CRUSHED ROCK AND CLAY AMELIORATION OF A NUTRIENT DEFICIENT, SANDY SOIL OF MAPUTALAND

Portia Odessyl Ceruti

BSc. Soil Science
California Polytechnic State University,
San Luis Obispo

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University of Cape Town
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This thesis is dedicated to

Caron Scholl

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Thanks for being such a wonderful friend and sharing so much of yourself.
You had an incredible gift in helping others and this along with your engaging smile and generous spirit will be sorely missed.
You made a big difference to my life, and
I was blessed to know you.

Goodbye angel.

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ABSTRACT

Various studies have suggested the possibility that food derived through subsistence agriculture in the Mseleni region of Maputaland contributes to malnutrition within the local community, particularly within the high proportion of the population which suffers from a severe, disabling form of osteoarthritis. This study was conducted to determine if the application of local crushed rock or black clay to these nutrient deficient, sandy soils would increase available nutrient concentrations and improve the growth of plants in the ameliorated soil.

A subtractive growth trial with maize (*Zea mays*) grown on a grey Fernwood sand of the Waterton family (a thermic, uncoated, Typic Quartzipsamment) was conducted in order to establish, through soil and plant tissue analyses, whether nutrient deficiencies exist in the soil. Once the fertility status of the soil was known, the effects were studied of ameliorating the soil with crushed dolerite and rhyolite from the adjacent Lebombo range, and black clay from localised depressions in this otherwise sandy landscape. Of the elements studied (P, K, Ca, Mg, S, Mn, Fe, Cu, Zn and B), the subtractive growth trial revealed sub-optimal levels of Bray-2-extractable P (4), 1 *M* NH_4OAc-extractable K (9), Ca (347) and Mg (20), 0.01 *M* $Ca(H_2PO_4)_2$ -extractable S (11), 0.02 *M* $(NH_4)_2$-EDTA-extractable Cu (0.13) and Zn (0.4), and $CaCl_2$-extractable B (0.03 mg kg^{-1}). Tissue analysis confirmed deficiencies of P (0.11), K (0.31), Ca (0.38) and Mg (0.27%), and of Cu (3) and Zn (14 mg kg^{-1}). Sulphur was additionally suspected of being deficient because in its absence there was too little plant material for analysis. These trends were reflected in relative yields of less 80% when Fe, Mo, Zn, Ca, P or S were withheld and a sub-optimal yield of 80 to 90% when Cu was withheld. In the amelioration trial, a crushed rock application rate of 300 g m^{-2} showed no significant increase in either soil or tissue nutrient concentration and no significant effect on plant growth.

At an amendment rate of about 5 kg m^{-2}, black clay produced a marked increase in extractable soil P, K, Ca and Mg (from 4, 5, 304 and 20 mg kg^{-1} to 10, 15, 438 and 58 mg kg^{-1}, respectively), but resulted in only a slight increase in yield. The yield data suggest that a simple combination of the mud amendment with nitrogen fertiliser will produce near-optimum plant growth, and that there is no further significant benefit from adding P, K or S. This soil has severe nutrient deficiencies and amelioration with an inexpensive, readily available amendment can increase the fertility status of the soil, crop yields and nutrient concentrations of plant tissue, thus enhancing the quantity and nutritional quality of food consumed and alleviating some of the malnourishment in this poor community.

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INTRODUCTION

The essence of Africa seems to be distilled within the vast coastal plain of Maputaland, with its tall shimmering sand forests and open iLala palm veld. Upon entering this world one is struck by the apparently contradictory sight of a striking variety of vegetation in an extensive sandy landscape. The rich flora includes a high level of species endemism and the fauna includes endemic dwarf species of chameleon and fish. Additionally, among the local inhabitants there is an unusually high prevalence of dwarfism and an endemic osteo-arthric condition, termed Mseleni Joint Disease (MJD). This rare disease begins with stiffness and pain in the joints and progresses to varying degrees of disability, with some of the afflicted requiring aid in walking and others unable to walk at all. Various studies have examined food, water, radiological, haematological, mycotoxicological, and genetic factors all in a futile attempt to determine a causative factor. While it is not the direct purpose of this thesis to examine the possible environmental factors relating to these unique conditions, it is speculative that nutrient deficiencies within the environment may be responsible for the rich and unusual local flora and fauna, as well as translocating through the food chain and affecting the local inhabitants. Rather, this is a backdrop with which to explain the necessity of exploring means of increasing the fertility of some aspects of this landscape, without irreparably altering the dystrophic nature this unique ecosystem.

To explore the avenue of nutrient deficiency within this environ, Pooley (1997) determined the elemental status of soils in the Mseleni area and the nutritional composition of plants grown in this soil, with special consideration of those elements essential to bone formation (Ca, P, Zn, Mn, Cu, B and Se). The soils were found to be moderately acidic and to have low clay, organic matter, cation exchange capacity (CEC) and sub-optimal levels of Ca, P, Zn and Cu for plant growth, while B and Mn were also low. Tissue analysis from plant growth trials in these soils showed deficient levels of P, Cu and B and sub-optimal levels of Ca and Zn.

Clearly, amendment of these soils could help to improve the crop yield and nutritional quality of food grown in this region. The sandy nature of the soils of the Mseleni region, however, makes amendment with a water-soluble fertiliser impractical due to loss of nutrients by leaching. Additionally, the parlous financial status and remoteness of the local population must be taken into consideration. Therefore, preference should be given to locally produced, low cost material. Two possibilities are crushed rocks from the nearby Lebombo Mountains, which may be inherently fertile, or clay from one of the numerous low points, or pans, which exist within the coastal plain.

Research in Australia and Mauritius with the addition of crushed basalt has shown increased yields, pH, CEC and exchangeable calcium and magnesium on old, infertile soils (Gillman,

1980; D'Hotman de Villiers, 1961). In Gillman's study these properties increased continually with time over a twelve-month study period. The same type of work with the addition of clay to coarse textured soil has resulted in a doubling of crop yield and marked improvement of the soil nutrient status (Cann, 1994; Dellar *et al.*, 1994). Local research on the Natal sands has shown an increase in yield with the application of lime, closely related to an increase in pH and a decrease in the exchangeable aluminium toxicity (Sumner, 1970).

In Maputaland the application of crushed rock or black clay may provide an inexpensive, slow release fertiliser that also enhances trace element concentrations and increases yields. Analyses of the elemental abundance of Bumbeni rhyolite and dolerite from the Bumbeni Complex of the Lebombo Mountains and of extractable nutrient concentrations of black clays from pans in Maputaland indicate they may prove useful in supplying nutrients (Cleverly *et al.*, 1984; Eales *et al.*, 1984; Pooley, 1997).

Studies determining the effects of crushed rock and clay addition on the extractable nutrient concentrations of a Maputaland soil, and on the yield and nutrient status of tissue from plant growth trials will be established. This will be pre-empted by the geochemical characterisation of the soil and amendment material, and by a subtractive plant growth trial to establish soil nutrient levels and confirm anticipated deficiencies.

The aim of this study is to provide an inexpensive means of increasing the yields of crops grown on Maputaland soils, and ultimately to enhance the nutritional quality of food consumed in this poor community, where malnourishment may be playing a role in the severity of MJD.

