and Keeping, 2000). As a result of the magnitude of Si exported, a temporary depletion of bio-available Si in soils could be a possible factor for the declining yields in ratoon crops. This implies an apparent need for an adequate Si supply in order to maintain good yields (Matichenkov and Bocharnikova, 2001).

Since sugarcane is one of the most common crops in KwaZulu-Natal and often grown on the same land for a prolonged period (Qongqo and Antwerpen, 2000), this mono-cropping practice leads to potential soil degradation (Meyer *et al.*, 1996) mainly through removal of nutrients. For sustained crop production, plant available nutrients need to be present in adequate amounts in the soil (Prasad and Power, 1997). However, many agricultural soils of the world are deficient in one or more of the essential nutrients to support healthy and productive plant growth (Baligar *et al.*, 2001). Furthermore, although Si is a major component of soil, the solubility of its compounds is not sufficient to supply Si to either rice or sugarcane that require large amounts for healthy growth (Ma and Takahashi, 2002).

In terms of sugarcane nutrient element needs in South Africa, much is known about the major nutrients (N, P and K), secondary nutrients (Ca, Mg and S) and micronutrients (Fe, Mn, Cu and Zn) (Meyer *et al.*, 1999), whereas investigations that included Si in the programme have only been under way since 1998 (SASEX, 1999). Under field conditions, a deficiency of Si in sugarcane is associated with a drastic reduction in growth and typical white leaf freckling on leaf blades directly exposed to full sunlight (Elawad *et al.*, 1982a; Marschner, 1986; Hunsigi, 1993). Subsequently, Wang *et al.* (2001) suggested that the application of Si fertilizers to sugarcane could improve nutritional balance between N, P, K and Si and increase both cane and sugar yield. However, Huang (1997) reported a negative effect on sugarcane production from over application of calcium silicate probably affecting soil pH.

To avoid nutrient excess or deficiency for yield optimization, Hunsigi (1993) proposed to quantify the fertilizer requirements of sugarcane and to use a mid-term correction or fine tuning to achieve desired yields. According to Leeper and Uren (1993), the way to find whether a soil needs any treatment adjustment is to try to find what nutrients are deficient, either by tests with pots in a green house, or by laboratory methods, where soil analysis is essential to determine the supplemental nutrient requirement of a crop. The objective of soil testing is to obtain a value that will help to predict the amount of nutrient needed to supplement the supply in the soil (Jones, 1998). To predict the nutrient needs of crops, the soil test must be calibrated against nutrient rate experiments in the field and in the greenhouse. Yield responses from various rates of applied nutrients can be then related to the quantity of available nutrients in the soil as indicated by the soil test (Tisdale *et al.*, 1993).

2.5. PREVIOUS STUDIES ON SILICON USE IN SUGARCANE.

Although Si has been recognized as an important plant nutrient since the days of Liebig (Hunsigi, 1993), its deficiency in crops was relatively unknown for many decades (Meyer and Keeping, 2000). It was discovered by D'Hotman de Villiers (1947) in Mauritius that supplying Si compounds to sugarcane soils might benefit cane growth. Highly weathered sugarcane soils were rejuvenated by a finely crushed basalt application. In subsequent studies based on soil and plant analysis, Halais and Parish cited by Meyer and Keeping (2000), confirmed that the soluble Si in basalt caused favourable yield increases. Since then, there has been a significant amount of research worldwide into the role of Si in sugarcane production systems (Berthelsen *et al.*, 2001b).

In Hawaii, Ayres (1966), reported significant yield responses in cane from calcium silicate application to soils with a high concentration of soluble Al. He concluded that there is a level of soil Si below which optimum yields cannot be obtained. Clements (1965), covering a larger number of Si amendments, observed that yield improvement could be obtained by using various other Si compounds. He concluded that the main factors probably responsible for the yield increases were decreased levels of Al and Mn, and increased levels of Si in the soil.

Fox *et al.* (1967b) obtained significantly increased cane and sugar yields through application of slag on highly weathered Humic Ferruginous Latosols in Hawaii. The large response was consistent with exceptionally low Si analysis for that soil. The low plant Si uptake corresponded closely with the findings of Clements (1965). Leaf freckle (Clements, 1967), which was very severe in the absence of applied silicate, was corrected by using slag. Fox *et al.* (1967b) found that sugarcane was likely to be deficient in Si if the water extractable soil Si was below 20ppm.

In Florida, Anderson *et al.* (1991), observed a long-term yield responses in sugarcane to a single application of calcium silicate slag in some low-Si soils of the Everglades. Gascho and Andreis (1974) conducted tests on soils with low levels of water-soluble Si, with a history of low sugarcane yields with pronounced leaf freckling. The results supported the hypothesis that Si is beneficial and possibly essential for sugarcane since it was the only element measured that correlated with yield of cane and sugar in all experiments. In a similar study to evaluate the response of field-grown sugarcane to various rates and sources of Si, Elawad *et al.* (1982a) indicated that addition of silicate materials to low-Si soils was necessary for satisfactory cane and sugar yields. Elawad *et al.* (1982b) reported that silicate materials increased leaf chlorophyll and corrected sugarcane leaf freckling.

In Australia, the early studies of Hurney (1973), Haysom and Chapman (1975), and Ridge *et al.* (1980), primarily focused on quantifying agronomic growth responses to Si-based materials. Berthelsen *et al.* (1999), focusing on the potential role of Si as a limiting factor in the sugarcane production system, proposed that the occurrence of the condition known as "yield decline' could in part be related to sub-optimal levels of Si found in investigated soils. In view of the scant attention paid to evaluating soil extractants to predict sub-optimal soil Si levels, Haysom and Chapman (1975) and Berthelsen *et al.* (2001b) evaluated a number of soil extractants (0.01M $CaCl_2$; 0.5M CH_3COONH_4; 0.005M H_2SO_4; 0.5M acetic acid; 0.1M citric acid; 0.1M CH_3COONH_4; and phosphate acetate) for their ability to predict cane yield. Based on the correlations obtained between soil tests and plant tissue levels of Si, the 0.01M $CaCl_2$ extractant was found to be the most suitable for estimating the Si present in the soil solution. This extractant, which is widely used to measure soil Si in Australia, was developed as an alternative to the distilled water extract method, to reduce interference caused by the dispersed clay fraction in water suspension (Rodriguez *et al.*, 2003).

In South Africa, Si deficiency together with Al toxicity was first identified in 1967 as a potential growth-limiting factor in the highly weathered Oxisol soils of the Natal Midlands cane areas (Bishop, 1967). Meyer (1970), in a field survey and through glasshouse experiments, investigated the reasons why sugarcane planted in fields previously under marked wattle trees exhibited a very marked 'tramline effect' in cane growth. The superior growth of cane along these lines was associated with the windrows of wattle brush that were burnt prior to land preparation. Soil analyses showed a marked reduction in soil acidity and labile aluminium, and an increase in exchangeable Ca, Mg, K, Si and P levels. Leaf analysis showed similar increases in nutrient levels particularly P and K. Results of pot experiments showed that the greatest responses in cane growth were obtained from the addition of wattle ash, lime or the Si treatment.

A second pot trial with sugarcane compared the relative efficiencies of limestone and various sources of Si on acid soils of the Natal Midlands (du Preez, 1970). All sources of Si gave significant responses except sodium silicate that caused an alkaline soil condition due to the large amounts of sodium added to the soil. The main factors thought to be responsible for yield increase were probably decreased levels of Al and Mn, and increased levels of Si in the soil. However, du Preez (1970) considered that the increased yields could not be due to the elimination of toxic amounts of Al and Mn, but that there was a level of soil Si below which optimum yields could not be obtained. Similarly, Moberly and Meyer (1975) reported increased soil pH from various sources of Si and lime in trials comparing the effectiveness of various forms of calcium silicate slag with lime. There is increasing evidence from the literature that in a wide range of crops, nutrients such as N and Si, play important roles in susceptibility and resistance to stalk borer damage (Meyer and Keeping, 2000; Meyer and Keeping, 2005). As *E. saccharina* is of major concern throughout the South African sugar industry, there is a need to investigate whether the Si content of sugarcane is linked to borer resistance. Keeping and Meyer (2002), throughout a pot trial, evaluated the influence of Si treatment on the resistance to the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae). Results to date have indicated that calcium silicate application in the field may achieve a substantial increase in resistance of sugarcane to *E. saccharina* attack, along with improved sucrose yield.

For assessing soil Si status, the South African Sugar Industry in early investigations Bishop (1967) adopted the 0.5M CH_3COONH_4 extractant adjusted to pH 4.8 (Ayres, 1966). But in recent years, the modified Truog 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant (Fox *et al.*, 1967b) has been found to correlate better with leaf Si analysis. In a later survey of the Si status of soils in the Sugar industry, it was found that Si extracted from soils by the modified Truog method were moderately well correlated with clay content (Meyer and Keeping, 2000).

2.6. SOUTH AFRICAN SUGAR RESEARCH INSTITUTE (SASRI) FERTILIZER ADVISORY SERVICE (FAS).

The South African Sugar Research Institute (SASRI) (formerly SASEX) has operated a Fertilizer Advisory Service (FAS) for the industry since 1954 (Wood, 1987; Schroeder *et al.*, 1995; Schroeder and Southey, 1996; Meyer *et al.*, 1997; Schroeder *et al.*, 1998). FAS was established to analyse soil, leaf, irrigation water and fertilizer samples from growers and researcher workers at SASRI, to provide fertilizer recommendations, salinity/sodicity assessments and specialist advice on sugarcane nutrition, and to ensure that the information relating to fertilizer advice is updated regularly (Schroeder *et al.*, 1995; Schroeder and Southey, 1996; Meyer *et al., 1997*). From the outset FAS has developed considerably through advances that have been made in soil and leaf analysis methodology, as well as the scope of fertilizer and salinity management advice (Meyer *et al.*, 1997).

Initially the need for the industry to have a fertilizer advisory service laboratory arose from concern by growers regarding the widespread, yellow appearance of the crop that is often linked to growth failure (Meyer *et al., 1997*). In 1950, potassium deficiency was identified as a growth-limiting factor for cane production throughout the industry (du Toit, 1951). The trials that followed confirmed that dramatic responses to applied potassium could be obtained on many soils. It was shown that soil and leaf analyses could be used to predict likely crop responses to applied K and P fertilizers as well as the economic quantity of fertilizers to apply (Meyer *et al.*, 1997).

After 20 years of producing fertilizer recommendations and improved crop performance, the FAS was able to introduce in 1975 whole cycle fertilizer advice for cane crop (Meyer *et al.*, 1997). Advice is based on laboratory soil and leaf tests that are specific to sugarcane and that have been especially calibrated to cover the wide range of soil types that occur in the sugar industry (SASEX, 1999). As such, both soil and leaf analyses are considered essential tools for ensuring balanced cane nutrition (du Toit, 1959; Schroeder *et al.*, 1995; Schroeder *et al.*, 1998), and providing cost effective and environmentally friendly fertilizer recommendations (Anon, 1994; Schroeder *et al.*, 1998).

Nowadays, the leaf testing service has been expanded to include other cane producing countries in Africa such as Swaziland, Mozambique, Tanzania, Uganda and Zambia, as well as sugarcane leaf samples from the Australian sugar industry (SASEX, 2003). Service is also offered to various other disciplines such as tea, coffee, nurseries and gardens (SASEX, 2002) that makes the FAS laboratory one of the leading soil and leaf testing laboratories in the world (Meyer *et al.*, 2004).

As a result of many years of research and development into improved methods, the FAS has achieved greater accuracy in K, P, Ca and Mg determinations and improved detection limits for many of these elements (SASEX, 1997). In addition to these routine tests including pH, FAS also provides more sophisticated determinations such as P and K fixation, soil organic matter, aluminium toxicity, textural analyses, and an estimate of potential volatilisation of ammonia from urea (SASEX, 1999). The standard leaf analysis program comprises N, P, K, Ca, Mg and S as well as trace elements Zn, Cu, Fe and Mn without any extra cost to the cane producer. Currently, Si has been included in the program with leaf analysis being the most reliable guide to identifying a potential silicon deficiency in sugarcane (SASEX, 2002). The FAS laboratory has shown marked growth during the past decade with an increase of over 100% in term of samples received and analysed (Figure 2.4).

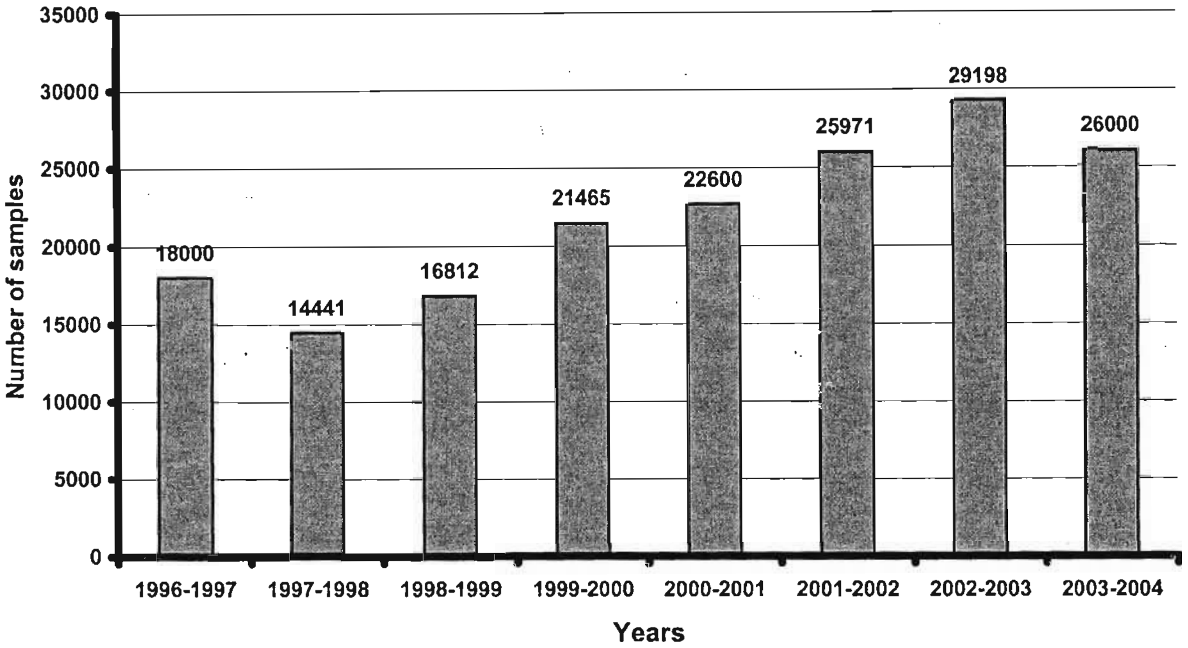

Figure 2.4. Samples received and analysed by FAS per year (from SASEX, 1996-2003; SASRI, 2004a).

This upward trend was partly achieved by the increase in soil and leaf samples submitted by sugar estates from neighbouring countries, and the establishment of a satellite soil and leaf preparation laboratory at the Komati SASRI research farm in Mpumalanga (SASEX, 2003). Although fewer samples were analysed in 2003/2004 than in previous seasons, FAS managed to cover all costs as user pays entry (SASRI, 2004b). It was pointed out by Meyer and van Antwerpen (2001) that the South African sugar industry greatly depends on soil and leaf analysis conducted by its Fertliser Advisory Service (FAS) for identifying and correcting nutrient disorder in sugarcane.

CHAPTER 3

AN ASSESSMENT OF SOIL EXTRACTION METHODS FOR PREDICTING PLANT AVAILABLE SILICON

3.1. INTRODUCTION.

Crop and sucrose loss from *Eldana saccharina* Walker (Lepidoptera: Pyralidae) damage still ranks as being the most important factor limiting productivity in the South African sugar industry. Recent studies at the South African Sugarcane Research Institute have emphasized the important role of applied silicon in improving the resistance of sugar cane to *Eldana* infestation even in the more tolerant varieties such as N21 and N33. Available results from trials have indicated that the silicon requirement of sugarcane is very much a function of soil type and properties such as soil pH, texture, organic matter and plant available silicon (Meyer and Keeping, 2005).

A reliable soil test procedure for diagnosing the silicon status of soils is crucial in determining the need for applying a silicate carrier such as calcium silicate to soils as well as the optimum amount of the carrier to apply, to ensure that the risk of damage from *Eldana* due to a potential lack of silicon is minimized (Meyer and Keeping, 2000). Several soil Si test methods have been reported by different authors including, Fox *et al.* (1967b), Khalid *et al.* (1978a), Barbosa-Filho (1996), Korndörfer *et al.* (1998), Berthelsen *et al.* (1999), and Snyder (2001). Six different soil extractants for estimating plant available Si, were evaluated in a glasshouse trial in which sorghum followed by sugar cane were exhaustively cropped on five soils treated with three candidate Si sources, applied at rates equivalent to 3 and 6 tons ha^{-1}, using a split-split-plot design with four replications. The objective was to identify the soil extractant that correlated the best with silicon uptake from the test crops.

In the first pot trial, the aim was to deplete the soils as much as possible of plant available Si before planting with sugarcane. Sorghum was chosen as test plant because of its rapid growth and a similar tendency to accumulate silicon as well as sugarcane. According to Krantz (1989), sorghum is grown successfully over a wide range of soils, from sands to clays, and is responsive to mineral fertilization. Furthermore, sorghum is a silicon accumulator plant that is responsive to Si fertilization.

3.2. MATERIALS AND METHODS.

3.2.1. Sample collection and preparation.

Bulk surface (0-15cm) soil samples (100kg) representing a range of important soil forms, were collected from five sugarcane fields that have been under continual cane production for many years. The first soil from the burning and trashing trial (BT1) at SASRI, Mount Edgecombe comprised the Arcadia (Ar) form (Chromic Vertisol, FAO; Vertisol, USDA) with a clay content of 44%. The second soil from Eshowe was of the Cartref (Cf) form (Greyic Luvisol, FAO; Inceptisol, USDA) with a clay content of 19%. The third soil from Kearsney was of the Glenrosa (Gs) form (Ochric Cambisol/Lithosol, FAO; Inceptisol/Aridisol, USDA) with a clay content of 13%. The fourth soil also from Mount Edgecombe, was the Longlands (Lo) form (Plinthic Gleysol, FAO; Inceptisol/Alfisol, USDA), with a clay content of 4%. All four soils were weakly weathered and located in the Coastal Lowlands Soil System, below an altitude of 310metres, with a warm and humid climate. The fifth soil from Paddock was of the Nomanci (No) form (Humic Cambisol/Acrisol, FAO; Inceptisol, USDA) with a clay content of 6%. This soil was a strongly weathered acid ferralitic soil from the Midlands Misbelt region, located between 310 and 1220m of altitude, with a cool and humid climate. Sub-samples of each soil were taken for laboratory analyses.

Each soil was thoroughly mixed, incubated in the glass house for at least a week at 25^0C with regular mixing and aeration, and subsequently air-dried and ground to pass through a 2mm screen. Thereafter the soil samples were placed into plastic pots and used for the glasshouse trial. Sub-samples were taken for laboratory analyses. Selected physical and chemical properties of each soil are shown in Table 3.1 and Table 3.2 respectively.

Soil Form	Particle size distribution				Clay Mineralogy
	Sand (%)	Silt (%)	Clay (%)	Texture	
Arcadia	41	15	44	Clay	Montmorillonite
Cartref	68	13	19	Sandy loam	Kaolinite
Glenrosa	81	6	13	Sandy loam	Kaolinite
Longlands	94	2	4	Sandy	Kaolinite
Nomanci	89	5	6	Sandy	Kaolinite

Table 3.1. Particle size distribution of the five soil forms investigated.

Soil form	pH (H_2O)	N CAT	CEC cmol$_c$ kg^{-1}	Si, P, and exchangeable cations (cmol kg^{-1})						
				Si	P	Ca	Mg	K	Na	Al
Arcadia	5.63	2	18.63	0.12	0.06	6.66	2.10	0.38	0.24	-
Cartref	5.17	1	6.10	0.04	0.18	1.28	0.35	0.20	0.12	0.17
Glenrosa	4.87	1	4.05	0.04	0.23	0.47	0.21	0.32	0.17	0.07
Longlands	4.82	1	1.43	0.03	0.02	0.29	0.11	0.09	0.13	0.28
Nomanci	5.59	2	1.90	0.01	0.04	0.23	0.05	0.11	0.12	-

Table 3.2. Some selected chemical properties of the five soil forms investigated.

3.2.2. Nature of silicon sources.

The silicon sources used were calmasil, a blast furnace calcium silicate slag produced as by-product from the stainless steel industry; slagment, a lowgrade cement and wollastonite that was supplied by a local grower, Mr Thompson. The elemental composition of the Si sources is shown in Table 3.3. The nutrient content of the Si sources varied greatly depending upon that of the various constituents. Although relatively Si-rich compounds, these Si carriers contained substantial quantities of Ca, Mg, as well as other nutrients (Table 3.3).

Si sources	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Si (%)
Calmasil	0.02	0.03	0.01	9.20	5.60	9.85
Slagment	0.01	0.01	0.02	9.00	6.21	15.20
Wollastonite	0.35	0.01	0.01	8.60	0.08	5.25

Table 3.3. Nutrient content of Si carriers (sources) used in the study.

It was observed that slagment was notably high in plant available Si (15.20%) content being approximately one and half that of calmasil (9.85%), which was in turn nearly double that of wollastonite (5.25%). The three silicon sources showed negligible values of N, K and P, variable levels of Mg and substantial levels of Ca. Calmasil is also known to contain traces of Al, Fe, Mn and Cr oxides.

3.2.3. Glasshouse procedure.

Three rates of each Si source, equivalent to 0, 3 and 6 tons ha^{-1}, were incorporated in a litre volume of each soil contained in 2litre freely draining plastic pots. Allowance was made for the variation in bulk density between soils in determining the rate of Si amendment to apply (Table 3.4).

Soil type	Mass soil pot^{-1} (g)	Volume soil pot^{-1} (cm^{3})	Bulk density soil (0-15cm) (g cm^{-3})	Soil mass ha^{-1}(0-15cm) (x 10^{6} kg)	Rate pot^{-1} [3 tons ha^{-1}] (g)	Rate pot^{-1} [6 tons ha^{-1}] (g)
Arcadia	1200	1120	1.071	1.607	2.240	4.480
Cartref	1200	1110	1.081	1.622	2.220	4.440
Glenrosa	1400	1130	1.239	1.859	2.260	4.520
Longlands	1600	1100	1.455	2.183	2.200	4.400
Nomanci	1600	1070	1.495	2.243	2.140	4.280

Table 3.4. Mass of soil and Si treatment rate used per pot

The trial comprising 140 pots was arranged on a large round table that could rotate, in a split split plot design with four replicates, where the soil forms were taken as plots, the Si sources as sub-plots, and the Si sources rates as sub-sub-plots. Sorghum (*Sorghum bicolor* L. Moench) was planted in each pot at a rate of 3gm (about 150 seeds) and covered by a thin layer of soil. Pots were watered by weight to approximate field moisture capacity, which was determined on each soil before potting (Table 3.5).

Soil form	Mass soil used (g)	H_2O added (ml)	H_2O drained by 100g soil (ml)	H_2O held by 100g soil (ml)	Mass Soil/pot (g)	FMC /pot (ml)	FMC (70%)	FMC (50%)
Arcadia	100	100	48	52	1200	624	437	312
Cartref	100	100	46	54	1200	648	454	324
Glenrosa	100	100	57	43	1400	602	421	301
Longlands	100	100	65	35	1600	560	392	280
Nomanci	100	100	68	32	1600	512	358	256

Table 3.5. Water holding capacity for different soil types investigated.

Four (4) pots of each replication were placed together in a tray containing water to permit permanent capillary ascension through the pot across the filter paper placed before the soil.

Each pot received a weekly basal solution containing adequate amounts on N, P, K, Ca, Mg, S, Cu, Cu, Zn, Fe and Mn. After four weeks of growth, plants were first harvested at about 10cm above the surface. The stalks and leaves were allowed to regenerate and a further two crops were harvested. In the case of the last crop the total aerial biomass was harvested. The harvested herbage was weighed fresh and oven dried at 75^0C for a week, weighed again before grinding in a stainless steel Wiley mill. The milled tissue was kept in an airtight container and stored in a cool and dark environment for silicon analysis. Soils were dried, and soil samples were taken from each pot for laboratory analyses.

3.2.4. Soil and plant analysis.

For extracting Si from soils, six published methods were used to compare changes in the Si status before and after cropping in order to correlate the changes with Si uptake by the crop and yield response of sorghum to applied Si treatment on the five soils. The objective was to identify the soil extractant that correlated the best with silicon uptake from the test crops. The extraction methods differ mainly in terms of the pH, strength of the extracting solution, solution to soil ratio, time of extraction and whether filtration or centrifugation is used. A summary of the extractants used is given in Table 3.6 while details of each procedure are listed in Appendix 1.

Si Extractant	Soil-solution Ratio	Shaking time (min)	Clear Extract	References
0.01M H_2SO_4 + $(NH_4)_2SO_4$	1:10	20	Centrifuge	Fox *et al.*, 1967b
Distilled water	1:10	20	Centrifuge	Fox *et al.*, 1967b
0.025M H_2SO_4	1:10	30	Filter	Rayment and Higginson, 1992
0.5M CH_3COOH	1:10	30	Filter	Korndörfer *et al.*, 1998
0.5M CH_3COONH_4 pH: 4.8	1:10	60	Filter	Fox *et al.*, 1967b
0.01M $CaCl_2.2H_2O$	1:10	960	Centrifuge	Haysom and Chapman, 1975

Table 3.6. Summary of the chemical extraction methods used for extracting plant available silicon.

For available nutrients, soil samples, sorghum and cane plant samples were analyzed at the SASRI Fertilizer Advisory Service (FAS) laboratory (Beater, 1962; Meyer *et al.*, 1997). Details of selected soil physical and chemical properties are presented in Tables 3.1, 3.2, 3.7 and 3.9; while sorghum nutrient content is showed in Table 3.12. Plant-available Si values showed in Tables 3.2, 3.7 and 3.9 were obtained using 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant (Appendix 1) at the SASRI analytical chemistry laboratory. The fertilizer Si content and the plant Si uptake were determined spectrophotometrically using the blue silicomolybdonous method (Fox *et al.*, 1969) (Appendix 1.2).

3.3. RESULTS AND DISCUSSIONS

3.3.1. Initial soil physical and chemical properties.

The selected physical and chemical properties of the investigated soils were given in Table 3.1 and Table 3.2. Soil pH as measured in water was greatest (5.63) in the *Arcadia* form soil and lowest (4.82) in the *Longlands* form soil, with intermediate values for other soil forms. The *Arcadia* and *Nomanci* form soils were moderately acid (5.59 and 5.63), whereas *Longlands*, *Glenrosa*, and *Cartref* were strongly acid (4.82; 4.87 and 5.17) (Leeper and Uren, 1993). According to Bohn *et al.* (2001), exchangeable Al^{3+} is present in appreciable quantities in acid soils (pH < 5.5). Similarly, the strongly acid soil forms exhibited exchangeable Al values varying from 0.07 to 0.28cmol kg^{-1}.

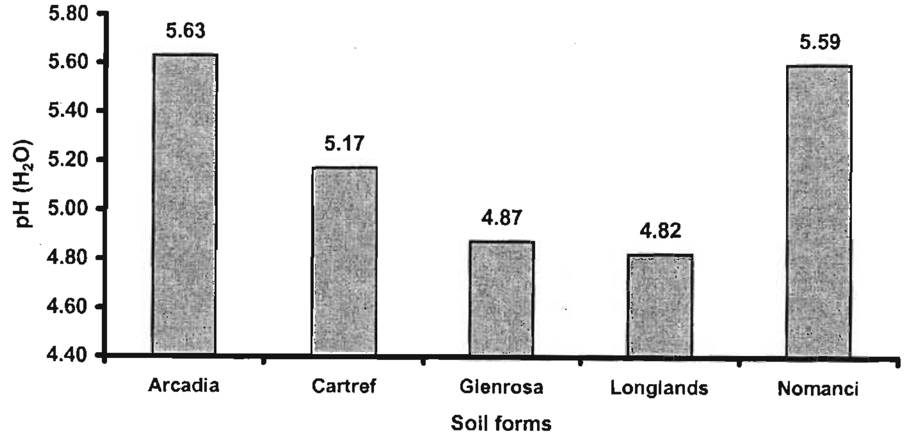

Figure 3.1. pH(H_2O) of the investigated soils before the silicon treatment.

The cation exchange capacity (CEC) is controlled primarily by the composition and mineralogy of the soil constituents particularly that of the clay fraction (Coventry *et al.*, 2001), was highest (18.63cmol$_c$ kg^{-1}) in *Arcadia* form soil and least (1.43 cmol$_c$ kg^{-1}) in the sandy *Longlands* form soil, in accordance with their respective clay contents of 44% and 4% (Table 3.2).

Exchangeable Ca^{2+} levels were adequate in the *Arcadia* and *Cartref* form soils (6.66 and 1.28cmol kg^{-1}) and greater than the critical level of 0.50cmol kg^{-1} or 450kg ha^{-1} (Meyer *et al.*, 2004). This confirms the findings of van Wambeke (1991) that large quantities of Ca^{2+} are common in Vertisols. Furthermore, Hubble (1984) and van Wambeke (1991) found that the K contents of clay soils such as *Arcadia* are adequate for crop production and are often high compared to other soil forms. Exchangeable Ca^{2+} levels were sub-optimal in other soil forms, varying from 0.23 to 0.47cmol kg^{-1}.

Exchangeable K^+ levels were greater than the optimum level of 0.29cmol kg^{-1} or 250kg ha^{-1} (Meyer *et al.*, 2004) in the Arcadia and *Glenrosa* form soils. The remaining three soils contained sub-optimal exchangeable K^+ levels varying from 0.11 to 0.20cmol kg^{-1}. Exchangeable Mg^{2+} levels were greater than the critical level of 0.10cmol kg^{-1} or 60kg ha^{-1} (Meyer *et al.*, 2004) in all soil forms except *Nomanci*. All soil forms exhibited P levels greater than the optimum of 0.04cmol kg^{-1} or 30kg ha^{-1} (Meyer *et al*, 2004) except *Longlands* form soil.

3.3.2. Effect of applied silicon sources on soil properties.

Analyses of composite treatment soil samples revealed some interesting effects of Si treatment on the $pH_{(water)}$, the exchangeable cations and the Truog-extractable silicon levels of the various soil forms (Table 3.7). There was a significant increase in Truog-extractable soil Si levels. Except for the controls, the amount of plant available Si increased with increased rates of applied Si sources. Although application of Si sources resulted in significant increases in Truog-extractable Si, the magnitude of this increase varied by soil form, Si carrier and the treatment levels. Slagment increased plant available silicon more than the calmasil, which in turn, increased plant available silicon more than the wollastonite. This was expected as long as slagment exhibited the highest level of 15.20% Si, calmasil followed with 9.85% Si and wollastonite came last with 5.25% Si (Table 3.3). The Si source content coupled with its solubility was likely to influence yield response and plant Si uptake.

Soil form	Si level	N CAT	pH (H_2O)	CEC ($cmol_c$ kg^{-1})	Soil element concentration (cmol kg^{-1})						
					Ca	Mg	K	Na	P	Al	Si
Arcadia	TO	2	5.62	19.47	6.84	2.26	0.39	0.30	0.07	0.14	0.18
	Calm L	2	5.87	21.70	7.73	2.55	0.36	0.27	0.07	0.09	0.62
	Calm H	2	5.97	27.26	9.86	3.29	0.35	0.30	0.06	-	1.07
	Slag L	2	5.80	20.16	7.11	2.47	0.38	0.33	0.06	-	1.72
	Slag H	2	5.78	19.14	6.91	2.26	0.41	0.30	0.05	-	1.82
	Woll L	2	5.70	20.40	7.34	2.22	0.44	0.36	0.06	-	0.26
	Woll H	2	5.69	19.85	7.26	2.18	0.38	0.30	0.06	-	0.20
Cartref	TO	3	5.14	3.92	1.17	0.35	0.23	0.16	0.21	-	0.07
	Calm L	2	5.24	5.51	1.73	0.58	0.18	0.30	0.20	-	0.45
	Calm H	2	5.38	6.47	2.18	0.71	0.21	0.14	0.20	-	0.77
	Slag L	3	5.32	4.80	1.15	0.35	0.21	0.18	0.19	-	1.17
	Slag H	3	5.45	4.56	1.16	0.37	0.22	0.17	0.19	-	2.28
	Woll L	3	5.22	4.63	1.29	0.36	0.22	0.20	0.21	0.11	0.12
	Woll H	3	5.22	4.11	1.41	0.33	0.23	0.17	0.21	0.10	0.06
Glenrosa	TO	1	4.84	2.15	0.54	0.21	0.25	0.19	0.26	0.05	0.02
	Calm L	1	5.25	3.34	1.02	0.36	0.22	0.15	0.26	0.03	0.65
	Calm H	1	5.65	4.95	1.61	0.56	0.21	0.18	0.26	-	0.93
	Slag L	1	5.23	2.09	0.57	0.24	0.22	0.14	0.26	0.04	1.64
	Slag H	1	5.38	2.14	0.57	0.24	0.18	0.13	0.26	-	2.07
	Woll L	1	5.05	2.37	0.63	0.21	0.21	0.17	0.26	0.03	0.11
	Woll H	1	5.27	2.62	0.76	0.22	0.19	0.15	0.26	0.03	0.05
Longlands	TO	1	4.80	1.35	0.38	0.16	0.11	0.16	0.02	0.17	0.01
	Calm L	1	5.14	4.33	1.43	0.46	0.12	0.20	0.02	0.10	0.40
	Calm H	1	5.49	5.91	2.08	0.64	0.10	0.15	0.02	-	0.81
	Slag L	1	5.24	1.46	0.38	0.14	0.09	0.14	0.02	0.16	0.82
	Slag H	1	5.40	1.82	0.40	0.16	0.12	0.18	0.02	-	1.92
	Woll L	1	4.97	2.04	0.55	0.14	0.10	0.16	0.02	0.13	0.10
	Woll H	1	5.14	2.14	0.59	0.13	0.13	0.17	0.02	0.11	0.04
Nomanci	TO	1	5.63	1.26	0.29	0.12	0.10	0.13	0.05	-	0.01
	Calm L	1	6.35	3.85	1.13	0.35	0.10	0.08	0.05	-	0.23
	Calm H	1	6.61	4.50	1.48	0.44	0.12	0.12	0.05	-	0.55
	Slag L	1	6.03	1.44	0.32	0.13	0.11	0.13	0.04	-	0.82
	Slag H	1	6.07	1.46	0.35	0.14	0.10	0.08	0.04	-	1.48
	Woll L	1	6.01	1.48	0.42	0.11	0.10	0.10	0.05	-	0.02
	Woll H	1	6.19	1.73	0.55	0.11	0.11	0.10	0.05	-	0.03

Table 3.7. Some selected chemical properties of the composite soil samples after application of different Si source levels.

Many of the beneficial effects of the Si application may be attributed to their effect on increasing soil pH (Lindsay, 1979; Matichenkov and Bocharnikova, 2001; Ma and Takahashi, 2002). A summary of the pH(water) minimum and pH(water) maxima changes of composite soil samples following Si treatment is given in Table 3.8.

Soil Form	$pH_{(water)}$ before Si treatment	$pH_{(water)}$ after Si treatment				$pH_{(water)}$ increase
		Minima	Treatment	Maxima	Treatment	
Arcadia	5.63	5.62	TO	5.97	Calm. H.	0.35
Cartref	5.17	5.14	TO	5.45	Slag. H.	0.31
Glenrosa	4.82	4.80	TO	5.49	Calm. H.	0.69
Longlands	4.87	5.63	TO	6.61	Calm. H.	0.98
Nomanci	5.57	4.84	TO	5.65	Calm. H.	0.81

Table 3.8. Changes in pH $_{(water)}$ of the composite soil samples after Si treatment.

Of interest is that the high rate of calmasil (6 tons ha^{-1}) produced the greatest increase in pH(water) in the *Arcadia*, *Glenrosa, Longlands* and *Nomanci* form soils. The high rate of slagment produced the greatest effect in the *Cartref* form soil. These findings confirmed these of Moberly and Meyer (1975) where yield responses obtained from various Si sources and lime also raised pH under field trial conditions.

On all five soil forms investigated, Si sources application increased the concentration of extractable cations Ca^{2+} and Mg^{2+} at both low and high levels (Table 3.7). This was attributed to the substantial release of these cations from the Si sources investigated (Table 3.3) following reaction with the soil. Similar results have been reported by Gascho and Andreis (1974), Moberly (1974), Elawad *et al.* (1982b), Anderson *et al.* (1991) and Berthelsen *et al.* (2001a, 2001b).

Phosphorus and exchangeable K^+ and Na^+ concentrations were not greatly increased by Si source treatment on all five soil forms investigated. The cation exchange capacity (CEC) was increased in proportion to Ca and Mg. The sequence of cations in this study follows the order of decreasing amounts $Ca^{2+} > Mg^{2+} > K^+ > Na^+$, and any deviation from this order can create ion-imbalance problems for plants (Bohn *et al.*, 2001). The increased concentrations of exchangeable cations with Si treatment were accompanied by an increase in soil pH and a decrease in exchangeable Al (Table 3.7 and Table 3.9. The reduction in Al may be due to the interaction between Si and Al in the soil solution (Mokolobate, 2000; Ma and Takahashi, 2002).

Soil form	Si level	N CAT	pH (H_2O)	CEC ($cmol_c$ kg^{-1})	Soil element concentration (cmol kg^{-1})						
					Ca	Mg	K	Na	P	Al	Si
Arcadia	TO	3	5.37	18.9	6.53	2.23	0.59	0.52	0.10	0.02	0.25
	Calm L	3	5.62	21.4	7.44	2.51	0.70	0.54	0.14	-	0.28
	Calm H	3	6.09	23.7	8.56	2.65	0.51	0.51	0.12	-	0.46
	Slag L	3	5.78	20.7	7.19	2.46	0.56	0.50	0.11	-	0.49
	Slag H	3	5.96	21.8	7.60	2.60	0.55	0.51	0.12	-	1.01
	Woll L	3	5.63	20.2	7.23	2.17	0.59	0.51	0.10	-	0.31
	Woll H	3	5.91	22.2	8.27	2.15	0.59	0.52	0.11	-	0.45
Cartref	TO	3	5.14	5.06	1.49	0.50	0.44	0.41	0.15	0.09	0.08
	Calm L	3	5.33	7.74	2.43	0.79	0.39	0.41	0.23	0.04	0.09
	Calm H	3	5.61	9.54	2.96	1.03	0.43	0.43	0.22	-	0.11
	Slag L	3	5.37	8.04	2.29	0.80	0.44	0.43	0.20	0.04	0.18
	Slag H	3	5.54	9.13	2.76	1.01	0.45	0.46	0.20	-	0.63
	Woll L	3	5.27	7.88	2.52	0.48	0.41	0.44	0.19	0.04	0.10
	Woll H	3	5.51	9.00	3.30	0.48	0.35	0.35	0.23	-	0.11
Glenrosa	TO	1	4.87	2.47	0.30	0.23	0.45	0.25	0.10	0.08	0.06
	Calm L	2	5.39	4.53	1.10	0.46	0.35	0.27	0.11	-	0.08
	Calm H	1	6.08	7.00	1.94	0.71	0.40	0.32	0.18	-	0.17
	Slag L	2	5.36	4.50	1.06	0.56	0.40	0.30	0.11	0.04	0.16
	Slag H	2	5.85	5.34	1.39	0.64	0.36	0.27	0.12	-	0.77
	Woll L	1	5.12	4.47	1.17	0.25	0.43	0.30	0.15	0.04	0.06
	Woll H	1	5.64	5.46	1.84	0.24	0.36	0.28	0.13	-	0.13
Longlands	TO	1	4.97	1.59	0.14	0.16	0.26	0.21	0.11	0.04	0.03
	Calm L	1	5.83	2.39	0.52	0.23	0.16	0.19	0.15	-	0.07
	Calm H	1	6.74	3.50	0.89	0.29	0.17	0.19	0.24	-	0.17
	Slag L	1	5.74	3.00	0.40	0.26	0.15	0.23	0.11	-	0.34
	Slag H	1	6.10	2.79	0.51	0.30	0.17	0.23	0.12	-	0.90
	Woll L	1	5.47	2.38	0.53	0.16	0.20	0.20	0.16	-	0.07
	Woll H	1	6.08	2.71	0.74	0.15	0.16	0.21	0.13	-	0.15
Nomanci	TO	1	5.27	2.66	0.47	0.27	0.39	0.27	0.51	0.04	0.03
	Calm L	1	6.79	4.74	1.19	0.48	0.35	0.30	0.60	-	0.06
	Calm H	1	7.57	6.78	2.06	0.71	0.35	0.29	0.64	-	0.19
	Slag L	1	6.62	4.37	1.01	0.48	0.41	0.24	0.65	-	0.22
	Slag H	1	6.94	5.23	1.33	0.59	0.39	0.25	0.64	-	0.73
	Woll L	1	6.54	4.00	1.15	0.28	0.36	0.26	0.56	-	0.07
	Woll H	1	6.83	5.42	1.80	0.30	0.35	0.23	0.59	-	0.11

Table 3.9. Some selected chemical properties of the soil samples after harvest of sorghum plants grown in the pots (mean of four replications).