CHAPTER 1

BACKGROUND TO THE ECOLOGY AND SOILS OF MAPUTALAND, AND STRATEGIES FOR SOIL AMELIORATION

1.1 INTRODUCTION

This thesis is divided into three sections, with this first chapter providing a background to Maputaland and a summary of the relevant literature on local soils and amelioration studies. The following two chapters present geochemical data and results of the two plant growth trials. The first trial is a subtractive trial which determines the fertility status of the soil, while the second trial consists of a soil amelioration study based on the results of the first trial. These trials were limited to pot experiments with a sample soil and provide a basis for planning field based trials in the future. The amelioration trial is the crux of the study and aimed to test the following two hypotheses:

1. Application of crushed rock or black clay to nutrient deficient sandy soils of Maputaland will increase extractable nutrient concentrations to above the critical threshold required for an adequate supply of plant nutrients.

2. Plants grown in soil ameliorated with crushed rock or black clay will exhibit enhanced growth associated with nutrient concentrations elevated above the critical level required by plants for adequate growth.

1.2 NATURAL FEATURES OF MAPUTALAND

Maputaland is located in the north-east corner of coastal South Africa, bordered on the east by the Indian Ocean, on the north by the Moçambique border and on the west by the Lebombo Mountain Range (Fig. 1.1). It is a sandy, coastal plain about 50 km in width on its northern boundary with Moçambique and is pinched to a close, 130 km south at Lake Saint Lucia, by the southeast progression of the Lebombo Mountain Range. Maputaland represents the southern extremity of the much larger Moçambique Coastal Plain which is as wide as 400 km in the region known as Gazaland.

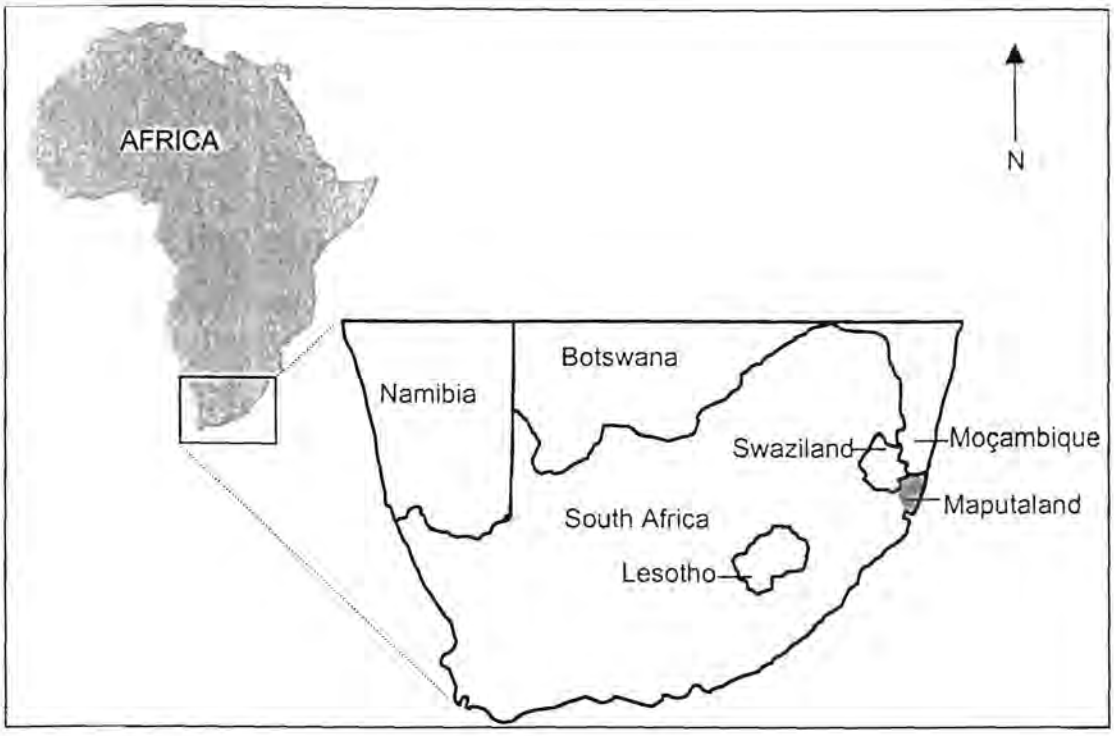

Figure 1.1 Location map of Maputaland on the north-eastern seaboard of South Africa, bordering Moçambique.

1.2.1 Mseleni Joint Disease

This study has been carried out in Maputaland because of the high prevalence of a local endemic disease. Mseleni Joint Disease (MJD) is an osteoarthritic condition, with an unknown aetiology that affects the rural, subsistence peasant community of Maputaland. There is no clear definition of MJD but it is typified by pain, stiffness, deformity and in some cases a lack of mobility, of multiple joints, but chiefly the hips. Mseleni Joint Disease is characterised by multiple epiphyseal dysplasia (malformation in growth of long bones), polyarticular osteoarthritis (arthritis of several joints), protrusio acetabuli (a hip disorder), and mild stunting of growth (Lockitch *et al.*, 1973b; Solomon *et al.*, 1986). Dwarfs also exist in the community and they have the same radiological features as MJD without any signs of achondroplasia, features typical of the most common genetic dwarfism (Lockitch *et al.*, 1973b; Viljoen *et al.*, 1993).

Extensive field investigations in 1970 found a high prevalence area, comprising the Mseleni region and the portions of Manabe and Mbazwana bordering it, with 39% of the women and 11% of the men being afflicted with MJD to some degree (Fig. 1.2.; Fellingham *et al.*, 1973). When only the adult population over 19 years is considered the prevalence rate increases to 66% for women and 25% for men (Fellingham *et al.*, 1973). The high proportion of the

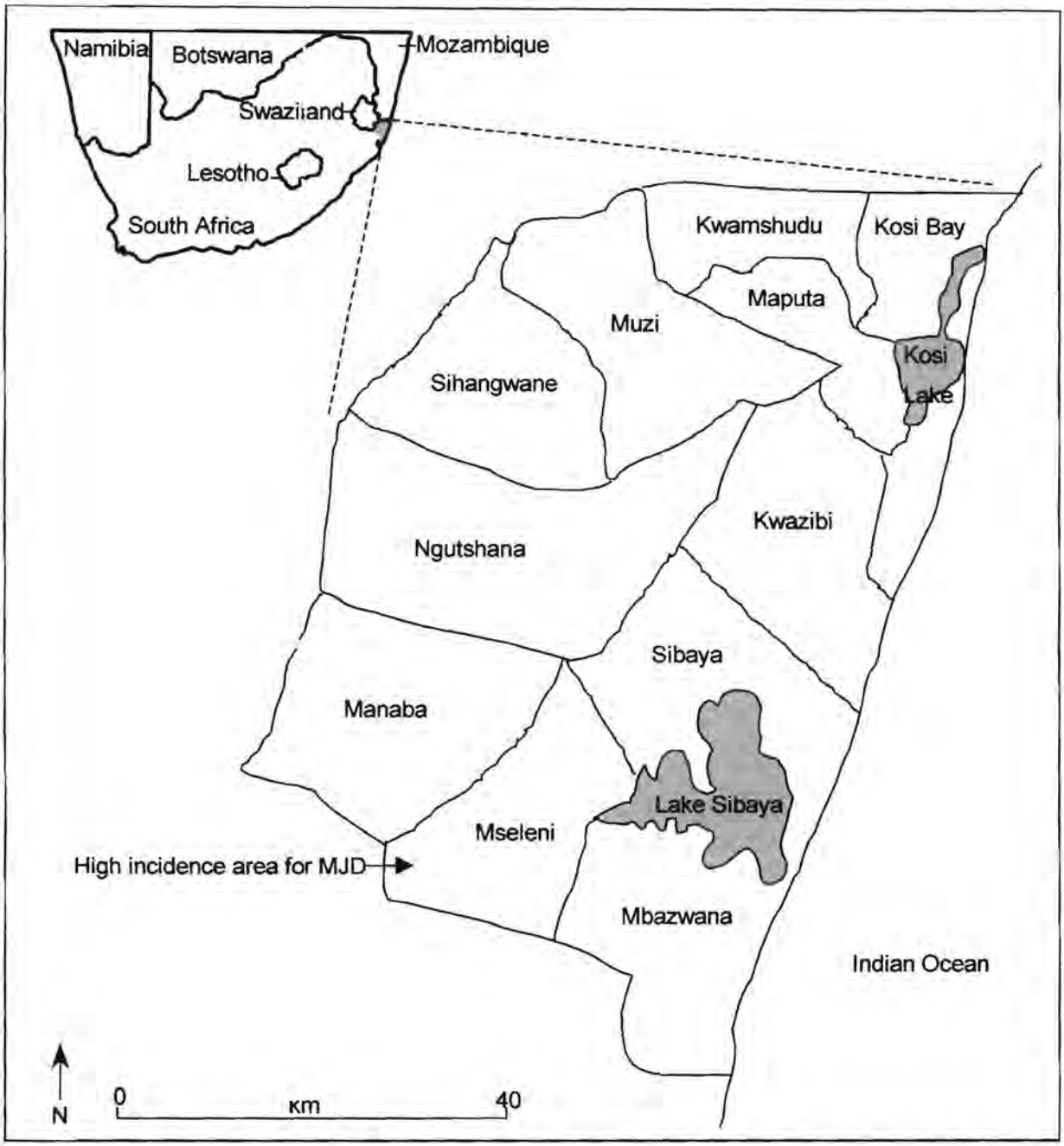

Figure 1.2 Areas within Maputaland that are known to have residents afflicted with MJD.

population suffering from MJD and the severity of the disease combine to have major social impacts on the community. Not only is the pain and suffering extreme but prosthetic hip replacements are costly and place a huge economic burden on a poor region. The families of MJD sufferers are subjected to an increased workload, often resulting in children leaving school at an early age tc support their parents (Mann, 1984).

A variety of studies have attempted to shed light on the causative factor or factors of MJD. Haematological tests limited to parameters that affect abnormal bone metabolism found low alkaline phosphate and moderately low inorganic phosphate and calcium phosphate

concentrations in blood serum compared with a control group of non-MJD persons from Mseleni (Burger *et al.*, 1973). Low Fe blood levels, as serum ferritin, were found to be highly prevalent among the Mseleni community, affecting 42% of women and 53% of men (Mayet *et al.*, 1985). This anaemia was not linked to parasite infection, but rather suspected to be associated with nutrient deficiencies due to Fe availability for absorption and not necessarily with an inadequate dietary Fe intake. A study on blood serum from women revealed low levels of calcium and magnesium which were suspected to be of nutritional origin (Fincham *et al.*, 1986). Simple Mendelian patterning has been ruled out and the more complicated genetic mechanism of imprinting remains unproven as a possible inheritable pattern (Ballo *et al.*, 1996).

Two diseases with similar radiological characteristics have often been compared with MJD and their aetiology and pathogenesis examined. Kashin-Beck, or Urov, disease which occurs in China, Korea and Russia, manifests as a chronic, progressively disabling polyarthritic symmetrical condition that does not affect the hips and was ultimately attributed to aflotoxins produced by *Fusarium poae* and *F. oxysporum* (du Toit, 1979; Marasas and Rensburg, 1986). This led to mycotoxicological studies in the Mseleni area with the finding that these species of *Fusarium* are not present, and a study of animals fed on grain infested by the most prevalent fungus, *F. moniliforme*, caused no abnormalities (Fincham *et al.*, 1985; Marasas and Rensburg, 1986). Handigodu disease in India is also an osteoarthritic condition associated with multiple epiphyseal dysplasia but differs in that it affects the shoulders primarily and is inherited by an autosomal dominant trait (du Toit, 1979; Ballo *et al.*, 1996; Agarwal *et al.*, 1997). The similarities of MJD and Handigodu disease led to renewed efforts to determine a genetic inheritance pattern which have remained fruitless. Because of some symptomatic similarities of MJD with Lyme disease, a tick-borne disease causing pain in the joints, and also the sporadic, localised and dynamic occurrence of MJD, a connection was sought (McGlashan *et al.*, 1992). No ticks in Maputaland were found to carry *Borrelia burgdorferi*, the spirochaete typically responsible for spreading Lyme disease, nor did any of the blood serum analyses from individuals with MJD test positive for Lyme disease (McGlashan *et al.*, 1997).

Several researchers have suggested the possibility of an elemental deficiency being a causative factor, especially Mn and Zn, which have been implicated in bone related disorders elsewhere (Xilinas, 1983; du Toit, 1979; Fincham *et al.*, 1981; Mackenzie, 1981). None of the early studies, however, determined the nutritional quality of food or quantified environmental factors. This avenue of research was partiallly addressed in 1996 in a study by Pooley (1997) that looked at the distribution of Ca, P, Zn, Mn, Cu, B, Mo and Se in soils over a transect through the high incidence area for MJD. Deficiencies of extractalbe soil Ca, P, Zn, Cu and B were found and plants grown in this soil were shown to be deficient in the same elements (Pooley, 1997). This evidence of multiple deficiencies points strongly to a dietary problem for people who subsist largely on local produce. Because of the variety of elements lacking it

would be difficult to establish which, if any, may be responsible for the degenerative conditions of MJD. As noted by Oliver (1997) and Mann (1984), of more importance than solving the riddle of this elusive disease would be to provide a basis for ensuring healthier nutrition, thus preventing ill health rather than attempting to cure it.

1.2.2 Climate

Maputaland has a warm, sub-tropical climate. It is typified by wet summers, dry winters, frost free days, high summer temperature and is dominated by the southern sub-tropical high-pressure belt.

The mean annual temperature from the Lake Sibayi weather station is 21.6 °C, ranging from 11.5 °C in July to 28.7 °C in January (Maud, 1980). The maximum and minimum relative humidity is 88 and 56% in winter and 83 and 60% in summer, respectively.

Rainfall in the region varies from 1000 mm at the coast to 800 mm at the western edge of Lake Sibayi before dropping to 600 mm at the centre of the coastal plain and rising again to 800 mm at the top of the Lebombo Mountain Range (Maud, 1980). These precipitation changes run roughly parallel to the coast and represent significant differences in localised moisture regimes over a relatively narrow region. Most of the rainfall occurs as erratic, cyclonic events between September and April. Fog and mist are not common on this coast, but sea haze is often observed to be brought in by the persistent north-easterly winds (Beater, 1950).