Lindsay (1979), Matichenkov and Bocharnikova (2001), and Jianjun *et al.* (2002) attributed the reduction of Al concentration in the soil solution firstly to the increased pH effect of applying Si-rich compounds. Secondly, monosilicic acids can be adsorbed onto Al hydroxides, impairing their mobility. Thirdly, there might be surface adsorption of mobile Al onto Si-rich compounds to form slightly soluble and non-toxic substances.

$$2H_4SiO_4 + 2Al^{3+} \leftrightarrow Al_2Si_2O_5 + 2H^+ + 3H_2O$$

$$2H_4SiO_4 + H_2O + 2Al^{3+} \leftrightarrow Al_2Si_2O_5\,(OH)_4 + 6H^+$$

All these mechanisms may work simultaneously, or a particular mechanism may prevail under a specific condition. With regard to soil fertility and crop root development, the greatly increased exchangeable Ca^{2+} concentrations, and concomitant decreases in exchangeable Al in Si-treated soils are of particular interest. McCray and Sumner (1990) reported that Ca^{2+} and Al in soil solution have antagonistic effects on plant root growth. Increased solution Ca^{2+} values will result in decreased susceptibility to Al toxicity. Consequently, the relative levels of Ca and Al in acid soils should always be considered (Judge, 2001).

The amount of Si extracted by the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ was below the critical level of 0.07cmol kg^{-1} or 45kg ha^{-1} (SASRI, 2004b) in the soil forms investigated except *Arcadia* that exhibited a Si content of 0.12cmol kg^{-1}. The *Arcadia* form soil was also the only one with clay values > 30% with the remaining four soils exhibiting clay content values lower than 20%. Clay soils with their frequently high pH and naturally high levels of exchangeable Ca and Mg are therefore not likely to show deficiencies of these nutrients (Hartemink, 1998).

3.3.3. Sorghum dry biomass yield.

The dry matter yield data (g kg^{-1} soil) for each of the three harvests of sorghum grown in pots are summarized in the Table 3.10. In general dry matter yield did not show major changes with Si treatment in the first two harvests. However, there were significant treatment differences between the sorghum in dry matter yield response in the third harvest. The considerable increase in overall mass in the third harvest was due to the inclusion of the total aerial biomass whereas the two previous harvests included tops over 10cm above the soil surface.

All the Si sources produced positive cumulative sorghum dry matter yield responses (Table 3.10). The highest cumulative dry matter yield on the *Arcadia*, *Glenrosa* and *Nomanci* form soils was attained with the high rate of calmasil (6 tons ha^{-1}). In general cumulative sorghum dry matter yield per pot declined in the order: *Arcadia* > *Cartref* > *Glenrosa* > *Longlands* > *Nomanci*. However, when sorghum dry matter yield responses to Si treatment were expressed as a percentage increase over the untreated controls (Table 3.10), the order of yield response changed and declined as follows: *Glenrosa* > *Longlands* > *Arcadia* > *Nomanci* > *Cartref.* Overall, the calmasil treatments were superior to the other two carriers, with significant responses recorded to the high rate of calmasil in all soils.

The highest sorghum dry matter yield was mostly observed at the highest soil pH values between 5.14 and 6.61. On the *Longlands* form soil; the highest sorghum dry matter yield was obtained at soil pH 6.35, the highest pH being 6.61. It is unlikely that the increase in yields were due only to the change in pH, as higher yield values were obtained from treatments having a lower soil pH. Large sorghum dry matter yield differences (%) were obtained on the *Glenrosa* and *Longlands* form soils with the lowest soil pH(water) values before Si treatment (Figure 3.2). The dry matter yield increase (%) revealed that the calmasil Si carrier, with a Si content of 9.85% performed better than other two Si carriers applied to the sorghum plants in the pots, despite the higher silicon content of 15.20% exhibited by slagment Si source (Table 3.3). This difference may be associated with the ability of the different Si carriers to release Si from the total Si pool as reported in the SASEX annual report (2002), that in turn may impact on yield responses. In general all Si sources showed an improvement in cumulative dry matter yields (Figures 3.2 to 3.6) but not all the treatment responses were significant.

Soil form	Si source	Si Level	Sorghum dry matter yield (g kg^{-1} soil) at different harvests						
			1st cut	2nd cut	3rd cut	TOTAL	% yield increase	Mean Si carrier	Mean soil form
Nomanci	Control	0t/ha	0.3898	0.3049	4.2407	4.9354	-		
	Calmasil	3t/ha	0.5458	0.6739	4.3386	5.5583	+13.1**		
		6t/ha	0.6806	0.7040	4.4396	5.8242	+18***	5.439	
	Slagment	3t/ha	0.6739	0.4417	4.3887	5.5043	+11.6**		
		6t/ha	0.5614	0.3967	4.1218	5.0799	+2.9ns	5.173	
	Wollastonite	3t/ha	0.6684	0.4961	4.0092	5.1737	+4.8ns		
		6t/ha	0.5430	0.6379	4.5791	5.7600	+16.7**	5.290	5.301
	LSD (5%)					0.3161		NS	
Glenrosa	Control	0t/ha	0.4223	0.2505	3.1212	3.7940	-		
	Calmasil	3t/ha	0.6136	0.6888	4.9878	6.2901	+59***		
		6t/ha	0.8645	1.1601	5.4131	7.4377	+88***	5.841	
	Slagment	3t/ha	0.5602	0.7147	4.6542	5.9291	+50***		
		6t/ha	0.6993	0.8871	5.1116	6.6980	+69***	5.474	
	Wollastonite	3t/ha	0.9152	0.7190	4.3168	5.9510	+50***		
		6t/ha	0.9198	0.7543	4.6900	6.3641	+61***	5.370	5.561
	LSD (5%)					0.3844		0.3002	
Longlands	Control	0t/ha	0.6494	0.7313	3.9453	5.3259	-		
	Calmasil	3t/ha	1.0005	0.8667	4.6669	6.5341	+22.69		
		6t/ha	1.0108	1.0060	4.4020	6.4188	+20.52	6.093	
	Slagment	3t/ha	0.8939	0.7272	4.7579	6.3790	+19.77		
		6t/ha	0.8553	0.7082	4.9459	6.5094	+22.22	6.071	
	Wollastonite	3t/ha	0.7939	0.7150	4.8155	6.3244	+18.75		
		6t/ha	0.8734	0.8769	5.0007	6.7510	+26.76	6.134	6.099
	LSD (5%)					0.2470		NS	
Cartref	Control	0t/ha	0.6971	0.7670	5.9903	7.4544	-		
	Calmasil	3t/ha	0.7869	0.9582	5.9594	7.7044	+3.33ns		
		6t/ha	0.9631	0.9892	6.0225	7.9748	+7.0**	7.711	
	Slagment	3t/ha	0.9308	0.8759	5.5589	7.3656	-1.2ns		
		6t/ha	1.0496	1.1341	6.1724	8.3560	+12***	7.725	
	Wollastonite	3t/ha	1.0213	0.9406	5.4962	7.4581	+1.2ns		
		6t/ha	0.7002	0.8809	6.0031	7.5842	+1.0ns	7.499	7.645
	LSD (5%)					0.3671		NS	
Arcadia	Control	0t/ha	0.7152	0.8473	5.7695	7.3319	-		
	Calmasil	3t/ha	0.7815	1.0046	6.2568	8.0429	+9.7**		
		6t/ha	0.8810	0.9304	6.8851	8.6966	+18***	8.024	
	Slagment	3t/ha	0.8710	0.8962	5.9837	7.7510	+5.7ns		
		6t/ha	0.7579	0.8929	6.1460	7.7968	+6.3ns	7.627	
	Wollastonite	3t/ha	0.8044	0.9048	6.0832	7.7923	+6.2ns		
		6t/ha	0.8342	0.9103	5.8789	7.6234	+3.97ns	7.583	7.744
	LSD (5%)					0.4908		0.289	
LSD (5%)						0.1564		0.109	0.187

Table 3.10. Effect of Si sources rates application and soil forms on the dry matter yield (average g dry weight kg^{-1} soil) of sorghum grown in the pots.

The *Glenrosa* and *Longlands* form soils showed highly significant sorghum dry matter yield responses ($P \leq 0.001$) to all the three Si sources compared with untreated pots (Figure 3.3 and Figure 3.4). These responses were consistent with relatively low initial soil test Si and soil pH (water) levels observed in those two soils. In contrast, the *Arcadia* form soil did not respond significantly to all the applied Si carriers (Figure 3.6) due to its initial high-test Si levels (Figure 3.1). However, the calmasil treatment produced a linear response for reasons that will be discussed later. The *Cartref* form soil showed significant dry matter yield responses ($P \leq 0.05$) with the slagment Si source at the higher rate (Figure 3.5). The sorghum dry matter yield response to Si was significant ($P \leq 0.05$) for calmasil and wollastonite Si sources at both lower and higher rates in the *Nomanci* form soil (Figure 3.2), but in the case of slagment the response was curvilinear with a yield depression noted at the higher rate. The *Glenrosa* and *Longlands* form soils with the lowest pH(water) values (pH < 5.0) produced highly significant sorghum dry matter yields ($P \leq 0.001$) to all the Si sources applied at the two different rates (Figure 3.3 and Figure 3.4). The sorghum dry matter yield significance was unlikely to be attributed only to an increase in soil pH.

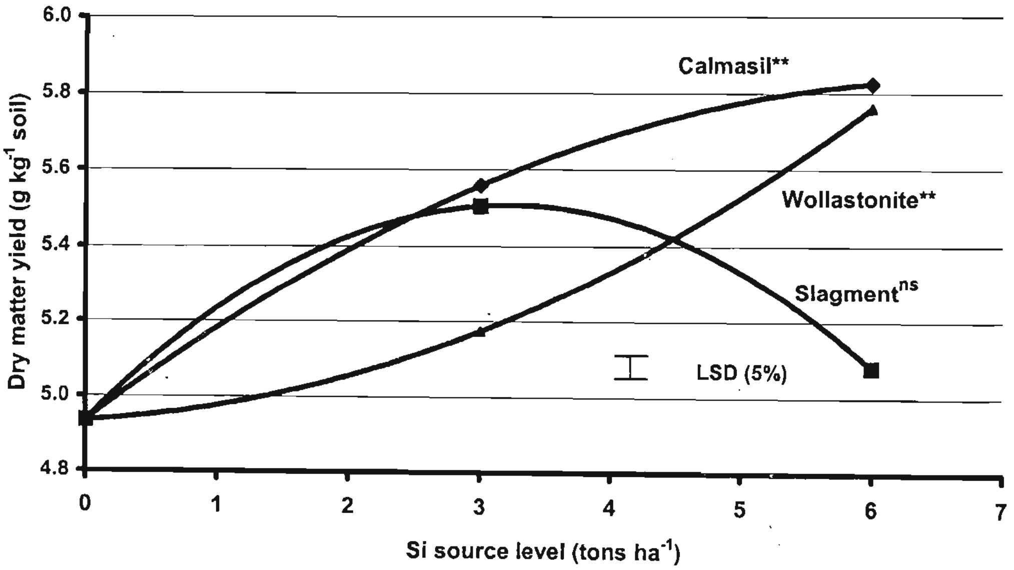

Figure 3.2. Effect of Si source application rates on the cumulative dry matter yield of sorghum plants grown in the pots with *Nomanci* form soil.

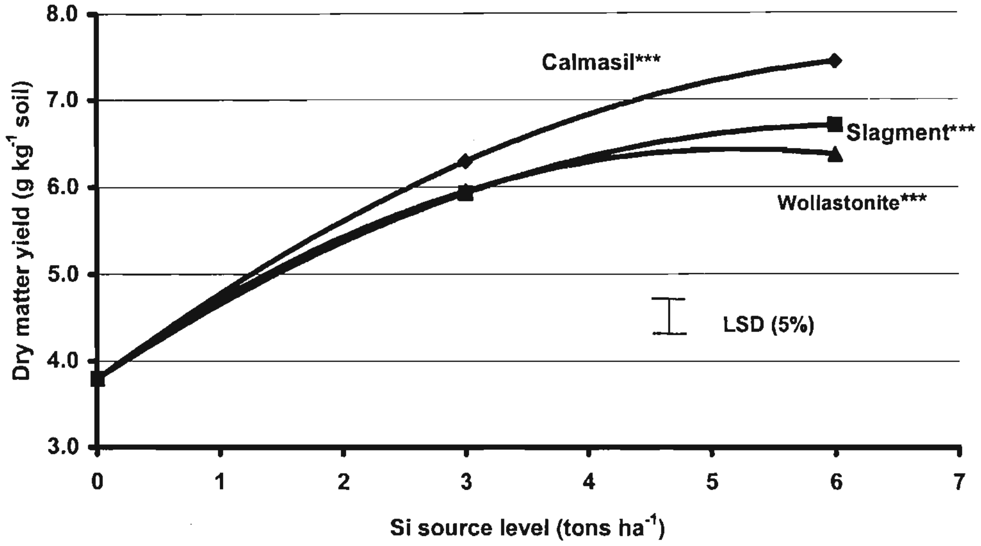

Figure 3.3. Effect of Si source application rates on the cumulative dry matter yield of the sorghum grown in pots on the *Glenrosa* form soil.

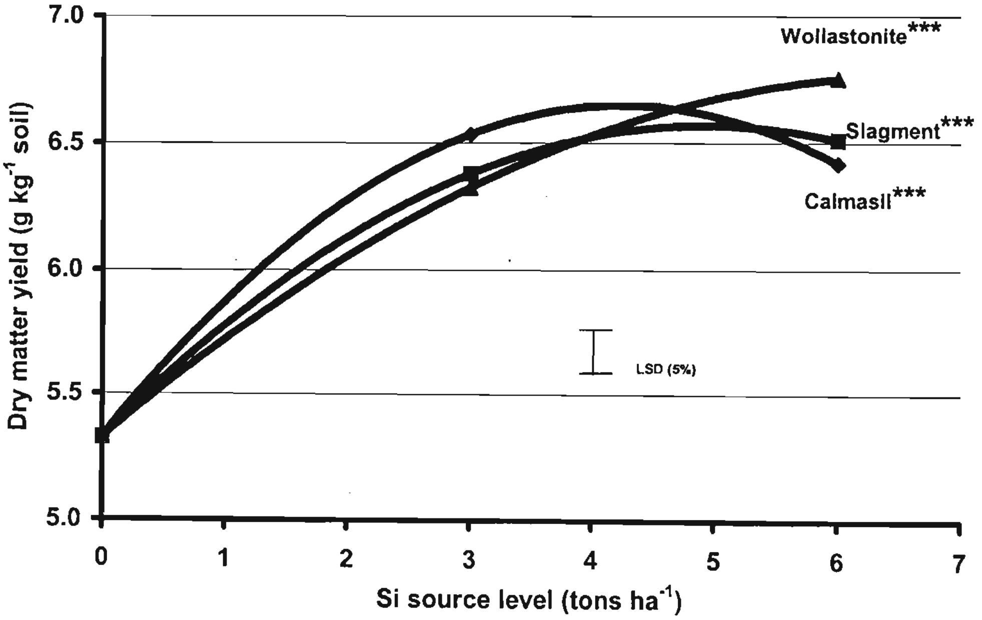

Figure 3.4. Effect of Si source application rates on the cumulative dry matter yield of sorghum plants grown in the pots with *Longlands* form soil.

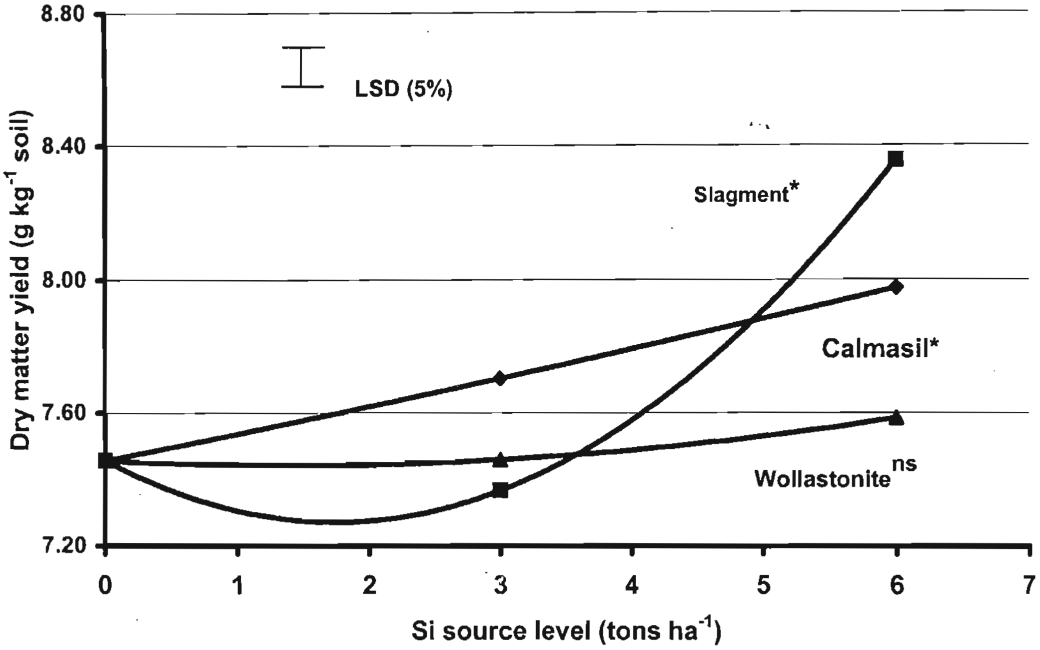

Figure 3.5. Effect of Si source application rates on the cumulative dry matter yield of sorghum plants grown in the pots with *Cartref* form soil.

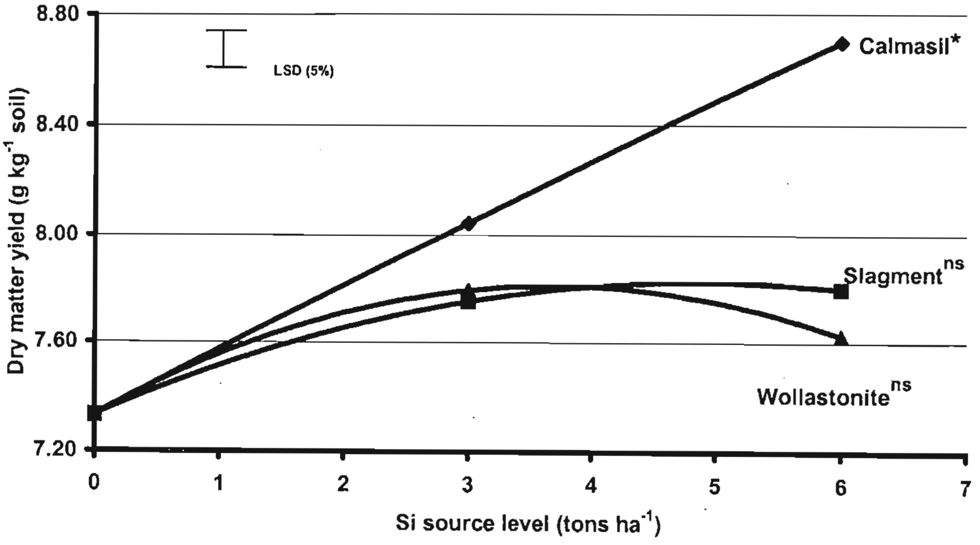

Figure 3.6. Effect of Si source application rates on the cumulative dry matter yield of sorghum plants grown in the pots with *Arcadia* form soil.

The difference in efficacy of the three Si sources might be explained largely on the basis of the initial soil properties and the different Si solubility of the three Si sources. It seems likely that the calmasil silicon source was more effective on the *Arcadia* form soil because of its more readily available silicon content compared with other Si sources, on a soil form with initially the highest silicon content and pH value (Figure 3.6). On one hand, it is likely that the slagment Si source, with a high Si content, coupled with its high alkalinity, caused a nutrient imbalance especially at the higher Si rate. The same scenario of yield depression at the higher Si rate appears to be likely for the *Nomanci* form soil that showed the highest initial soil $\mathrm{pH}_{(\mathrm{water})}$ after the *Arcadia* form soil. On the other hand, the slagment Si source produced highly significant sorghum dry matter yield responses ($P \leq 0.001$) on the *Glenrosa* and *Longlands* form soils that showed the lowest initial values of soil pH. The wollastonite silicon source appeared to be the most efficient on the *Longlands* form soil.

3.3.5. Silicon uptake by sorghum plants.

The greater effectiveness of the Si source treatments might be associated, as stated by Meyer and Keeping (2000), with an increase of Si concentration in the plant. The effect of the different Si sources on the Si uptake by sorghum for the different soils is shown in Table 3.11 (mean of four replicates). Detailed uptake data by sorghum plants in terms of the respective harvests; Si carriers' application rates and soil forms are given in Appendices 5 to 7.

It was observed from Table 3.11, Figures 3.7 to 3.11, and Appendices 5 to 7, that increasing rates of Si sources applied to the soil forms had a direct effect on sorghum Si uptake in all the soil forms as indicated by the concentration of Si (cmol kg^{-1} soil) in the sorghum dry straw. Averaged across all the soil forms, plant silicon levels in treatments receiving Si were generally more than double those in plants from untreated pots (Table 3.11). Another observation was that sorghum plants removed marked quantities of Si at the lower rate (3 tons ha^{-1}) of Si sources in the *Arcadia* form soil.

Soil form	Si source	Si level	Sorghum Si uptake (cmol kg^{-1} soil) at different cuts						
			1st cut	2nd cut	3rd cut	TOTAL	% increase in uptake	Mean Si carrier	Mean soil form
Glenrosa	Control	0t/ha	0.0071	0.0052	0.0438	0.0562	-		
	Calmasil	3t/ha	0.0171	0.0153	0.1296	0.1621	+188***		
		6t/ha	0.0321	0.0339	0.2384	0.3046	+441***	0.1743	
	Slagment	3t/ha	0.0264	0.0275	0.1760	0.2301	+309***		
		6t/ha	0.0345	0.0373	0.2488	0.3208	+470***	0.2024	
	Wollastonite	3t/ha	0.0311	0.0216	0.1529	0.2058	+266***		
		6t/ha	0.0406	0.0294	0.2358	0.3061	+444***	0.1894	0.1887
	LSD (5%)					0.0366		NS	
Nomanci	Control	0t/ha	0.0108	0.0042	0.0708	0.0859	-		
	Calmasil	3t/ha	0.0249	0.0200	0.1682	0.2133	+148***		
		6t/ha	0.0409	0.0281	0.2524	0.3216	+274***	0.2069	
	Slagment	3t/ha	0.0366	0.0185	0.1883	0.2434	+183***		
		6t/ha	0.0272	0.0228	0.2589	0.3091	+259***	0.2128	
	Wollastonite	3t/ha	0.0230	0.0122	0.1491	0.1843	+114***		
		6t/ha	0.0287	0.0306	0.3513	0.4108	+378***	0.2270	0.2156
	LSD (5%)					0.0231		NS	
Cartref	Control	0t/ha	0.0172	0.0109	0.0949	0.1230	-		
	Calmasil	3t/ha	0.0318	0.0294	0.1906	0.2520	+104***		
		6t/ha	0.0485	0.0427	0.3416	0.4331	+252***	0.2694	
	Slagment	3t/ha	0.0495	0.0440	0.2733	0.3671	+198***		
		6t/ha	0.0624	0.0687	0.4149	0.5464	+344***	0.3455	
	Wollastonite	3t/ha	0.0376	0.0250	0.1807	0.2435	+97***		
		6t/ha	0.0386	0.0337	0.3177	0.3902	+217***	0.2523	0.2891
	LSD (5%)					0.0399		0.018	
Longlands	Control	0t/ha	0.0120	0.0098	0.0776	0.0995	-		
	Calmasil	3t/ha	0.0495	0.0346	0.2601	0.3443	+246***		
		6t/ha	0.0645	0.0601	0.3502	0.4751	+377***	0.3063	
	Slagment	3t/ha	0.0370	0.0283	0.2826	0.3482	+249***		
		6t/ha	0.0448	0.0310	0.3240	0.4000	+302***	0.2826	
	Wollastonite	3t/ha	0.0572	0.0318	0.3082	0.3975	+299***		
		6t/ha	0.0674	0.0545	0.3673	0.4895	+391***	0.3288	0.3059
	LSD (5%)					0.0396		NS	
Arcadia	Control	0t/ha	0.0453	0.0354	0.2691	0.3501	-		
	Calmasil	3t/ha	0.0537	0.0567	0.3964	0.5072	+44***		
		6t/ha	0.0590	0.0663	0.3908	0.5165	+47***	0.4580	
	Slagment	3t/ha	0.0567	0.0658	0.3932	0.5162	+47***		
		6t/ha	0.0549	0.0654	0.3943	0.5151	+47***	0.4610	
	Wollastonite	3t/ha	0.0469	0.0572	0.3523	0.4568	+47***		
		6t/ha	0.0658	0.0731	0.3676	0.5070	+44***	0.4380	0.4520
	LSD (5%)					0.0636		NS	
LSD (5%)						0.0178		0.01389	0.0171

Table 3.11. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si uptake (cmol kg^{-1} soil) by sorghum plants grown in the pots (with *, **, and * statistically significant, P< 0.5, 0.01 and 0.001).**

The increase in removed Si was > 30% at the lowest rate of all applied Si sources over the control, while the higher rates increased by 2.65% and 14.34% respectively from calmasil and wollastonite Si sources, and decreased by 0.32% from slagment Si source. The cumulative Si uptake at the highest rate of slagment Si source increased from 47.12% in the *Arcadia* form soil to 470.82% over the control in the *Glenrosa* form soil.

Amendment with all Si sources resulted in significant ($P \leq 0.05$) to highly significant ($P \leq 0.001$) increases in sorghum uptake in all soils. Overall the relative response in Si uptake to Si treatment declined in the order: *Glenrosa* > *Longlands* > *Nomanci* > *Cartref* > *Arcadia*. In general the response in Si uptake was linear on all soils except the *Arcadia* form soil that showed a curvilinear uptake in Si with Si treatment (Figures 3.7 to 3.11). When Si sources were compared, non-significant differences in effectiveness in Si uptake were found. Slagment was marginally better than wollastonite and calmasil in terms of overall Si uptake in the *Arcadia, Cartref* and *Glenrosa* form soils. In the *Longlands* and *Nomanci* form soils, wollastonite appeared the most effective.

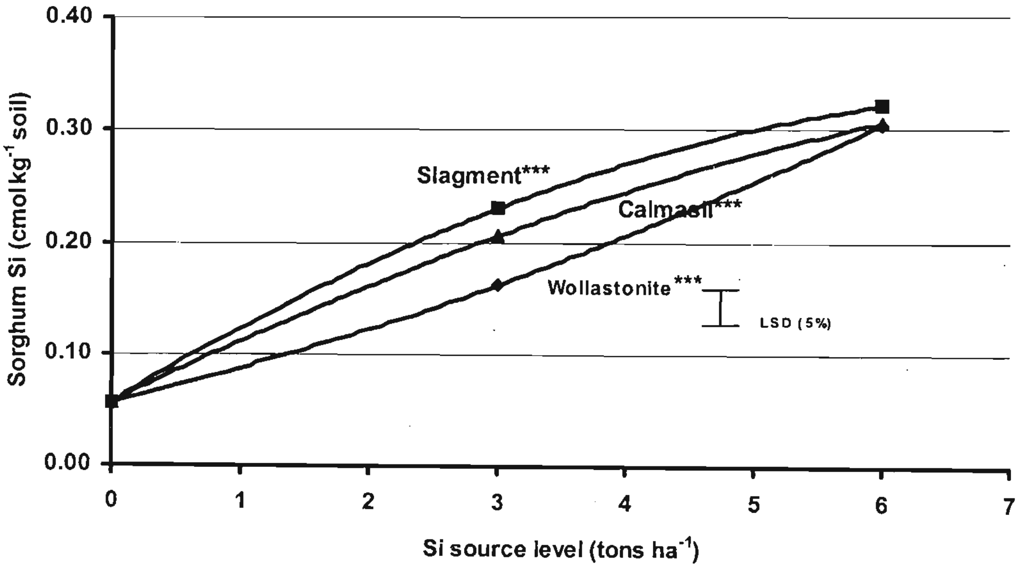

Figure 3.7. Effect of Si source application rates (tons ha^{-1}) on the total Si uptake (cmol kg^{-1} soil) of three crop cuts of sorghum plants grown in the pots with *Glenrosa* form soil.

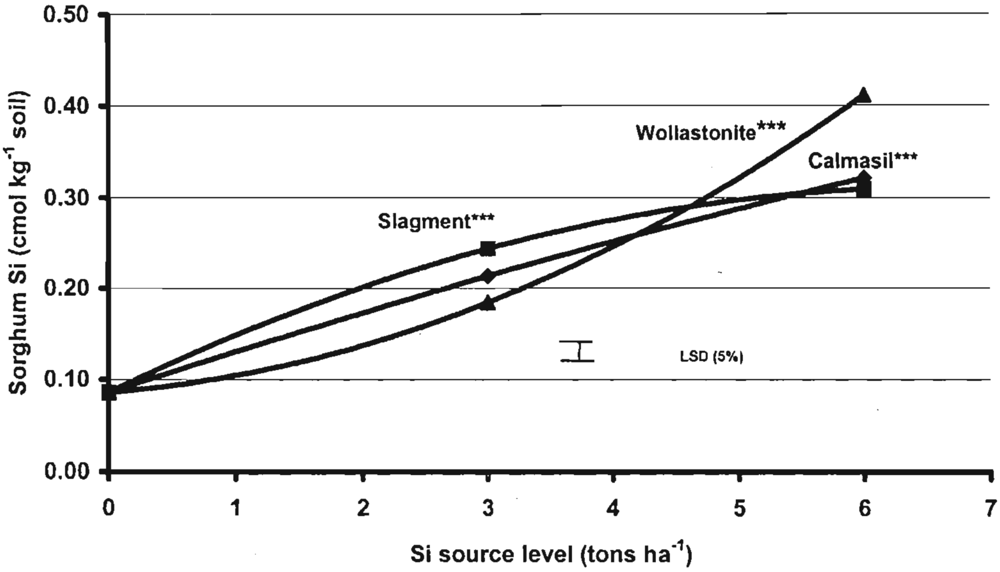

Figure 3.8. Effect of Si source application rates (tons ha^{-1}) on the total Si uptake (cmol kg^{-1} soil) of three crop cuts of sorghum plants grown in the pots with *Nomanci* form soil.

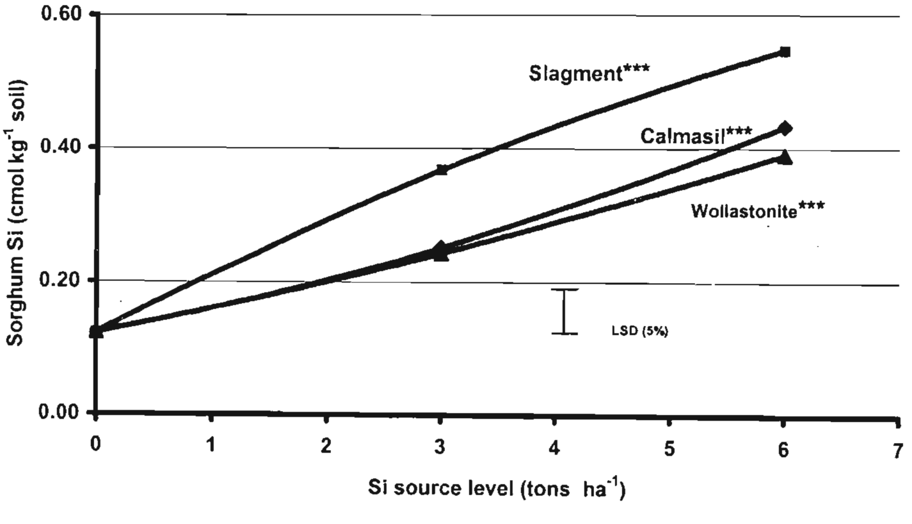

Figure 3.9. Effect of Si source application rates (tons ha^{-1}) on the total Si uptake (cmol kg^{-1} soil) of three crop cuts of sorghum plants grown in the pots with *Cartref* form soil.

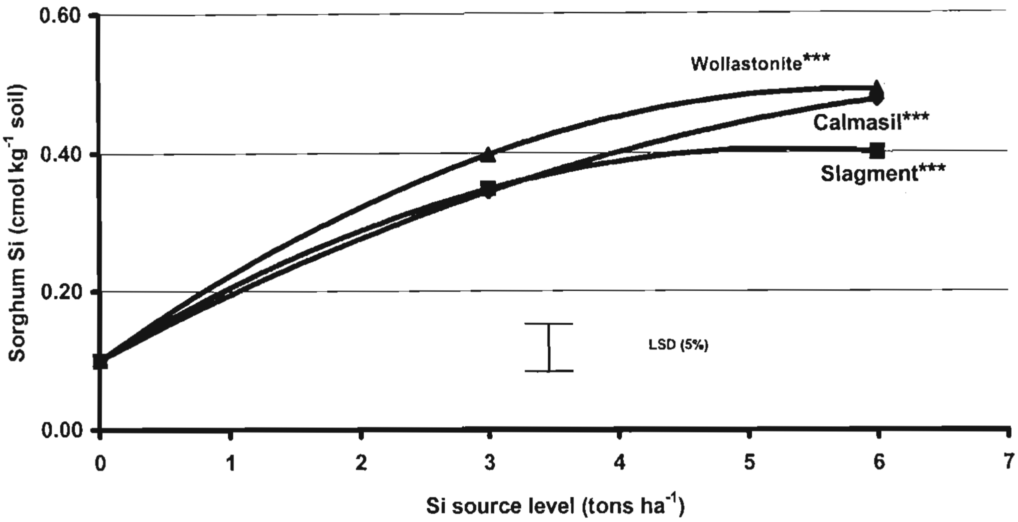

Figure 3.10. Effect of Si source application rates (tons ha^{-1}) on the total Si uptake (cmol kg^{-1} soil) of three crop cuts of sorghum plants grown in the pots with *Longlands* form soil.

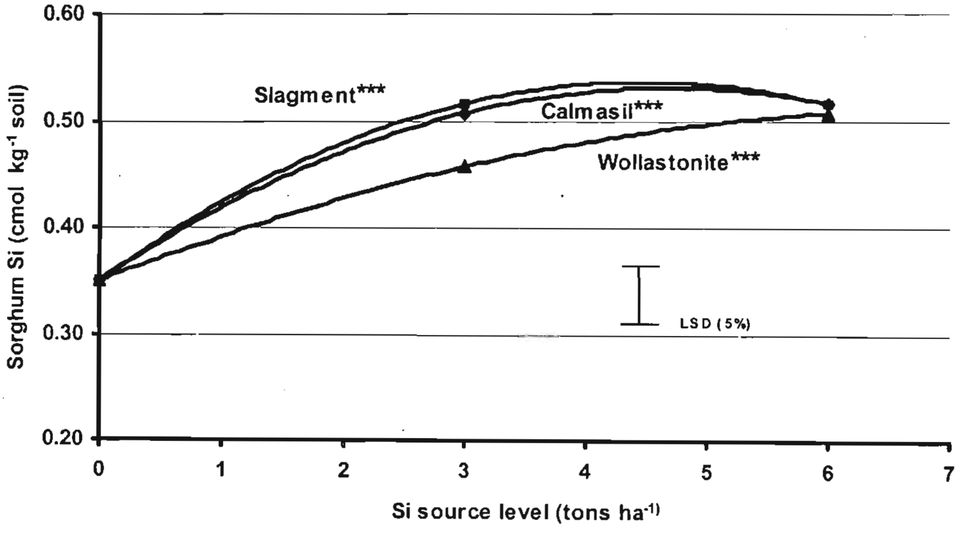

Figure 3.11. Effect of Si source application rates (tons ha^{-1}) on the total Si uptake (cmol kg^{-1} soil) of three crop cuts of sorghum plants grown in the pots with *Arcadia* form soil.

The Si uptake by sorghum showed a strong association with soil Si levels. For example the *Nomanci* form soil with the lower soil Si levels, exhibited considerably lower plant Si uptake when compared with the other soil forms investigated. As in the case of dry matter yields, Si uptake interacted significantly with the soil properties and the amount of Si applied. In general the Si uptake correlated with the Si content of the Si carriers shown in Table 3.3. However, in the *Longlands* and *Nomanci* form soils, the highest Si uptake was not associated with slagment but with wollastonite. It is possible that the lower alkalinity of wollastonite caused a lower nutrient imbalance in the sandy soils *Longlands* and *Nomanci* form soils than the more strongly alkaline slagment and calmasil Si sources.

Silicon has a wide range distribution in plants varying from 0.1 to 10% on a dry matter weight basis with variations between different species and genotypes (Matichenkov *et al.*, 1999; Neumann and de Figueiredo, 2002). The sorghum Si content in this study ranged from 0.41 to 2.06% (Appendix 5 to Appendix 7). Sorghum plants removed larger quantities of Si from soils treated with Si than from untreated soil and this trend was present, though of a different magnitude, in all the five soil forms investigated.

The comparison within factors through values of Si uptake by sorghum plants grown in the pots revealed a highly significant difference ($P \leq 0.001$) between soil forms, led by the *Arcadia* form soil. The *Cartref* and *Longlands* form soils came second, followed by *Nomanci* and *Glenrosa*. The analysis of variance also revealed significantly different ($P \leq 0.001$) means between soil forms and Si carriers and the soil forms x treatments interactions. The *Arcadia* form soil showed a statistically higher mean Si uptake. In the soil forms x treatments interaction, the *Arcadia* form soil showed the highest mean ($P \leq 0.05$) Si uptake while the 6 tons ha^{-1} Si source rate mean was statistically ($P \leq 0.05$) higher than that of the control (0 tons ha^{-1}), but the former did not differ from that of 3 tons ha^{-1} Si source rate. This means that the best combination of factors could be the 3 tons ha^{-1} rate of calmasil, slagment or wollastonite Si sources in the *Arcadia* form soil.

The results of this study confirm the findings of Matichenkov *et al.* (1999) that sorghum has an active Si transport mechanism, because Si uptake increased in response to Si fertilization. In all treatments, the Si uptake by sorghum was clearly controlled by the Si levels in the soil. It was also observed that sorghum plants removed more Si from the untreated *Arcadia* pots than from other soil forms (Table 3.11). Results in this study agreed with those reported by Moberly and Meyer (1975) and Berthelsen *et al.* (1999). The latter found positive yield response due to the addition of various silicate sources through their ability to increase plant available soil Si levels and therefore the Si plant uptake. The former authors attributed the greater effectiveness of the application of silicon compounds in acid soils with an increase in silicon concentration in the plant.

The results of this study also confirm the observations by Colwell (1994) that fertilizer trials carried out on soils with severe nutrient deficiencies may produce highly significant results, simply because the treatment effects are large and obvious. In contrast, when experiments are carried out on a soil with no nutrient deficiencies, even high quality experiments with very small standard errors will produce non-significant results, because there are no treatment effects.

3.3.5. Sorghum nutrient uptake.

An elemental analysis of plant samples from the sorghum aerial biomass was conducted to estimate the plant nutrient uptake until the sampling date. The results (Table 3.12) demonstrate that all the Si sources applied to the different soil forms investigated increased sorghum Si uptake, particularly at the higher rate (6 tons ha^{-1}). Although the various treatments had an effect on the chemical status of the different soil forms investigated, in particular Ca, Mg and K, this was not evident in uptake levels in the plant. In general, there was no significant effect on any other nutrient element except Si as a result of the treatments. With the exception of Ca and K that showed concentrations slightly below the recommended critical levels (Meyer *et al*, 2004) respectively in the *Glenrosa* and *Longlands* form soil (Table 3.7), all other nutrients were present in adequate concentrations. These lower K and Ca concentrations were corrected by including the elements through weekly fertigation of nutrients from planting to harvest.

Soil form	Si source	Si level	Sorghum nutrient content (%) at harvest					
			N	P	K	Ca	Mg	Si
Arcadia	Control	0t/ha	0.983	0.310	2.555	0.808	0.655	1.418
	Calmasil	3t/ha	0.815	0.318	2.503	1.178	0.718	1.765
		6t/ha	0.883	0.295	2.558	0.770	0.710	1.830
	Slagment	3t/ha	0.955	0.288	2.488	0.908	0.713	1.920
		6t/ha	0.838	0.285	2.533	0.645	0.788	1.955
	Wollastonite	3t/ha	0.875	0.290	2.398	0.538	0.638	1.680
		6t/ha	0.873	0.310	2.640	0.613	0.655	2.058
	F probability		*0.002*	*0.370*	*0.283*	*0.076*	*0.204*	*≤ 0.001*
Cartref	Control	0t/ha	1.005	0.223	2.670	0.575	0.518	0.510
	Calmasil	3t/ha	0.903	0.230	2.668	0.543	0.585	0.978
		6t/ha	0.960	0.240	2.550	0.575	0.573	1.403
	Slagment	3t/ha	0.898	0.240	2.700	0.498	0.648	1.423
		6t/ha	0.773	0.200	2.508	0.533	0.563	1.750
	Wollastonite	3t/ha	0.868	0.253	2.708	0.588	0.483	0.878
		6t/ha	0.833	0.248	2.578	0.710	0.495	1.348
	F probability		*0.002*	*0.004*	*0.002*	*0.213*	*0.013*	*≤ 0.001*
Glenrosa	Control	0t/ha	1.285	0.260	3.180	0.688	1.028	0.408
	Calmasil	3t/ha	0.948	0.300	2.753	0.775	0.987	0.720
		6t/ha	0.938	0.303	2.620	0.870	0.853	1.030
	Slagment	3t/ha	0.910	0.270	2.710	0.585	0.798	1.130
		6t/ha	0.965	0.283	2.598	0.545	0.798	1.303
	Wollastonite	3t/ha	0.965	0.250	2.748	0.570	0.788	0.920
		6t/ha	0.940	0.303	2.865	0.375	0.748	1.240
	F probability		*≤ 0.001*	*0.007*	*≤ 0.001*	*0.355*	*≤ 0.001*	*≤ 0.001*
Longlands	Control	0t/ha	0.933	0.303	2.948	0.338	0.522	0.483
	Calmasil	3t/ha	0.740	0.310	2.828	0.418	0.605	1.355
		6t/ha	0.998	0.240	2.693	0.385	0.665	1.893
	Slagment	3t/ha	1.155	0.265	2.785	0.250	0.530	1.308
		6t/ha	0.750	0.285	2.610	0.270	0.523	1.518
	Wollastonite	3t/ha	0.773	0.293	2.540	0.340	0.378	1.678
		6t/ha	0.690	0.240	2.630	0.298	0.335	1.983
	F probability		*0.512*	*0.006*	*≤ 0.001*	*0.495*	*0.936*	*≤ 0.001*
Nomanci	Control	0t/ha	0.855	0.305	3.110	0.233	0.648	0.550
	Calmasil	3t/ha	0.668	0.273	2.933	0.267	0.600	1.068
		6t/ha	0.893	0.303	2.903	0.343	0.668	1.465
	Slagment	3t/ha	0.780	0.340	3.140	0.430	0.913	1.300
		6t/ha	1.143	0.318	3.028	0.393	0.720	1.563
	Wollastonite	3t/ha	0.950	0.330	3.098	0.360	0.600	0.910
		6t/ha	0.970	0.345	2.990	0.390	0.660	1.655
	F probability		*0.141*	*0.294*	*0.110*	*≤ 0.001*	*0.317*	*≤ 0.001*
F probability			*≤ 0.001*	*0.689*	*≤ 0.001*	*0.384*	*0.434*	*≤ 0.001*

Table 3.12. Effect of soil forms and Si source application rates on nutrient uptake by sorghum plants grown in the pots (average percent for four replications).

Phosphorus, K and Mg in sorghum straw generally exceeded published critical concentrations regardless of treatments (Table 3.12 and Table 3.13). This agrees with studies in the Everglades by Elawad *et al.* (1982a, 1982b) and Snyder *et al.* (1986), and in Lousiana by Viator *et al.* (2002). In the sandy *Longlands* and *Nomanci* form soils, calcium straw contents were lower than the published critical level (Table 3.12), perhaps as a result of dilution by the taller growing sorghum plants, this agreeing with the findings of du Preez (1970), Elawad *et al.* (1982b) and Ernst and Stivers (1982).

Concentrations of some nutrients such as N and K (Table 3.12) were higher in the untreated pots with a lower dry matter weight of sorghum straw yield. These higher concentrations, as reported by Ernst and Stivers (1982), could be the result of continuing accumulation of nutrients in plants under stress. Application of Si source rates increased sorghum yields. However, since the different Si sources contained varying amounts of plant nutrients (Table 3.3), the reason for the increase must be carefully assessed. Si source rates application significantly influenced plant elemental content for certain nutrients (Table 3.12), but changes were not as marked as those for Si.

Nutrient element	Sorghum straw nutrient content (%)	
	Data from literature	Data from present study
Calcium	0.400	0.532 (0.250-1.178)
Phosphorus	0.170	0.281 (0.223-0.345)
Potassium	1.400	2.736 (2.398-3.180)
Magnesium	0.320	0.660 (0.335-1.028)
Silicon	1.450	1.326 (0.408-1.955)

Table 3.13. Relationship between sorghum nutrient content in the study and sorghum nutrient content from the literature (from Wall and Blessin, 1970; Chantereau and Nicou, 1994).

The nutrient uptake data (Table 3.12) were examined in an attempt to determine the nutrients responsible for the increases in sorghum dry matter yield and for the differences in yields between the various treatments. The sorghum Ca uptake may have been influenced by the soil form's initial Ca concentration and was correlated to the clay content, thus the *Arcadia* form soil showed the highest sorghum Ca uptake, followed by *Cartref*, *Glenrosa*, *Nomanci* and *Longlands* form soils, in descending order of their clay content (Table 3.1). The nutrients P and Mg were not affected by Si source application whereas N and K decreased in plant tissue with increasing rates of Si sources.

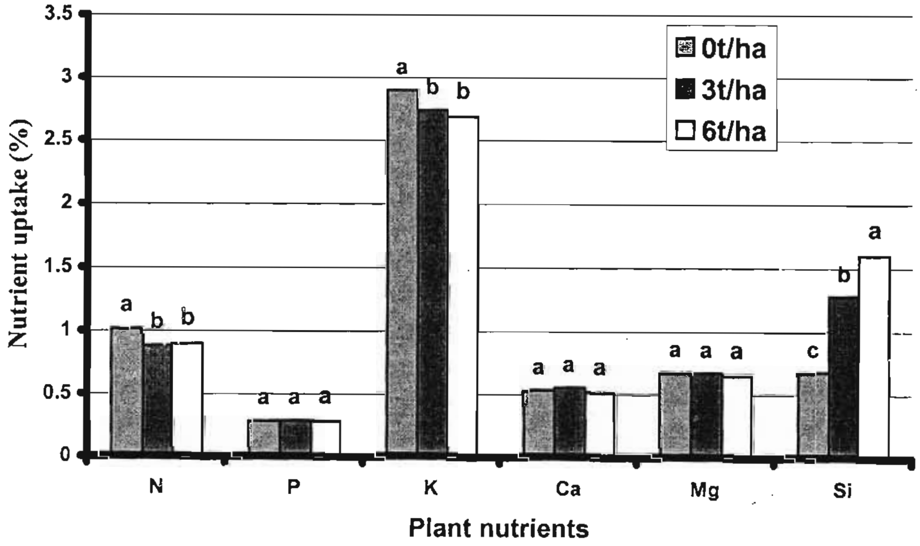

Fig 3.12. Nutrient uptake (%) of sorghum plants grown in pots with various levels of silicon. Means with the same letter within the graph are not significantly different ($P \leq 0.05$) according to Fisher's Least Significant Difference (LSD 0.05) (Rayner, 1969; Dallal, 2001).

In an attempt to explain the origin of differences in nutrient content revealed by the statistical analysis (Table 3.12), the comparison of treatment means using the Fisher's Least Significant Difference (LSD 0,05) (Figure 3.12) showed that unlike silicon, that increased significantly ($P \leq 0.05$), Nitrogen and Potassium in sorghum straw decreased significantly ($P \leq 0.05$) in the presence of Si compared with those of Si-free treatment or control; while P, Ca and Mg were found not to be significantly different ($P > 0.05$). Si was thus found to reduce N and P concentrations in the sorghum straw by 13% and 7% respectively (Table 3.12 and Figure 3.12), thus confirming the findings of Liang *et al.* (2001). The differences in N and K concentrations were observed between untreated pots and the lower Si rate (3 tons ha^{-1}), whereas both Si levels (3 tons ha^{-1} and 6 tons ha^{-1}) were not significantly different (Figure 3.12).

Except for Si, there were no positive significant treatment differences in the concentrations of N, P, K, Ca and Mg in the sorghum plants. The uptake data indicated that none of the elemental nutrients other than Si were deficient (Table 3.12) and that they were therefore not responsible for the yield differences. The evidence in this study suggests that the main effect of the Si sources was to provide plant available Si. The low Si status of the soil forms investigated other than *Arcadia* appears to be a factor that can limit yield of Si accumulator plants such as sorghum and sugarcane. It does not appear that sorghum yield increases can be accounted for by the elements, other than Si, examined in this study, that were contained in the Si carriers. It may be worthwhile to consider Si fertilization in other acid soils where difficulties are encountered with plant production, especially Si accumulators.

3.4. CONCLUSION.

In this chapter, the application of Si-rich alkaline carrier rates increased the soil pH through neutralization of soil acidity. The amount of plant available Si increased in proportion to the increased rates of applied Si sources. Lindsay (1979), Wild (1986), Jianjun *et al.* (2002) and Matichenkov *et al.* (1999) found similar results. The increase of exchangeable cations Ca^{2+} and Mg^{2+} was attributable to the substantial amount of these elements in the Si sources investigated. Part of the nutrients was supplied to the soil in the pots through the weekly dressing solution application to avoid any deficiency other than that of the element under investigation.

The sorghum dry matter yield and the Si uptake were mainly influenced by the different soil forms through their fertility status as well as Si source application rates, rather than the Si sources themselves; which showed no significant differences in their respective Si supply to the soil solution, and hence, to the sorghum plants despite their difference in Si content. Overall, sorghum grown in the *Arcadia* form soil performed better than in the other soil forms, due undoubtedly to a better initial fertility status. The lower Si source application rate (3 tons ha^{-1}) showed a mean that was significantly higher ($P \leq 0.05$) than that of control (0 tons ha^{-1}) but not significantly different from that of the higher rate (6 tons ha^{-1}).

The P, Ca and Mg sorghum uptake was not affected by different Si source application rates. In accordance with the findings of Liang *et al.* (2001), the N and K contents in sorghum straw decreased significantly ($P \leq 0.05$) in the presence of Si treatment compared with the Si-free treatment or control. The present study has demonstrated that application of Si-rich materials to soil with sub-optimal levels of plant available Si can result in significant responses in the sorghum plant crop. The positive yield responses observed in this trial were due to the addition of the various Si sources and their ability to increase plant available soil Si levels and therefore plant Si uptake.

CHAPTER 4

RESIDUAL EFFECT OF APPLIED Si CARRIERS ON CANE YIELD AND SILICON UPTAKE FOLLOWING ROTATION WITH SORGHUM

4.1. INTRODUCTION.

The evaluation of soil nutrient element status and the calibration of soil test values with yield response data form an essential part of the prediction of optimum rates of mineral fertilization (Thibaud, 1991). Accordingly, the Si status of soil is commonly determined by measuring the Si concentration in an extract of the soil. In this chapter, the routine testing is being continued in order to identify the method that correlates best with cane plant tissue Si levels after Si source application.

The objective of the second part of this experiment was to measure the amount of residual soil Si taken up by sugarcane (*Saccharum officinarum* L.) plants after the sorghum harvest and to compare this with the amount of Si removed from soils by the exhaustive soil chemical extraction methods. To do so, the same five soils that were used in the sorghum cropping trial were investigated to evaluate the response of sugarcane to residual Si fertilization. The mechanism of Si retention in the soil forms investigated was unspecified, and consequently, the present study was conducted to determine residual effects of Si-rich compounds application rates on sugarcane production following rotation with sorghum.

4.2. MATERIALS AND METHODS.

After the sorghum harvest, the soils were air-dried, roots removed and soil samples were taken from each and every pot for laboratory analyses. The remaining soils were repotted and planted to single eyed setts of variety N35. No new Si fertilizers were applied to the soils. The experimental design remained the same using a split-split-plot with four replications. The pots were watered three times a week to 70% field capacity with deionised water, and plants were systematically rotated within the glasshouse every day.

To ensure that yield responses were due only to Si and no other nutrients in the Si carriers, basal nutrients were added to all pots in the second week after planting. Each pot received a weekly 10ml basal application solution of 0.2g L^{-1} of $(NH_4)_2SO_4$; 10.0g L^{-1} of $MgSO_4.7H_2O$; 6.0g L^{-1} of $(NH_4)H_2PO_4$; 8.3g L^{-1} of K_2SO_4; 6.6g L^{-1} of $CaCl_2.2H_2O$ and 1.7g L^{-1} of KCl. After twelve (12) weeks of growth, this basal nutrient solution was upgraded to supply more nitrogen to the young cane plants.

Cane plants were grown for forty-two (42) weeks before harvesting the total aerial biomass. Cane leaf surface area per pot was measured. Stalks and tops were dried in an oven at 75^0C overnight, weighed and ground in a stainless steel Wiley mill. The milled tissue was stored for later elemental analyses. Yield was estimated through stalk and top dry matter production at forty-two (42) weeks of crop age. After harvest, soils were dried for two weeks before removing the bulk of the roots. The soils were sampled, air-dried, reground and stored for later silicon and routine analyses. The silicon analysis followed the same extraction methods as those described in the previous chapter. Roots were washed and dried in an oven at 75^0C and ground in a stainless steel Wiley mill. The milled tissue was stored for later silicon analysis. Analysis of variance (ANOVA) was performed using the Genstat 7.1 computer programme (Payne *et al.*, 2003). A probability of 0.05 or less was considered to be statistically significant.

4.3. RESULTS AND DISCUSSION.

4.3.1. Soil properties after cane harvest.

The soil $pH(H_2O)$ values after cane harvest were generally lower when compared with those before cane establishment. The residual effects of the low and high rates of the three silicon carriers on soil pH were still clearly evident after three crops of sorghum and one crop of cane (Table 4.1 and Figure 4.1).

Soil form	Si level	pH (H_2O)	CEC ($cmol_c$ kg^{-1})	Nutrient element concentration in the soil (cmol kg^{-1}) at cane harvest						
				Ca	Mg	K	Na	Mn	Si	Mn/Si ratio
Arcadia	TO	4.63	37.85	10.40	5.33	3.23	2.49	0.179	0.16	1.12
	Calm L	4.86	38.37	11.28	5.18	2.82	2.14	0.137	0.21	0.65
	Calm H	5.24	41.30	12.56	5.51	2.57	2.14	0.137	0.30	0.46
	Slag L	4.88	37.99	11.31	5.18	2.48	2.07	0.143	0.21	0.68
	Slag H	5.18	39.71	11.56	5.69	2.49	2.33	0.154	0.34	0.45
	Woll L	4.81	37.78	11.21	4.95	2.67	2.25	0.145	0.20	0.73
	Woll H	4.98	40.47	12.66	4.92	2.70	2.29	0.140	0.27	0.52
	Mean	4.94	39.07	11.57	5.25	2.71	2.24	0.150	0.24	0.63
Cartref	TO	4.29	13.69	1.56	2.50	3.32	1.88	0.006	0.06	0.10
	Calm L	4.55	15.08	1.78	3.00	2.76	1.84	0.013	0.08	0.16
	Calm H	4.87	13.47	1.48	2.84	2.91	1.44	0.023	0.11	0.21
	Slag L	4.60	15.91	1.85	3.19	3.20	1.91	0.018	0.11	0.16
	Slag H	4.79	16.63	2.16	3.33	3.09	1.80	0.029	0.25	0.12
	Woll L	4.49	14.95	2.28	2.52	2.99	1.58	0.007	0.10	0.07
	Woll H	4.73	13.08	2.09	2.32	2.53	1.22	0.010	0.11	0.09
	Mean	4.62	14.69	1.89	2.81	2.97	1.67	0.020	0.12	0.17
Glenrosa	TO	4.21	10.14	1.87	1.27	2.48	0.72	0.004	0.05	0.08
	Calm L	4.63	12.65	1.78	2.43	2.63	1.03	0.015	0.08	0.19
	Calm H	5.23	12.09	1.65	2.38	2.49	0.92	0.016	0.13	0.12
	Slag L	4.66	12.40	1.65	2.43	2.71	1.00	0.016	0.05	0.32
	Slag H	5.17	11.81	1.37	2.58	2.61	1.00	0.022	0.24	0.09
	Woll L	4.39	11.03	1.52	1.98	2.57	0.99	0.003	0.02	0.15
	Woll H	4.95	9.93	1.56	1.48	2.90	0.85	0.008	0.05	0.16
	Mean	4.75	11.44	1.63	2.08	2.63	0.93	0.010	0.09	0.11
Longlands	TO	4.49	6.53	1.25	0.77	1.43	0.70	0.053	0.02	2.65
	Calm L	5.64	5.04	0.61	0.77	1.34	0.75	0.065	0.03	2.17
	Calm H	6.21	5.24	0.65	0.87	1.33	0.67	0.069	0.06	1.15
	Slag L	5.73	6.39	0.91	0.99	1.62	0.72	0.080	0.14	0.57
	Slag H	6.05	5.81	0.76	0.98	1.44	0.66	0.075	0.58	0.13
	Woll L	5.23	6.12	0.88	0.93	1.59	0.72	0.070	0.02	3.50
	Woll H	5.86	5.32	0.68	0.68	1.35	0.71	0.064	0.04	1.60
	Mean	5.60	5.78	0.82	0.86	1.44	0.70	0.070	0.13	0.54
Nomanci	TO	4.52	8.55	1.15	1.22	2.75	0.69	0.006	0.02	0.30
	Calm L	4.88	9.23	1.38	1.46	2.41	0.62	0.014	0.03	0.47
	Calm H	5.55	9.08	1.30	1.44	2.38	0.83	0.015	0.07	0.21
	Slag L	5.05	8.58	1.03	1.30	2.96	0.59	0.012	0.06	0.20
	Slag H	5.34	9.54	1.56	1.46	2.38	0.84	0.015	0.33	0.05
	Woll L	4.69	8.72	1.29	1.27	2.49	0.82	0.005	0.02	0.25
	Woll H	5.08	8.54	1.22	1.28	2.30	0.89	0.003	0.05	0.06
	Mean	5.02	8.89	1.28	1.35	2.52	0.75	0.010	0.08	0.13
Total Mean		4.98	15.97	3.44	2.47	2.45	1.26	0.050	0.13	0.38

Table 4.1. Some selected chemical properties of the soil samples after cane harvest.

The exchangeable cations in all soil forms and all treatments after cane harvest increased (Table 4.1) compared with their respective concentrations before cane planting (Table 3.9). This was due to in part to the impact of drying on nutrient release and the weekly application of a nutrient solution containing basic cations.

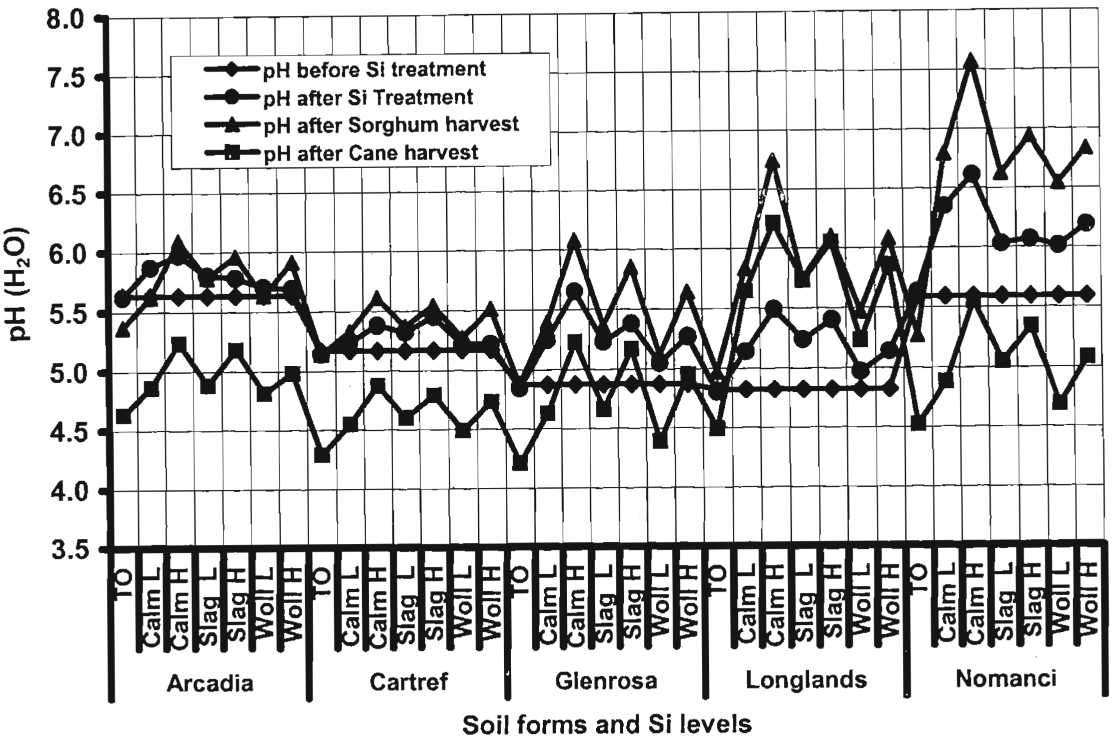

Figure 4.1. Soil pH (H_2O) changes as measured after sampling, Si treatment, sorghum and cane crop harvest.

Large quantities of Ca^{2+} and Mg^{2+} are common in vertisols as carbonates of Ca and Mg. This was the case with the *Arcadia* form soil that exhibited more exchangeable bases than the rest of the soil forms investigated. Hubble (1984) stated that in cases where Mg is co-dominant with Ca, Na levels also tend to be higher. The high concentration of NH_4^+ in ammonium amended-soils could enhance this mechanism by displacing K, Ca, Mg and Na from specific adsorption sites on the 2:1 clay minerals, thereby further increasing the concentration of the basic cations in the soil solution (Hileman cited by Judge, 2001).

The soil CEC was highest in the *Arcadia* form soil with values ranging from 37.78 to 41.30cmol kg^{-1} and lowest in the *Longlands* form soil with values ranging from 5.24 to 6.53cmol kg^{-1} (Table 4.1). These trends are in agreement with the findings of Bohn *et al.* (2001) and Jones (2001) that CEC is related to the soil texture. Thus, the sandy soils had a CEC ranging from 1.0 to 8.0cmol kg^{-1}, while in clay loam and clay soils CEC ranged from 29.0 to more than 40.0cmol kg^{-1}.

The Modified Truog extractable soil silicon values after cane harvest (Table 4.1) were overall lower than those before cane establishment (Table 5.9). This was expected as no additional Si was applied prior to cane planting and showed that the cane plants removed part of soil silicon. According to Essington (2004), acid soils may contain an appreciable amount of exchangeable Mn^{2+} that can be toxic to plant growth. The soil manganese was highest in *Arcadia* form soil with values ranging from 0.140 to 0.179cmol kg^{-1}; followed by the *Longlands* form soil with values ranging from 0.053 to 0.080cmol kg^{-1}. The *Cartref, Glenrosa* and *Nomanci* form soils showed the lowest values ranging from 0.003 to 0.029cmol kg^{-1}. The Mn/Si ratio was generally below unity (1.0) in all the soil forms except *Longlands* where it slightly exceeded unity (1.0) in the control, calmasil and wollastonite Si treatments. According to Liang *et al.* (2001), the lower the Mn/Si ratio the better the plants will grow.

4.3.2. Cane dry biomass yield.

The cane dry biomass yield results are summarized in Table 4.2 (average mean g kg^{-1} of four soil replications). In general, compared with the previous sorghum dry matter yield results on the same soil forms and Si sources applied at the same rates, there was a significant cane dry biomass yield increase ($P \leq 0.05$) with increasing residual rates of Si source application on all soil forms except *Arcadia* where there was a significant cane dry biomass yield decrease ($P \leq 0.05$). Overall the response to Si treatment declined in the order: *Nomanci* > *Longlands* > *Glenrosa* > *Cartref* > *Arcadia*. When Si sources were compared, calmasil again performed the best particularly at the low rate of application.

Soil form	Si source	Si level	Cane dry biomass yield (g kg^{-1} soil)					
			Stalks	Tops	TOTAL	% yield increase	Mean Si carrier	Mean soil form
Nomanci	Control	0t/ha	4.494	4.602	9.096	-		
	Calmasil	3t/ha	7.360	11.709	19.069	+109.6***		
		6t/ha	4.861	11.315	16.176	+77.8***	14.78	
	Slagment	3t/ha	6.871	4.599	11.470	+26.10ns		
		6t/ha	7.063	11.901	18.964	+108.4***	13.18	
	Wollastonite	3t/ha	6.307	11.167	17.475	+92.1***		
		6t/ha	7.452	10.450	17.902	+96.8***	14.82	14.26
	LSD (5%)				2.554		NS	
Glenrosa	Control	0t/ha	5.686	5.268	10.954	-		
	Calmasil	3t/ha	6.391	11.267	17.657	+61.19**		
		6t/ha	6.016	13.219	19.235	+75.6***	15.95	
	Slagment	3t/ha	4.718	11.380	16.098	+46.96*		
		6t/ha	6.780	13.464	20.244	+84.8***	15.77	
	Wollastonite	3t/ha	9.193	11.557	20.750	+89.4***		
		6t/ha	10.756	7.916	18.672	+70.46**	16.79	16.17
	LSD (5%)				4.399		NS	
Longlands	Control	0t/ha	6.598	8.148	14.745	-		
	Calmasil	3t/ha	13.449	14.742	28.191	+91.1***		
		6t/ha	11.622	15.469	27.091	+83.7***	23.34	
	Slagment	3t/ha	11.878	13.606	25.481	+72.8***		
		6t/ha	13.695	13.756	27.451	+86.1***	22.56	
	Wollastonite	3t/ha	10.657	12.405	23.063	+56.4***		
		6t/ha	11.677	14.278	25.955	+76.0***	21.25	22.39
	LSD (5%)				4.352		NS	
Arcadia	Control	0t/ha	16.514	19.294	35.808	-		
	Calmasil	3t/ha	11.587	18.348	29.935	-16.40**		
		6t/ha	13.493	17.247	30.740	-14.15*	32.16	
	Slagment	3t/ha	15.301	18.478	33.778	-5.67ns		
		6t/ha	14.162	18.002	32.164	-10.18ns	33.92	
	Wollastonite	3t/ha	15.839	17.098	32.937	-8.0ns		
		6t/ha	14.160	16.418	30.578	-14.61**	33.11	33.06
	LSD (5%)				3.815		NS	
Cartref	Control	0t/ha	15.052	18.182	33.234	-		
	Calmasil	3t/ha	18.803	17.196	35.999	+8.32ns		
		6t/ha	12.536	20.666	33.203	-0.09ns	34.15	
	Slagment	3t/ha	18.841	19.905	38.746	+16.5***		
		6t/ha	17.484	17.624	35.108	+5.64ns	35.70	
	Wollastonite	3t/ha	18.131	17.604	35.735	+7.53ns		
		6t/ha	9.383	21.417	30.804	-7.31ns	33.26	34.37
	LSD (5%)				3.329		NS	
LSD (5%)					1.608		NS	2.079

Table 4.2. Effect of Si source application rates and soil forms on the dry matter yield (average g dry weight kg^{-1} soil) of cane plants grown in the pots (with *, **, and * statistically significant, P< 0.5, 0.01 and 0.001).**

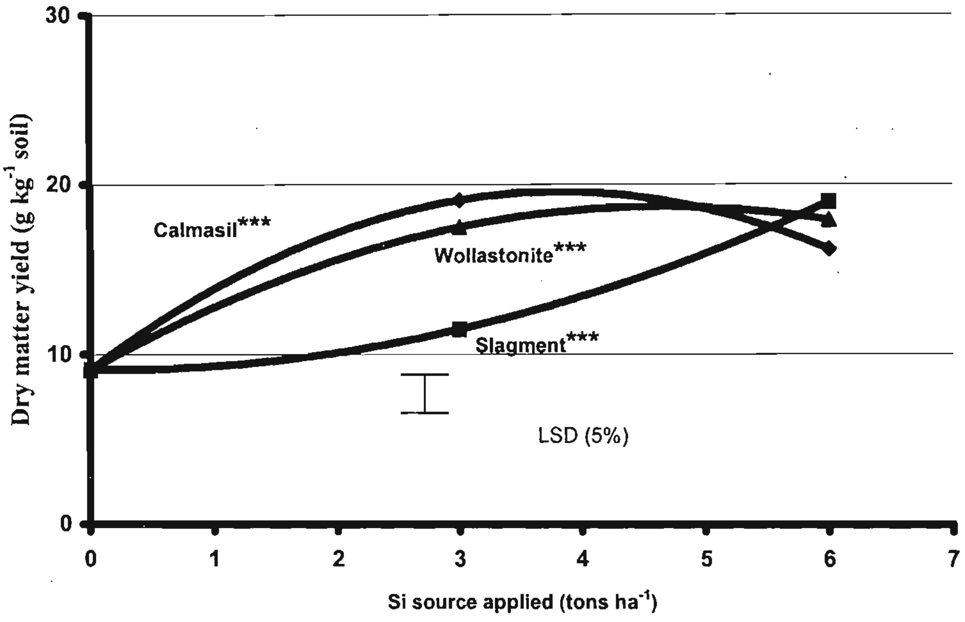

Figure 4.2. Effect of Si source application rates (tons ha^{-1}) on the dry biomass yield (g kg^{-1} soil) of cane plants grown in the pots with *Nomanci* form soil.

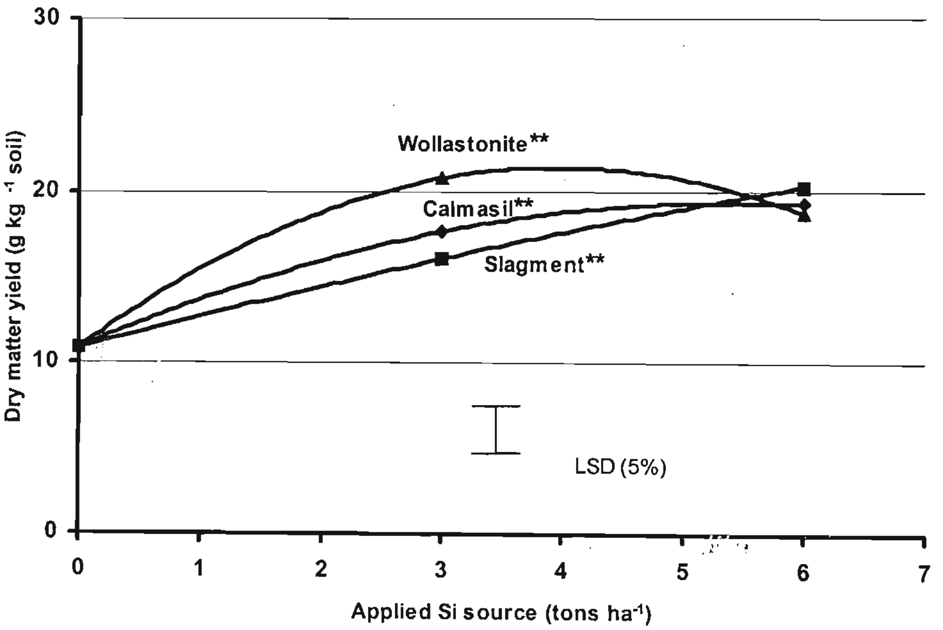

Figure 4.3. Effect of Si source application rates (tons ha^{-1}) on the dry biomass yield (g kg^{-1} soil) of cane plants grown in the pots with *Glenrosa* form soil.

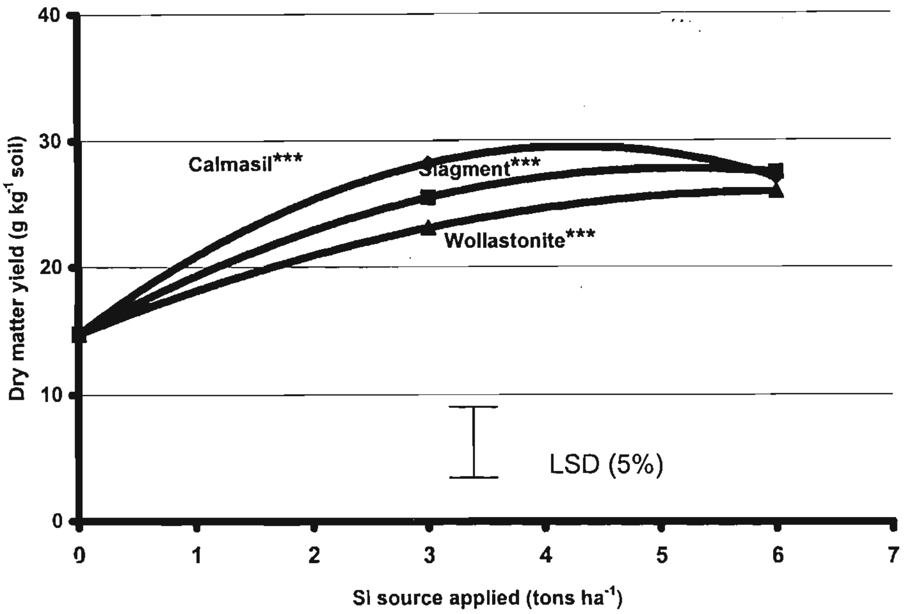

Figure 4.4. Effect of Si source application rates (tons ha^{-1}) on the dry biomass yield (g kg^{-1} soil) of cane plants grown in the pots with *Longlands* form soil.

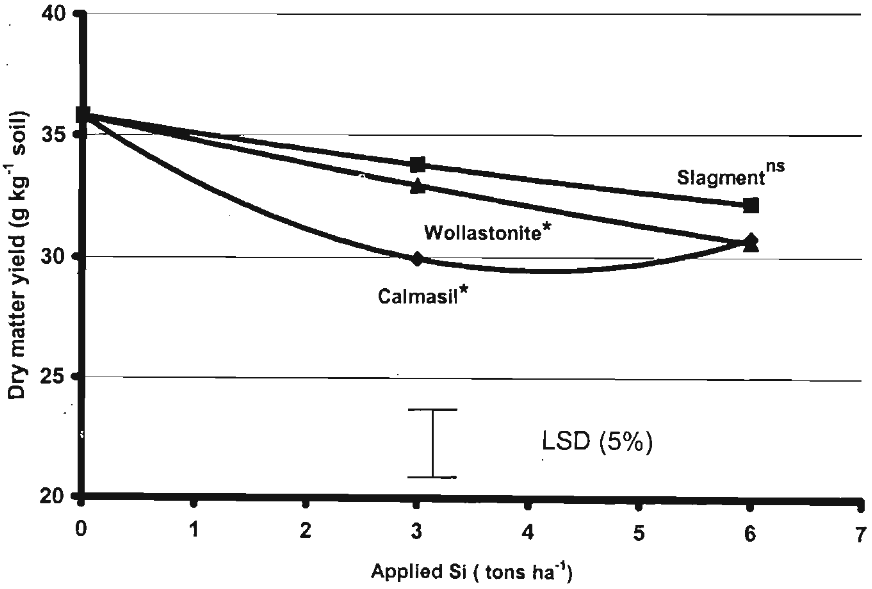

Figure 4.5. Effect of Si source application rates (tons ha^{-1}) on the dry biomass yield (g kg^{-1} soil) of cane plants grown in the pots with *Arcadia* form soil.

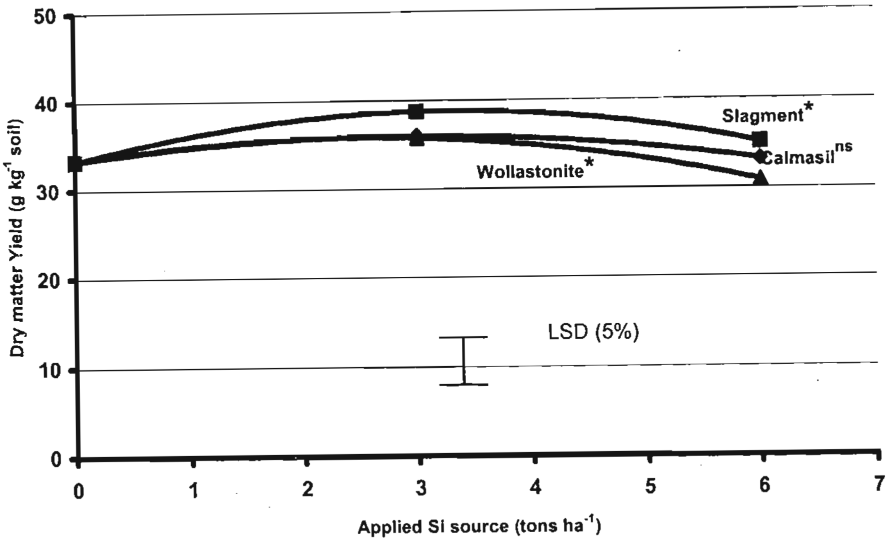

Figure 4.6. Effect of Si source application rates (tons ha^{-1}) on the dry biomass yield (g kg^{-1} soil) of cane plants grown in the pots with *Cartref* form soil.

The downward trend in cane dry biomass yield (Figure 4.5) suggested that the control level of Si was sufficient on the *Arcadia* form soil and no further Si was needed. The upward trend lines (Figures 4.2 to 4.4 and Figure 4.6) on the remaining soil forms showed a need for increased Si fertilization following their sub-optimal initial Si test values. However, in most cases the low rate of carrier (3 tons ha^{-1}) was sufficient to sustain adequate yields.

The analysis of variance showed that the cane dry biomass yield means were highest on *Arcadia* and *Cartref* form soils and differed significantly ($P \leq 0.05$) from the mean yields obtained on the other soil forms. There was a significant difference ($P \leq 0.05$) between treatment means. In general the lower rate (3 tons ha^{-1}) of Si sources yielded significantly higher ($P \leq 0.05$) than that of the control, and in most instances the yields did not differ significantly from the higher rate (6 tons ha^{-1}) of Si treatment yields. This suggests the lower rates as the most responsive. There was also a significant ($P \leq 0.001$) soil form x treatment interaction that was expressed by firstly a significant yield biomass decrease in the *Arcadia* soil form, and secondly by a significant biomass yield increase in the other soil forms.

4.3.3. Cane canopy development.

The beneficial effect of Si-rich materials application to Si accumulator plants includes the canopy development expressed as leaf surface area. According to Smit *et al.* (2004), the crop canopy plays an important role in the formation of sugarcane yields. It intercepts solar radiation that drives the processes of photosynthesis and crop evaporation. Marschner (1986), Inman-Bamber cited by Smit *et al.* (2004) reported a negative effect on sugarcane of water stress that can affect canopy development, by slowing down the production of new shoots and leaves, and by accelerating shoot and leaf senescence.

With the exception of the *Arcadia* form soil, amendment of soils with Si sources significantly increased the cane canopy development (Table 4.3). There was a significant increase of the total cane leaf surface area per pot with the increasing rates of Si source application. The soil forms influenced differently the cane canopy development and the soil forms' means were significantly different ($P<0.001$). Canopy development on the *Arcadia* and *Cartref* form soils was best overall and the Si treatment means differed significantly ($P<0.001$) from those of the *Longlands, Nomanci* and *Glenrosa* form soils.

When Si sources were compared, calmasil was found to be the most effective in its ability to influence the cane canopy development. Slagment and wollastonite source means did not differ significantly between them; however, they differed significantly ($P<0.001$) from the calmasil Si source's mean.