Evaporation is greater than rainfall at the coast, with values of 2.0 to 5.8 mm per day at Lake Sibayi, and extremes of 10.7 mm per day recorded in the summer at this location (Maud, 1980). Strong seasonal winds are observed with northeasterly winds having an average velocity of 6.6 m s^{-1} dominating in summer and a balance between southerly and northerly winds occurring in winter with an average wind velocity of 7.0 m s^{-1} (Ramsey, 1991).

1.2.3 Geology

The Maputaland coastal plain comprises Cretaceous, Tertiary and Quarternary sediments deposited on the eastward sloping Lebombo rhyolites as a consequence of transgression and regression of the sea (Hobday, 1979). The exposed surface is a low-lying, level plain with a maximum elevation of 150 m, bordered on the west by the eastward sloping Lebombo monocline of the Karoo igneous province, which reaches a height of 600 m.

The Lebombo monocline is a north-south flexure running from Hluhluwe west of Lake Saint Lucia and north to the Moçambique border and into Swaziland (Fig. 1.3). It comprises

Jurassic, rhyolitic rocks of the Jozini Formation overlying Letaba basalts. The Letaba basalts are present on the western side of the mountains while small outcrops of younger Movene basalts are found in some eastern locations and in the northern and southern portion of the mountain range. Throughout the Lebombos doleritic dykes and sills are common. The mountain range is therefore made up of acid volcanic rocks interspersed with basic rocks.

At the time of the formation of the Lebombo Mountains, during the breakup of Gondwanaland, the sea lapped the eastern flank of the mountains and the eastwardly inclined slopes of rhyolite extended beneath the sea (Maud, 1980). Following this Mesozoic fragmentation there was a series of epeirogenic uplifts resulting in either emergence of the coastal margin or marine transgression. In addition to this tectonic activity, lithospheric plate activity and glacio-eustatic processes were also responsible for major sea-level changes during the Cenozoic era. These processes combined to result in the deposition of sediments on the submerged rhyolitic slopes.

During the early Cretaceous period terrigenous conglomerates were laid down conformably on the Jozini rhyolites (Hobday, 1979). The Lebombo-derived conglomerate bed grades from boulders and pebbles to sands, marls and silts upward and eastward, and is about 26 m thick. It is covered with a shallow to deep-water marine deposition that is rich in fossils. The Cretaceous layer outcrops today at the footslope of the Lebombos and has a maximum thickness in northern Maputaland of 3 000 m, which makes up most of the sedimentary material underlying the Maputaland plain.

The early Tertiary was a period of uplift and erosion and a thin layer of Lebombo conglomerates was again laid down followed by a 30 to 50 m layer of greyish-white sandy limestone deposited in a shallow sea (Maud, 1980). There was a brief hiatus during the Oligocene and then shelly limestones and calcarenites were laid down in a marine environment in the late Tertiary. The shelly limestone is referred to as the pecten beds and comprise a thin ferruginous layer representing a marine transgression overlain by fossiliferous coquina-like limestone with a total thickness of 5 m. The calcarenites are a well bedded, fossiliferous, quartzitic sparry calcite (Maud, 1980).

The Port Durnford Beds were laid down on top of the flat Tertiary rocks in the Pleistocene and comprise sands, clayey limestones and diatomites up to 50 m thick (Heeg and Breen, 1982). The clayey deposits were laid down in a brackish lagoon environment and are overlain by up to 2.5 m of lignite or peat.

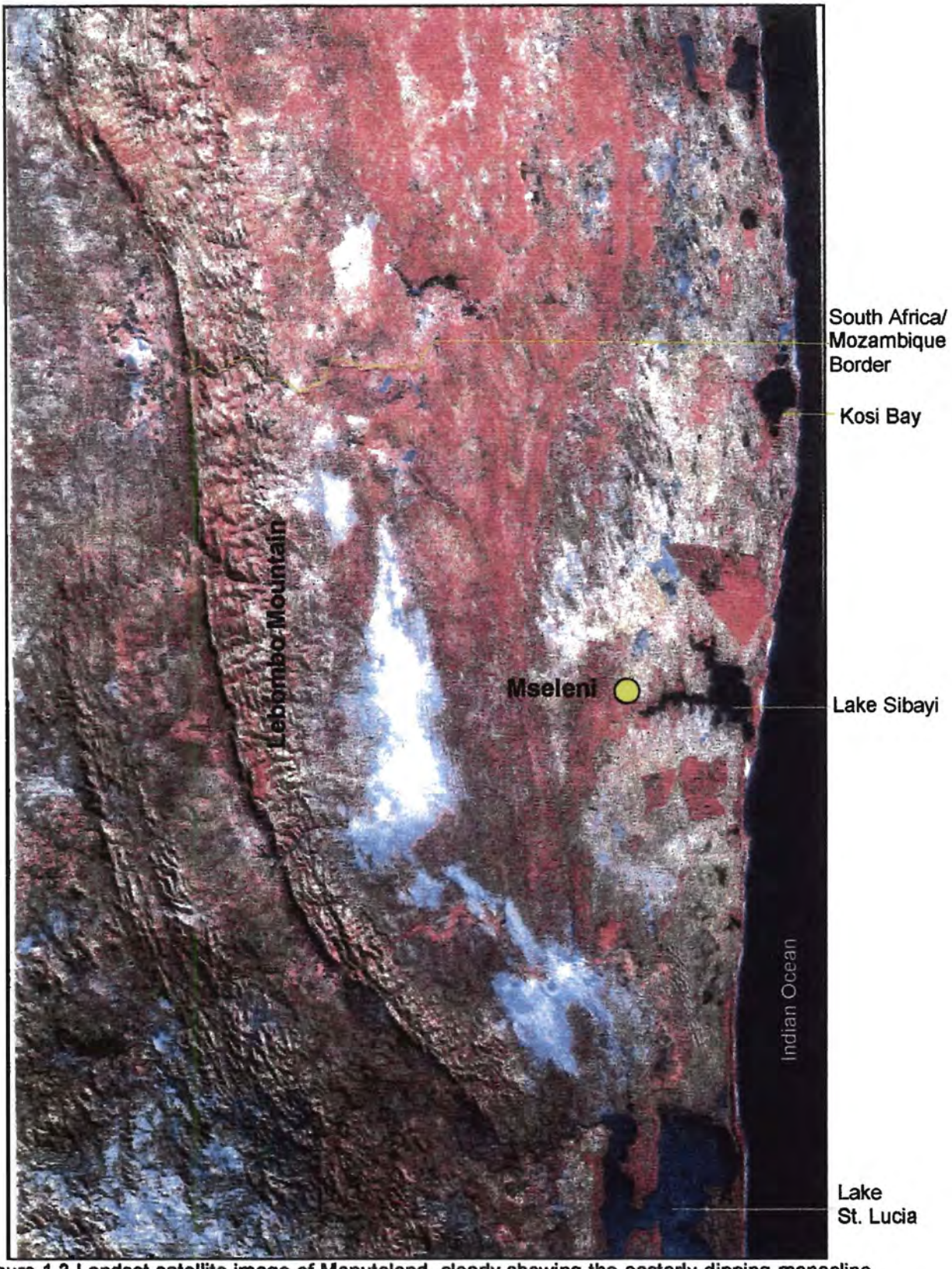

Figure 1.3 Landsat satellite image of Maputaland, clearly showing the easterly dipping monocline of the Lebombo Mountain Range on the left, with the Pongolo River running northward to Moçcambique along its right edge, and the flat topography of the Quaternary sediments extending east of the Lebombo mountains to the Indian Ocean.