There were interactions between soil form x treatment ($P<0.00$) and soil form x Si source ($P<0.05$) indicating that the treatments as well as the Si sources were influencing the canopy development differently according to the soil forms. It was observed that *Arcadia* and *Cartref* form soils gave the best results with Si sources and their treatment levels compared with other soil forms.

Soil form	Silicon level	Silicon sources			Mean treatment	Mean soil form
		Calmasil	Slagment	Wollastonite		
Nomanci	0 tons/ha	243	243	243	243	442
	3 tons/ha	606	235	558	466	
	6 tons/ha	671	637	543	617	
	Mean	506	371	448	-	
	LSD (5%)	90			110	
Glenrosa	0 tons/ha	321	321	321	321	482
	3 tons/ha	658	645	419	574	
	6 tons/ha	710	639	306	552	
	Mean	563	535	349	-	
	LSD (5%)	161			175	
Longlands	0 tons/ha	436	436	436	436	575
	3 tons/ha	580	529	616	575	
	6 tons/ha	739	621	781	713	
	Mean	585	529	611	-	
	LSD (5%)	NS			155	
Cartref	0 tons/ha	740	740	740	740	688
	3 tons/ha	551	501	543	532	
	6 tons/ha	888	603	883	791	
	Mean	726	615	722	-	
	LSD (5%)	NS			151	
Arcadia	0tons/ha	731	731	731	731	717
	3tons/ha	810	721	668	733	
	6tons/ha	655	749	655	686	
	Mean	732	733	684	-	
	LSD (5%)	NS			NS	
Total mean		623	557	563	-	-
LSD (5%)		49			65	112

Table 4.3. Effect of soil forms and Si source application rates (tons ha^{-1}) on the cane canopy development through leaf surface area (cm^2).

4.3.4. Silicon uptake by cane plants.

Residual Si treatment effect on Si uptake by cane plants is summarized in Table 4.4. Of the five soil forms investigated, cane plants removed varying quantities of Si related to the increasing rates of silicon application before planting cane. In the present study, the concentration of Si in cane tops varied from 0.13 to 0.88% for *Longlands* and *Arcadia* soil forms respectively, which is in proportion to their initial Si content (Table 3.3). Matichenkov and Calvert (2002) reported a crop removal of Si by sugarcane exceeding uptake by macronutrients such as N, P and K. The concentration of Si in sugarcane leaves usually varies from 0.1 to 3.2%, which is also a much wider range than for other macronutrients. Amendment of soils with Si resulted in highly significant (P<0.001) increases in cane plant Si levels (Table 4.4). Averaged across all soil forms, cane Si levels in treatments receiving Si-rich material were significantly higher (P<0.001) than those in cane taken from untreated pots.

Silicon concentration in the cane plants was significantly influenced by the soil forms (P<0.001) and could be related to the initial soil Si content. This outcome is in agreement with the findings of Datnoff *et al.*, (1992), given that plant species or cultivar tissue levels of silicon, vary in relation to soil Si availability. Overall the relative response in Si uptake to Si treatment declined in the order: *Nomanci* > *Glenrosa* > *Longlands* > *Cartref* > *Arcadia* (Figure 4.7 to Figure 4.11). Although there was depression of cane dry biomass yield on the *Arcadia* soil form, there was surprisingly no reduction in cane Si uptake. As stated by Korndörfer *et al.* (2002), there is no expectation for an increased yield with Si material application when the soil Si level is above the critical level. This suggests that the current Si concentration in the *Arcadia* form soil was sufficient to sustain yields. Furthermore, several elements have critical values that have universal application at both the deficiency as well as the sufficiency level (Jones, 2001). Tisdale *et al.* (1993) indicated that nutrient sufficiency occurs over a wide concentration range, wherein yield is unaffected. However, elements absorbed in excessive quantities can reduce plant yield directly through toxicity or indirectly by reducing the concentration of other nutrient elements below the critical range.

Soil form	Si source	Si level	Cane Si uptake (cmol kg^{-1} soil)					
			Stalks	Tops	TOTAL	% uptake increase	Mean Si carrier	Mean soil form
Nomanci	Control	0t/ha	0.008	0.007	0.015	-		0.049
	Calmasil	3t/ha	0.015	0.045	0.060	+300***	0.049	
		6t/ha	0.020	0.050	0.070	+373***		
	Slagment	3t/ha	0.021	0.020	0.041	+173***	0.049	
		6t/ha	0.019	0.072	0.091	+506***		
	Wollastonite	3t/ha	0.011	0.052	0.063	+320***	0.051	
		6t/ha	0.016	0.057	0.073	+393***		
	LSD (5%)				0.010		NS	
Glenrosa	Control	0t/ha	0.010	0.017	0.027	-		0.067
	Calmasil	3t/ha	0.021	0.049	0.070	+159***	0.069	
		6t/ha	0.031	0.079	0.110	+307***		
	Slagment	3t/ha	0.022	0.056	0.078	+188***	0.073	
		6t/ha	0.042	0.072	0.114	+322***		
	Wollastonite	3t/ha	0.023	0.052	0.075	+174***	0.060	
		6t/ha	0.032	0.048	0.080	+196***		
	LSD (5%)				0.021		NS	
Longlands	Control	0t/ha	0.009	0.040	0.049	-		0.095
	Calmasil	3t/ha	0.030	0.085	0.115	+134***	0.101	
		6t/ha	0.034	0.105	0.139	+183***		
	Slagment	3t/ha	0.039	0.081	0.120	+144***	0.100	
		6t/ha	0.042	0.090	0.132	+169***		
	Wollastonite	3t/ha	0.026	0.054	0.080	+63.2**	0.085	
		6t/ha	0.049	0.078	0.127	+159***		
	LSD (5%)				0.019		NS	
Cartref	Control	0t/ha	0.020	0.086	0.107	-		0.139
	Calmasil	3t/ha	0.039	0.099	0.138	+28.9***	0.138	
		6t/ha	0.042	0.129	0.170	+58.8***		
	Slagment	3t/ha	0.038	0.102	0.140	+30.8***	0.130	
		6t/ha	0.045	0.100	0.145	+35.5***		
	Wollastonite	3t/ha	0.041	0.101	0.142	+33.6***	0.149	
		6t/ha	0.039	0.160	0.199	+85.0***		
	LSD (5%)				0.016		NS	
Arcadia	Control	0t/ha	0.112	0.121	0.233	-		0.323
	Calmasil	3t/ha	0.117	0.168	0.285	+22.32*	0.299	
		6t/ha	0.147	0.234	0.381	+63.5***		
	Slagment	3t/ha	0.142	0.247	0.389	+66.9***	0.356	
		6t/ha	0.154	0.292	0.448	+92.2***		
	Wollastonite	3t/ha	0.129	0.217	0.346	+48.5***	0.312	
		6t/ha	0.151	0.208	0.358	+53.6***		
	LSD (5%)				0.039		NS	
LSD (5%)					0.012		NS	0.014

Table 4.4. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si uptake (cmol kg^{-1} soil) by cane plants grown in the pots (with *, **, and * statistically significant, P< 0.5, 0.01 and 0.001).**

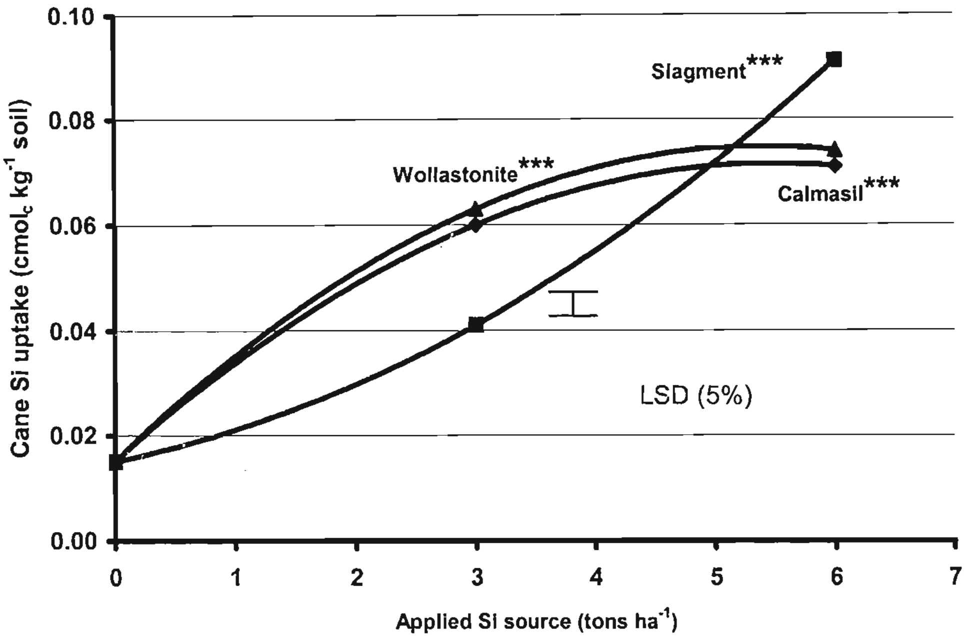

Figure 4.7. Effect of Si source application rates (tons ha^{-1}) on the Si uptake by cane plants (cmol kg^{-1} soil) grown in the pots with *Nomanci* form soil.

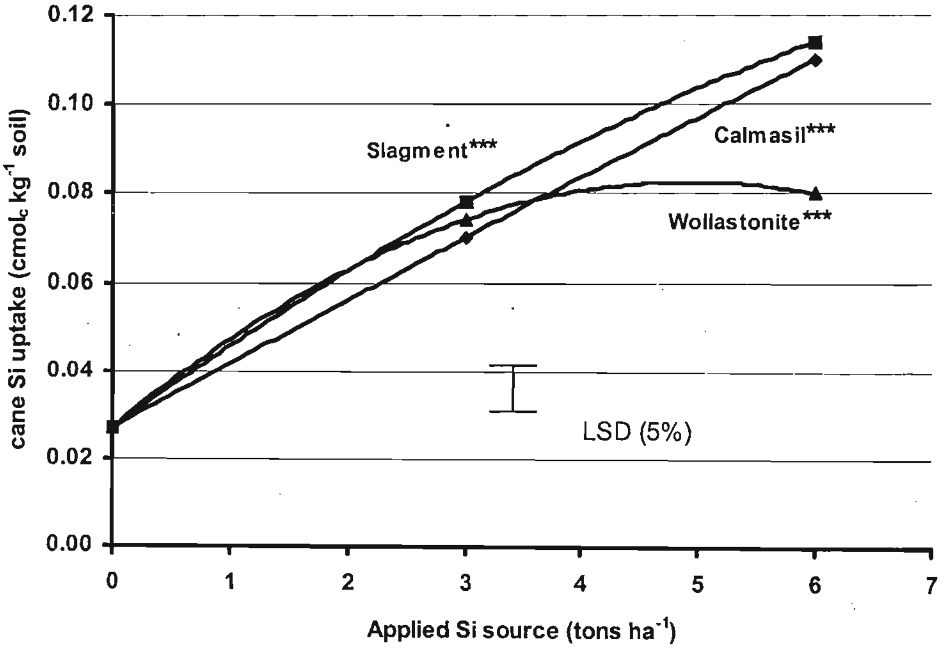

Figure 4.8. Effect of Si source application rates (tons ha^{-1}) on the Si uptake by cane plants (cmol kg^{-1} soil) grown in the pots with *Glenrosa* form soil.

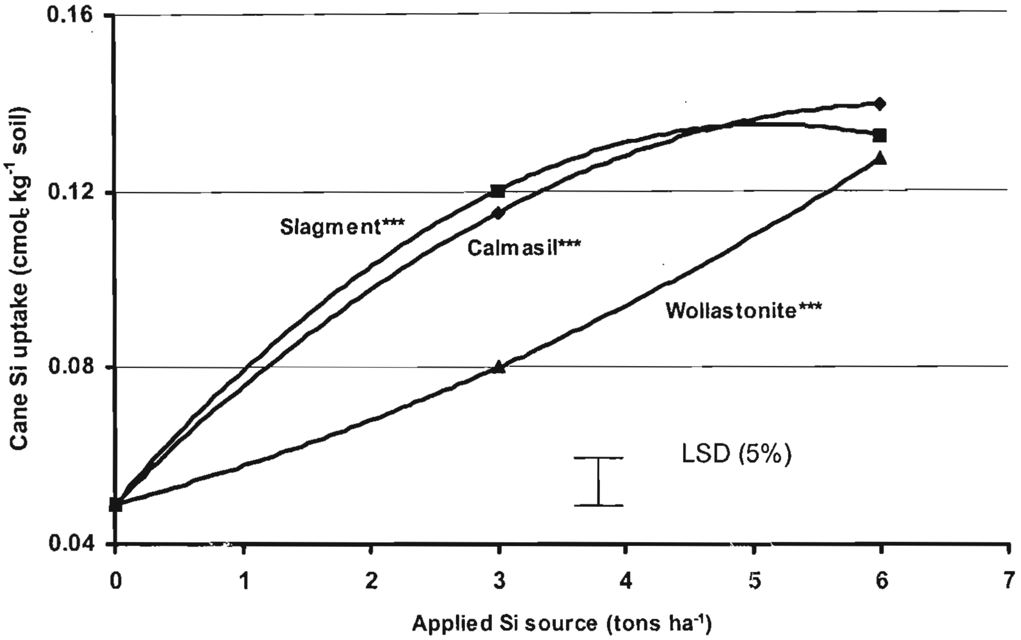

Figure 4.9. Effect of Si source application rates (tons ha^{-1}) on the Si uptake by cane plants (cmol kg^{-1} soil) grown in the pots with *Longlands* form soil.

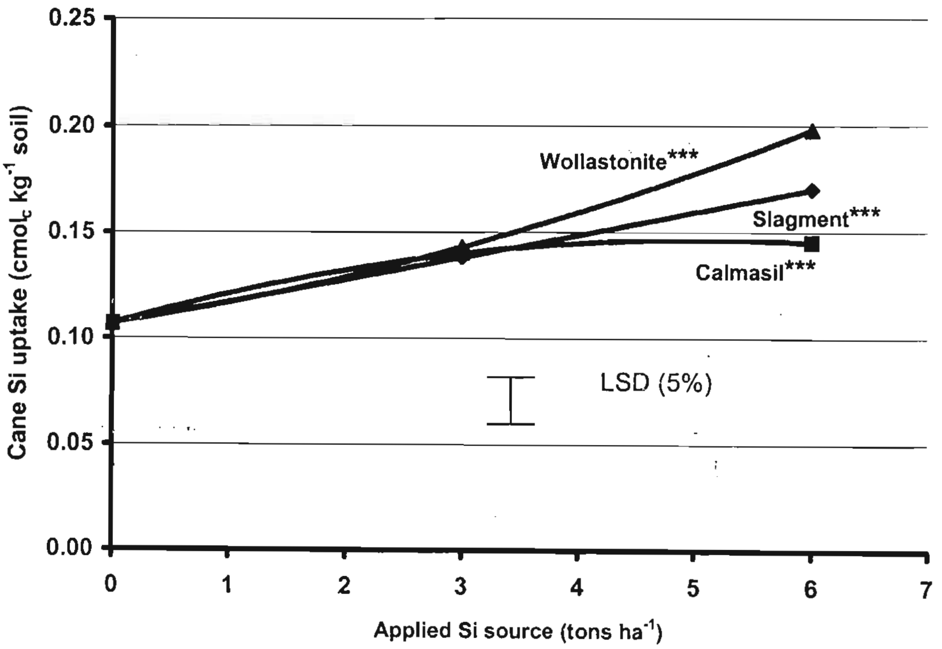

Figure 4.10. Effect of Si source application rates (tons ha^{-1}) on the Si uptake by cane plants (cmol kg^{-1} soil) grown in the pots with *Cartref* form soil.

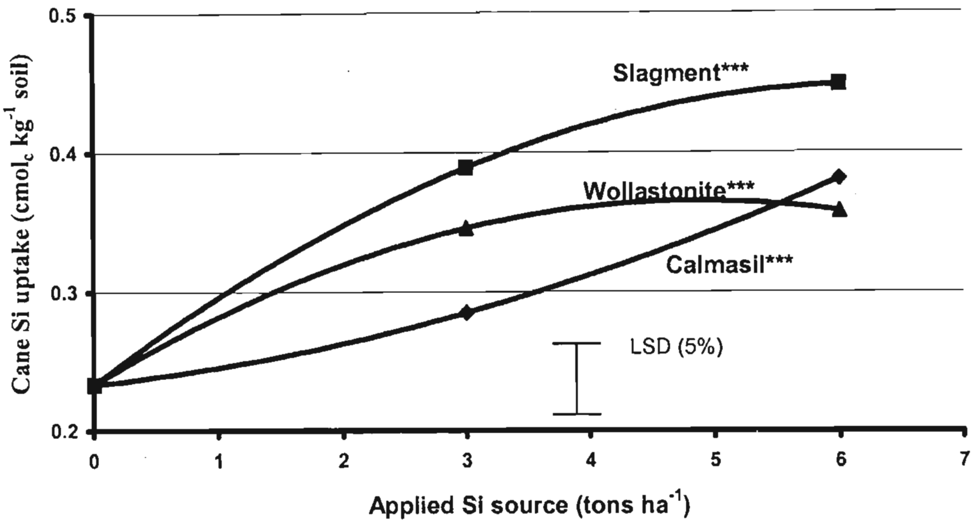

Figure 4.11. Effect of Si source application rates (tons ha^{-1}) on the Si uptake by cane plants (cmol kg^{-1} soil) grown in the pots on the *Arcadia* form soil.

Significant differences ($P<0.001$) in top and stalk Si were observed among treatment levels within Si sources, with plant Si values showing a largely consistent increase compared with the control, low and high treatment levels (Figures 4.7 to 4.11). In general, the higher the Si dose applied the higher the plant tissue concentrations of Si. Similar results were reported by Raid *et al.* (1992) and Keeping and Meyer (2003).

Plant analysis of the cane tops and stalks demonstrated that all the Si sources resulted in significantly higher ($P\leq0.001$) concentrations of Si compared to the control, particularly at the higher application rate of 6 tons ha^{-1}. Similar results were obtained by Berthelsen *et al.* (2001a). However, when Si sources were compared, no difference was observed between them, although slagment showed a mean (0.142cmol kg^{-1} soil) that was numerically higher than those of calmasil (0.131cmol kg^{-1} soil) and wollastonite (0.132cmol kg^{-1} soil). There was no interaction between Si carrier x treatment because the Si sources were not statistically different within them.

The most interesting interaction was between soil form x treatment. This interaction was highly and positively significant ($P<0.001$) on all soil forms and within different treatments. This interaction demonstrated that treatments performed differently on different soil forms, and that there was also a significant ($P<0.05$) interaction between soil form x Si carrier as well as soil form x Si carrier x treatment. The former demonstrated that Si carriers were performing differently on different soil forms, with the best performance in absolute Si uptake shown by slagment on the *Arcadia* form soil. The continued uptake of Si from Si treatment on the *Arcadia* form soil was surprising given the reduced yields, suggesting possible luxury uptake of Si.

4.3.5. Silicon content in the cane roots.

According to Yoshida cited by Matichenkov and Calvert (2002), plants and microorganisms can absorb only monosilicic acid (H_4SiO_4) identified by Lindsay (1979) as a product of Si-rich mineral dissolution. It is the same form of Si that is found in the aboveground part of the plant as well as in the roots as a result of a possible active transport as stated by Hull (2004). As observed for the aboveground cane biomass Si uptake (Table 4.4), amendment of soils with Si-rich materials also increased the root Si significantly ($P<0.001$) on all soil forms in accordance with the treatments (Table 4.5). The order followed by the soil forms was the same as that in the aboveground cane biomass Si content, assuming that Si in the cane roots was related to the Si in the aboveground cane biomass. The lowest root Si content was observed in the *Nomanci* sandy soil form and which agrees with the findings of Matichenkov and Calvert (2002), that the lowest concentration of soluble and biochemically active Si is found in sandy soils.

There was a highly significant difference ($P<0.001$) between soil forms' means led by *Arcadia*, followed by *Cartref, Longlands, Glenrosa* and *Nomanci* form soils. Addition of Si-rich materials to soils increased root Si content with increasing rates and rate means were highly significantly different ($P<0.001$) from each other in their increasing order (0, 3 and 6 tons ha^{-1}). There was also a highly significant difference ($P<0.001$) between silicon sources with the slagment Si mean significantly higher than that of the calmasil and wollastonite mean values.

Soil form	Silicon level	Silicon sources			Mean treatment	Mean soil form
		Calmasil	Slagment	Wollastonite		
Nomanci	0 tons/ha	0.368	0.368	0.368	0.368	
	3 tons/ha	0.543	0.593	0.560	0.565	
	6 tons/ha	0.633	0.670	0.698	0.667	
	Mean	0.514	0.543	0.542	-	0.533
	LSD (5%)	NS			0.030	
Glenrosa	0 tons/ha	0.380	0.380	0.380	0.380	
	3 tons/ha	0.558	0.668	0.618	0.614	
	6 tons/ha	0.683	0.720	0.725	0.709	
	Mean	0.540	0.589	0.574	-	0.568
	LSD (5%)	NS			0.045	
Longlands	0 tons/ha	0.453	0.453	0.453	0.453	
	3 tons/ha	0.548	0.563	0.638	0.583	
	6 tons/ha	0.660	0.740	0.728	0.709	
	Mean	0.553	0.585	0.709	-	0.581
	LSD (5%)	NS			0.067	
Cartref	0 tons/ha	0.473	0.473	0.473	0.473	
	3 tons/ha	0.563	0.705	0.583	0.617	
	6 tons/ha	0.750	0.900	0.713	0.788	
	Mean	0.595	0.693	0.589	-	0.626
	LSD (5%)	0.044			0.052	
Arcadia	0tons/ha	0.642	0.643	0.643	0.643	
	3tons/ha	0.705	0.768	0.640	0.704	
	6tons/ha	0.840	0.783	0.723	0.782	
	Mean	0.729	0.731	0.668	-	0.709
	LSD (5%)	NS			0.075	
Total mean		0.586	0.628	0.596	-	-
LSD (5%)		0.020			0.023	0.050

Table 4.5. Effect of soil forms and Si source application rates (tons ha^{-1}) on the cane root Si content (%).

The interaction between soil form x Si sources was significant ($P<0.01$); which demonstrated how Si sources influenced the cane root Si differently on different soil forms, with slagment performing better than the other two Si sources on most soil forms. An interaction between soil form x treatment ($P<0.001$) was also observed suggesting that different treatment levels of Si source, positively and significantly influenced the cane root Si content on different soil forms. The higher Si rate of 6 tons ha^{-1} produced the highest Si content in roots across all soil forms. There was no interaction between Si sources and treatments or between soil forms, Si sources and treatments; indicating that the Si sources as well as the treatments were more influenced by the soil forms than by each other.

4.4. CONCLUSION.

In this chapter, it was found that the three Si carriers increased Si available to sugarcane compared to the control. Similar results were obtained by different workers such as Lindsay (1979), Wild (1986), Jianjun *et al.* (2002) and Matichenkov *et al.* (1999). Soil exchangeable Ca, Mg, K and Na also increased after cane harvest, but this effect was mainly attributable to the content of these cations in the weekly-applied basal nutrient solution. Different Si sources did not show a significant difference in their respective Si supply to the soil solution, and hence to the cane plants, despite the difference in Si content. The main benefit of Si treatment was the significant improvement in cane yield in three out of the five soils that were investigated, with relative yield response declining in the order: *Nomanci* >> *Longlands* >> *Glenrosa*. The *Arcadia* and *Cartref* form soils did not respond to Si treatment, dry matter yields were significantly better than the other three soil forms, suggesting that the Si status of these soils was sufficient. Different Si sources did not differ in their ability to influence the cane Si uptake. All Si source treatment rates (3 and 6 tons ha^{-1}) significantly increased the cane Si uptake ($P<0.001$) in all soil forms. Soil forms, Si sources as well as treatments significantly influenced ($P<0.001$) the cane root Si content.

CHAPTER 5

EVALUATION OF EXTRACTANTS FOR ESTIMATING PLANT-AVAILABLE SILICON.

5.1. SILICON EXTRACTION FROM SOIL SAMPLES BEFORE SOIL AMENDMENT WITH SILICON SOURCES.

5.1.1. Amount of soil Si extracted by different extractants before soil treatment.

A considerable range of Si values was obtained for all the Si extraction methods used in this study (Table 5.1), which values undoubtedly affected the sorghum dry matter yield as well as the sorghum Si uptake. The 0.5M CH_3COOH extractant produced the greatest range of Si concentration (0.027 to 0.332cmol kg^{-1}) followed by the 0.025M H_2SO_4 extractant (0.016 to 0.325cmol kg^{-1}) and 0.01M $CaCl_2.2H_2O$ extractant (0.013 to 0.179cmol kg^{-1}).

Soil form	Soil initial silicon concentration (cmol kg^{-1})						
	0.5M NH_4OAc	0.01M H_2SO_4 + $(NH_4)_2SO_4$	Distilled water	0.01M $CaCl_2.2H_2O$	0.025M H_2SO_4	0.5M HOAc	Mean soil form
Arcadia	0.086	0.168	0.189	0.179	0.325	0.332	0.2132
Cartref	0.023	0.039	0.020	0.013	0.077	0.059	0.0385
Glenrosa	0.011	0.018	0.061	0.059	0.036	0.041	0.0377
Longlands	0.011	0.009	0.029	0.068	0.023	0.030	0.0283
Nomanci	0.011	0.011	0.029	0.061	0.016	0.027	0.0258
Mean extractant	0.028	0.049	0.065	0.076	0.095	0.098	
LSD (5%)	NS						0.0562

Table 5.1. Plant available silicon (cmol kg^{-1}) extracted by different extraction methods investigated before Si source application to the soils.

Si extraction with distilled water produced intermediate values (0.020 to 0.189cmol kg^{-1}) whereas 0.01M H_2SO_4 + $(NH_4)_2SO_4$ and 0.5M CH_3COONH_4 extractants were the least effective with regard to extracted Si concentrations of 0.009 to 0.168 and 0.011 to 0.086cmol kg^{-1} respectively. Acid extractants (0.025M H_2SO_4 and 0.5M CH_3COOH) removed the greatest quantities of Si in the soil forms investigated. This supported the findings of Kato and Owa cited by Barbosa-Filho *et al.* (2001) and Rodriguez *et al.* (2003) where acid extractants such as citric acid were found to remove the greatest quantities of Si in calcareous soils, dissolved from calcium silicates, which are soluble in acids but not easily taken up by plants. This may explain the lower results obtained with 0.5M CH_3COONH_4 pH 4.8 and 0.01M H_2SO_4 + $(NH_4)_2SO_4$, since the pH of both extractants is higher when compared with the 0.5M CH_3COOH and the 0.025M H_2SO_4 extractants. Given the very low initial Si values (Table 5.1), there was no significant difference between extractant means. A significant difference ($P<0.001$) was observed between the *Arcadia* form soil mean and the other soil form means, the latter showing little difference between them.

5.1.2. Correlation between different silicon extractants.

The highly significant correlation coefficients (r) between all the Si extraction methods used in this study (Table 5.2) suggests that extractable Si by the various extraction methods were closely correlated with each other. The highest correlation coefficient (r=0.9996***) was obtained between 0.025M H_2SO_4 and 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractants while the lowest (r=0.8585**) was between 0.025M H_2SO_4 and 0.01M $CaCl_2.2H_2O$.

It was evident that all the extraction methods showed significance in their ability to estimate soil available silicon for plants, and that the two best correlated extraction methods might be extracting the same form of Si. An assessment of the available Si in soils could be obtained from the ratio of easily extractable Si to the free or easily extractable sesquioxides. The higher the Si/Al or Si/Fe ratios, the greater will be the uptake of Si by plants (Rodriguez *et al.*, 2003).

Extractant	Distilled water	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	0.5M HOAc	0.5M NH_4OAc
0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.9488**				
0.025MH_2SO_4	0.9480**	0.9996***			
0.5M HOAc	0.9677**	0.9964***	0.9961***		
0.5M NH_4OAc	0.9437**	0.9987***	0.9984***	0.9965***	
0.01M $CaCl_2.2H_2O$	0.9477**	0.8597**	0.8585***	0.8998***	0.8678***

Table 5.2. Correlation coefficients (r) between silicon extracting methods before Si application (with *, **, * significant at 5, 1, and 0.1% respective probability levels: n=5).**

Similarly, Haysom and Chapman (1975) found that the 0.01M $CaCl_2.2H_2O$ method was highly correlated with distilled water extracted Si, which removed water soluble Si. Soluble Si in the soil is mainly ortho silicic acid (H_4SiO_4) that can exist over a wide range of pH (2.0 to 9.0) and is in equilibrium with amorphous silica (SiO_2). The results of untreated soil showed that the 0.5M acetic acid extractable Si values were the most closely correlated with distilled water-extracted Si levels, followed by the 0.025M H_2SO_4 and combined 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractants (Table 5.2).

5.1.3. Relationship of soil extractable-Si with initial soil properties.

The correlation coefficients between Si extracted by different extracting methods and selected soil properties are presented in Table 5.3. All the soil extractable Si values were positively correlated with soil exchangeable Ca, Na, Mg and clay content. No highly significant correlation ($P \leq 0.01$) was found between the soil $pH_{(water)}$ and the extractable Si, but the highest correlation ($P \leq 0.05$) was attained with 0.01M H_2SO_4 + $(NH_4)_2SO_4$. Surprisingly no significant correlation was found between the soil P and the extractable Si in the present experiment, suggesting that there was a smaller effect of soil P on soil available Si than either clay, Ca, Na, K or Mg content in the investigated soil forms (Xu *et al.*, 2001). The clay content was highly correlated with all the extractants and the highest correlation was attained with 0.01M H_2SO_4 + $(NH_4)_2SO_4$.

Soil properties	Distilled water	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	0.5M HOAc	0.5M NH_4OAc	0.01M $CaCl_2.2H_2O$
pH	0.511*	0.597*	0.576*	0.586*	0.608*	0.516*
K	0.799***	0.737***	0.737***	0.729***	0.704***	0.591*
Ca	0.952***	0.999***	0.999***	0.998***	0.999***	0.871***
Na	0.985***	0.911***	0.914***	0.932***	0.899***	0.911***
Mg	0.964***	0.998***	0.998***	0.999***	0.997***	0.884***
P	-0.155ns	-0.160ns	-0.161ns	-0.207ns	-0.206ns	-0.430ns
Clay	0.910***	0.980***	0.976***	0.962***	0.971***	0.764***
CEC	0.940***	0.995***	0.994***	0.985***	0.988***	0.817***

Table 5.3. Correlation coefficients between soil properties and available extracted Si by six extractants from soil forms investigated before Si application (with *, **, * significant at 5, 1, and 0.1% probability levels: n=5).**

In a survey of the Si status of soils in the South African Sugar industry, the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant was considered by Meyer and Keeping (2000) as the best Si extraction method for plant available Si because it was better correlated with the soil clay content. In the present study, the same extractant 0.01M H_2SO_4 + $(NH_4)_2SO_4$ was found to correlate better with the clay content than any of the other extractants.

5.2. SILICON EXTRACTION FROM SOIL SAMPLES AFTER TREATMENT AND BEFORE SORGHUM PLANTING.

5.2.1. Amount of silicon extracted by different extractants after soil treatment.

The results from the composite Si treated soil samples analyzed by different extractants clearly showed changes in Si availability in relation to the rates of Si sources across the five soil forms investigated.

Soil Form	Si source level	Soil silicon concentration after treatment (cmol kg^{-1})								
		Water (H_2O)	0.5M NH_4OAc	0.01M $CaCl_2.2H_2O$	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.5M HOAc	0.025M H_2SO_4	Mean Si level	Mean Si source	Mean soil form
No	TO	0.032	0.007	0.057	0.014	0.025	0.054			
	Calm L	0.043	0.218	0.257	0.236	0.343	0.479			
	Calm H	0.093	0.261	0.339	0.550	0.954	0.861			
	Slag L	0.021	0.032	0.164	0.821	0.871	0.754			
	Slag H	0.025	0.136	0.204	1.489	1.721	1.386	0.032^{N}	0.268^{C}	
	Woll L	0.029	0.011	0.032	0.025	0.039	0.075	0.247^{L}	0.434^{S}	
	Woll H	0.029	0.029	0.046	0.032	0.054	0.096	0.461^{H}	0.038^{W}	
	Mean	0.037	0.079	0.135	0.355	0.451	0.424			0.247
Lo	TO	0.036	0.096	0.075	0.021	0.039	0.054			
	Calm L	0.061	0.164	0.246	0.650	0.589	0.507			
	Calm H	0.096	0.350	0.268	0.929	1.200	0.896			
	Slag L	0.039	0.007	0.221	1.643	1.029	0.825			
	Slag H	0.036	0.029	0.236	2.071	1.625	1.436	0.054^{N}	0.349^{C}	
	Woll L	0.029	0.050	0.061	0.114	0.054	0.075	0.354^{L}	0.529^{S}	
	Woll H	0.032	0.007	0.061	0.046	0.054	0.125	0.528^{H}	0.057^{W}	
	Mean	0.045	0.099	0.146	0.613	0.519	0.447			0.312
Gs	TO	0.046	0.007	0.046	0.007	0.025	0.061			
	Calm L	0.068	0.229	0.268	0.404	0.493	0.696			
	Calm H	0.093	0.482	0.625	0.811	0.700	1.021			
	Slag L	0.125	0.014	0.229	0.818	1.436	1.214			
	Slag H	0.032	0.032	0.525	1.929	1.461	1.750	0.032^{N}	0.338^{C}	
	Woll L	0.036	0.011	0.054	0.104	0.046	0.118	0.354^{L}	0.542^{S}	
	Woll H	0.021	0.061	0.057	0.043	0.050	0.107	0.544^{H}	0.050^{W}	
	Mean	0.057	0.094	0.211	0.459	0.473	0.565			0.310
Cf	TO	0.039	0.032	0.164	0.075	0.046	0.146			
	Calm L	0.075	0.243	0.318	0.446	0.618	0.596			
	Calm H	0.161	0.425	0.446	0.768	1.311	1.286			
	Slag L	0.121	0.021	0.393	1.179	1.254	1.289			
	Slag H	0.032	0.029	0.504	2.286	1.371	2.236	0.084^{N}	0.400^{C}	
	Woll L	0.014	0.057	0.029	0.125	0.050	0.136	0.387^{L}	0.623^{S}	
	Woll H	0.039	0.011	0.029	0.057	0.061	0.121	0.621^{H}	0.068^{W}	
	Mean	0.062	0.098	0.246	0.565	0.534	0.678			0.364
Ar	TO	0.193	0.054	0.186	0.179	0.236	0.393			
	Calm L	0.300	0.239	0.561	0.618	1.039	1.186			
	Calm H	0.207	0.761	0.661	1.075	1.829	1.386			
	Slag L	0.189	0.071	0.246	1.725	1.343	1.282			
	Slag H	0.204	0.064	0.293	1.821	3.261	2.529	0.207^{N}	0.617^{C}	
	Woll L	0.200	0.082	0.193	0.257	0.229	0.404	0.565^{L}	0.793^{S}	
	Woll H	0.189	0.093	0.354	0.196	0.211	0.407	0.863^{H}	0.225^{W}	
	Mean	0.208	0.164	0.318	0.692	0.958	0.930			0.545
Total mean		0.082	0.107	0.211	0.537	0.587	0.609	0.609	-	-
LSD (5%)		0.1815						0.164	0.162	NS

Table 5.4. Amount of soil silicon extracted (cmol kg^{-1}) by different extractants from soil samples after Si treatment and before sorghum planting (with N=control or 0 tons ha^{-1}; L=3 tons ha^{-1}; H=6 tons ha^{-1}; C=calmasil, S=slagment and W=wollastonite Si sources).

Among the six extractants used in this study, the 0.025M H_2SO_4 extracted most silicon, followed by 0.5M CH_3COOH and 0.01M H_2SO_4 + $(NH_4)_2SO_4$ with respective averaged values of 0.742, 0.733 and 0.673cmol kg^{-1} soil (Table 5.4). The amount of Si extracted was roughly proportional to the rate of Si applied. The remaining three extractants namely distilled water, 0.5M CH_3COONH_4 pH 4.8, and 0.01M $CaCl_2.2H_2O$ extracted smaller amounts of Si varying from 0.085, 0.126 to 0.241cmol kg^{-1} respectively. In general, the amount of Si extracted by these weaker extractants was not always proportional to the amount of Si source applied. The *Arcadia* form soil showed the highest range of extracted soil silicon using any of the extractants.

5.2.2. Correlation between different silicon extractants, dry matter relative yield and silicon uptake by sorghum plants grown in the pots.

The choice of a soil test method is mainly based on correlation studies between soil test values and yield of plants and/or uptake from a number of experiments conducted on various soils of different fertility levels (Sonar and Palwe, 2002).

Si source	Si level	Sorghum dry matter relative yield (%) by soil form				
		Arcadia	*Cartref*	*Glenrosa*	*Longlands*	*Nomanci*
Control	0t/ha	84.31	89.25	53.17	78.89	84.74
Calmasil	3t/ha	92.48	92.22	84.57	96.79	95.51
	6t/ha	100.00	95.57	100.00	95.08	100.00
Slagment	3t/ha	89.13	88.18	79.72	94.49	94.56
	6t/ha	89.65	100.00	90.05	96.42	87.22
Wollastonite	3t/ha	89.60	90.27	80.01	93.68	88.83
	6t/ha	87.66	90.17	85.57	100.00	98.90
LSD	($P \leq 0.05$)	5.64	4.53	5.31	3.65	5.42
Overall Si carrier means	3 tons ha^{-1}	90.40	90.22	81.43	94.99	92.97
	6 tons ha^{-1}	92.44	95.25	91.87	97.17	95.37

Table 5.5. Dry matter relative yield (%) per soil form and Si source application levels of the sorghum plants grown in the pots.

The observed dry biomass relative yield (Table 5.5) was calculated individually for each soil as the percentage the maximum treatment yield obtained for each soil (Locke and Hanson cited by Fernandez *et al.*, 2000). Crop relative yield (%) is often effectively used in soil testing calibration to eliminate the experiment site influences (Xu *et al.*, 2001).

The comparison of Si extraction methods was based on the correlation coefficient obtained between the soluble soil Si extracted by the different extractants. Statistical analyses of the data set showed strong correlation ($P \leq 0.001$) among the quantities of Si extracted by 0.01M H_2SO_4 + $(NH_4)_2SO_4$, 0.5M CH_3COOH and 0.025M H_2SO_4, with the simple correlation coefficient (r) ranging from 0.85*** to 0.94*** (Table 5.6). The percentage of Si in the sorghum straw was positively and significantly correlated with the dry matter relative yield (Table 5.6), indicating that both variables had the same precision for predicting the response of sorghum in relation to Si extracted from the soils.

Extractant	H_2O solution	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	0.5M HOAc	0.5M NH_4Oac	0.01M $CaCl_2.2H_2O$	Relative yield
0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.15ns						
0.025MH_2SO_4	0.38*	0.90***					
0.5M HOAc	0.41*	0.85***	0.94***				
0.5M NH_4OAc	0.41*	0.08ns	0.25ns	0.29ns			
0.01M $CaCl_2.2H_2O$	0.54***	0.56***	0.71***	0.59***	0.67***		
Relative yield	0.60***	0.30ns	0.42**	0.32ns	0.37*	0.58***	
Si uptake	0.55***	0.47**	0.52***	0.48**	0.25ns	0.46**	0.70***

Table 5.6. Correlation coefficients (r) between various silicon extraction methods and sorghum biological parameters after Si application to different soils (with *, **, * significant at 5, 1, and 0.1%: n=35).**

Across the entire population of 35 composite soil samples, a high correlation (R^2=0.88***) was obtained between the 0.025M H_2SO_4 and 0.5M CH_3COOH extractions (Figure 5.1). This relationship suggests that both methods may extract the similar forms of Si. A lower linear correlation (R^2=0.82) was observed between the 0.025M H_2SO_4 and the 0.01M + $(NH_4)_2SO_4$ extractions (Figure 5.2). A much lower correlation (R^2=0.71) was found between the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ and the 0.5M CH_3COOH extractions (Figure 5.3). It is likely that where the methods are poorly correlated different forms of Si are extracted.

The three extractants, namely 0.025M H_2SO_4, 0.5M CH_3COOH, and 0.01M H_2SO_4 + $(NH_4)_2SO_4$, were related linearly to each other with positive and highly significant correlation coefficients (r) values ranging from 0.85*** to 0.94*** (Table 5.6) and R^2 values ranging from 0.71*** to 0.88*** (Figure 5.1 to Figure 5.3), suggesting that the three extractants removed similar forms of Si. Despite the excellent correlation between the 0.5M CH_3COOH and the 0.025M H_2SO_4 methods, the high correlation alone between these extractants does not justify their substitution by the currently used 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant.

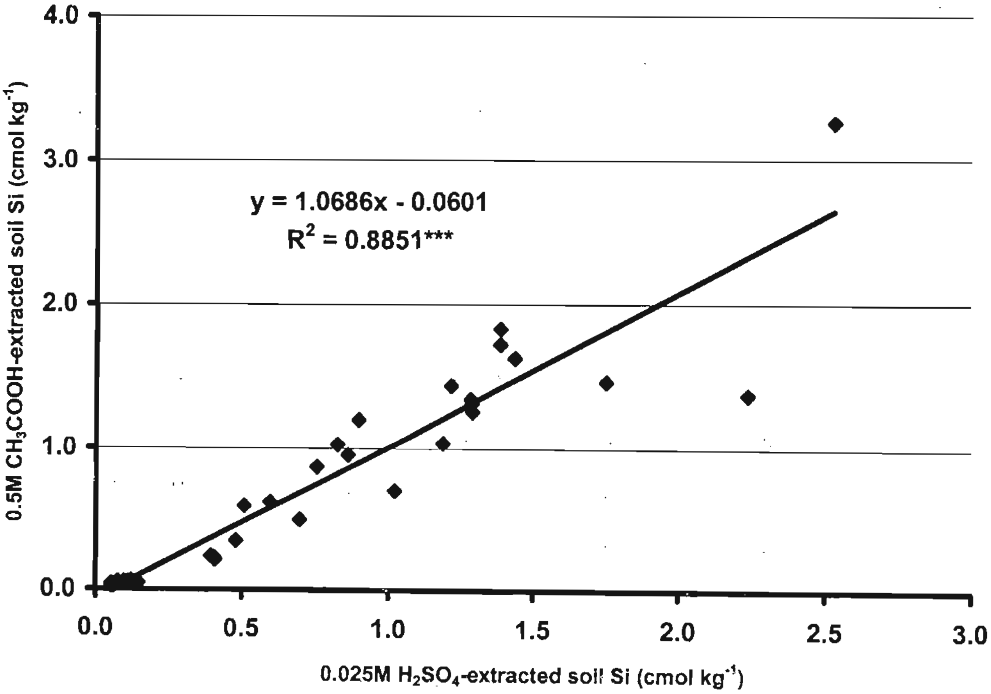

Figure 5.1. Relationship between 0.025M H_2SO_4 and 0.5M CH_3COOH -extractable soil Si (cmol kg^{-1}) after Si treatment of the five soil forms investigated.

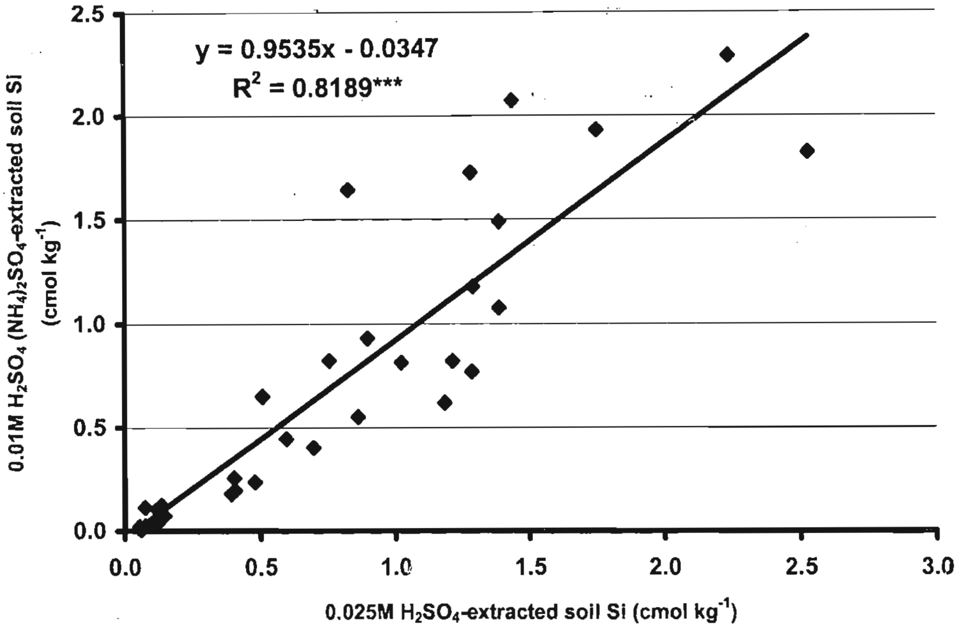

Figure 5.2. Relationship between 0.025M H_2SO_4 and 0.01M H2SO4 + $(NH_4)_2SO_4$ -extractable soil Si (cmol kg^{-1}) after Si treatment of the five soil forms investigated.

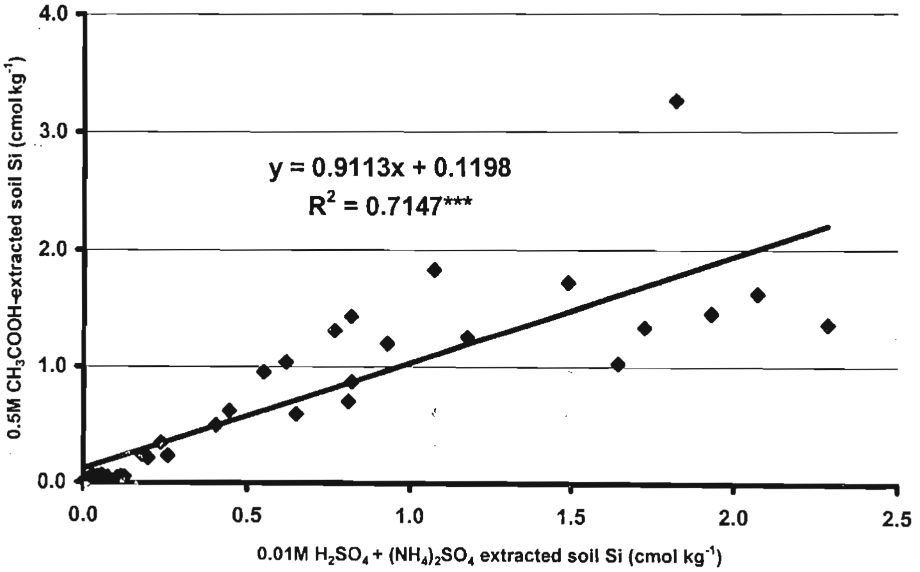

Figure 5.3. Relationship between 0.01M H_2SO_4 + $(NH_4)_2SO_4$ and 0.5M CH_3COOH-extractable soil Si (cmol kg^{-1}) after Si treatment of the five soil forms investigated.

5.3. SILICON EXTRACTION FROM SOIL SAMPLES AFTER SORGHUM HARVEST AND BEFORE CANE PLANTING.

5.3.1. Amount of soil Si extracted by different extractants after sorghum harvest and before cane planting.

The data for Si extracted by the different extractants from the soil samples after sorghum harvest and before cane planting are presented in Table 5.7. The 0.025M H_2SO_4 exhibited the highest mean of 0.264cmol kg^{-1} followed by 0.01M H_2SO_4 + $(NH_4)_2SO_4$ and 0.5M CH_3COOH with means of 0.223 and 0.182cmol kg^{-1} respectively. The other Si extractants showed much lower means. The 0.025M H_2SO_4 extractant removed on average more than seven times the amount of Si recovered by the 0.5M CH_3COONH_4 extractant.

The low levels of soil Si extracted by 0.01M $CaCl_2.2H_2O$ and 0.5M CH_3COONH_4 were significantly related to distilled water-extracted Si values or readily soluble soil Si levels. However, there was poor correlation with soil Si levels obtained when stronger acid extractants were used. Similar observations have been reported by Fox *et al.* (1967b), Medina-Gonzalez *et al.* (1988) and Berthelsen *et al.* (2001b).

Since there were no significant differences between the Si sources investigated in this study regarding their influence on the cane dry biomass yield (Table 4.2) or the Si taken up by cane plants in the pots (Table 4.4), it seems unlikely that the differences in soil Si test values between the different extractants were attributable to the difference in solubility of the various Si sources in the Si extractants. Even though the 0.025M H_2SO_4 and the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ were more highly correlated than the other extractants, it appears that any choice could be made before further investigation.

Soil form	Si level	Soil silicon concentration (cmol kg^{-1}) at sorghum harvest								
		0.5M NH_4OAc	Water (H_2O)	0.01M $CaCl_2$. $2H_2O$	0.5M HOAc	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	Mean Si level	Mean Si source	Mean soil form
No	TO	0.0071	0.0250	0.0589	0.0196	0.0295	0.0518			
	Calm L	0.0188	0.0241	0.0607	0.0375	0.0625	0.1000			
	Calm H	0.0259	0.0321	0.0705	0.1080	0.1875	0.1991			
	Slag L	0.0161	0.0277	0.0625	0.1473	0.2250	0.2277			
	Slag H	0.0188	0.0285	0.0679	0.6857	0.7339	0.7196	0.032^N	0.062^C	
	Woll L	0.0161	0.0250	0.0598	0.0232	0.0723	0.0828	0.071^L	0.175^S	
	Woll H	0.0196	0.0321	0.0679	0.0661	0.1116	0.1348	0.184^H	0.050^W	
	Mean	0.015	0.027	0.063	0.125	0.165	0.180			0.096
Gs	TO	0.0179	0.0482	0.0661	0.0188	0.0571	0.0545			
	Calm L	0.0223	0.0616	0.0723	0.0357	0.0786	0.0857			
	Calm H	0.0339	0.0696	0.0777	0.0866	0.1661	0.2027			
	Slag L	0.0196	0.0598	0.0670	0.1241	0.1634	0.2098			
	Slag H	0.0170	0.0634	0.0759	0.6366	0.7768	0.7893	0.044^N	0.070^C	
	Woll L	0.0152	0.0563	0.0634	0.0295	0.0589	0.0839	0.073^L	0.181^S	
	Woll H	0.0170	0.0625	0.0777	0.0625	0.1286	0.2143	0.198^H	0.063^W	
	Mean	0.020	0.058	0.070	0.115	0.172	0.194			0.105
Cf	TO	0.0205	0.0134	0.0500	0.0464	0.0786	0.1196			
	Calm L	0.0286	0.0143	0.0580	0.0473	0.0902	0.1536			
	Calm H	0.0339	0.0223	0.0652	0.0795	0.1116	0.2491			
	Slag L	0.0295	0.0205	0.0634	0.1446	0.1848	0.3009			
	Slag H	0.0366	0.0241	0.0813	0.5625	0.6363	0.8759	0.055^N	0.071^C	
	Woll L	0.0277	0.0330	0.0580	0.0339	0.1027	0.1152	0.084^L	0.183^S	
	Woll H	0.0339	0.0393	0.0723	0.0491	0.1098	0.1580	0.180^H	0.065^W	
	Mean	0.028	0.022	0.061	0.117	0.163	0.246			0.106
Lo	TO	0.0089	0.0446	0.0696	0.0143	0.0286	0.0446			
	Calm L	0.0205	0.0527	0.0813	0.0536	0.0750	0.1348			
	Calm H	0.0402	0.0438	0.1036	0.1223	0.1688	0.2214			
	Slag L	0.0188	0.0321	0.0732	0.4473	0.3420	0.3839			
	Slag H	0.0241	0.0313	0.0759	0.8759	0.9045	0.8643	0.035^N	0.074^C	
	Woll L	0.0152	0.0313	0.0796	0.0455	0.0741	0.1036	0.115^L	0.238^S	
	Woll H	0.0182	0.0313	0.0911	0.0652	0.1455	0.1455	0.221^H	0.059^W	
	Mean	0.019	0.040	0.079	0.184	0.200	0.221			0.124
Ar	TO	0.0616	0.0732	0.1518	0.1402	0.2536	0.2563			
	Calm L	0.0857	0.0920	0.1804	0.1964	0.2795	0.2955			
	Calm H	0.1170	0.0893	0.1973	0.3188	0.4571	0.5670			
	Slag L	0.0982	0.0821	0.1821	0.3455	0.4866	0.6080			
	Slag H	0.1018	0.0875	0.2027	0.9455	1.0143	1.2438	0.156^N	0.212^C	
	Woll L	0.0920	0.0920	0.1902	0.2000	0.3107	0.3973	0.233^L	0.351^S	
	Woll H	0.1098	0.1098	0.2259	0.3036	0.4545	0.4563	0.389^H	0.215^W	
	Mean	0.088	0.086	0.182	0.303	0.418	0.479			0.259
Total mean		0.034	0.046	0.091	0.169	0.223	0.264			
LSD (5%)		0.103						0.097	0.095	0.122

Table 5.7. Amount of soil silicon (cmol kg^{-1}) extracted by different extractants from soil samples collected after sorghum harvest in the pots (with N=control or 0 tons ha$^{-1;}$ L=3 tons ha^{-1}; H=6 tons ha^{-1}; C=calmasil; S=slagment; and W=wollastonite Si sources).

5.3.2. Relationship of soil extractable-Si with soil properties before cane establishment, cane biomass relative yield and cane Si uptake.

The cane relative biomass yield (Table 5.8) in this study was calculated individually for each soil as the percentage of observed yield over the mean high yield (Locke and Hanson cited by Fernandez *et al.*, 2000). Xu *et al.* (2001) stated that the relative dry biomass yield expressed as a percent is often used effectively in soil testing calibration with the objective of eliminating the experiment site influences.

Silicon Source	Silicon level	Cane dry biomass relative yield (%) by soil form				
		Arcadia	*Cartref*	*Glenrosa*	*Longlands*	*Nomanci*
Control	0t/ha	100.00	85.77	52.79	52.31	47.70
Calmasil	3t/ha	83.60	92.91	85.10	100.00	100.00
	6t/ha	85.85	85.69	92.70	96.10	84.83
Slagment	3t/ha	94.33	100.00	77.58	90.39	60.15
	6t/ha	89.92	90.61	97.56	97.37	99.45
Wollastonite	3t/ha	91.98	92.23	100.00	81.81	91.64
	6t/ha	85.39	72.01	83.47	92.07	93.88
LSD	($P \leq 0.05$)	10.66	7.84	21.20	15.44	13.40
Overall Si carrier means	3 tons ha^{-1}	89.97	95.05	87.56	90.73	83.93
	6 tons ha^{-1}	87.05	82.77	91.24	95.18	92.72

Table 5.8. Dry biomass relative yield (%) per soil form and Si source application levels (tons ha^{-1}) of the cane plants grown in the pots.

The correlation coefficients between soil Si values extracted by different extractants and selected soil properties; cane biomass relative yield and Si uptake are presented in Table 5.9. The soil extracted Si values for all the six extractants showed a highly significant correlation ($P<0.001$) with soil Ca, Mg, Na, CEC, and the cane plant Si uptake. The pH was only significantly correlated with the soil Si values from those extractants that gave the highest soil extracted Si values, namely the 0.025M H_2SO_4, 0.01M (H_2SO_4) +

$(NH_4)_2SO_4$, and 0.5M CH_3COOH. The values for Si taken up by cane plants in the pots (Table 4.4) were positively and significantly correlated ($P<0.001$) with the cane biomass relative yield (Table 5.8), suggesting that both variables could be used to predict the response of cane in relation to extracted soil Si. The cane Si uptake values were positively and significantly correlated with soil Si values as extracted by all the soil Si extractants, but more strongly correlated with readily soluble soil Si as extracted by distilled water, 0.5M CH_3COONH_4 and 0.01M $CaCl_2.2H_2O$.

Extractant	H_2O solution	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	0.5M HOAc	0.5M NH_4OAc	0.01M $CaCl_2.2H_2O$	Relative yield
pH	-0.002ns	0.273***	0.273**	0.294**	0.061ns	0.118ns	0.055ns
K	0.538***	0.179ns	0.179ns	0.086ns	0.631***	0.57***	0.248*
Ca	0.731***	0.384***	0.384***	0.274**	0.948***	0.91***	0.51***
Mg	0.716***	0.450***	0.450**	0.35***	0.933***	0.90***	0.49***
Na	0.468***	0.264**	0.264**	0.180ns	0.749***	0.65***	0.59***
CEC	0.752***	0.382***	0.382***	0.280**	0.926***	0.903***	0.113ns
Si uptake	0.678***	0.495***	0.495***	0.42***	0.924***	0.89***	0.65***
Relative yield	0.148ns	0.231*	0.231*	0.197*	0.492***	0.38***	-

Table 5.9. Correlation coefficients (r) between extracted soil-Si (cmol kg^{-1}) before cane establishment, soil properties and biological parameters of cane grown in the pots (*, **, * significant at 5, 1, and 0.1%: n=35).**

Fox *et al.* (1967b) and Medina-Gonzales *et al.* (1988) reported similar results with a highly significant relationship between plant Si and water extractable Si, whereas Berthelsen *et al.* (2001b) found a significant relationship between readily available soil Si extracted with 0.01M $CaCl_2.2H_2O$, plant Si concentration and yield response. Van Erp and Van Beusichem (1998) suggested that a close relationship exists between soil fertility status, fertilizer application and crop response. Consequently, the soil Si content determined by reliable extractants could be positively related to the plant Si uptake. An extractant should not be regarded as reliable if its extracted soil Si values do not correlate or only correlate weakly with the plant Si uptake values.

5.4. ESTIMATING SILICON FERTILIZER REQUIREMENTS FOR SUGARCANE USING DIFFERENT SILICON EXTRACTANTS.

5.4.1. Correlation between extracted soil Si values using different extractants.

The evaluation and comparison of Si extraction methods was initially based on the correlation coefficients obtained between the soluble soil Si values removed by different extractants. Variable amounts of Si were extracted from the soils by the different extraction procedures used in this study before soil treatment (Table 5.1); after soil treatment but before sorghum planting (Table 5.4); after sorghum harvest but before cane planting (Table 5.7); and after cane harvest (Table 5.10). Relatively small amounts were extracted by the three weaker extractants (distilled water; 0.01M $CaCl_2.2H_2O$; and 0.5M CH_3COONH_4), while much larger amounts were extracted by the three stronger extractants (0.01M H_2SO_4 + $(NH_4)_2SO_4$; 0.025M H_2SO_4 and 0.5M CH_3COOH). All the data sets showed the best correlations ($P \leq 0.001$) between the quantities of Si extracted by the three stronger extractants.

One of the crucial stages in soil research concerns the quantification of the fraction of Si present in the soil that is available for plant absorption (de Resende *et al.*, 2002). Chemical extraction can only at best estimate a proportion of a soil nutrient that ends up in plant tissue (Schindler *et al.*, 2002), and most of the soil test methods give some evaluation of the quantity factor, measuring at least a part of the labile amount that may be available to plants (Van Raij, 1998). Among the methods that provide evaluation of the intensity factor are water and dilute salt solutions such as 0.01M $CaCl_2.2H_2O$ that measure the readily available Si, while stronger extractants such as 0.025M H_2SO_4 provide a measure of capacity since the slightly available and insoluble structural forms of Si are solubilized. For instance, there is a limitation of some weak methods to predict plant-available Si in soils where non-exchangeable Si contributes substantially to Si nutrition in plants such as Si accumulators. Cox and Joern (1996) and Cox *et al.* (1998) attributed this to the method's inability to extract plant-available non-exchangeable Si.

Soil form	Si source level	Soil silicon concentration at cane harvest (cmol kg^{-1})								
		0.5M NH_4OAc	Water (H_2O)	0.01M $CaCl_2.2H_2O$	0.5M HOAc	0.01M H_2SO_4 + $(NH_4)_2SO_4$	0.025M H_2SO_4	Mean Si level	Mean Si source	Mean soil form
Gs	TO	0.005	0.010	0.023	0.032	0.048	0.054			
	Calm L	0.015	0.011	0.042	0.047	0.079	0.079			
	Calm H	0.020	0.037	0.045	0.065	0.129	0.143			
	Slag L	0.013	0.022	0.054	0.039	0.054	0.115			
	Slag H	0.017	0.043	0.072	0.120	0.242	0.268	0.029^N	0.049^C	
	Woll L	0.006	0.029	0.053	0.022	0.019	0.056	0.042^L	0.068^S	
	Woll H	0.014	0.041	0.076	0.032	0.049	0.106	0.084^H	0.038^W	
	Mean	0.011	0.024	0.046	0.047	0.080	0.103			0.052
No	TO	0.004	0.031	0.035	0.024	0.018	0.034			
	Calm L	0.009	0.022	0.064	0.033	0.026	0.075			
	Calm H	0.023	0.039	0.086	0.043	0.072	0.110			
	Slag L	0.012	0.031	0.066	0.068	0.063	0.105			
	Slag H	0.014	0.029	0.079	0.173	0.298	0.327	0.024^N	0.042^C	
	Woll L	0.011	0.027	0.062	0.034	0.020	0.058	0.044^L	0.078^S	
	Woll H	0.012	0.036	0.072	0.047	0.031	0.084	0.088^H	0.036^W	
	Mean	0.010	0.031	0.059	0.052	0.063	0.096			0.052
Cf	TO	0.005	0.008	0.011	0.031	0.061	0.066			
	Calm L	0.022	0.011	0.017	0.038	0.084	0.104			
	Calm H	0.027	0.017	0.029	0.056	0.114	0.188			
	Slag L	0.017	0.012	0.013	0.050	0.113	0.178			
	Slag H	0.024	0.009	0.035	0.104	0.250	0.370	0.030^N	0.049^C	
	Woll L	0.021	0.014	0.021	0.046	0.099	0.113	0.054^L	0.075^S	
	Woll H	0.026	0.019	0.035	0.063	0.114	0.154	0.091^H	0.050^W	0.058
	Mean	0.017	0.012	0.020	0.050	0.106	0.145			
Lo	TO	0.006	0.027	0.034	0.019	0.015	0.019			
	Calm L	0.009	0.034	0.051	0.031	0.025	0.063			
	Calm H	0.018	0.042	0.078	0.051	0.059	0.084			
	Slag L	0.011	0.040	0.061	0.171	0.137	0.176			
	Slag H	0.014	0.040	0.086	0.224	0.377	0.530	0.020^N	0.037^C	
	Woll L	0.006	0.034	0.068	0.029	0.017	0.084	0.058^L	0.110^S	
	Woll H	0.013	0.044	0.077	0.029	0.042	0.114	0.107^H	0.038^W	
	Mean	0.010	0.035	0.058	0.066	0.078	0.123			0.062
Ar	TO	0.057	0.050	0.107	0.093	0.159	0.216			
	Calm L	0.073	0.071	0.137	0.135	0.213	0.251			
	Calm H	0.106	0.074	0.157	0.204	0.299	0.367			
	Slag L	0.087	0.066	0.129	0.152	0.208	0.304			
	Slag H	0.097	0.079	0.163	0.357	0.322	0.454	0.114^N	0.154^C	
	Woll L	0.080	0.066	0.138	0.132	0.197	0.286	0.151^L	0.172^S	
	Woll H	0.100	0.071	0.170	0.170	0.272	0.326	0.210^H	0.149^W	
	Mean	0.079	0.064	0.143	0.159	0.221	0.293			0.159
Total mean		0.026	0.033	0.064	0.075	0.109	0.152			
LSD (5%)		0.067						0.064	NS	0.063

Table 5.10. Amount of soil silicon extracted (cmol kg^{-1}) by different extractants from soil samples after cane harvest (with N=control or 0 tons ha^{-1}; L=3 tons ha^{-1}; H=6 tons ha^{-1}; C=calmasil; S=slagment and W=wollastonite Si sources).

5.4.2. Correlation between treatment Si levels, plant biomass relative yield and Si uptake with soil Si values as extracted by different extractants.

The knowledge of soil nutrient availability is the starting point for assessing the need for fertilizers. The evaluation of Si extraction methods was based on the correlation between the extracted soil Si with the plant Si uptake and biomass relative yield as well as the treatment Si levels. Van Erp and van Beusichem (1998) argued that the nutrients taken up by plants should be positively correlated with the nutrient concentration in the soil solution and that may be a good indicator of the actual nutrient availability in the soil. It was suggested that a close relationship exists between soil fertility status, fertilizer application and crop response.

For both the sorghum and cane crops, the Si taken up from the soil was positively and significantly correlated with the dry matter relative yield (Table 5.6 and Table 5.9), suggesting that both variables showed similar precision for predicting the plant response in relation to soil extracted Si. However, strong extractants either did not correlate or correlated weakly with the plant biomass relative yield (Table 5.6 and Table 5.9). The explanation could be that since the plants were grown for only a relatively short time, rather than to maturity, the yields recorded may not have been a true reflection of the plant's potential growth (Simonis and Setatou, 1996).

Even though the correlation coefficients relating plant biomass relative yield and Si uptake with the weak extractants were significant (Table 5.6 and Table 5.9), they were not sufficiently high to be referred to for predicting sugarcane silicon needs. The explanation is that the plants extracted more Si than the extractants from all soil forms investigated. As confirmed by Khalid and Silva (1978b), growing plants continuously removed Si from the soil solution (although at a decreasing rate with time), allowing continued release of Si from soil to the soil solution. Therefore, the sorghum and cane plants extracted more Si than the extractants, because the total extraction time for plants was longer and possibly because of the greater efficiency of Si removal by plant roots than that of distilled water, 0.01M $CaCl_2.2H_2O$ and 0.5M CH_3COONH_4 extractants.

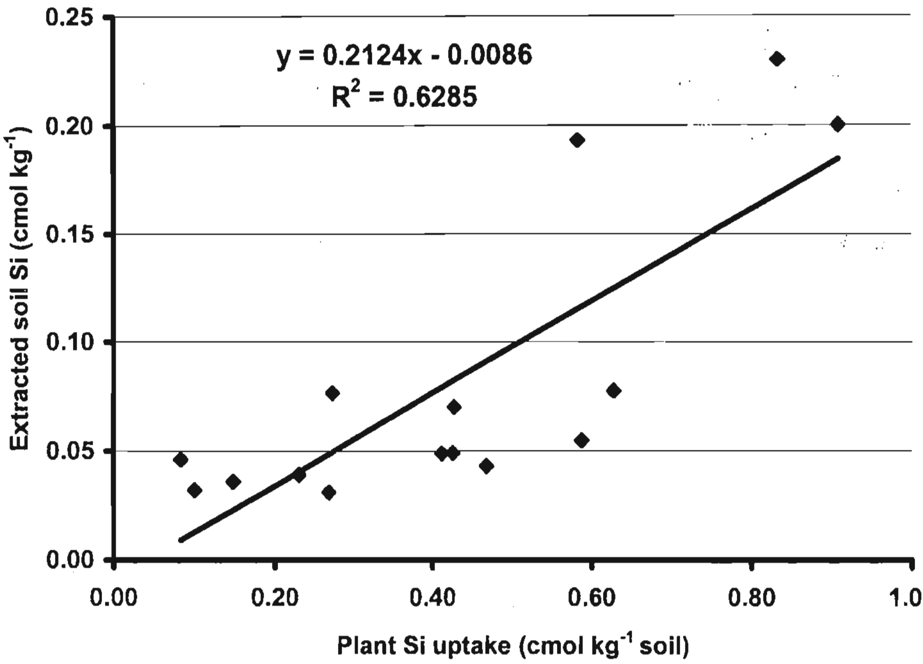

Figure 5.4. Soil Si extracted by distilled water as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

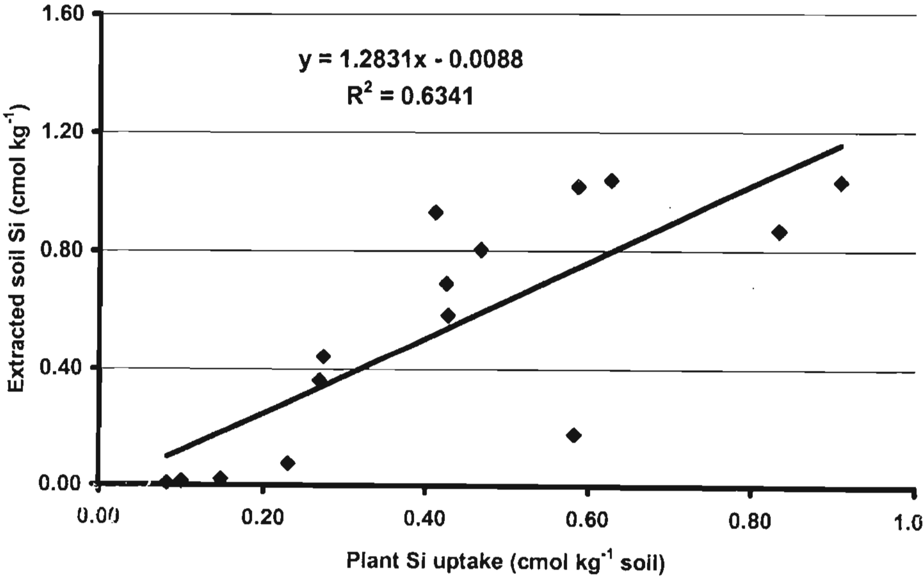

Figure 5.5. Soil Si extracted by 0.01M H_2SO_4 + $(NH_4)_2SO_4$ as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

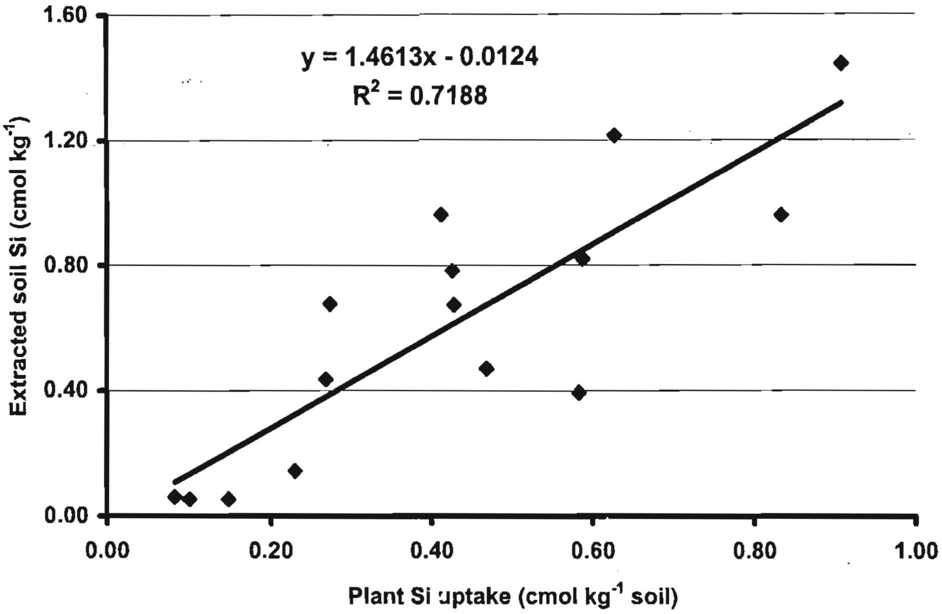

Figure 5.6. Soil Si extracted by 0.025M H_2SO_4 as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

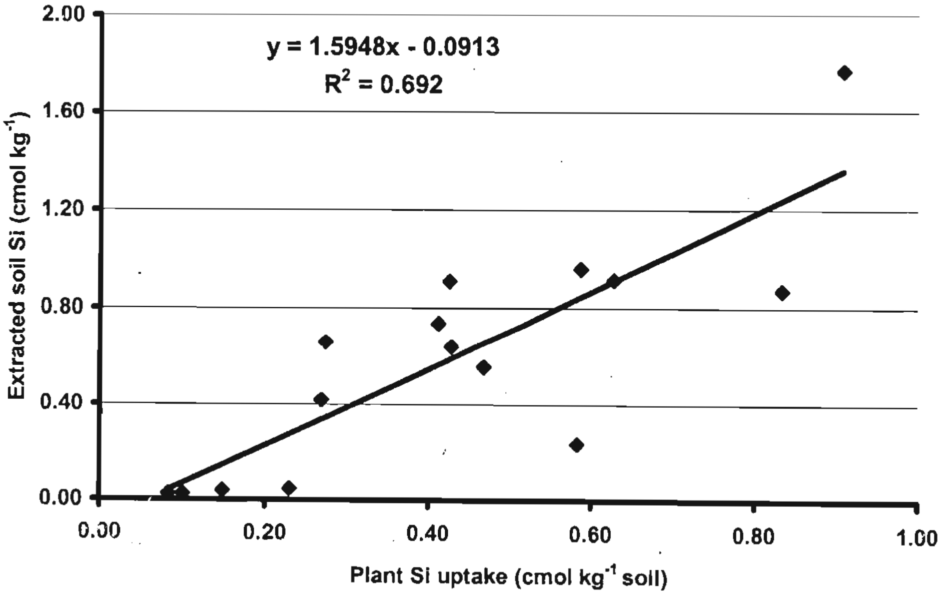

Figure 5.7. Soil Si extracted by 0.5M CH_3COOH as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

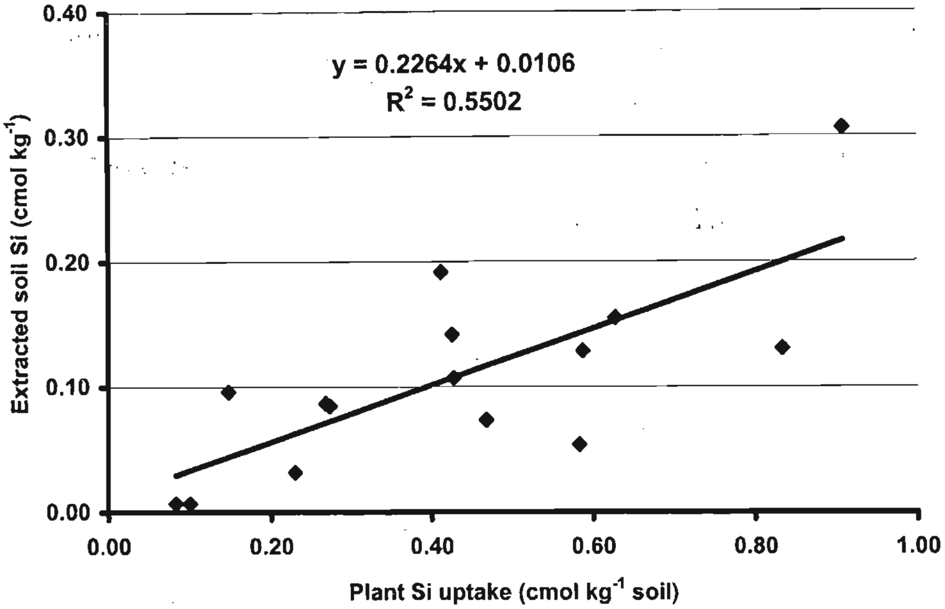

Figure 5.8. Soil Si extracted by 0.5M CH_3COONH_4 pH 4.8 as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

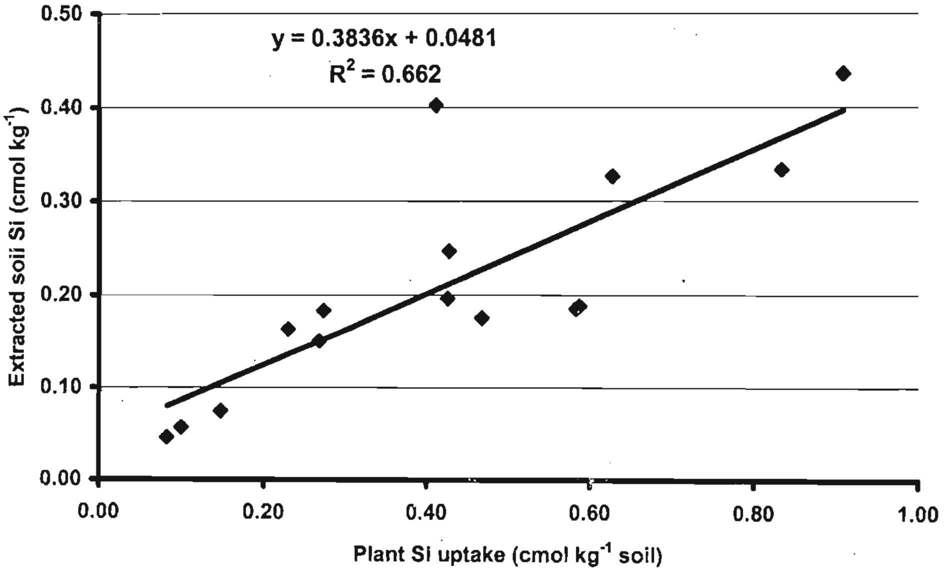

Figure 5.9. Soil Si extracted by 0.01M $CaCl_2.2H_2O$ as a function of cumulative Si uptake (cmol kg^{-1} soil) by sorghum and cane plants grown in the pots.

In this evaluation of Si extractants, soil Si values as extracted by different extractants after amendment of the soil by different Si sources (Table 5.4) were plotted as a function of the Si accumulated in the above-ground part of both the three crop cuts of sorghum (Table 3.11) and the plant cane crop (Table 4.4) grown in the pots. The correlations between the total Si taken up by sorghum and cane plants and the extracted soil Si (Figure 5.4 to Figure 5.9) were statistically significant ($P \leq 0.05$ to $P \leq 0.001$), meaning that all the methods were good indicators of the Si availability of the soils under investigation. However, the best correlation with total Si uptake was obtained with 0.025M H_2SO_4 extractant (R^2=0.7188***) and was appreciably superior to other extractants. The best correlation was obtained by the quantity or capacity method in accordance with the assumption that intensive growing of plants, under the experimental conditions in the pots, was mainly dependant on the quantity parameters (Simonis and Setatou, 1996).

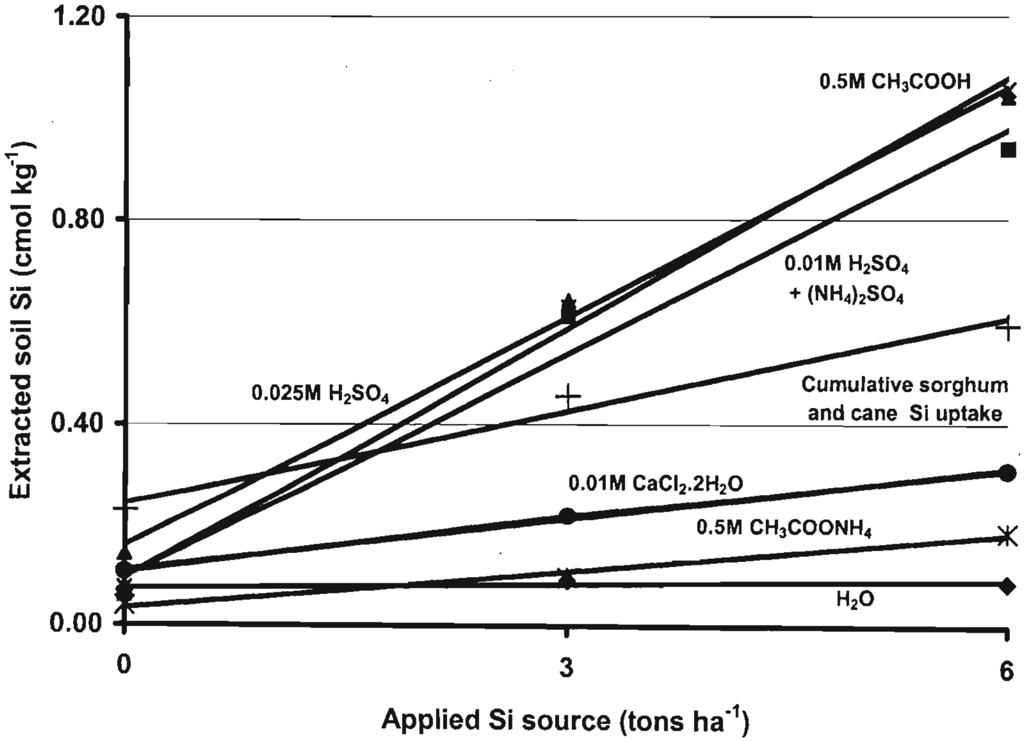

Figure 5.10. Averaged extracted soil Si (cmol kg^{-1}) by the different extractants and cumulative Si removed by three crop cuts of sorghum and the plant cane crop as a function of applied Si source levels (tons ha^{-1}).