From this point onwards a series of Quaternary glacial regressions and transgressions are responsible for the shifting sea level and changing wind patterns with consequent reworking and redistribution of cover sands and formation of coastal dunes (Tinley, 1985). The glacial periods caused decreased sea temperatures, which inhibited rain development and increased wind velocities. This resulted in minimal sediment transfer to the coast and maximum reworking of exposed sandy surfaces with major dune building during marine regressions. Interglacial periods were typified by increased temperature and precipitation, and with lowered wind velocities. The rising sea level submerged coastlines and higher river flow caused sedimentation of river mouths.

The gradually eastward moving coastline resulted in a system of north-south longshore dunes developing from the reworked Port Durnford Beds and it is these six paleo-dune cordons that typify the current landscape of the Maputaland Plain (Hobday, 1979). Subsequent weathering has altered the character of these deposits and which will be discussed in the later section dealing with soils. Associated with the alternating coastline are a series of calcarenites, wave cut terraces, beach sandstones and conglomerate deposits.

The present coastline comprises a very young high coastal dune system that reaches heights of up to 200 m (Hobday, 1979; Tinley, 1985). These dunes are a relict of a lower sea level, as the current beaches are too narrow to provide adequate sand while the wind regime is destructive. This dune system has resulted in a blockage to eastward water flow from the Lebombo Mountains, with subsequent infilling of former estuaries, such as Lake Sibayi, and the northward progression of rivers. The Pongola River, which had a previous outlet through Lake Sibayi, now flows 160 km north and captures the eastward flow of the Usutu and Ingwavuma Rivers before reaching the sea at Baia de Maputo in Moçambique.

1.2.4 Biology

The vegetation varies markedly across the Maputaland plain and includes abrupt changes related to climate and soils (Moll, 1980). The region is recognised as a "hot-spot" in that it has high species richness, high concentrations of endemic species and high rates of habitat modification and loss (Cowling and Hilton-Taylor, 1994). The coastal plain comprises fifteen major types of vegetation communities (Moll, 1980). These include a variety of forest, savannah, grassland, palmveld, thicket, swamp and floodplain vegetation. The distribution of vegetation types within the plain follows the same pattern as rainfall, in that it occurs in strips running parallel to the coast.

Lake Sibayi is the largest fresh water coastal lake in South Africa and has a conspicuous presence in the Maputaland region (Whyte, 1999). As indicated in the geology section it represents the drowned river valley of the Pongola River and maintains clear residual signs of

its estuarine origin. It is sporadically fed by the intermittent Mseleni River and is essentially an extension of the high watertable found in the plain. It is unique in that it is a near-pristine oligotrophic-mesotrophic freshwater coastal lake with N, K, P, Mn, Zn and Cu all suggested as being limiting to the primary productivity of the lake (Whyte, 1999).

1.3 SOILS OF MAPUTALAND

The soils of the Maputaland Plain can be divided into two types: those derived from alluvial deposition along rivers and in low lying depressions, and those weathered from aeolian deposits. Although the soils formed from both types of parent material will be considered here, the greatest emphasis will be placed on the formation and properties of the aeolian sands, as they are the main focus of this study.

On the western edge of the Coastal Plain, in the Lebombo foothills (Fig. 1.3) occur soils formed from rhyolite and dolerite. These soils are not generally included in surveys of Maputaland, but are mentioned here because of their potential as amendment material due to their higher fertility. Deep clay soils of the Arcadia, Bonheim and Rensburg forms occur on doleritic parent material. Due to the high clay and the total elemental concentrations of the doleritic rock (Eales *et al.*, 1984) these soils have high exchangeable concentrations of elements that are not found in the local sandy soils and are dominated by montmorillonitic clay material (Beater, 1950).

Along the fringes of the Pongola River, which runs north along the footslope of the Lebombo Mountains (Fig. 1.3), alluvial terraces and extensive pans are found (Maud, 1980). There are also protrusions in this area of the underlying Cenozoic sediments, particularly the Cretaceous conglomerates, but there are no reports of soils formed from these materials. The main soils formed in the alluvium along the Pongola River are the Msinga, Shorrocks, Makatini, Rensburg, Glendale and Sunvalley series (Hensley, 1969). The Msinga, Shorrocks and Makatini soils are similar in that they are medium textured, structureless, highly permeable and have high cation exchange capacities and exchangeable nutrients, and any clay present is dominated by montmorillonite (Hensley, 1969). The Glendale soil is a fine, sandy clay loam to fine, sandy clay with moderate permeability, a sharp increase in the exchangeable sodium percentage (ESP) from 4.3 to 9 and is dominated by kaolinite. The dark brown, sandy clays have slow permeability, strong structure, a sharp ESP increase from 15 to 40, the presence of calcite concretions and is dominated by montmorillonite. The Rensburg soil has a high clay content, slow permeability, a high ESP and a fairly high salt content throughout. It is also characterised by calcareous concretions below 10 cm and the presence of slickenslides, indicating that montmorillonite is the dominant clay present.

Along the terrace between the Lebombo Mountains and the Pongola River there has been some aeolian deposition. In this free draining position it has weathered to form red, apedal, sandy clay loams to clays of the Hutton form (Hensley, 1969). These soils are medium- to coarse-textured, freely drained, with poor structure and are very low in soluble salts (Hensley, 1969). They are composed of a light brown sand over a deep horizon of deep brown, red sand representing a zone of accumulation, and overlying a yellowish brown substratum (Beater, 1950). The Hutton soils have a higher fertility than the grey Fernwood sands and are known to produce better crops (Croft, 1969).

The extensive pan system that occurs throughout the Maputland Coastal Plain, which is known as the Mosi Swamps, is typified by the accumulation of black clay in low-lying depressions (Hensley, 1969). These are referred to as the mudpans or bottomlands. The swamps are saturated with water for several months, and in wet years can be full the entire year, and are up to 4.5 m deep and 30 to 150 m wide (Hensley, 1969). The soil found within the pans are classified in the Rensburg form (Hensley, 1969). Most are neutral with a pH_{H_2O} of near 7 (Beater, 1950; Hensley, 1969; Pooley, 1997), although some are acidic with pHs of 4 being observed (Hensley, 1964). They have high cation exchange capacities of between 22 and 44 meq per 100 g, and a high clay content that is consistent with depth and has been observed to be between 40 and 63% to 3 m (Hensley, 1964; Hensley, 1969). These soils are farmed successfully by local farmers, with some using the material as an amendment on nearby soil with lower fertility (Beater, 1950).

Along the coast under the thick swamp forests at Kosi Bay, Lake Sibayi and Lake St Lucia deep organic soils are found. These belong to the Champagne form and, due to their high organic matter content, are relatively fertile and have a high moisture holding capacity (Louw, 1984). Drainage systems are set up with mounds and the soils are used mainly for banana crops, as well as vegetables. These soils offer some of the most productive farming on the eastern rim of the Maputaland Plain.

The vast portion of the Maputaland coastal plain soils are derived from aeolian sands, with a total area of about 1 000 000 ha of sandy soils occurring in Natal (Beater, 1950). The entire Maputaland Plain comprises almost exclusively Fernwood soils, which are the poorest soils in the area in terms of fertility (Beater, 1950). The red Hutton soils which are found mainly on the higher terraces near the Pongola River, mentioned previously, do occur to a small degree within the plain, but are still freely drained and in slightly higher positions. The other soils in this region are the younger coastal dunes and some soils formed from aeolinites MacVicar *et al.*, 1984). A unique occurrence in the coastal sands of this region is the large amounts of heavy mineral deposits of ilmenite, rutile and zircon (Beater, 1950) which are mined extensively further south along the coast near Richards Bay.

The Fernwood soils are grey sands, highly leached, with pH values between 6.8 and 4.4, a low cation exchange capacity of 2 to 3 meq per 100 g and are dominated by kaolinite in the clay fraction (Hensley, 1969; Beater, 1950). Various researchers have shown the Fernwood sands to be deficient in most elements including N, P, K, S, Ca, Cu, Zn and B (Lonsdale, 1970; Sumner, 1970; and Pooley, 1997).

The general processes that allow pedogenesis to occur in coastal aeolian sands begin with the stabilisation of dunes by plants. Carbonates and bases are leached out and over time an acidification process occurs, which is offset to some degree by marine aerosol deposition of Ca, Na, Cl and to a lesser degree Mg, K and P, and the recycling of bases by deep-rooted woody plants (Tinley, 1985). Carbonate material which is transferred downward in the profile can accumulate and cause cementation of sand or complete decalcification of the profile, both of which are observed in Maputaland (Tinley, 1985; Beater, 1950). The accumulation of plant material results in the release of hydrogen ions from humic acids, which has an acidifying affect.

The change from an alkaline to an acidic environment, brought on by leaching of bases and the effects of humus accumulation, results in a corresponding alteration in the chemical behaviour of elements. In an alkaline environment deficiencies of Co, Cu, Fe, Mn, Zn, B, P and K are common, due to either insolubility or inhibition of availability (Tinlely, 1985). Deficiencies of Zn, Cu, B, K, and P, commonly found in Maputaland soils (Lonsdale, 1970; Sumner 1970; Pooley 1997) are exacerbated by a high pH. Under acid conditions it is more common to find deficiencies of P, Zn and Cu (Sumner *et al.*, 1991) and toxicities of Mn and Al (Sumner, 1970). Aluminium toxicity can cause poor root development as has been observed in local soils (Sumner, 1970), even though these soils are generally known to have no physical barriers to root development, unless a cemented layer is encountered (Hensley, 1969). Waterlogged conditions in the Mosi swamps result in high concentrations of extractable Mn and Fe which can cause toxicities (Staples, 1993).

Coastal sands are often found to be hydrophobic (Tinley, 1985) due to the accumulation of plant waxes and the presence of fungal mycelea (Dekker, 1998). This results in surface runoff, uneven water infiltration and patchy germination (Tinley, 1985; Dellar, *et al.*, 1994), which lend to poor crop production.

Some variability is expected in the chemical properties of the sandy coastal soils although they are essentially derived from the same parent material; natural variation is observed in coastal aeolian soils due to the inshore availability of shell fragments or lime sediment at beach and river mouths (Tinley, 1985). The result is a mosaic pattern of acidic and calcareous sands throughout the landscape (Tinley, 1985). Variation in chemical parameters

were observed in a study of soil properties through two transects of the Maputaland sands (Pooley, 1997).

The loose packing and porous nature of sands cause them to be well aerated and to exhibit seasonal and daily temperature changes, being hot during the day and in summer and cool during night and in winter. The mean soil temperature within 30 cm of the surface in a Natal soil is 22.2 °C with a range of 8.5 °C (Beater, 1950). Due to high temperatures in Maputaland it is estimated that the surface temperature of soil will rise to over 32.2 °C on hot days and even frequently exceed 37.7 °C (Beater, 1950). Sands are poor conductors of heat and have a markedly temperature decrease from the surface inwards. Because they reach high temperatures during the day and are then rapidly cooled in the evening, if the temperature falls below the dew point, internal dew formation can occur (Tinley, 1985). This can serve as an important form of moisture availability during drought periods.

The distinguishing feature of the sandy soils of the Maputaland Plain is their red or grey colour. Luminescence dating has shown these soils to be of a similar age (Maud, personal communication) so the colour difference cannot be accounted for by a difference in source material or a difference in weathering regimes as was previously thought (Beater, 1950). The variation in colour is due to differing topographic positions and their resulting hydrological conditions. Red soils form as a result of weathering of feldspars and heavy minerals and subsequent precipitation of hydrous oxides on the silicate surface (Tinley, 1985; van Huyssteen and Ellis, 1997). Under anaerobic conditions iron is reduced to a more soluble form and is then removed form the soil profile through leaching, resulting in grey sands (Tinley, 1985). This soluble iron can be deposited lower in the profile resulting in concretions, which are found scattered throughout the grey Maputaland sands, as laterites and podzols (Beater, 1950). Free iron oxides have a high aggregate stability which enhances the coherence of the sand and increases the resistance to erosion (Tinley, 1985) and the red Hutton soils are observed to have better soil structure than the grey Fernwood sand (Beater, 1950).

In addition to poor soil fertility and climatic constraints, poor yields have been attributed to the effects of pests and diseases on plant growth in Natal sands (Channon and Farina, 1991; Roe, 1994; Croft, 1969; Thompson, 1983). No soil microbiological studies have been completed on these sands, but they are known to have high populations of soil nematodes. The most common genus of nematode in soils of Natal sugarcane fields with poor plant growth is *Meloidogyne* with an occurrence of 89% (Thompson, 1983). The occurrence of other nematodes parasitic to sugarcane are 91% *Pratylenchus*, 45% *Xiphinema* and 86% *Trichodorus* in sandy soils of Natal (Thompson, 1983). Stalk and root rot has been shown to decrease yields of maize in Natal, caused primarily by *Stenocarpella maydis*, *Fusarium* sp., *Phaeocytostroma ambiguum*, *Macrophomina phaseolina* and *Colletotrichum graminicola*, and

with some indication of extreme root rot from *Exserohilum pedicellatum* and *Phialophora zeicola* (Channon and Farina, 1991). Field trials in Maputaland had decreased maize yields due to bacterial infection by *E. carotovora* (Croft, 1969) and flower disease of cashew from *Oidium anacardii* and *Colletotrichum gloeosporioides* (Roe, 1994). Field trials in Maputaland have also suffered from streak disease due to *Balclutha mbila*, cobworms causing a low shelling percentage in maize due to *Heliothis armigera*, and stalk rot from *Erwinia cartovora* f. sp. *zeae* (Lonsdale, 1970). Even if the fertility aspect of the Maputaland sands is overcome poor crop yields may still occur due to plant disease, and although healthier plants have increased resistance to disease, this issue must be addressed in any crop production management programme.