When different Si source treatment levels were applied to the soil as revealed by the soil Si extractants (Figure 5.10), both the soil Si and plant Si uptake consequently increased. This was in agreement with findings of Pereira *et al.* (2004) and reinforces the idea that Si is undeniably beneficial to both sorghum and sugarcane. With regard to the soil Si curves representing different extractants (Figure 5.10), the 0.025M H_2SO_4 showed the best correlation (R^2=0.9959***) compared to the other two strong extractants namely the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ (R^2=0.9946***) and 0.5M CH_3COOH (R^2=0.9792***).

The curves for the other three extractants namely the distilled water (R^2=0.576**), 0.5M CH_3COONH_4 (R^2=0.9854***) and 0.01M $CaCl_2.2H_2O$ (R^2=0.9966***) were below the plant Si uptake curve, indicating that these extractants underestimated plant available Si. By the same token soil extractant curves above the plant Si uptake seemed to overestimate the plant available soil Si. However, it should be noted that if the root Si uptake by both the sorghum and cane crops had been included, the plant Si uptake curve would have conformed more closely with the slope of the 0.025M H_2SO_4 Si extraction curve.

5.4.3. Residual effect of applied Si sources to soil after sorghum and cane harvest as measured with Si extractants.

Changes in extracted Si values for each extraction after soil treatment with Si sources, after sorghum and cane harvest are shown in Figure 5.11. In general, the slopes of the strong acid extractants were far steeper than the slopes of the weak extractant Si curves. These Si extracted Si by the stronger extractants (0.01M H_2SO_4 + $(NH_4)_2SO_4$; 0.025M H_2SO_4 and 0.5M CH_3COOH) may be an index of an adsorbed form of Si (capacity factor), while the weaker extractant (distilled water, 0.5M CH_3COONH_4 and 0.01M $CaCl_2.2H_2O$) Si values may be a measure of intensity or the solution concentration at equilibrium with the soil system (intensity factor) (Fox *et al.*, 1967b; Khalid *et al.*, 1978a).

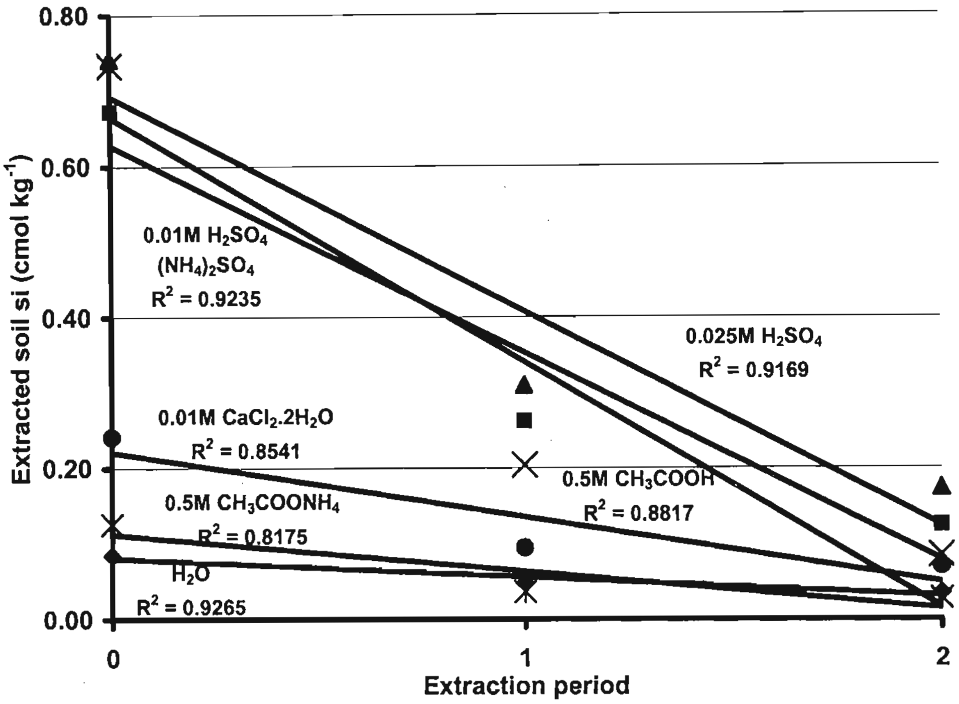

Figure 5.11. Effect of repeated soil Si extractions with different extractants on the mean residual soil Si following Si application and plant removal of Si after treatment (0), sorghum (1) and cane (2) harvest.

It is clear from Figure 5.11 that the soil Si content as extracted by different extraction methods decreased sharply with stage of cropping. Although the variability of the soil Si was considerable, the slope of the trend lines representing extracted soil Si using the weaker extractants declined very slowly after the sorghum and cane crops; while the stronger extractants' trend lines showed a more significant decline in residual Si.

From the trend lines representing the stronger extractants, the solubility of applied Si sources was more consistent with 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant than the 0.025M H_2SO_4 extractant. However, the 0.5M CH_3COOH extractant was the least consistent in soil Si extraction declining more sharply with time compared with the other two other stronger extractants.

There was a high degree of similarity between trend lines representing Si extractants in both Figure 5.11 and Figure 5.12 where extracted soil Si values after treatment were plotted respectively as a function of cumulative plant Si uptake after each crop stage, indicating that both methods could be used to evaluate soil residual Si. However, correlations were generally better using total plant Si uptake (Figure 5.12) and could have been better if Si taken up by the sorghum and cane roots had been included.

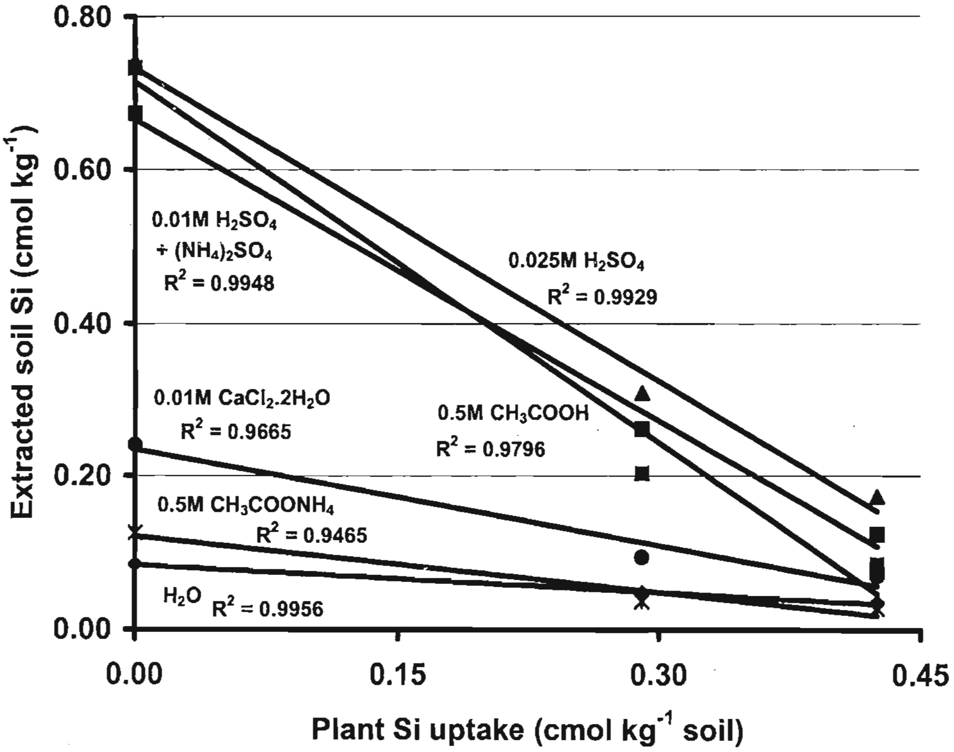

Figure 5.12. Effect of total Si taken up (cmol kg^{-1} soil) by sorghum (0.29) and cane (0.13) crops on average residual extracted soil Si (cmol kg^{-1}) with different extractants.

When the solubility of different Si sources was compared within extractants following repeated soil Si extractions after treatment, after sorghum and cane harvest, calmasil with intermediate Si content was more soluble in weak extractants (Figure 5.13 and Appendix 44), whereas slagment with the highest initial Si content (Table 3.3) was more soluble in strong extractants (Figure 5.14 and Appendix 45).

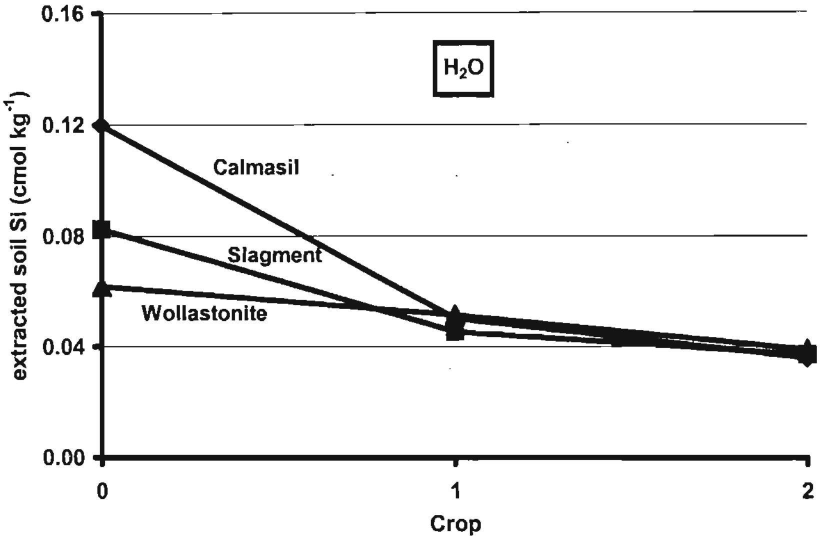

Figure 5.13. **Residual effect of Si sources on average extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) with the distilled water extraction method.**

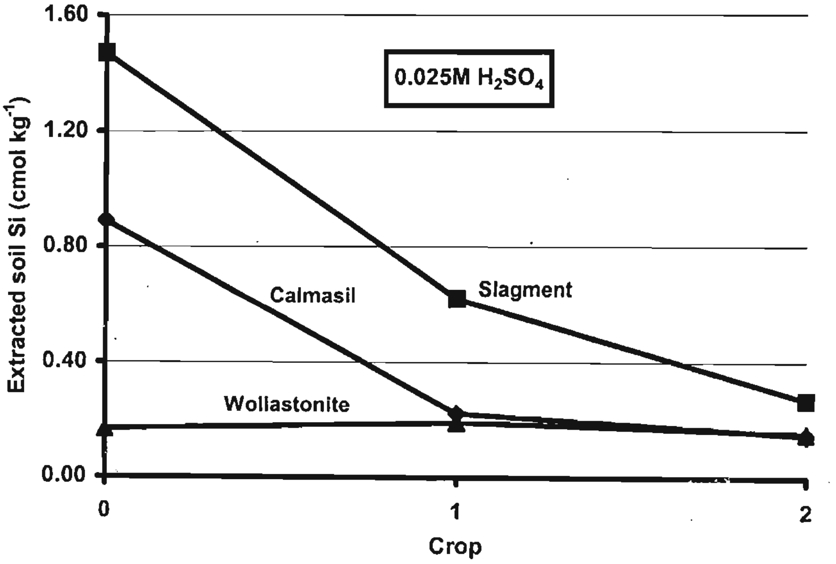

Figure 5.14. **Residual effect of Si sources on average extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) with the 0.025M H_2SO_4 extraction method.**

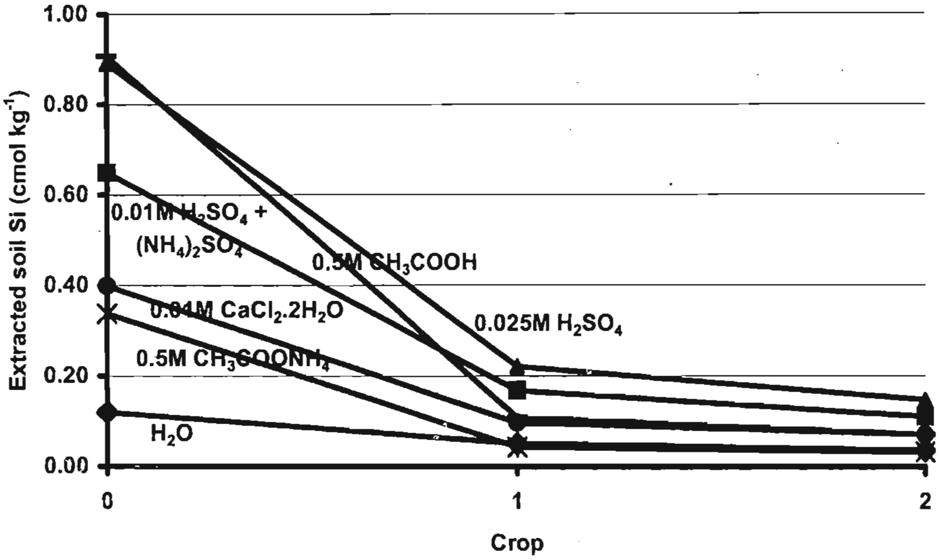

Figure 5.15. Evaluation of extractants through average extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) with the calmasil Si source.

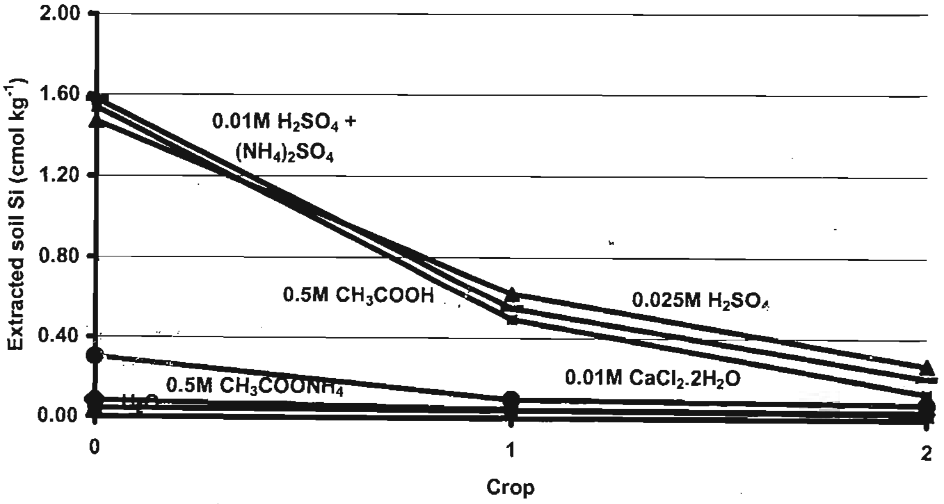

Figure 5.16. Evaluation of extractants through average extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) with the slagment Si source.

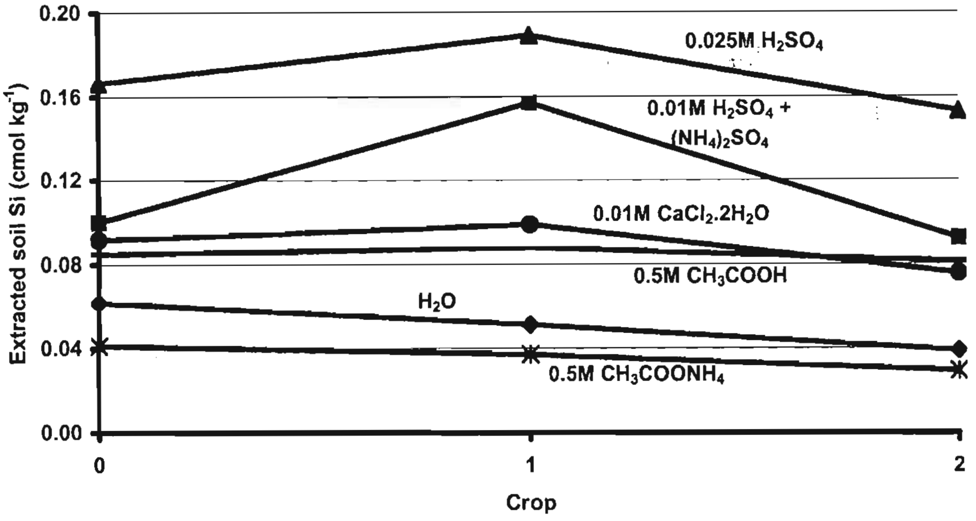

Figure 5.17. Evaluation of extractants through average extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) with the wollastonite Si source.

When different Si extractants were compared within different Si sources (Figure 5.15 to Figure 5.17), it was observed that all the Si sources were more soluble in strong than in weak extractants, and the highest residual soil Si values were obtained with the 0.025M H_2SO_4 extractant. Slagment Si source showed the highest residual soil Si values (Figure 5.16), followed by calmasil (Figure 5.15) and wollastonite (Figure 5.17) Si sources, in the same descending order as their initial Si content (Table 3.3). The solubility of wollastonite Si source was improved with time (Figure 5.17), indicating that it was dissolving less quickly than the other two Si sources investigated.

Among all the soil Si test methods that have been investigated in this study, the strong extractants in general, and the 0.025M H_2SO_4 in particular were more consistent with treatment effects than the weak extractants in predicting plant Si needs. The weak extractants were not promising since they only removed very small amounts of extractable or native soil Si compared with the Si uptake by sorghum and cane plants, and thus, estimation of Si fertilizer requirements would be difficult.

5.5. CALIBRATION OF 0.025M H_2SO_4 EXTRACTANT WITH CANE RESPONSE.

The objective of this exercise was to determine to what extent the 0.025M H_2SO_4 extractant could predict soil Si deficiency with respect to cane Si requirements. As stated by Rodriguez *et al.* (2003), soils reflecting test Si values below or equal to the critical soil test Si values require some measure of Si fertilization. In this study, the Si extracted by 0.025M H_2SO_4 was significantly correlated with both the relative biomass yield ($P \leq 0.05$) as well as the Si uptake ($P \leq 0.001$), of cane plants grown in the pots; which variables were in turn significantly correlated ($P \leq 0.001$) with each other, indicating that they had the same precision for predicting cane response in relation to Si extracted from soils. The cane biomass relative yield used in this study (Table 5.8) was defined as the percentage of observed biomass yield over the mean high biomass yield (Fernandes *et al.* 2000). Responsive populations were those with ≤ 90% relative yield. Application of nutrient is normally made when the supply is below the critical soil nutrient level, and not made when the soil nutrient concentration is above the critical level, when additional crop response is unlikely (Cate and Nelson, 1971).

The data partitioning method of Cate Nelson (1971) was used to determine a critical soil Si test level for each soil for which there was a crop response to silicon addition. The graphical method of Cate and Nelson (Cate and Nelson, 1965, 1971) as described by Nelson and Anderson cited by Jackson (2000) and Maftoun *et al.* (2003) was used to separate the soil test results into "deficient" and "not deficient" groups and to estimate for each soil form the critical soil Si level for the best performing 0.025M H_2SO_4 Si extractant. The percentage yield was plotted against the Si soil test producing a scatter plot that is separated into four quadrants (Figures 5.18 to 5.22) by a vertical and a horizontal line. These lines were adjusted to maximize the number of data points in the "+" quadrants. The point where the vertical line crosses the *x*-axis is defined as the critical soil test level. The point where the horizontal line crosses the *y*-axis varied but was less than five percentage points above or below 90% yield.

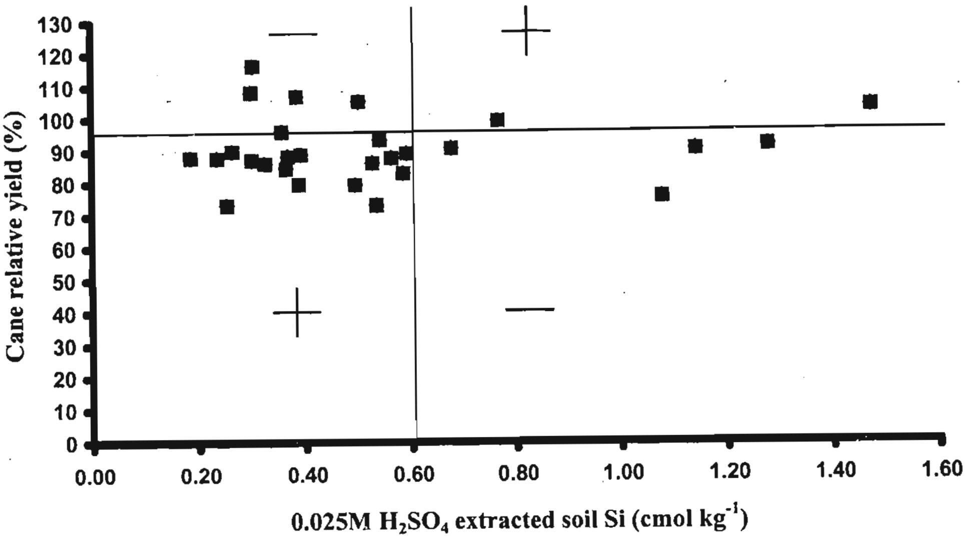

Figure 5.18. Cate-Nelson scatter diagram of 0.025M H_2SO_4 extractable Si (cmol kg^{-1}) and relative yield (%) of cane plants grown in the pots with *Arcadia* form soil. Each point represents a composite soil sample of four replications: n=35.

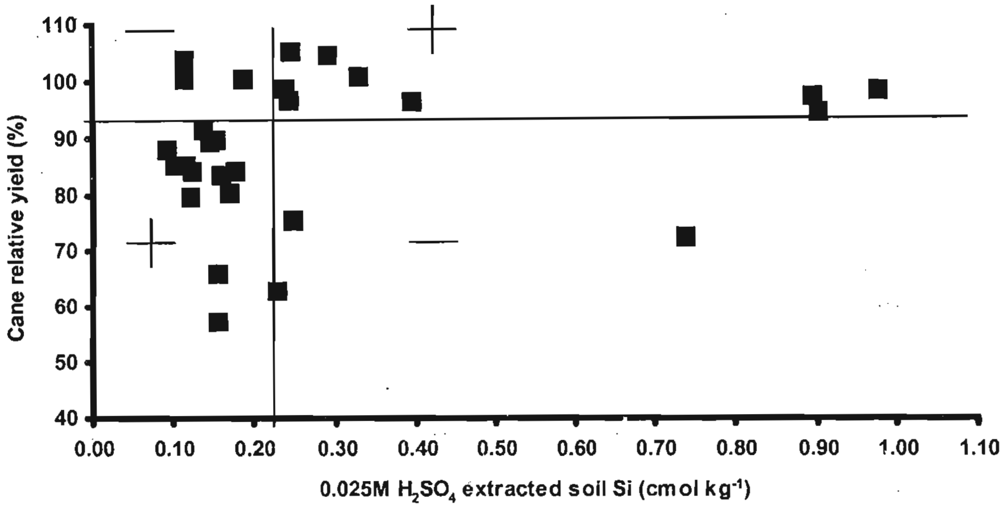

Figure 5.19. Cate-Nelson scatter diagram of 0.025M H_2SO_4 extractable Si (cmol kg^{-1}) and relative yield (%) of cane plants grown in the pots with *Cartref* form soil. Each point represents a composite soil sample of four replications: n=35.

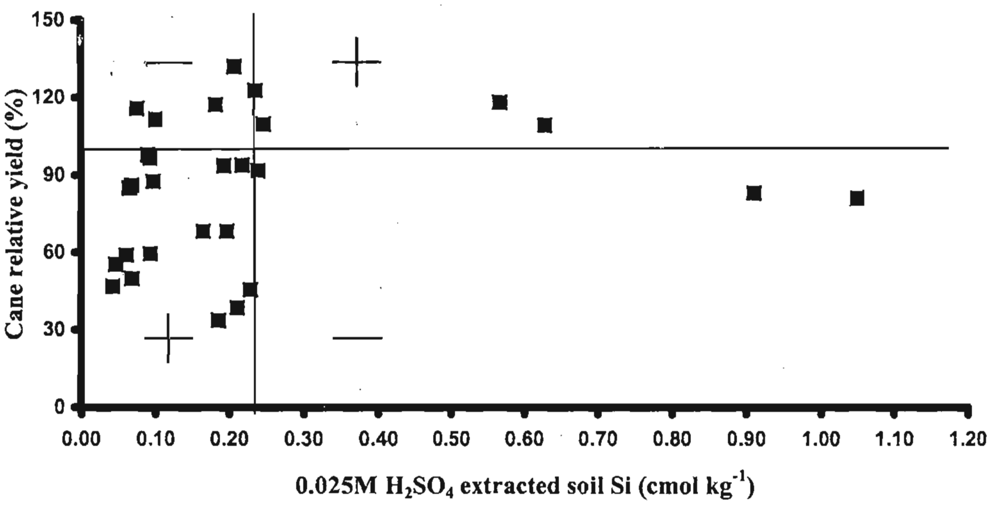

Figure 5.20. Cate-Nelson scatter diagram of 0.025M H_2SO_4 extractable Si (cmol kg^{-1}) and relative yield (%) of cane plants grown in the pots with *Glenrosa* form soil. Each point represents a composite soil sample of four replications: n=35.

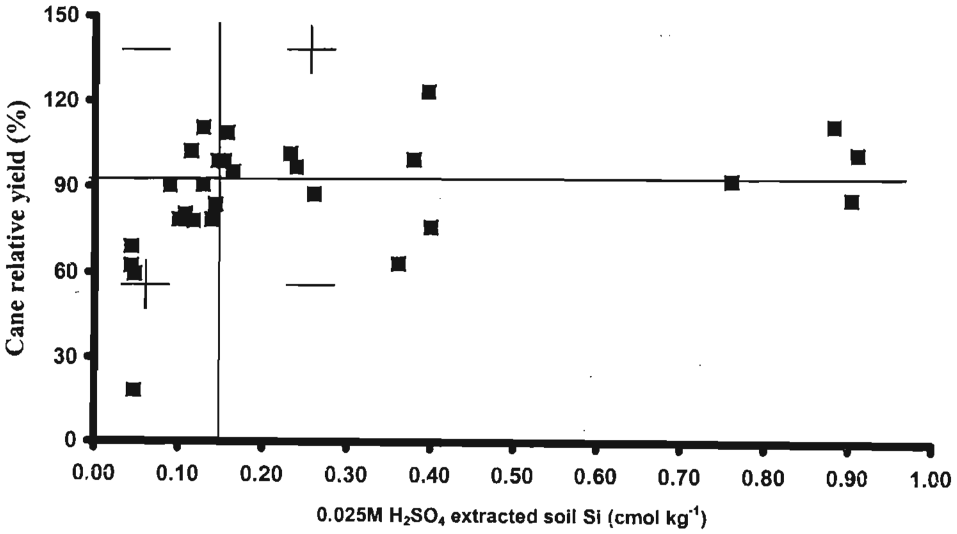

Figure 5.21. Cate-Nelson scatter diagram of 0.025M H_2SO_4 extractable Si (cmol kg^{-1}) and relative yield (%) of cane plants grown in the pots with *Longlands* form soil. Each point represents a composite soil sample of four replications: n=35.

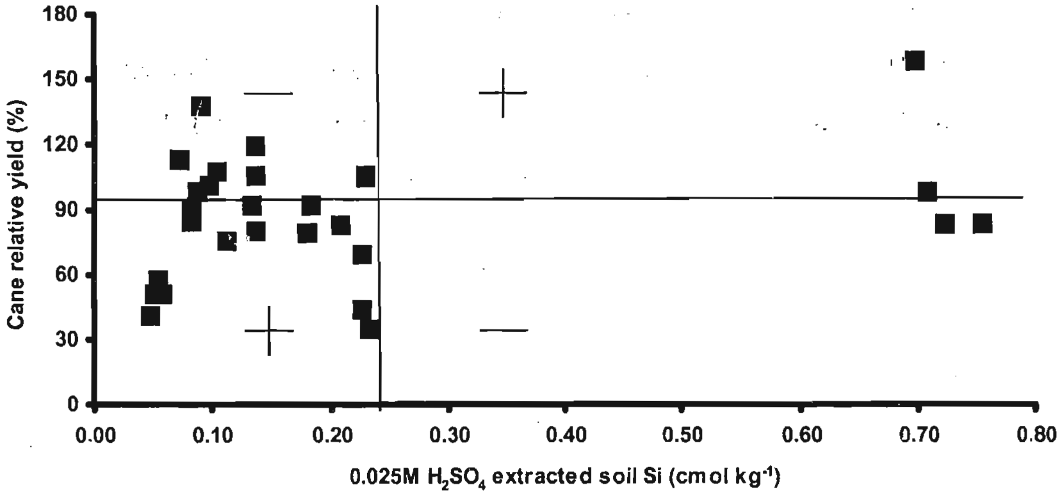

Figure 5.22. Cate-Nelson scatter diagram of 0.025M H_2SO_4 extractable Si (cmol kg^{-1}) and relative yield (%) of cane plants grown in the pots with *Nomanci* form soil. Each point represents a composite soil sample of four replications: n=35.

In the Cate-Nelson graphical method, the relative cane biomass yield (%) was regressed versus the 0.025M H_2SO_4-extracted Si values for each soil form investigated. The estimated critical soil Si test levels, as interpolated from Figure 5.18 to Figure 5.22 are compiled in Table 5.11.

Soil investigated		Critical soil Si test level	
Soil location	Soil form	cmol kg^{-1}	mg kg^{-1}
BT1*	*Arcadia*	0.60	168
ESHOWE	*Cartref*	0.23	64
KEARSNEY	*Glenrosa*	0.23	64
LONGLANDS*	*Longlands*	0.16	45
PADDOCK	*Nomanci*	0.24	67

Table 5.11. Cate-Nelson estimated soil Si levels for different soil forms investigated. (* = soil from Mount Edgecombe).

In general, the recommended fertilizer application rates lead to relatively high nutrient use efficiencies. When fertilizer application exceeds the recommended rates, nutrients will certainly be left in the soil profile at harvest. The mobile nutrients are then subject to leaching while the immobile nutrients may remain in the rooting zone of the soil profile and increase the soil fertility status. Subsequent, if fertilizer application rates are not adjusted to the soil fertility status, the risk of nutrient losses through leaching, denitrification or surface run-off may increase accordingly (Van Erp and Van Beusichem, 1998).

The results of soil Si calibration tests showed different critical Si values for the respective soil forms investigated. Such results were expected as long as the soil forms had different chemical properties especially the clay content; which impacts on the nutrient availability in the soil solution. Thus soil forms might have soil Si test critical levels in direct proportion to their clay content. Thus a sandy soil is expected to have lower soil Si test critical level than a clay soil, as was the case in the present study. The sandy soil of *Longlands* form soil with 6% clay content had a Si critical level of 0.16cmol kg^{-1} (45mg kg^{-1}) whereas the *Arcadia* form soil with 40% clay content had a critical Si level of 0.60cmol kg^{-1} (168mg kg^{-1}).

5.8. CONCLUSION.

The evaluation of Si extractants showed that strong extractants in general, and the 0.025M H_2SO_4 extractant in particular, were more consistent with treatment effects than weak extractants in predicting the Si needs of sugarcane. The weak extractants namely distilled water; 0.5M CH_3COONH_4 and 0.01M $CaCl_2.2H_2O$ were only removing small amounts of Si. A limitation of these weaker extractants was to predict plant-available Si where non-exchangeable Si contributed substantially to Si nutrition in sorghum and cane crops. The 0.025M H_2SO_4 correlated better with the cumulative Si uptake by sorghum and cane crops grown in pots and was appreciably superior to the other extractants.

CHAPTER 6

GENERAL CONCLUSIONS

The experiment demonstrated that application of Si-rich materials to soil having sub-optimal levels of plant available Si resulted in significant responses in sorghum and cane crops. Application of Si-rich compounds increased the soil pH through increased amounts of bases such as Ca and Mg in the soil solution. The amount of plant available Si increased in proportion to the rates of applied Si sources. The increase of exchangeable cations Ca, Mg, K and Na and consequently the CEC was attributable to the substantial amounts of these cations in the Si sources investigated. Also as a result of the alleviating effect of Si on Al, and the substantial content of these cations in the weekly applied basal solution supplied to the sorghum and cane crops grown in the pots.

Plants removed larger quantities of Si from soils which had received Si treatments than from the untreated soils, and this trend was present in both plant and ratoon crops. The responses obtained in this study resulted in an average increase in sorghum and cane dry matter yield of 18% and 23% from Si application, as well as an average increase in sorghum and cane Si uptake of 154% and 85% respectively. The sorghum dry matter yield and Si uptake was more influenced by the different soil forms through their fertility status and Si source application rates, than the Si sources themselves; which did not show a significant difference in their ability to supply Si to the soil solution, and hence to the sorghum plants, despite their inherent difference in Si content.

Whilst the magnitude of the responses was not the same for all soil forms investigated, they were probably influenced by their initial soil fertility status recorded prior to the trial. Accordingly, a yield depression occurred on the *Arcadia* form soil at the lower and higher (3 and 6 tons ha^{-1}) Si source application rates, and on the *Cartref* form soil at the higher (6 tons ha^{-1}) Si source application rate. This depression may be attributed to a micronutrient imbalance such as the micronutrients Zn, Cu, Mn or Fe.

The quantities of Si extracted by the sorghum plant crop were generally higher than those extracted by the cane crop. This suggests that the sorghum plant crop might have removed most of the easily available forms of Si from the soil, resulting in a decrease in the rate of Si released to the soil solution during cane growth. Amendment of soils with Si rich materials increased the cane root Si and cane canopy development respectively, indicating a closer relationship of these two factors with the dry matter yield.

Plant nutrient uptake was examined in an attempt to determine the nutrient responsible for the increases in sorghum dry matter yield, and for differences in yields between the various treatments. Except for Si, the uptake data indicated that none of the elemental nutrients were deficient and that they were therefore not responsible for the yield differences. There were no positive significant treatment differences in the concentrations of N, P, K, Ca and Mg in the sorghum plants. It was found that the nutrients P, Ca and Mg were not affected by the Si source application, whereas N and K decreased in plant tissue with increasing rates of the Si sources. This confirmed the findings of Liang *et al.* (2001) where Si was found to reduce N and P concentrations in the sorghum straw by 13% and 7% respectively. Hence, it does not appear that sorghum yield increases can be accounted for any elements, other than Si.

The relationship between extractable soil Si and plant parameters such as plant biomass yield and Si uptake showed that the selected extractants did not perform equally. Apart from plant relative yield, plant Si uptake was seemingly the best indicator of soil Si availability for all the extractants. Even though the correlation coefficients between relative biomass yield and sorghum Si uptake with the distilled water or the 0.01M $CaCl_2.2H_2O$ extraction methods were significant, they were much lower than of those of other preferred extractants for predicting the requirements for Si fertilizers. Furthermore, a chemical extractant can only at best estimate a proportion of soil nutrient that will end up in plant tissue (Schindler *et al.*, 2002); which implies that distilled water and 0.01M $CaCl_2.2H_2O$ extractants were not suitable as indicator test extractants.

Among the Si extractants studied, the 0.025M H_2SO_4 appeared to be the most suitable for evaluating Si availability in acid soils of the South African Sugar Industry. It is recommended that the 0.025M H_2SO_4 extractant should be adopted by the South African Sugar Industry as a standard Si extraction procedure for sugarcane, though further field application and calibration work may be necessary for advisory purposes. Critical soil Si levels as interpolated from the relative cane biomass yield plots as a function of the 0.025M H_2SO_4 extracted soil Si levels were of 6.0 mmol kg^{-1} (168 mg kg^{-1}) for *Arcadia*, 2.3 mmol kg^{-1} (64 mg kg^{-1}) for *Cartref*, 2.3 mmol kg^{-1} (64 mg kg^{-1}) for *Glenrosa*, 1.6 mmol kg^{-1} (45 mg kg^{-1}) for *Longlands*, and 2.4 mmol kg^{-1} (67 mg kg-1) for *Nomanci* form soils respectively.

The results of this study suggest that the positive yield responses observed in this trial were due to the addition of the various Si sources and their ability to increase plant available soil Si and, therefore, plant uptake. They support the hypothesis that Si is beneficial and possibly essential to sugarcane growth since it was the only element measured that was related to yield and Si uptake of sorghum and cane crops. The low Si status of the various soil forms investigated, other than *Arcadia* form soil, appears to be a factor that can limit yield of Si accumulator plants such as sorghum and sugarcane. It may be worthwhile to consider Si fertilization in other acid soils where difficulties are encountered with plant production.

The present study has confirmed the suitability of the 0.025M H_2SO_4 extractant for predicting the Si requirement of sugarcane on essentially highly weathered acid soils. Only one of the soils tested (*Arcadia* form soil) did not fall into the highly weathered category and the results showed that a much higher threshold value would need to be applied compared to the more weathered soils. The question of how suitable would this extractant be for crops other than sugarcane, would require similar calibration studies based on greenhouse trials and laboratory analysis of soil and plant material. If the crop in question is a silicon accumulator, then there is a high probability that the 0.025M H_2SO_4 extractant would be applicable for diagnostic purposes, but even then follow up investigation would be needed to determine the soil threshold value.

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APPENDICES

Appendix 1. Soil and plant Si extraction.

1.1. Soil Si extraction methods used in this study.

1.1.1. Modified Truog (0.01M H_2SO_4 + $(NH_4)_2SO_4$) (Fox *et al.*, 1967b).

1.1.1.1.Extracting solution.

Dissolve 15g of $(NH_4)_2SO_4$ in a 5L volumetric flask with twice de-ionized water. Add 100ml of 0.5M H_2SO_4 and make up to mark with twice de-ionized water.

1.1.1.2.Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50ml of extracting solution and stopper the tube. Shake the tube continuously end over end for 20 minutes at 220 RPM. Remove caps and centrifuge samples for five minutes at a high-speed (90X3000RPM) to separate the extracts.

1.1.2. Distilled water (H_2O) (Fox *et al.*, 1967b).

1.1.2.1.Extracting solution.

The water here refers to pure water, free from any dissolved ions or other substances. Such water may be obtained preferably by means of double distillation of tap water.

1.1.2.2. Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50ml of extracting solution and stopper the tube. Shake the tube continuously end over end for 20 minutes at 220 RPM. Remove cap and centrifuge sample for five minutes at a high-speed (90X3000RPM) to separate the extract.

1.1.3. 0.025M H_2SO_4 (Rayment and Higginson, 1992).

1.1.3.1. Extracting solution.

Dilute 1.40ml of concentrated H_2SO_4 in 1L volumetric flask and make up to mark with twice de-ionized water. Store in a clean polyethylene container.

1.1.3.2. Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50ml of extracting solution and stopper the tube. Shake the tube continuously end over end for 30 minutes at 220 RPM. Remove cap and filter to get a clear extract.

1.1.4. 0.5M CH_3COOH (Korndörfer *et al.*, 1998).

1.1.4.1. Extracting solution.

Dilute 29.00ml of glacial CH_3COOH in 1L volumetric flask and make up to mark with twice de-ionized water.

1.1.4.2. Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50mL of extracting solution and stopper the tube. Shake the tube continuously end over end for 30 minutes at 220 RPM. Remove cap and filter to get a clear extract.

1.1.5. 0.5M CH_3COONH_4 pH 4.8 (Fox *et al.*, 1967b*)*.

1.1.5.1. Extracting solution.

Weight 39g of CH_3COONH_4 in 1L beaker. Add 800ml twice de-ionized water and stir mechanically until all crystals have dissolved completely. Add drop wise acetic acid and stir constantly to adjust the pH of the solution to pH 4.8. Then transfer the solution quantitatively into a 1L volumetric flask, and make up to mark with twice de-ionized water.

1.1.5.2. Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50ml of extracting solution and stopper the tube. Shake the tube continuously end over end for one hour at 220 RPM. Remove cap and filter to get a clear extract.

1.1.6. 0.01M $CaCl_2.2H_2O$ (Haysom and Chapman, 1975)

1.1.6.1. Extracting solution.

Weight 1.47g $CaCl_2.2H_2O$ into a 1L volumetric flask and bring to volume with twice de-ionized water.

1.1.6.2. Extraction procedure.

Weigh 5g-soil sample and transfer it into a centrifuge tube. Add 50ml of extracting solution and stopper the tube. Shake the tube continuously end over end for 16 hours at 220 RPM. Remove cap and centrifuge samples for five minutes at a high-speed to clarify the extract.

1.2. Plant (leaf) silicon extraction.

1.2.1. Extracting solution.

Dissolve 150g NaOH pellets in 1L volumetric flask. Make to mark with twice-deionised water. Then dilute 54ml of concentrated HCl in 1L volumetric flask. Make to mark with twice-deionised water.