Additional considerations for crop production besides the low fertility status include wind erosion, surface crusting, low moisture holding capacity and rapid percolation (Hensley, 1969). Due to the pattern of rainfall events this last factor is important as excessive leaching of nutrients is likely, as has been observed with applications of water soluble fertililser on Maputaland soils (Hensley, 1969; Lonsdale, 1970; and Croft, 1969). These factors will not be addressed in this study but should be kept in mind for future field based trials.

1.4 AMELIORATION STUDIES

The idea of clay amelioration is not a new one, with references dating as far back as 372 B.C when Theophrastus suggested mixing different soils as a means of "remedying defects and adding heart to the soil" (Tisdale *et al.*, 1985). The idea has also been applied locally as there are references of farmers in Maputaland removing black clay from depressions and scattering it over the land with beneficial results (Beater, 1950). Termite mounds also known to increase soil fertility when spread on adjacent nutrient deficient soil (Watson, 1977; Fraser, 1993) and superior growth has been reported for sugarcane grown on termitaria in comparison with adjacent plants on a Fernwood sand in Natal (Thompson, 1983).

Internationally clay application has proved to be successful in increasing crop yields in both large and small scale farming (Dellar *et al.*, 1994; Reuter, personal communication). Clay application was initially investigated in Australia as a means of overcoming hydrophobicity and causing even germination (Carter *et al.*, 1998) but was found to be an economically feasible means of increasing crop yields as long as a local source of clay was available (Mann, 1984). Crops yields have been doubled with clay application rates varying from 100 to 250 t ha^{-1} for sandy soils and 40 to 100 t ha^{-1} on sandy clays (Mann, 1984), while on small scale plots a rate of 5 kg m^2 was found to be successful (Reuter, personal communication). Benefits of clay application include increased effectiveness of pre-emergent herbicides, improved germination, increased water permeability, moisture retention, soil nutrient concentrations, pH, cation exchange capacity and better crop yields (Gillman, 1980; Mann,

1984). Proper incorporation of the clay material into the top ten to fifteen centimetres of the soil surface has been found to be essential to achieve the greatest benefit (Mann, 1984). Kaolinitic clays reduce water repellency more than bentonite and smectite (McKissock, 1998), while montmorillonitic clays produce the greatest fertility benefits (Reuter, personnel communication).

Studies on the effect of crushed rock addition have shown similar results to that of clay (D'Hotman de Villiers, 1961; Gillman, 1980). The addition of crushed basalt to Oxisols in Australia resulted in increased soil pH, cation exchange capacity, Ca, Mg and K, and with all parameters increasing over a period of twelve months (Gillman, 1980).

Clay application is a sustainable technique in that the applied nutrients are not readily leached and the increased fertility is maintained long term (Reuter, 1999), with some studies showing improved pasture production for at least thirty years (Carter *et al.*, 1998). The objective of this study was to quantify the results of crushed rock and clay amendment so that a sound fertility management programme can eventually be recommended to local farmers based on field trials.

1.5 CONCLUSIONS

There is abundant evidence that the grey sands of Maputaland are deficient in multiple elements. There is also an indication that amendment with an inexpensive, locally available material may be successful in improving crop yields. It is with the intention of manipulating geochemical conditions to enhance human nutritional standards in an area with a high incidence of disease that the following is undertaken. This thesis comprises an exercise to chemically quantify the fertility aspect of increasing the clay content of the soil.

CHAPTER 2

FERTILITY ASSESSMENT OF A FERNWOOD SOIL BASED ON MAIZE RESPONSE TO NUTRIENT AMENDMENT

2.1 INTRODUCTION

Nutrient availability in Fernwood soils from Maputaland has been the subject of previous studies (Lonsdale, 1970; Sumner, 1970; and Pooley, 1997). However, due to the spatial heterogeneity of available nutrient concentrations within this landscape (Pooley, 1997) it is essential to make a specific assessment of the soil collected for the present study. The purpose of this fertility assessment was to provide a basis for designing the subsequent trial aimed at alleviating nutrient deficiencies using locally obtainable mineral amendments. The subtractive growth trial was selected as the most appropriate technique for this initial fertility assessment.

Subtractive growth trials involved a procedure in which a supposedly ideal suite of elements is applied to the soil as a complete treatment, with additional treatments testing the effect of withholding one element at a time from the complete treatment. This single-element omission technique helps to determine the capacity of the soil to provide the withheld nutrient to plants by observing the effect of withholding each element on plant growth, as well as on soil and foliar composition. As discussed in Chapter 1, these types of trials have already been used to study nutrient related problems in similar soils of the study area (Croft, 1969; Lonsdale, 1970; Sumner, 1970; and Pooley, 1997).

Although field trials are ultimately a more reliable method of assessing soil fertility their use at this stage would be premature because it is first necessary to determine experimentally if the remediation trials have the potential for in-field success. The scope of this study has been restricted to the use of pot trials in a controlled environment which will serve as a basis for field experiments in future.

In this chapter, the grey Fernwood sand selected for plant growth trials will be geochemically characterised and compared with a red sand from the same area in order to broaden the potential scope for applying the results of the soil fertility trials. The remainder of the chapter is devoted to the fertility assessment of the Fernwood soil using subtractive growth trials.

2.2 MATERIALS AND METHODS

2.2.1 Soil sampling and preparation

A one-day sampling exercise was carried out on July 25th 1998, during which the grey and red sand samples were obtained for geochemical analysis, and the grey sand also for use in both the subtractive and amendment growth trials.

A typical grey sand representative of the nutrient deficient sands in Maputaland was sampled, with an orthic A horizon over a thick E horizon diagnostic for the Fernwood form (Soil Classification Working Group, 1991). The sample came from an uncultivated field about 8 m from the eastern side of the north-south road between Phelandaba and Mseleni, 2 km south of the intersection with the eastward road to Kosi Bay (Fig. 2.1). A profile was dug, the appropriate characteristics noted (Appendix 2) and 75 kg soil obtained from between 0 and 25 cm (Fig. 2.2).