1.2.2. Extraction procedure.

Weigh 0.5g oven dried and ground plant material and ash for 6 hours at 650^0C. Transfer the ashed material into a nickel crucible. Add 5ml of 15% NaOH and evaporate at a low heat on a hot plate until dry. Add a little twice-deionised water to dissolve the sample and transfer into 250ml volumetric flask containing 100ml 0.6N HCl. Make to mark with twice-deionized water. Select an aliquot 1-5ml (2ml) into 50ml volumetric flask.

1.3. Soil and plant (leaf) silicon concentration determination.

1.3.1. Reagents.

1.3.1.1.Reducing solution.

Dissolve 0.7g of Na_2SO_3 in 10ml of twice-de-ionized water. Add 0.15g of 1-amino-2-naphtol-4-sulfonic acid, and stir the mixture until the salt dissolve. Dissolve 9g of $Na_2S_2O_5$ in 90ml of twice-de-ionized water, and mix it with the solution above. Store the solution in a plastic bottle.

1.3.1.2. Ammonium Molybdate solution.

Dissolve 7.5g of ammonium molybdate in 75ml of water. Add 10ml of 9M H_2SO_4, and dilute the solution to a volume of 100ml with twice-de-ionized water. Store the solution in a plastic bottle.

1.3.1.3. Oxalic acid solution 10%.

Dissolve 100g of $H_2C_2O_4.2H_2O$ in 1L volumetric flask and make up to mark with twice-de-ionized water.

1.3.1.4. 9M H_2SO_4.

Dilute in 100ml volumetric flask 50ml of concentrated H_2SO_4 and make up to mark with twice de-ionized water.

1.3.1.5. Soil silicon standards.

Dilute 10ml of 1000mg kg^{-1} silicon standard in 100ml volumetric flask and make up with the extracting solution to obtain 100mg kg^{-1} silicon standard. Use it to prepare 0, 1, 2, 4, 6, 8, 12 and 16mg kg^{-1} standards. Soil conversion will be 0, 10, 20, 40, 60, 80, 120 and

160mg kg^{-1} because 5g of soil are taken in 50ml of extracting solution (soil-solution ratio:1:10).

1.3.1.6. Plant (leaf) silicon standards.

Dilute 10ml of 1000ppm silicon standard in 100ml volumetric flask and make up with the extracting solution to obtain 100 mg kg^{-1} silicon standard. Then use it to prepare 5, 10, 15, 20 and 40 mg kg^{-1}. That corresponds to 0.25, 0.50, 0.75, 1.00 and 2.00% of leaf silicon because the dilution factor is (0.5/250) x 10000 = 20 (10000mg kg^{-1}=1% for leaf silicon).

1.3.2. Instrument settings.

Zero instrument (UV/Visible Spectrophotometer) with the blank. Calibrate instrument using 4ppm standard solution at 40 (mg kg^{-1}) for soil samples (40mg kg^{-1} standard solution at 2.00 (%) for plant samples). Reference setting and follow reading of other remaining standards and unknowns. When making standards, top with extracting solution.

1.3.3. Silicon concentration determination procedure.

Withdraw 5ml of the soil sample solution (2 ml for plant or leaf sample solution) with a pipette, and transfer the aliquot to a 50ml volumetric flask. Treat a 5ml soil sample (2ml plant or leaf sample) aliquot of the reference blank solution and other standards in the same manner as the sample solution. Add 3ml of twice de-ionized water into 50ml volumetric flask. Add 1ml of the ammonium molybdate reagent solution, swirling the contents of the flask during addition. Mix the solutions well and allow the flask to stand for 30 minutes at room temperature. Now add 3ml of the oxalic acid solution (10%) while swirling the contents of the flask, and mix the solution well. Add 1ml of the reducing solution while swirling the contents of the flask and make up to mark with twice de-ionised water. Stopper the flask, mix the contents well and allow the flask to stand for at least 30 minutes. Read the standards and unknowns at 660nm (ppm for soil samples and percent (%) for leaf samples).

Appendix 2. Effect of soil forms and Si source application rates (tons ha^{-1}) on the dry matter yield (g kg^{-1} soil) of sorghum plants grown in the pots (first cut).

Soil form	Rep. No	Sorghum yield (g kg^{-1} soil) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.834	1.035	1.117	1.044	0.815	0.936	1.095
	2	0.708	0.828	1.019	0.897	0.947	1.119	0.932
	3	1.136	1.157	0.822	0.797	0.861	0.812	0.745
	4	0.712	0.998	0.764	0.846	0.948	0.752	0.870
Cartref	1	0.664	0.901	0.929	0.985	1.092	0.981	0.683
	2	0.832	1.002	0.981	0.777	1.117	1.104	0.618
	3	0.924	1.031	1.034	0.792	1.136	0.971	0.733
	4	0.649	0.892	1.043	0.949	1.178	1.029	0.752
Glenrosa	1	0.534	0.777	1.004	0.427	1.024	1.021	0.771
	2	0.273	0.499	0.943	0.291	0.579	0.834	0.959
	3	0.295	0.541	0.935	0.876	0.685	0.754	0.733
	4	0.588	0.638	0.576	0.646	0.510	1.053	1.216
Longlands	1	0.680	1.067	0.969	1.082	0.748	0.872	0.857
	2	0.654	0.895	0.951	0.860	0.844	0.864	0.821
	3	0.699	1.046	1.089	0.723	0.994	0.791	1.011
	4	0.564	0.994	1.034	0.811	0.836	0.648	0.806
Nomanci	1	0.271	0.645	0.784	0.623	0.639	0.580	0.533
	2	0.379	0.493	0.878	0.694	0.496	0.648	0.581
	3	0.467	0.662	0.496	0.645	0.793	0.499	0.378
	4	0.443	0.384	0.564	0.747	0.318	0.947	0.681

Appendix 3. Effect of soil forms and Si source application rates (tons ha^{-1}) on the dry matter yield (g kg^{-1} soil) of sorghum plants grown in the pots (second cut).

Soil form	Rep. No	Sorghum yield (g kg^{-1} soil) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.834	1.035	1.117	1.044	0.815	0.936	1.095
	2	0708	0.828	1.019	0.897	0.947	1.119	0.932
	3	1.136	1.157	0.822	0.797	0.861	0.812	0.745
	4	0.712	0.998	0.764	0.848	0.948	0.752	0.870
Cartref	1	0.664	0.901	0.929	0.985	1.092	1.040	0.825
	2	0.832	1.002	0.981	0.777	1.117	0.922	0.840
	3	0.923	1.031	1.034	0.792	1.136	1.041	0.717
	4	0.649	0.892	1.043	0.949	1.178	1.088	0.947
Glenrosa	1	0.845	0.808	1.142	0.753	1.101	0.766	0.749
	2	0.227	0.431	1.332	0.491	0.972	0.822	0.899
	3	0.249	0.700	1.187	0.992	0.754	0.688	0.492
	4	0.324	0.816	0.980	0.623	0.722	0.600	0.877
Longlands	1	0.757	0.797	1.278	0.745	0.704	0.818	0.945
	2	0.884	0.914	0.885	0.732	0.718	0.677	0.813
	3	0.729	0.940	1.041	0.714	0.699	0.719	0.857
	4	0.555	0.817	0.819	0.719	0.713	0.646	0.892
Nomanci	1	0.153	0.603	0.633	0.382	0.481	0.452	0.628
	2	0.358	0.664	0.699	0.424	0.467	0.697	0.654
	3	0.444	0.840	0.674	0.597	0.380	0.388	0.566
	4	0.265	0.608	0.810	0.364	0.259	0.447	0.704

Appendix 4. Effect of soil forms and Si source application rates (tons ha^{-1}) on the dry matter yield (g kg^{-1} soil) of sorghum plants grown in the pots (third cut).

Soil form	Rep. No	Sorghum yield (g kg^{-1} soil) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	5.345	6.517	6.717	6.448	6.339	6.057	6.200
	2	5.948	6.057	6.807	5.823	5.869	6.533	6.433
	3	6.306	5.933	7.122	5.709	6.105	6.607	5.690
	4	5.479	6.521	6.894	5.955	6.271	5.970	6.026
Cartref	1	5.896	5.715	6.390	5.827	6.040	6.036	5.866
	2	6.213	5.761	5.577	5.305	6.367	5.190	5.825
	3	6.169	6.422	6.300	5.465	6.441	5.268	5.990
	4	5.682	5.940	5.823	5.639	6.841	5.491	6.332
Glenrosa	1	3.199	5.106	5.761	4.746	5.400	4.504	4.646
	2	3.133	4.790	5.524	4.211	5.133	4.044	4.716
	3	3.083	4.996	5.413	4.724	5.819	4.464	4.722
	4	3.070	5.059	5.954	4.935	5.095	4.255	4.676
Longlands	1	3.804	4.769	4.905	4.862	4.897	4.585	5.247
	2	3.958	4.613	4.041	4.980	5.086	5.305	4.893
	3	3.866	4.641	4.594	4.476	4.912	4.524	4.755
	4	4.152	4.645	4.064	4.713	4.908	4.849	5.107
Nomanci	1	4.206	4.558	4.603	4.612	4.194	3.902	4.668
	2	4.051	4.475	3.609	4.306	4.450	4.468	4.887
	3	4.367	4.017	5.125	4.595	3.833	4.286	4.141
	4	4.339	4.305	4.422	4.042	4.010	3.381	4.621

Appendix 5. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si uptake (%) by sorghum plants grown in the pots (first cut).

Soil form	Rep. No	Si uptake (%) per sorghum plants per pot						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	1.86	2.09	2.07	1.62	2.19	1.49	2.34
	2	1.65	1.93	1.59	1.98	1.86	1.83	2.37
	3	1.86	1.91	1.94	1.89	2.22	1.47	2.14
	4	1.71	1.82	1.91	1.86	1.81	1.79	1.89
Cartref	1	0.69	1.30	1.30	1.58	1.87	1.11	1.58
	2	0.69	1.01	1.51	1.69	1.61	1.01	1.59
	3	0.74	0.93	1.64	1.08	1.44	1.02	1.55
	4	0.63	1.43	1.23	1.58	1.73	0.99	1.49
Glenrosa	1	0.52	0.39	1.28	1.40	1.52	1.02	0.73
	2	0.60	0.62	1.26	0.98	0.97	1.04	1.52
	3	0.35	1.19	0.50	1.33	1.59	0.72	1.34
	4	0.43	1.03	1.13	1.41	1.28	0.98	1.27
Longlands	1	0.50	1.33	1.78	1.04	1.78	2.50	2.06
	2	0.46	1.10	1.93	1.16	1.45	1.75	2.05
	3	0.61	1.47	1.75	1.28	1.14	1.95	2.30
	4	0.50	1.61	1.70	1.20	1.59	1.80	2.20
Nomanci	1	0.98	1.46	1.80	1.10	1.10	1.07	1.19
	2	0.83	1.25	1.82	1.61	1.29	0.98	1.44
	3	0.76	1.08	1.57	1.91	1.68	1.01	1.62
	4	0.62	1.35	1.40	1.42	1.18	0.86	1.67

Appendix 6. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si uptake (%) by sorghum plants grown in the pots (second cut).

Soil form	Rep. No	Si uptake (%) per sorghum plants per pot						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	1.35	1.77	1.65	1.77	1.67	1.72	2.27
	2	1.08	1.60	2.09	2.20	2.14	1.79	2.42
	3	1.09	1.39	2.13	2.27	2.11	1.69	2.27
	4	1.18	1.59	2.23	2.05	2.24	1.89	2.02
Cartref	1	0.38	0.90	1.07	1.53	1.81	0.62	0.99
	2	0.29	0.87	1.38	1.39	1.75	0.67	1.20
	3	0.45	0.72	1.20	1.32	1.65	0.88	1.36
	4	0.48	0.97	1.14	1.36	1.60	0.57	1.03
Glenrosa	1	0.35	0.65	0.90	1.02	0.97	1.11	1.14
	2	0.31	0.53	0.89	1.07	1.28	0.78	0.99
	3	0.34	0.71	0.70	1.16	1.28	0.79	1.12
	4	0.42	0.57	0.77	1.02	1.25	0.64	1.14
Longlands	1	0.28	1.20	1.81	1.01	1.23	1.28	1.50
	2	0.37	0.88	1.36	1.05	1.22	1.19	1.80
	3	0.42	1.17	1.59	1.20	1.32	1.41	2.02
	4	0.45	1.24	1.90	1.11	1.13	1.08	1.67
Nomanci	1	0.37	0.92	1.26	1.22	1.80	0.71	1.44
	2	0.44	0.76	0.85	1.20	1.36	0.61	1.38
	3	0.38	0.82	1.07	1.05	1.61	0.73	1.37
	4	0.35	0.81	1.28	1.28	1.72	0.75	1.20

Appendix 7. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	Si uptake (%) per sorghum plants per pot						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	1.26	1.80	1.36	2.03	1.24	1.69	2.10
	2	1.05	1.71	1.76	1.84	2.18	1.50	1.61
	3	1.41	1.43	1.68	1.73	1.95	1.39	1.50
	4	1.51	2.12	1.55	1.74	1.85	1.91	1.76
Cartref	1	0.40	1.03	1.34	1.41	1.47	1.01	1.55
	2	0.32	1.04	1.44	1.50	1.84	0.83	1.36
	3	0.29	0.79	1.84	1.65	1.95	0.96	1.62
	4	0.79	0.74	1.73	0.96	2.23	0.87	1.40
Glenrosa	1	0.47	0.66	1.34	0.85	1.14	0.98	1.30
	2	0.30	0.76	1.17	0.68	1.31	0.85	1.67
	3	0.40	0.55	1.25	1.26	1.62	1.01	1.24
	4	0.40	0.94	1.16	1.39	1.41	1.12	1.42
Longlands	1	0.55	1.55	2.26	1.41	1.76	1.82	2.08
	2	0.69	1.37	2.01	1.49	1.73	1.81	2.16
	3	0.56	1.59	2.31	1.45	2.14	1.96	1.61
	4	0.41	1.73	2.31	2.31	1.17	1.59	2.35
Nomanci	1	0.43	1.09	1.68	1.15	1.70	0.80	2.17
	2	0.49	1.15	2.28	1.28	1.82	0.93	2.20
	3	0.53	1.09	1.35	1.18	1.50	1.18	2.06
	4	0.42	1.01	1.22	1.20	2.00	1.29	2.15

Appendix 8. Effect of Si source application rates (tons ha^{-1}) on the pH(water) of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil pH(water) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	5.61	5.70	6.05	5.76	5.99	5.57	5.83
	2	5.34	5.64	6.02	5.73	5.85	5.68	5.92
	3	5.24	5.57	6.12	5.87	6.02	5.62	6.00
	4	5.28	5.58	6.17	5.74	5.99	5.64	5.88
Cartref	1	5.17	5.30	5.59	5.33	5.56	5.38	5.50
	2	5.17	5.35	5.65	5.30	5.56	5.21	5.60
	3	5.13	5.36	5.62	5.44	5.49	5.22	5.53
	4	5.10	5.31	5.59	5.41	5.55	5.28	5.42
Glenrosa	1	4.90	5.32	6.06	5.37	5.83	5.28	5.42
	2	4.83	5.36	6.08	5.41	5.77	5.02	5.86
	3	4.90	5.42	5.96	5.42	5.92	5.14	5.69
	4	4.84	5.45	6.20	5.23	5.89	5.04	5.59
Longlands	1	5.34	6.61	7.78	6.71	6.91	6.58	6.56
	2	5.39	6.82	7.67	6.63	6.98	6.26	6.67
	3	5.17	6.77	7.54	6.57	6.95	6.68	7.22
	4	5.16	6.95	7.48	6.56	6.90	6.64	6.86
Nomanci	1	5.12	5.95	6.65	5.75	6.25	5.45	6.15
	2	4.87	5.75	6.67	5.78	6.05	5.41	5.95
	3	4.97	5.78	6.87	5.68	5.95	5.55	6.15
	4	4.92	5.85	6.78	5.74	6.15	5.45	6.07

Appendix 9. Effect of Si source application rates (tons ha^{-1}) on the P (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil P (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.55	0.17	0.11	0.10	0.13	0.10	0.12
	2	0.11	0.12	0.14	0.15	0.13	0.10	0.13
	3	0.14	0.12	0.13	0.07	0.14	0.11	0.10
	4	0.11	0.16	0.11	0.11	0.10	0.09	0.10
Cartref	1	0.17	0.23	0.24	0.19	0.26	0.19	0.24
	2	0.15	0.23	0.19	0.23	0.22	0.22	0.20
	3	0.14	0.22	0.23	0.21	0.17	0.18	0.18
	4	0.15	0.25	0.21	0.19	0.17	0.18	0.29
Glenrosa	1	0.10	0.13	0.13	0.09	0.15	0.12	0.20
	2	0.11	0.11	0.14	0.14	0.12	0.17	0.11
	3	0.07	0.10	0.27	0.07	0.11	0.15	0.11
	4	0.11	0.12	0.18	0.13	0.08	0.16	0.12
Longlands	1	0.13	0.11	0.33	0.12	0.16	0.15	0.07
	2	0.09	0.12	0.32	0.13	0.10	0.12	0.09
	3	0.13	0.15	0.12	0.06	0.13	0.17	0.17
	4	0.10	0.24	0.19	0.14	0.11	0.21	0.19
Nomanci	1	0.44	0.60	0.71	0.75	0.49	0.64	0.51
	2	0.66	0.55	0.65	0.71	0.74	0.55	0.56
	3	0.55	0.60	0.55	0.58	0.63	0.51	0.68
	4	0.42	0.66	0.67	0.56	0.70	0.55	0.60

Appendix 10. Effect of Si source application rates (tons ha^{-1}) on the K (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil K (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.32	0.80	0.51	0.53	0.57	0.59	0.59
	2	0.65	0.65	0.55	0.65	0.56	0.64	0.59
	3	0.69	0.65	0.55	0.45	0.52	0.59	0.62
	4	0.68	0.72	0.43	0.62	0.56	0.56	0.58
Cartref	1	0.48	0.40	0.47	0.43	0.47	0.36	0.31
	2	0.43	0.34	0.36	0.43	0.46	0.43	0.31
	3	0.42	0.40	0.47	0.49	0.47	0.44	0.34
	4	0.41	0.43	0.42	0.41	0.41	0.40	0.45
Glenrosa	1	0.47	0.35	0.30	0.42	0.38	0.47	0.43
	2	0.47	0.35	0.36	0.44	0.40	0.47	0.30
	3	0.44	0.36	0.49	0.32	0.30	0.38	0.36
	4	0.42	0.33	0.47	0.42	0.36	0.41	0.34
Longlands	1	0.25	0.16	0.19	0.16	0.18	0.28	0.16
	2	0.23	0.12	0.24	0.16	0.13	0.12	0.16
	3	0.28	0.14	0.11	0.14	0.19	0.22	0.17
	4	0.27	0.21	0.14	0.16	0.20	0.20	0.13
Nomanci	1	0.38	0.22	0.36	0.40	0.34	0.34	0.32
	2	0.40	0.35	0.34	0.43	0.37	0.30	0.31
	3	0.36	0.47	0.32	0.41	0.40	0.38	0.44
	4	0.43	0.35	0.38	0.38	0.45	0.44	0.35

Appendix 11. Effect of Si source application rates (tons ha^{-1}) on the Ca (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil Ca (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	7.01	7.57	8.71	7.19	7.29	7.81	8.26
	2	6.36	7.44	8.66	7.51	7.78	7.01	8.28
	3	6.56	7.66	8.43	7.49	7.93	7.21	7.86
	4	6.19	7.11	8.43	6.59	7.41	6.89	8.68
Cartref	1	1.51	2.41	3.35	2.28	2.80	2.52	3.29
	2	1.55	2.49	1.51	2.24	2.69	2.59	3.30
	3	1.45	2.42	3.61	2.37	2.77	2.48	3.34
	4	1.45	2.40	3.39	2.30	2.78	2.48	3.26
Glenrosa	1	0.31	1.03	1.86	1.09	1.29	1.02	1.96
	2	0.32	1.05	2.00	1.02	1.48	1.20	1.70
	3	0.28	1.07	1.85	1.09	1.49	1.14	1.91
	4	0.30	1.25	2.04	1.05	1.30	1.33	1.78
Longlands	1	0.13	0.48	1.13	0.38	0.49	0.52	0.64
	2	0.13	0.44	1.07	0.39	0.49	0.41	0.71
	3	0.14	0.55	0.72	0.41	0.51	0.58	0.89
	4	0.14	0.61	0.66	0.41	0.57	0.59	0.89
Nomanci	1	0.45	1.17	1.91	0.99	1.32	1.17	1.78
	2	0.49	1.20	2.01	0.89	1.37	1.10	1.80
	3	0.48	1.15	2.00	1.05	1.36	1.18	1.90
	4	0.45	1.23	2.34	1.12	1.29	1.16	1.72

Appendix 12. Effect of Si source application rates (tons ha^{-1}) on the Mg (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil Mg (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	2.30	2.55	2.76	2.47	2.63	2.30	2.22
	2	2.22	2.51	2.72	2.51	2.67	2.18	2.10
	3	2.22	2.51	2.59	2.47	2.63	2.18	2.06
	4	2.18	2.47	2.55	2.39	2.47	2.02	2.22
Cartref	1	0.51	0.82	1.07	0.85	1.01	0.48	0.44
	2	0.51	0.80	0.81	0.77	1.05	0.49	0.47
	3	0.48	0.78	1.15	0.81	0.99	0.48	0.49
	4	0.50	0.78	1.10	0.77	1.00	0.48	0.52
Glenrosa	1	0.24	0.42	0.63	0.57	0.59	0.23	0.23
	2	0.23	0.43	0.72	0.58	0.68	0.26	0.22
	3	0.22	0.47	0.75	0.54	0.70	0.24	0.25
	4	0.22	0.51	0.73	0.54	0.57	0.28	0.26
Longlands	1	0.15	0.21	0.39	0.25	0.29	0.14	0.12
	2	0.13	0.20	0.35	0.27	0.27	0.12	0.16
	3	0.19	0.23	0.18	0.26	0.29	0.18	0.19
	4	0.15	0.29	0.24	0.26	0.35	0.18	0.13
Nomanci	1	0.28	0.39	0.68	0.49	0.56	0.28	0.26
	2	0.26	0.45	0.67	0.50	0.60	0.28	0.26
	3	0.27	0.57	0.74	0.46	0.64	0.28	0.35
	4	0.25	0.53	0.75	0.48	0.57	0.29	0.32

Appendix 13. Effect of Si source application rates (tons ha^{-1}) on the Na (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil Na (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.51	0.51	0.54	0.54	0.57	0.52	0.54
	2	0.54	0.52	0.53	0.54	0.54	0.53	0.52
	3	0.52	0.61	0.50	0.48	0.49	0.48	0.47
	4	0.50	0.53	0.47	0.43	0.45	0.51	0.55
Cartref	1	0.42	0.42	0.46	0.46	0.43	0.41	0.33
	2	0.47	0.36	0.42	0.43	0.54	0.45	0.33
	3	0.37	0.46	0.40	0.42	0.44	0.50	0.37
	4	0.39	0.40	0.44	0.40	0.43	0.42	0.37
Glenrosa	1	0.30	0.24	0.27	0.30	0.24	0.30	0.22
	2	0.18	0.26	0.31	0.29	0.35	0.33	0.28
	3	0.24	0.28	0.35	0.25	0.26	0.28	0.27
	4	0.29	0.30	0.33	0.37	0.24	0.29	0.36
Longlands	1	0.20	0.18	0.19	0.21	0.24	0.28	0.28
	2	0.13	0.19	0.19	0.22	0.20	0.14	0.22
	3	0.26	0.16	0.18	0.23	0.20	0.21	0.14
	4	0.25	0.22	0.21	0.24	0.29	0.16	0.20
Nomanci	1	0.23	0.29	0.30	0.26	0.23	0.25	0.20
	2	0.31	0.28	0.28	0.29	0.24	0.26	0.19
	3	0.33	0.33	0.27	0.22	0.26	0.23	0.25
	4	0.21	0.28	0.33	0.20	0.27	0.30	0.27

Appendix 14. Effect of Si source application rates (tons ha^{-1}) on the Al (cmol kg^{-1}) content of soil samples collected after harvest of sorghum plants grown in the pots.

Soil form	Rep. No	Soil Al (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-
	3	0.02	-	-	-	-	-	-
	4	0.03	-	-	-	-	-	-
Cartref	1	0.07	0.04	-	-	-	-	-
	2	0.10	-	-	0.04	-	0.04	-
	3	0.10	-	-	-	-	0.04	-
	4	0.09	-	-	-	-	0.05	-
Glenrosa	1	0.07	-	-	-	-	0.04	-
	2	0.09	-	-	-	-	0.04	-
	3	0.09	-	-	-	-	0.04	-
	4	0.07	-	-	0.04	-	0.04	-
Longlands	1	-	-	-	-	-	-	-
	2	-	-	-	-	-	-	-
	3	0.04	-	-	-	-	-	-
	4	0.04	-	-	-	-	-	-
Nomanci	1	0.05	-	-	-	-	-	-
	2	0.04	-	-	-	-	-	-
	3	0.04	-	-	-	-	-	-
	4	0.04	-	-	-	-	-	-

Appendix 15. Effect of soil forms and Si source application rates (tons ha^{-1}) on the N uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	N uptake (%)by sorghum plants in the pots per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.97	0.77	0.77	1.11	0.96	0.82	0.90
	2	0.99	0.73	0.85	1.04	0.80	0.85	0.82
	3	0.99	0.82	0.77	0.80	0.82	0.90	0.85
	4	0.98	0.94	1.14	0.87	0.87	0.92	0.92
Cartref	1	0.97	1.02	0.94	1.14	0.79	0.88	0.79
	2	0.94	0.82	0.94	0.79	0.80	1.00	0.82
	3	1.07	0.85	0.99	0.82	0.71	0.77	0.92
	4	1.04	0.92	0.97	0.84	0.79	0.82	0.80
Glenrosa	1	1.36	1.15	0.86	1.13	0.92	1.04	0.92
	2	1.29	0.86	0.90	0.96	0.92	0.84	0.52
	3	1.32	0.82	0.88	0.75	1.04	0.94	1.23
	4	1.17	0.96	1.11	0.80	0.98	1.04	1.09
Longlands	1	0.75	0.61	0.66	1.31	0.85	0.58	0.59
	2	1.14	1.17	1.00	1.53	0.47	0.83	0.92
	3	0.61	0.71	1.17	0.71	0.80	0.76	0.75
	4	1.23	0.47	1.16	1.07	0.88	0.92	0.50
Nomanci	1	0.81	0.68	0.65	0.92	1.47	0.96	1.31
	2	0.72	0.57	1.36	0.48	1.39	0.79	0.87
	3	0.79	0.70	0.89	0.87	0.82	0.98	1.03
	4	1.10	0.72	0.67	0.85	0.89	1.07	0.67

Appendix 16. Effect of soil forms and Si source application rates (tons ha^{-1}) on the P uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	P uptake (%)by sorghum plants in the pots per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.31	0.30	0.29	0.29	0.30	0.27	0.32
	2	0.34	0.32	0.27	0.27	0.25	0.28	0.33
	3	0.29	0.33	0.29	0.28	0.31	0.28	0.30
	4	0.30	0.32	0.33	0.31	0.28	0.33	0.29
Cartref	1	0.24	0.24	0.25	0.23	0.21	0.26	0.28
	2	0.22	0.23	0.26	0.23	0.21	0.24	0.24
	3	0.22	0.23	0.22	0.26	0.19	0.25	0.23
	4	0.21	0.22	0.23	0.24	0.19	0.26	0.24
Glenrosa	1	0.28	0.31	0.31	0.29	0.27	0.25	0.30
	2	0.22	0.32	0.29	0.28	0.24	0.22	0.28
	3	0.25	0.25	0.29	0.25	0.30	0.28	0.28
	4	0.29	0.32	0.32	0.26	0.32	0.25	0.35
Longlands	1	0.30	0.28	0.30	0.33	0.29	0.32	0.24
	2	0.30	0.31	0.25	0.27	0.23	0.29	0.23
	3	0.30	0.32	0.21	0.24	0.30	0.31	0.25
	4	0.31	0.33	0.20	0.22	0.32	0.25	0.24
Nomanci	1	0.30	0.27	0.31	0.32	0.26	0.38	0.34
	2	0.34	0.25	0.32	0.34	0.34	0.32	0.35
	3	0.29	0.29	0.28	0.38	0.34	0.33	0.37
	4	0.29	0.28	0.30	0.32	0.33	0.29	0.32

Appendix 17. Effect of soil forms and Si source application rates (tons ha^{-1}) on the K uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	K uptake (%)by sorghum plants in the pots per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	2.63	2.43	2.65	2.53	2.42	2.43	2.77
	2	2.45	2.49	2.45	2.43	2.28	2.45	2.52
	3	2.80	2.58	2.47	2.28	2.73	2.28	2.92
	4	2.34	2.51	2.66	2.71	2.70	2.43	2.35
Cartref	1	2.71	2.79	2.54	2.64	2.75	2.62	2.68
	2	2.60	2.65	2.61	2.67	2.42	2.82	2.61
	3	2.69	2.61	2.57	2.71	2.40	2.73	2.64
	4	2.68	2.62	2.48	2.78	2.46	2.66	2.38
Glenrosa	1	3.31	3.33	2.57	2.72	2.63	2.59	2.97
	2	2.99	2.66	2.48	2.78	2.55	2.69	2.80
	3	3.06	2.43	2.68	2.68	2.54	2.82	2.97
	4	3.36	2.59	2.75	2.66	2.67	2.89	2.72
Longlands	1	2.72	3.70	2.45	2.92	2.69	2.50	2.65
	2	2.99	3.01	2.73	2.72	2.57	2.57	2.62
	3	3.08	2.67	2.80	2.98	2.65	2.60	2.53
	4	3.00	2.93	2.79	2.52	2.53	2.49	2.74
Nomanci	1	2.95	2.84	2.83	3.40	2.80	3.02	2.98
	2	3.23	2.87	3.03	2.94	3.03	2.87	3.05
	3	3.10	3.07	2.88	3.04	3.20	3.16	3.01
	4	3.16	2.95	2.87	3.18	3.08	3.34	2.92

Appendix 18. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Ca uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	Ca uptake (%)by sorghum plants in the pots per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.50	1.12	0.73	1.06	0.86	0.57	0.47
	2	0.69	1.06	0.64	0.80	0.56	0.48	0.65
	3	1.03	0.93	0.82	0.82	0.57	0.60	0.84
	4	1.01	1.20	0.89	0.95	0.59	0.50	0.49
Cartref	1	0.53	0.64	0.56	0.63	0.45	0.75	0.61
	2	0.57	0.55	0.64	0.43	0.51	0.53	0.69
	3	0.67	0.57	0.62	0.58	0.59	0.53	0.83
	4	0.53	0.41	0.48	0.35	0.58	0.54	0.71
Glenrosa	1	0.64	0.74	1.26	0.61	0.48	0.53	0.40
	2	0.55	0.82	0.75	0.73	0.47	0.46	0.38
	3	0.78	0.77	0.55	0.59	0.76	0.53	0.41
	4	0.78	0.77	0.92	0.41	0.47	0.76	0.31
Longlands	1	0.29	0.40	0.45	0.30	0.34	0.32	0.28
	2	0.36	0.44	0.38	0.26	0.22	0.35	0.28
	3	0.34	0.39	0.41	0.21	0.21	0.30	0.33
	4	0.36	0.44	0.30	0.23	0.31	0.39	0.30
Nomanci	1	0.21	0.23	0.36	0.43	0.38	0.37	0.37
	2	0.25	0.29	0.30	0.40	0.44	0.34	0.43
	3	0.23	0.28	0.34	0.44	0.36	0.35	0.38
	4	0.24	0.37	0.45	0.39	0.38	0.39	0.38

Appendix 19. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Mg uptake (%) by sorghum plants grown in the pots (third cut).

Soil form	Rep. No	Mg uptake (%) by sorghum plants in the pots per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.59	0.71	0.59	0.63	0.36	0.52	0.58
	2	0.74	0.71	0.63	0.80	0.70	0.58	0.70
	3	0.69	0.68	0.74	0.70	0.80	0.66	0.67
	4	0.60	0.77	0.88	0.72	0.79	0.79	0.67
Cartref	1	0.56	0.64	0.57	0.66	0.55	0.51	0.48
	2	0.49	0.60	0.57	0.67	0.63	0.48	0.53
	3	0.48	0.54	0.58	0.68	0.53	0.51	0.52
	4	0.54	0.56	0.57	0.58	0.54	0.43	0.45
Glenrosa	1	1.02	1.06	0.88	0.70	0.86	0.76	0.84
	2	1.02	0.97	0.84	0.85	0.71	0.54	0.67
	3	1.02	0.93	0.74	0.66	0.94	0.68	0.85
	4	1.05	0.95	0.98	0.68	1.17	0.63	0.62
Longlands	1	0.44	0.67	0.67	0.57	0.61	0.32	0.31
	2	0.51	0.52	0.83	0.59	0.52	0.40	0.32
	3	0.44	0.57	0.54	0.44	0.46	0.38	0.31
	4	0.60	0.66	0.62	0.52	0.50	0.41	0.40
Nomanci	1	0.58	0.49	0.59	0.81	0.55	0.64	0.71
	2	0.77	0.63	0.69	0.86	0.72	0.48	0.74
	3	0.63	0.64	0.66	0.97	0.65	0.73	0.68
	4	0.61	0.64	0.73	1.01	0.96	0.55	0.51

Appendix 20. Effect of soil forms and Si source application rates (tons ha^{-1}) on the dry matter yield (g kg^{-1} soil) from the stalks of cane plants grown in the pots.

Soil form	Rep. No	Cane dry stalk yield (g kg^{-1} soil) per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	19.361	8.044	14.669	14.338	14.937	15.609	9.955
	2	11.798	16.184	16.796	13.523	13.660	15.562	17.772
	3	18.493	9.667	10.253	15.355	14.164	14.941	13.927
	4	16.407	12.451	12.253	17.986	13.888	17.245	14.986
Cartref	1	12.249	17.996	15.754	18.629	17.728	17.980	3.836
	2	13.907	18.019	13.315	19.554	10.670	20.012	7.307
	3	15.425	19.496	16.229	16.327	20.133	14.596	5.759
	4	18.628	19.702	4.487	20.855	21.406	19.933	20.648
Glenrosa	1	5.116	10.739	10.284	3.089	7.444	8.065	20.462
	2	7.658	5.196	80.53	5.977	10.888	12.628	6.735
	3	7.849	8.673	3.717	6.387	9.326	9.508	20.538
	4	6.671	6.067	6.822	7.195	4.883	13.924	3.897
Longlands	1	10.633	18.848	16.810	23.176	17.758	16.048	15.444
	2	2.628	21.924	15.449	10.055	23.810	12.430	19.111
	3	11.054	14.605	15.403	17.306	15.926	13.544	17.541
	4	12.633	19.938	17.422	15.980	19.196	17.657	13.293
Nomanci	1	6.179	11.421	6.843	15.955	13.925	4.099	8.955
	2	5.407	12.690	7.504	6.144	8.382	9.851	6.492
	3	7.291	10.990	10.133	5.260	9.189	9.221	11.027
	4	6.290	6.118	2.741	11.119	8.057	12.150	15.257

Appendix 21. Effect of soil forms and Si source application rates (tons ha^{-1}) on the dry matter yield (g kg^{-1} soil) from the tops of cane plants grown in the pots.

Soil form	Rep. No	Cane dry top yield (g kg^{-1} soil) per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	22.267	18.168	13.726	15.308	21.891	22.039	18.513
	2	19.617	14.987	14.557	18.323	18.565	16.007	15.625
	3	20.186	20.545	20.546	20.041	18.490	15.813	12.203
	4	15.103	19.693	20.161	20.240	13.050	14.533	19.332
Cartref	1	20.776	17.499	24.912	18.846	19.924	14.736	18.532
	2	18.737	20.975	25.073	21.376	17.463	20.296	23.840
	3	17.686	15.229	13.073	22.823	16.492	16.296	25.067
	4	15.528	15.082	19.608	16.576	16.620	19.088	18.228
Glenrosa	1	6.552	13.661	18.905	6.498	12.637	13.745	12.394
	2	6.162	16.223	14.781	17.387	16.242	16.238	4.608
	3	4.573	15.425	13.269	20.935	20.022	11.632	15.108
	4	8.000	8.770	16.498	9.803	15.728	13.859	5.890
Longlands	1	13.995	21.547	23.210	25.434	22.133	14.703	20.313
	2	4.574	21.713	22.744	14.880	20.027	19.290	19.934
	3	16.222	16.329	19.072	21.930	17.788	17.444	19.981
	4	10.836	22.967	21.597	13.932	17.087	18.033	19.731
Nomanci	1	6.755	15.797	16.298	10.688	25.692	17.372	14.248
	2	5.019	22.052	12.460	5.053	16.287	13.099	13.798
	3	5.643	14.609	16.396	3.626	11.714	15.715	15.697
	4	8.352	13.111	18.212	6.386	12.955	16.351	14.777

Appendix 22. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si content (cmol kg^{-1} soil) in the stalks of cane plants grown in the pots.

Soil form	Rep. No	Si uptake (cmol kg^{-1} soil) by cane stalks per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.125	0.102	0.163	0.143	0.159	0.135	0.119
	2	0.076	0.158	0.157	0.126	0.164	0.126	0.150
	3	0.123	0.082	0.139	0.143	0.154	0.123	0.173
	4	0.124	0.127	0.131	0.156	0.139	0.134	0.160
Cartref	1	0.019	0.052	0.045	0.033	0.047	0.044	0.014
	2	0.021	0.032	0.050	0.047	0.033	0.040	0.035
	3	0.024	0.034	0.054	0.026	0.044	0.039	0.024
	4	0.016	0.039	0.019	0.046	0.057	0.044	0.082
Glenrosa	1	0.008	0.021	0.046	0.012	0.054	0.015	0.056
	2	0.010	0.016	0.035	0.022	0.051	0.028	0.018
	3	0.009	0.036	0.017	0.027	0.045	0.020	0.046
	4	0.013	0.012	0.027	0.026	0.017	0.027	0.009
Longlands	1	0.006	0.026	0.035	0.054	0.046	0.028	0.040
	2	0.004	0.036	0.031	0.021	0.053	0.022	0.056
	3	0.010	0.020	0.029	0.042	0.034	0.022	0.057
	4	0.016	0.037	0.043	0.039	0.036	0.033	0.043
Nomanci	1	0.013	0.021	0.016	0.036	0.016	0.006	0.015
	2	0.008	0.019	0.018	0.011	0.016	0.011	0.013
	3	0.003	0.012	0.041	0.012	0.023	0.014	0.014
	4	0.009	0.008	0.006	0.025	0.020	0.014	0.024

Appendix 23. Effect of soil forms and Si source application rates (tons ha^{-1}) on the Si content (cmol kg^{-1} soil) in the tops of cane plants grown in the pots.

Soil form	Rep. No	Si uptake (cmol kg^{-1} soil) by cane tops per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.119	0.125	0.201	0.204	0.345	0.313	0.251
	2	0.135	0.123	0.204	0.232	0.272	0.196	0.177
	3	0.117	0.210	0.274	0.298	0.362	0.190	0.136
	4	0.114	0.214	0.255	0.252	0.189	0.168	0.266
Cartref	1	0.101	0.096	0.154	0.091	0.123	0.088	0.135
	2	0.103	0.125	0.149	0.099	0.085	0.116	0.178
	3	0.070	0.091	0.086	0.126	0.098	0.097	0.177
	4	0.072	0.083	0.125	0.091	0.095	0.105	0.149
Glenrosa	1	0.019	0.048	0.091	0.028	0.055	0.051	0.060
	2	0.013	0.052	0.073	0.075	0.075	0.068	0.021
	3	0.011	0.067	0.070	0.087	0.080	0.045	0.075
	4	0.026	0.031	0.082	0.035	0.078	0.044	0.036
Longlands	1	0.047	0.086	0.111	0.110	0.137	0.041	0.071
	2	0.016	0.089	0.122	0.070	0.073	0.052	0.082
	3	0.061	0.063	0.085	0.095	0.069	0.059	0.075
	4	0.035	0.102	0.101	0.049	0.080	0.063	0.085
Nomanci	1	0.008	0.036	0.052	0.033	0.105	0.059	0.063
	2	0.005	0.065	0.035	0.017	0.069	0.040	0.049
	3	0.010	0.048	0.052	0.012	0.055	0.046	0.059
	4	0.008	0.030	0.062	0.019	0.059	0.063	0.059

Appendix 24. Amount of soil silicon (cmol kg^{-1}) extracted with distilled water extractant from soil samples after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.0643	0.0964	0.0964	0.0786	0.0821	0.1036	0.0964
	2	0.0750	0.0750	0.0964	0.0786	0.0893	0.0786	0.1179
	3	0.0750	0.0929	0.0893	0.0821	0.0821	0.0929	0.1179
	4	0.0786	0.1036	0.0750	0.0893	0.0964	0.0929	0.1071
Cartref	1	0.0071	0.0170	0.0286	0.0321	0.0179	0.0286	0.0393
	2	0.0071	0.0179	0.0179	0.0179	0.0250	0.0286	0.0429
	3	0.0143	0.0107	0.0179	0.0143	0.0214	0.0250	0.0429
	4	0.0250	0.0179	0.0250	0.0179	0.0321	0.0500	0.0321
Glenrosa	1	0.0393	0.0536	0.0536	0.0500	0.0571	0.0607	0.0607
	2	0.0500	0.0607	0.0714	0.0679	0.0679	0.0571	0.0643
	3	0.0536	0.0750	0.0679	0.0607	0.0679	0.0500	0.0679
	4	0.0500	0.0571	0.0857	0.0607	0.0607	0.0571	0.0571
Longlands	1	0.0571	0.0607	0.0500	0.0393	0.0321	0.0357	0.0321
	2	0.0357	0.0429	0.0536	0.0321	0.0286	0.0250	0.0286
	3	0.0464	0.0571	0.0393	0.0321	0.0357	0.0286	0.0357
	4	0.0393	0.0500	0.0321	0.0250	0.0286	0.0357	0.0286
Nomanci	1	0.0214	0.0250	0.0393	0.0321	0.0321	0.0250	0.0286
	2	0.0143	0.0214	0.0250	0.0250	0.0286	0.0214	0.0357
	3	0.0321	0.0250	0.0286	0.0286	0.0286	0.0321	0.0321
	4	0.0321	0.0250	0.0357	0.0250	0.0250	0.0214	0.0321

Appendix 25. Amount of soil silicon extracted (cmol kg^{-1}) with 0.02N H_2SO_4 + $(NH_4)_2SO_4$ extractant from soil samples collected after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.2429	0.2143	0.4393	0.4679	0.8964	0.3679	0.4250
	2	0.2571	0.3464	0.5000	0.5143	0.9750	0.2679	0.4429
	3	0.2643	0.2929	0.4714	0.5571	1.0893	0.2893	0.4929
	4	0.2500	0.2643	0.4179	0.4071	1.0964	0.3179	0.4571
Cartref	1	0.0821	0.1286	0.1214	0.1786	0.5071	0.1000	0.1071
	2	0.1071	0.0786	0.0964	0.2143	0.6964	0.0929	0.1143
	3	0.0643	0.0750	0.1000	0.1643	0.6214	0.1321	0.1107
	4	0.0607	0.0786	0.1286	0.1821	0.7214	0.0857	0.1071
Glenrosa	1	0.0679	0.0786	0.1821	0.1643	1.0071	0.0571	0.1250
	2	0.0536	0.0786	0.1607	0.1464	0.4429	0.0500	0.1286
	3	0.0607	0.0750	0.1536	0.1857	0.8321	0.0571	0.1429
	4	0.0464	0.0821	0.1679	0.1571	0.8250	0.0714	0.1179
Longlands	1	0.0179	0.0714	0.1964	0.3143	0.9214	0.0750	0.1321
	2	0.0464	0.0679	0.1714	0.3750	0.8607	0.0607	0.1286
	3	0.0286	0.0714	0.1536	0.3214	0.9321	0.0857	0.1714
	4	0.0214	0.0893	0.1536	0.3571	0.9036	0.0750	0.1500
Nomanci	1	0.0214	0.0714	0.1893	0.2286	0.7107	0.0571	0.1143
	2	0.0429	0.0607	0.1643	0.2000	0.7607	0.0679	0.1036
	3	0.0286	0.0571	0.2071	0.2286	0.7107	0.0893	0.1143
	4	0.0250	0.0607	0.1893	0.2429	0.7536	0.0750	0.1143

Appendix 26. Amount of soil slicon extracted (cmol kg^{-1}) with 0.025M H_2SO_4 extractant from soil samples collected after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si application source rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.3036	0.2536	0.4964	0.5857	1.4750	0.5036	0.3893
	2	0.2357	0.3000	0.5643	0.5929	1.1429	0.3679	0.5429
	3	0.3000	0.3643	0.5286	0.7679	1.2786	0.3250	0.5357
	4	0.1857	0.2643	0.6786	0.4857	1.0786	0.3929	0.3571
Cartref	1	0.1000	0.1357	0.2893	0.2393	0.8929	0.1214	0.1536
	2	0.1750	0.1857	0.2357	0.2429	0.7357	0.1107	0.1679
	3	0.1143	0.1429	0.2464	0.3286	0.9000	0.1179	0.1536
	4	0.0893	0.1500	0.2250	0.3929	0.9750	0.1107	0.1571
Glenrosa	1	0.0429	0.0893	0.1821	0.2107	1.0500	0.0964	0.2071
	2	0.0464	0.0679	0.2393	0.2179	0.6286	0.0750	0.2286
	3	0.0679	0.0929	0.1964	0.2464	0.5679	0.0643	0.2357
	4	0.0607	0.0929	0.1929	0.1643	0.9107	0.1000	0.1857
Longlands	1	0.0429	0.1143	0.2321	0.3964	0.9107	0.1179	0.1286
	2	0.0464	0.1286	0.2393	0.3607	0.8821	0.1071	0.1464
	3	0.0429	0.1393	0.2607	0.3786	0.9036	0.1000	0.1643
	4	0.0464	0.1571	0.1536	0.4000	0.7607	0.0893	0.1429
Nomanci	1	0.0500	0.1036	0.1821	0.2286	0.6964	0.0821	0.1321
	2	0.0464	0.0893	0.1786	0.2250	0.7071	0.0821	0.1357
	3	0.0571	0.0964	0.2286	0.2321	0.7214	0.0857	0.1357
	4	0.0536	0.1107	0.2071	0.2250	0.7536	0.0814	0.1357

Appendix 27. Amount of soil silicon extracted (cmol kg^{-1}) with 0.5M CH_3COOH extractant from soil samples after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.1500	0.1857	0.3321	0.3643	1.0000	0.1821	0.2607
	2	0.1250	0.2179	0.2679	0.3464	0.8679	0.2107	0.2750
	3	0.1357	0.1786	0.3821	0.4214	0.9536	0.2143	0.3464
	4	0.1500	0.2036	0.2929	0.2500	0.9607	0.1929	0.3321
Cartref	1	0.0429	0.0429	0.0536	0.1071	0.4893	0.0321	0.0464
	2	0.0643	0.0500	0.0857	0.1250	0.5071	0.0357	0.0464
	3	0.0536	0.0464	0.0821	0.1964	0.6607	0.0321	0.0464
	4	0.0250	0.0500	0.0964	0.1500	0.5929	0.0357	0.0571
Glenrosa	1	0.0179	0.0321	0.0857	0.1429	0.8679	0.0321	0.0607
	2	0.0179	0.0393	0.0893	0.1107	0.4786	0.0250	0.0714
	3	0.0214	0.0357	0.0786	0.1500	0.6571	0.0321	0.0536
	4	0.0179	0.0357	0.0929	0.0929	0.5429	0.0286	0.0643
Longlands	1	0.0107	0.0536	0.1036	0.3821	0.9036	0.0429	0.0500
	2	0.0143	0.0571	0.1250	0.4821	0.7393	0.0571	0.0714
	3	0.0179	0.0500	0.1393	0.4929	0.9643	0.0464	0.0607
	4	0.0143	0.0536	0.1214	0.4321	0.8964	0.0357	0.0786
Nomanci	1	0.0143	0.0179	0.0857	0.1464	0.6000	0.0107	0.0893
	2	0.0107	0.0179	0.1429	0.1607	0.8036	0.0143	0.0821
	3	0.0321	0.0357	0.1071	0.1286	0.6821	0.0214	0.0393
	4	0.0214	0.0786	0.0964	0.1536	0.6571	0.0464	0.0536

Appendix 28. Amount of soil silicon extracted (cmol kg^{-1}) with 0.5M CH_3COONH_4 extractant from soil samples after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.0643	0.0857	0.1286	0.0964	0.1036	0.0857	0.1036
	2	0.0607	0.0821	0.1143	0.0929	0.1143	0.0929	0.1143
	3	0.0571	0.0964	0.1214	0.1036	0.1000	0.1071	0.1107
	4	0.0643	0.0786	0.1036	0.1000	0.0893	0.0821	0.1107
Cartref	1	0.0143	0.0286	0.0286	0.0214	0.0321	0.0250	0.0286
	2	0.0107	0.0286	0.0357	0.0321	0.0393	0.0250	0.0357
	3	0.0321	0.0214	0.0357	0.0286	0.0393	0.0286	0.0393
	4	0.0250	0.0357	0.0357	0.0357	0.0357	0.0321	0.0321
Glenrosa	1	0.0179	0.0214	0.0321	0.0214	0.0179	0.0071	0.0179
	2	0.0214	0.0286	0.0286	0.0321	0.0143	0.0107	0.0143
	3	0.0143	0.0179	0.0393	0.0143	0.0143	0.0321	0.0179
	4	0.0179	0.0214	0.0357	0.0107	0.0214	0.0107	0.0179
Longlands	1	0.0107	0.0214	0.0464	0.0321	0.0286	0.0107	0.0214
	2	0.0071	0.0179	0.0429	0.0143	0.0214	0.0107	0.0250
	3	0.0107	0.0214	0.0393	0.0143	0.0214	0.0179	0.0086
	4	0.0071	0.0214	0.0321	0.0143	0.0250	0.0214	0.0179
Nomanci	1	0.0071	0.0179	0.0286	0.0214	0.0179	0.0179	0.0179
	2	0.0071	0.0286	0.0214	0.0250	0.0214	0.0071	0.0179
	3	0.0071	0.0214	0.0250	0.0071	0.0143	0.0071	0.0250
	4	0.0071	0.0071	0.0286	0.0107	0.0214	0.0321	0.0179

Appendix 29. Amount of soil silicon extracted (cmol kg^{-1}) with 0.01M $CaCl_2.2H_2O$ extractant from soil samples after sorghum harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.1464	0.1821	0.1964	0.1786	0.2000	0.1964	0.2143
	2	0.1464	0.1786	0.1964	0.1821	0.2071	0.1821	0.2321
	3	0.1536	0.1821	0.2036	0.1929	0.2143	0.1964	0.2250
	4	0.1607	0.1786	0.1929	0.1750	0.1893	0.1857	0.2321
Cartref	1	0.0536	0.0571	0.0643	0.0643	0.0786	0.0571	0.0714
	2	0.0464	0.0571	0.0607	0.0714	0.0786	0.0607	0.0714
	3	0.0500	0.0571	0.0679	0.0607	0.0786	0.0571	0.0679
	4	0.0500	0.0607	0.0679	0.0571	0.0893	0.0571	0.0786
Glenrosa	1	0.0536	0.0786	0.0714	0.0857	0.0750	0.0607	0.0750
	2	0.0679	0.0750	0.0857	0.0607	0.0786	0.0536	0.0786
	3	0.0714	0.0571	0.0679	0.0607	0.0714	0.0714	0.0786
	4	0.0714	0.0786	0.0857	0.0607	0.0786	0.0679	0.0786
Longlands	1	0.0714	0.0893	0.1036	0.0714	0.0714	0.0786	0.0893
	2	0.0750	0.0750	0.1107	0.0821	0.0786	0.0857	0.0929
	3	0.0536	0.0821	0.1036	0.0679	0.0750	0.0821	0.0929
	4	0.0786	0.0786	0.0964	0.0714	0.0786	0.0714	0.0893
Nomanci	1	0.0536	0.0607	0.0714	0.0607	0.0679	0.0607	0.0607
	2	0.0679	0.0500	0.0714	0.0643	0.0714	0.0643	0.0786
	3	0.0536	0.0643	0.0679	0.0679	0.0679	0.0607	0.0714
	4	0.0607	0.0679	0.0714	0.0571	0.0643	0.0536	0.0607

Appendix 30. Amount of soil silicon (cmol kg^{-1}) extracted with distilled water extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.039	0.064	0.079	0.061	0.079	0.057	0.068
	2	0.046	0.071	0.089	0.068	0.082	0.068	0.064
	3	0.057	0.075	0.064	0.068	0.075	0.071	0.079
	4	0.057	0.071	0.064	0.068	0.079	0.068	0.071
Cartref	1	0.007	0.021	0.025	0.011	0.014	0.021	0.014
	2	0.011	0.007	0.007	0.011	0.007	0.007	0.029
	3	0.007	0.007	0.007	0.018	0.007	0.018	0.014
	4	0.007	0.007	0.029	0.007	0.007	0.011	0.018
Glenrosa	1	0.007	0.007	0.007	0.014	0.039	0.014	0.018
	2	0.014	0.021	0.046	0.032	0.039	0.036	0.043
	3	0.007	0.007	0.054	0.029	0.046	0.032	0.054
	4	0.011	0.007	0.039	0.014	0.046	0.032	0.050
Longlands	1	0.054	0.021	0.036	0.043	0.032	0.036	0.043
	2	0.011	0.032	0.039	0.029	0.039	0.036	0.046
	3	0.029	0.032	0.054	0.046	0.046	0.036	0.039
	4	0.014	0.050	0.039	0.043	0.043	0.029	0.046
Nomanci	1	0.036	0.036	0.032	0.039	0.032	0.025	0.032
	2	0.029	0.014	0.036	0.021	0.036	0.032	0.043
	3	0.036	0.018	0.043	0.029	0.029	0.014	0.039
	4	0.025	0.021	0.046	0.036	0.021	0.036	0.029

Appendix 31. Amount of soil silicon (cmol kg^{-1}) extracted with 0.01M H_2SO_4 + $(NH_4)_2SO_4$ extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.164	0.218	0.307	0.196	0.300	0.186	0.271
	2	0.168	0.196	0.318	0.193	0.354	0.196	0.275
	3	0.146	0.225	0.321	0.243	0.314	0.200	0.271
	4	0.157	0.211	0.250	0.200	0.321	0.207	0.271
Cartref	1	0.050	0.079	0.118	0.107	0.232	0.104	0.114
	2	0.061	0.089	0.111	0.114	0.275	0.089	0.125
	3	0.071	0.082	0.114	0.114	0.250	0.093	0.107
	4	0.061	0.086	0.114	0.118	0.243	0.111	0.111
Glenrosa	1	0.050	0.089	0.121	0.104	0.211	0.014	0.039
	2	0.046	0.079	0.121	0.036	0.243	0.021	0.043
	3	0.054	0.068	0.125	0.039	0.229	0.018	0.064
	4	0.043	0.082	0.146	0.039	0.286	0.021	0.050
Longlands	1	0.014	0.036	0.043	0.129	0.357	0.011	0.036
	2	0.014	0.021	0.068	0.143	0.418	0.029	0.054
	3	0.018	0.018	0.068	0.125	0.386	0.014	0.043
	4	0.014	0.025	0.057	0.150	0.346	0.014	0.036
Nomanci	1	0.029	0.036	0.054	0.057	0.279	0.025	0.031
	2	0.011	0.029	0.089	0.057	0.300	0.014	0.029
	3	0.014	0.018	0.071	0.079	0.296	0.018	0.029
	4	0.018	0.021	0.075	0.061	0.318	0.021	0.036

Appendix 32. Amount of soil silicon (cmol kg^{-1}) extracted with 0.025M H_2SO_4 extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.218	0.254	0.361	0.250	0.521	0.271	0.321
	2	0.214	0.246	0.368	0.318	0.482	0.296	0.325
	3	0.218	0.243	0.371	0.318	0.475	0.293	0.325
	4	0.214	0.261	0.368	0.329	0.482	0.282	0.332
Cartref	1	0.071	0.129	0.182	0.193	0.371	0.104	0.179
	2	0.061	0.107	0.182	0.171	0.371	0.114	0.150
	3	0.071	0.089	0.189	0.182	0.382	0.118	0.146
	4	0.061	0.093	0.196	0.164	0.354	0.114	0.143
Glenrosa	1	0.061	0.086	0.129	0.111	0.300	0.071	0.089
	2	0.046	0.086	0.114	0.125	0.286	0.043	0.093
	3	0.043	0.075	0.139	0.111	0.232	0.054	0.125
	4	0.068	0.071	0.189	0.114	0.254	0.057	0.118
Longlands	1	0.018	0.057	0.079	0.154	0.471	0.079	0.118
	2	0.029	0.064	0.104	0.171	0.507	0.089	0.111
	3	0.014	0.061	0.071	0.193	0.568	0.075	0.107
	4	0.014	0.071	0.082	0.186	0.575	0.093	0.121
Nomanci	1	0.025	0.071	0.107	0.096	0.304	0.050	0.079
	2	0.029	0.068	0.104	0.107	0.329	0.064	0.086
	3	0.039	0.082	0.100	0.104	0.332	0.061	0.086
	4	0.043	0.079	0.129	0.114	0.343	0.057	0.086

Appendix 33. Amount of soil silicon (cmol kg^{-1}) extracted with 0.5M CH_3COOH extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.071	0.154	0.236	0.164	0.364	0.129	0.146
	2	0.079	0.114	0.218	0.139	0.346	0.129	0.171
	3	0.111	0.129	0.179	0.157	0.361	0.143	0.164
	4	0.111	0.143	0.186	0.146	0.357	0.129	0.196
Cartref	1	0.029	0.036	0.057	0.043	0.093	0.046	0.075
	2	0.029	0.039	0.054	0.054	0.125	0.046	0.064
	3	0.036	0.043	0.054	0.050	0.107	0.050	0.064
	4	0.032	0.036	0.061	0.054	0.089	0.043	0.046
Glenrosa	1	0.032	0.046	0.068	0.050	0.114	0.018	0.036
	2	0.036	0.043	0.075	0.043	0.107	0.018	0.029
	3	0.029	0.050	0.071	0.036	0.114	0.021	0.050
	4	0.032	0.050	0.079	0.029	0.143	0.032	0.014
Longlands	1	0.018	0.025	0.039	0.082	0.368	0.021	0.032
	2	0.011	0.025	0.043	0.086	0.257	0.032	0.032
	3	0.014	0.025	0.046	0.107	0.250	0.021	0.032
	4	0.032	0.050	0.075	0.407	0.021	0.039	0.018
Nomanci	1	0.021	0.036	0.039	0.043	0.218	0.021	0.036
	2	0.025	0.029	0.050	0.029	0.200	0.036	0.039
	3	0.018	0.021	0.046	0.046	0.236	0.021	0.039
	4	0.032	0.046	0.036	0.214	0.039	0.057	0.075

Appendix 34. Amount of soil silicon (cmol kg^{-1}) extracted with 0.5M CH_3COONH_4 extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.061	0.068	0.096	0.082	0.100	0.079	0.096
	2	0.057	0.071	0.100	0.089	0.093	0.075	0.107
	3	0.054	0.075	0.111	0.086	0.096	0.079	0.100
	4	0.057	0.079	0.118	0.089	0.100	0.089	0.096
Cartref	1	0.004	0.021	0.025	0.014	0.029	0.018	0.025
	2	0.004	0.036	0.032	0.014	0.021	0.018	0.025
	3	0.007	0.014	0.021	0.018	0.025	0.021	0.029
	4	0.007	0.018	0.029	0.021	0.021	0.025	0.025
Glenrosa	1	0.004	0.011	0.018	0.018	0.014	0.007	0.011
	2	0.007	0.014	0.021	0.018	0.014	0.004	0.014
	3	0.007	0.018	0.018	0.007	0.025	0.007	0.021
	4	0.004	0.018	0.021	0.011	0.014	0.007	0.011
Longlands	1	0.004	0.018	0.014	0.011	0.014	0.004	0.011
	2	0.007	0.007	0.018	0.011	0.011	0.004	0.025
	3	0.007	0.007	0.014	0.007	0.021	0.011	0.011
	4	0.007	0.004	0.025	0.014	0.011	0.007	0.007
Nomanci	1	0.004	0.007	0.014	0.018	0.018	0.011	0.014
	2	0.007	0.011	0.014	0.011	0.014	0.011	0.007
	3	0.004	0.011	0.007	0.011	0.007	0.011	0.014
	4	0.004	0.007	0.018	0.007	0.018	0.011	0.011

Appendix 35. Amount of soil silicon (cmol kg^{-1}) extracted with 0.01M $CaCl_2.2H_2O$ extractant from soil samples after cane harvest.

Soil form	Rep. No	Soil silicon concentration (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.079	0.143	0.125	0.132	0.150	0.139	0.182
	2	0.104	0.136	0.171	0.125	0.171	0.125	0.157
	3	0.118	0.136	0.182	0.132	0.164	0.139	0.182
	4	0.129	0.132	0.150	0.129	0.164	0.150	0.157
Cartref	1	0.007	0.018	0.032	0.018	0.039	0.018	0.025
	2	0.014	0.018	0.029	0.011	0.025	0.021	0.039
	3	0.011	0.014	0.025	0.011	0.046	0.032	0.039
	4	0.011	0.018	0.029	0.011	0.029	0.014	0.036
Glenrosa	1	0.021	0.032	0.039	0.050	0.068	0.043	0.075
	2	0.018	0.046	0.043	0.064	0.075	0.054	0.079
	3	0.029	0.046	0.046	0.050	0.075	0.054	0.079
	4	0.025	0.043	0.050	0.054	0.071	0.061	0.071
Longlands	1	0.029	0.050	0.079	0.054	0.079	0.057	0.075
	2	0.039	0.046	0.093	0.057	0.086	0.064	0.071
	3	0.032	0.054	0.068	0.064	0.089	0.079	0.079
	4	0.036	0.054	0.071	0.068	0.089	0.071	0.082
Nomanci	1	0.036	0.064	0.079	0.061	0.086	0.054	0.079
	2	0.036	0.068	0.082	0.064	0.075	0.061	0.071
	3	0.032	0.057	0.089	0.071	0.071	0.057	0.071
	4	0.036	0.068	0.093	0.068	0.082	0.075	0.068

Appendix 36. Effect of Si source application rates (tons ha^{-1}) on root silicon content (%) of cane plants grown in the pots.

Soil form	Rep. No	Cane root Silicon content (%) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	0.71	0.70	0.84	0.83	0.69	0.60	0.72
	2	0.61	0.60	0.86	0.74	0.91	0.68	0.71
	3	0.63	0.73	0.85	0.98	0.79	0.75	0.74
	4	0.62	0.79	0.81	0.52	0.74	0.53	0.72
Cartref	1	0.41	0.51	0.75	0.84	0.81	0.59	0.67
	2	0.46	0.56	0.76	0.73	0.94	0.58	0.70
	3	0.48	0.58	0.80	0.62	0.90	0.55	0.68
	4	0.54	0.60	0.69	0.63	0.95	0.61	0.80
Glenrosa	1	0.32	0.57	0.70	0.65	0.69	0.61	0.71
	2	0.39	0.44	0.69	0.67	0.71	0.65	0.74
	3	0.44	0.63	0.64	0.58	0.72	0.62	0.69
	4	0.37	0.59	0.70	0.67	0.76	0.59	0.76
Longlands	1	0.41	0.60	0.66	0.58	0.55	0.58	0.72
	2	0.47	0.52	0.78	0.64	0.96	0.78	0.80
	3	0.44	0.57	0.63	0.51	0.71	0.67	0.82
	4	0.49	0.50	0.57	0.52	0.74	0.52	0.57
Nomanci	1	0.30	0.55	0.65	0.57	0.64	0.58	0.75
	2	0.37	0.47	0.61	0.60	0.68	0.56	0.67
	3	0.41	0.56	0.65	0.59	0.66	0.56	0.70
	4	0.39	0.59	0.62	0.61	0.70	0.54	0.67

Appendix 37. Effect of soil forms and Si source application rates (tons ha^{-1}) on the canopy development (cm^2 of leaf surface area) of cane plants grown in the pots.

Soil form	Rep. No	Cane leaf surface area (cm^2) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	750.75	1024.80	451.50	647.50	841.75	864.50	1023.75
	2	980.00	525.00	489.30	840.00	717.50	682.50	502.25
	3	693.00	848.40	882.00	575.75	770.00	682.50	420.00
	4	499.80	841.75	798.00	820.05	665.00	441.00	673.75
Cartref	1	924.00	453.25	981.75	451.50	514.50	451.50	833.00
	2	654.50	819.00	1011.50	514.50	952.00	616.00	1232.00
	3	735.00	532.00	663.60	577.50	462.00	612.50	1015.00
	4	647.50	399.00	896.00	462.00	483.00	490.00	451.50
Glenrosa	1	350.00	647.50	808.50	288.75	453.25	490.00	346.50
	2	325.50	812.00	551.25	850.50	476.00	428.75	227.50
	3	178.50	868.00	750.75	1085.00	735.00	367.50	378.00
	4	431.20	306.25	728.00	357.00	892.00	388.50	273.00
Longlands	1	659.75	756.00	796.25	567.00	808.50	428.75	1190.00
	2	154.00	539.00	918.75	577.50	532.00	665.00	546.00
	3	616.00	462.00	735.00	654.50	714.00	714.00	635.25
	4	315.00	563.50	504.00	315.00	430.50	654.50	750.75
Nomanci	1	252.00	647.50	693.00	236.25	796.25	612.50	577.50
	2	252.00	756.00	379.75	227.50	535.50	588.00	577.50
	3	189.00	542.50	560.00	220.50	542.50	504.00	630.00
	4	280.00	476.00	1050.00	253.75	672.00	526.75	388.50

Appendix 38. Effect of Si source application rates (tons ha^{-1}) on the K (cmol kg^{-1}) content of soil samples collected after harvest of cane plants grown in the pots.

Soil form	Rep. No	Soil K (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	3.14	2.57	2.61	2.23	2.29	2.48	2.37
	2	3.13	2.69	2.45	2.54	2.58	2.77	2.80
	3	3.24	3.09	2.57	2.71	2.43	2.83	3.30
	4	3.41	2.92	2.67	2.46	2.66	2.59	2.35
Cartref	1	3.49	2.46	2.51	3.50	2.75	3.14	2.86
	2	3.10	2.73	3.04	2.87	3.16	2.99	2.58
	3	3.30	2.82	2.98	3.31	3.27	3.11	2.44
	4	3.39	3.02	3.10	3.12	3.17	2.72	2.24
Glenrosa	1	2.42	2.37	2.37	2.97	2.94	2.80	2.50
	2	2.79	2.48	2.26	2.59	2.58	2.56	3.42
	3	2.43	3.14	2.31	2.10	2.18	2.58	2.39
	4	2.28	2.54	3.03	3.19	2.75	2.34	3.30
Longlands	1	1.36	1.44	1.13	1.51	1.30	2.04	1.32
	2	1.62	1.35	0.82	1.74	1.49	1.57	1.32
	3	1.47	1.35	1.88	1.39	1.72	1.34	1.24
	4	1.26	1.22	1.48	1.83	1.26	1.42	1.53
Nomanci	1	2.96	2.12	2.64	2.78	1.99	2.55	2.20
	2	2.74	1.96	2.97	3.41	2.35	2.55	2.38
	3	2.82	2.72	2.07	3.10	2.39	2.48	2.24
	4	2.47	2.84	1.85	2.56	2.79	2.40	2.38

Appendix 39. Effect of Si source application rates (tons ha^{-1}) on the Ca (cmol kg^{-1}) content of soil samples collected after harvest of cane plants grown in the pots.

Soil form	Rep. No	Soil Ca (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	10.54	11.15	11.87	10.92	11.79	11.32	12.87
	2	11.58	10.59	11.77	11.22	10.52	11.49	12.68
	3	9.14	12.11	14.57	11.13	11.92	11.27	12.91
	4	10.32	11.28	12.01	11.98	12.00	10.75	12.17
Cartref	1	1.44	1.70	1.54	1.90	1.88	2.57	1.76
	2	1.52	1.61	1.71	1.96	1.94	2.25	2.20
	3	1.21	1.89	1.14	1.62	2.24	1.89	2.25
	4	2.06	1.92	1.43	1.93	2.58	2.41	2.15
Glenrosa	1	2.02	1.33	1.75	1.87	1.04	1.65	1.48
	2	2.40	1.94	1.49	1.94	1.42	1.55	1.40
	3	1.40	1.85	1.57	1.67	1.39	1.51	1.77
	4	1.67	2.01	1.77	1.11	1.63	1.37	1.57
Longlands	1	1.37	0.47	0.54	0.98	0.79	1.05	0.83
	2	1.26	0.51	0.87	0.66	0.69	0.81	0.63
	3	1.42	0.65	0.55	1.04	0.95	0.97	0.58
	4	0.93	0.79	0.65	0.97	0.62	0.70	0.67
Nomanci	1	0.98	1.40	1.15	0.92	1.33	1.56	1.29
	2	1.24	1.18	1.19	1.27	1.78	1.32	1.07
	3	1.22	1.48	1.41	0.95	1.60	1.15	1.29
	4	1.17	1.44	1.47	0.98	1.55	1.14	1.23

Appendix 40. Effect of Si source application rates (tons ha^{-1}) on the Mg (cmol kg^{-1}) content of soil samples collected after harvest of cane plants grown in the pots.

Soil form	Rep. No	Soil Mg (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	6.02	4.86	5.48	5.10	5.71	5.17	5.04
	2	5.15	5.23	5.50	5.23	5.69	4.85	5.06
	3	5.09	5.30	5.62	4.97	5.71	5.13	4.92
	4	5.04	5.34	5.45	5.43	5.61	4.64	4.65
Cartref	1	2.70	2.99	2.95	3.10	3.22	2.81	2.17
	2	2.51	3.03	2.96	3.02	3.33	2.57	2.24
	3	2.35	2.65	2.76	3.20	3.30	2.13	2.14
	4	2.42	3.31	2.67	3.44	3.46	2.58	2.72
Glenrosa	1	1.14	2.30	2.32	2.10	2.53	2.01	1.53
	2	1.95	2.51	2.25	2.63	2.69	2.09	1.68
	3	1.01	2.29	2.23	2.43	2.38	1.90	1.47
	4	0.97	2.62	2.71	2.54	2.72	1.92	1.23
Longlands	1	0.78	0.74	0.64	0.95	0.91	1.21	0.80
	2	0.76	0.81	0.75	1.10	0.95	0.84	0.75
	3	0.87	0.80	1.17	0.85	1.18	0.80	0.81
	4	0.65	0.74	0.93	1.04	0.86	0.88	1.00
Nomanci	1	1.37	1.42	1.52	1.34	1.35	1.20	1.22
	2	1.20	1.30	1.55	1.34	1.57	1.36	1.20
	3	1.24	1.58	1.34	1.37	1.43	1.28	1.29
	4	1.08	1.54	1.36	1.15	1.49	1.23	1.42

Appendix 41. Effect of Si source application rates (tons ha^{-1}) on the Na (cmol kg^{-1}) content of soil samples collected after harvest of cane plants grown in the pots.

Soil form	Rep. No	Soil Na (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	2.85	1.88	2.01	2.14	2.42	2.47	2.41
	2	2.46	2.21	2.04	2.06	2.44	2.10	2.29
	3	2.33	2.31	2.30	1.93	2.23	2.30	2.17
	4	2.33	2.15	2.22	2.16	2.23	2.14	2.27
Cartref	1	1.91	1.84	1.78	2.05	1.73	1.68	1.26
	2	1.92	1.98	1.37	1.88	1.71	1.68	1.38
	3	1.77	1.64	1.06	1.89	1.94	1.28	0.95
	4	1.95	1.90	1.55	1.81	1.84	1.70	1.28
Glenrosa	1	0.72	0.93	0.89	0.73	0.82	0.88	0.76
	2	0.87	1.10	0.89	1.25	1.04	1.17	0.90
	3	0.60	0.92	0.73	1.06	0.96	1.06	0.98
	4	0.66	1.18	1.15	0.95	1.16	0.86	0.74
Longlands	1	0.75	0.79	0.56	0.70	0.62	0.83	0.70
	2	0.59	0.79	0.52	0.77	0.73	0.72	0.57
	3	0.82	0.73	0.96	0.60	0.70	0.63	0.69
	4	0.64	0.69	0.62	0.80	0.58	0.70	0.86
Nomanci	1	0.83	0.84	0.82	0.72	0.84	0.83	0.65
	2	0.63	0.85	0.94	0.54	0.84	0.87	0.68
	3	0.70	1.00	0.77	0.61	0.73	0.83	1.25
	4	0.62	0.70	0.81	0.50	0.94	0.74	1.00

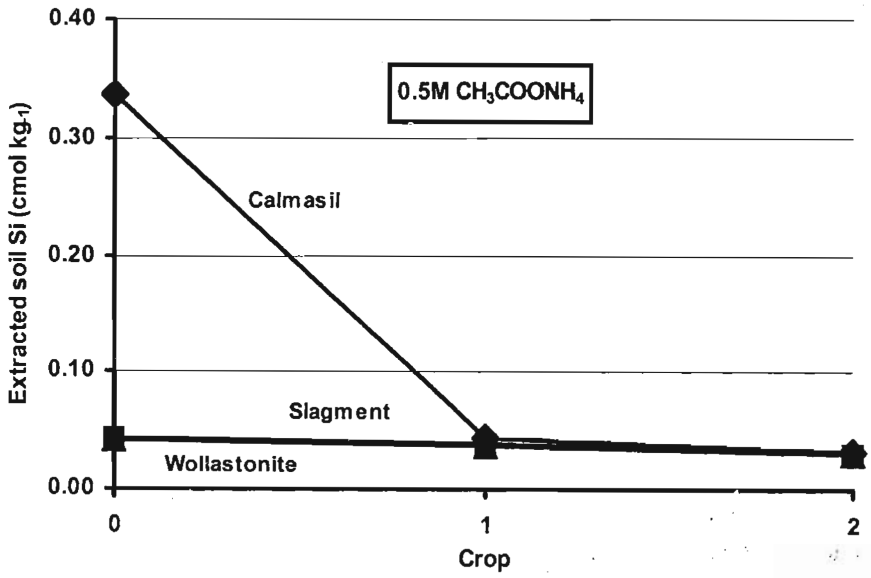
Appendix 42. Effect of Si source application rates (tons ha^{-1}) on the Mn (cmol kg^{-1}) content of soil samples collected after harvest of cane plants grown in the pots.

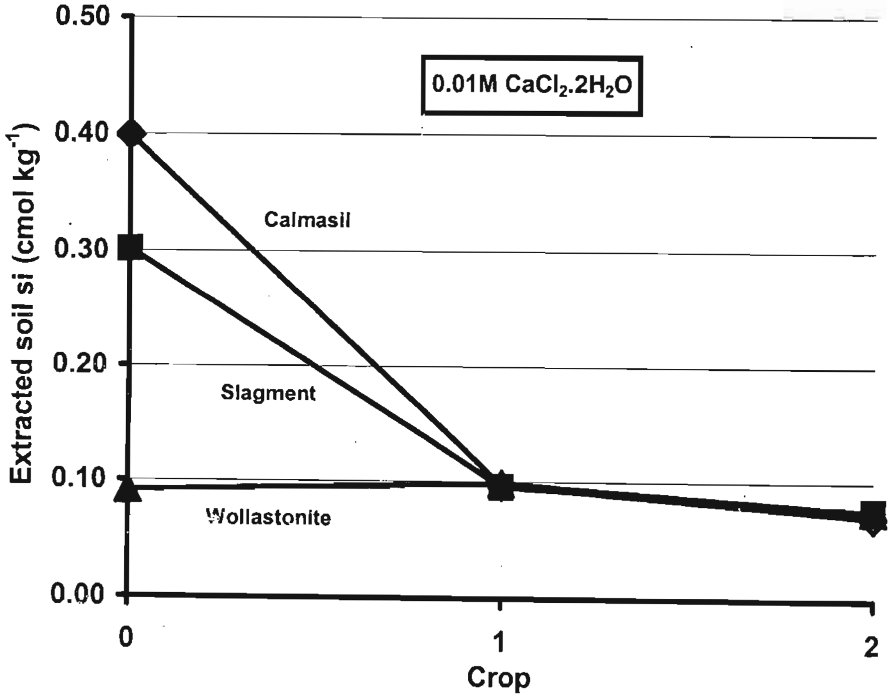
Soil form	Rep. No	Soil Mn (cmol kg^{-1}) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	2.057	1.529	1.438	1.311	1.584	1.420	1.456
	2	1.675	1.425	1.438	1.420	1.529	1.547	1.529
	3	1.729	1.321	1.220	1.402	1.547	1.493	1.256
	4	1.693	1.218	1.402	1.584	1.493	1.347	1.347
Cartref	1	0.066	0.140	0.215	0.191	0.289	0.111	0.080
	2	0.062	0.129	0.185	0.184	0.346	0.051	0.142
	3	0.055	0.122	0.268	0.166	0.253	0.058	0.106
	4	0.056	0.137	0.264	0.175	0.255	0.060	0.066
Glenrosa	1	0.086	0.095	0.138	0.180	0.235	0.024	0.053
	2	0.031	0.182	0.155	0.167	0.211	0.027	0.067
	3	0.020	0.122	0.178	0.171	0.202	0.024	0.102
	4	0.024	0.204	0.171	0.116	0.224	0.025	0.100
Longlands	1	0.371	0.728	0.637	0.728	0.801	0.764	0.655
	2	0.601	0.601	0.728	0.819	0.801	0.673	0.582
	3	0.582	0.655	0.764	0.764	0.728	0.637	0.692
	4	0.546	0.619	0.619	0.874	0.673	0.710	0.637
Nomanci	1	0.102	0.153	0.153	0.115	0.144	0.111	0.031
	2	0.058	0.157	0.166	0.122	0.157	0.035	0.035
	3	0.035	0.135	0.116	0.120	0.157	0.031	0.027
	4	0.029	0.095	0.155	0.107	0.153	0.029	0.027

Appendix 43. Effect of Si source application rates (tons ha^{-1}) on the pH(water) of soil samples collected after harvest of cane plants grown in the pots.

Soil form	Rep. No	Soil pH(water) presented per Si source application rates						
		Control	Calmasil		Slagment		Wollastonite	
		0t/ha	3t/ha	6t/ha	3t/ha	6t/ha	3t/ha	6t/ha
Arcadia	1	4.61	4.84	5.29	4.96	5.21	4.79	4.96
	2	4.61	4.87	5.27	4.85	5.17	4.87	4.99
	3	4.69	4.86	5.15	4.88	5.15	4.76	4.94
	4	4.60	4.86	5.23	4.84	5.19	4.83	5.03
Cartref	1	4.28	4.52	4.79	4.59	4.76	4.48	4.71
	2	4.29	4.58	4.88	4.53	4.82	4.47	4.77
	3	4.28	4.55	4.92	4.61	4.81	4.51	4.77
	4	4.32	4.54	4.87	4.66	4.75	4.50	4.67
Glenrosa	1	4.36	4.67	5.28	4.68	5.16	4.43	4.88
	2	4.11	4.63	5.23	4.63	5.17	4.39	4.95
	3	4.18	4.54	5.14	4.66	5.20	4.42	5.00
	4	4.18	4.66	5.25	4.67	5.16	4.32	4.96
Longlands	1	4.44	5.68	6.10	5.71	6.09	5.18	5.81
	2	4.60	5.62	6.21	5.72	6.06	5.24	5.87
	3	4.45	5.66	6.28	5.74	6.04	5.22	5.91
	4	4.48	5.61	6.25	5.75	6.00	5.26	5.86
Nomanci	1	4.54	4.90	5.51	4.99	5.33	4.81	5.16
	2	4.55	4.88	5.53	5.06	5.31	4.73	5.10
	3	4.49	4.85	5.56	5.07	5.35	4.63	5.04
	4	4.51	4.88	5.60	5.09	5.35	4.59	5.02

Appendix 44. Residual effect of Si sources on extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) within the 0.5M CH_3COONH_4 and 0.01M $CaCl_2.2H_2O$ extracting methods.





Appendix 45. Residual effect of Si sources on extracted soil Si (cmol kg^{-1}) values after treatment (crop 0), after sorghum (crop 1) and after cane (crop 2) within the 0.01M H_2SO_4 + $(NH_4)_2SO_4$ and 0.5M CH_3COOH extracting methods.