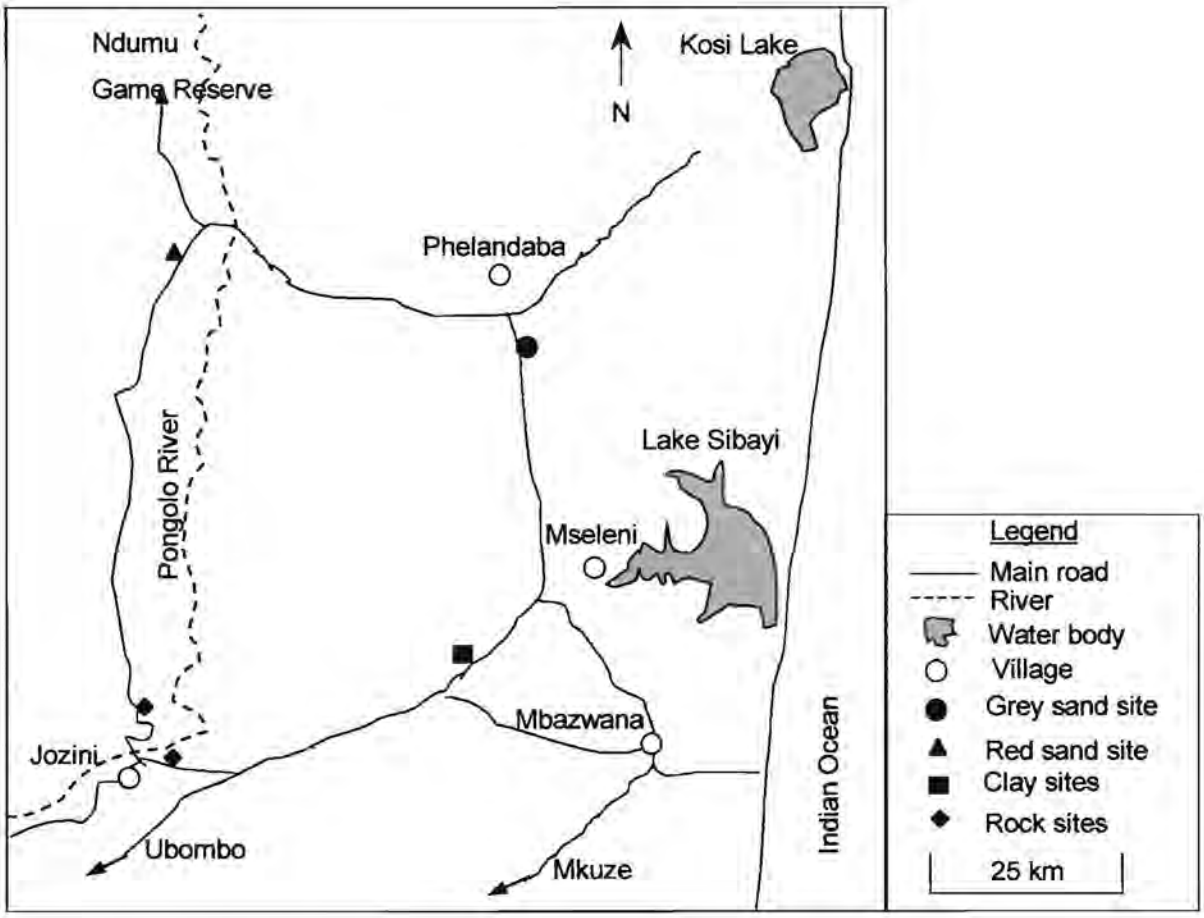

Figure 2.1 Site sampling localities within Maputaland of soil, clay and rock samples used in the subtractive and amendment growth trials.

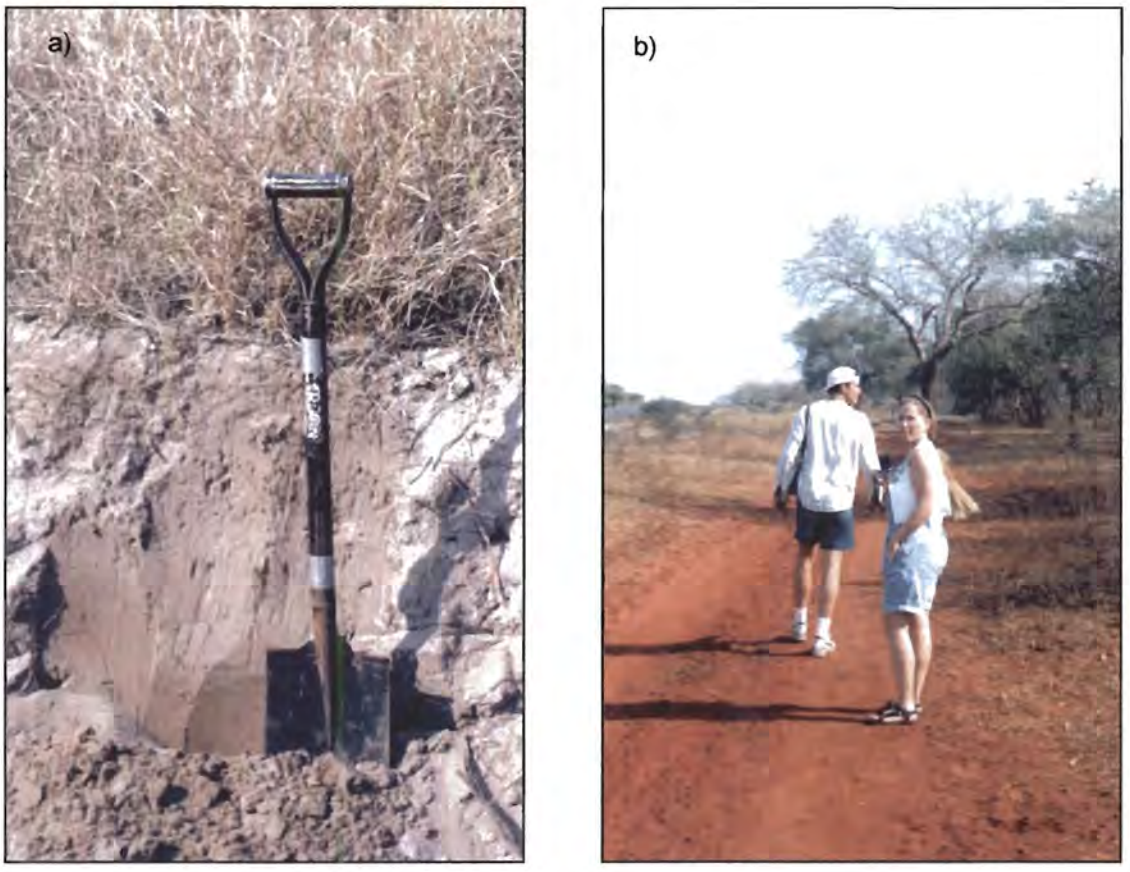

Figure 2.2 a) Soil profile of the grey Fernwood sand, the distance between silver tape on the shovel handle is 50 cm; b) Exposed surface of the red Hutton sand.

For comparative purposes and in order to widen the potential applicability of soil fertility experiments on the Fernwood soil, a sample of red, sandy soil was obtained from a higher elevation to the west (Fig. 2.2). This was near Lake View, about 11 m west of the north-south road between Jozini and Ndumo, and 6 km south of the Ndumu Game Reserve turnoff (Fig. 2.1). Two kilograms of soil was taken from between 0 and 25 cm (Appendix 2).

The soil was spread over a large plastic sheet and allowed to air-dry for 24 h, after which it was quartered, thoroughly mixed and passed through a 2 mm stainless steel screen.

2.2.2 Growth trials

2.2.2.1 Soil preparation

The grey Fernwood sand was used for the growth trials. For watering purposes the water holding capacity (WHC) was determined according to the "sticky point" method, which is based on the preparation method for a saturation extract (Rhoades, 1982). For details see Appendix 1. This soil was determined to have a WHC of 117 g water kg^{-1} soil, which is consistent with published levels (Hensley, 1966).

2.2.2.2 Nutrient solutions

The subtractive trial consisted of one treatment with all of the elements desired included in a nutrient solution, called the complete treatment. The complete treatment included N, P, K, Ca, Mg, S, B, Mo, Cu, Mn, Zn and Fe and was prepared at the concentrations and with the constituents listed in Table 2.1. Additional solutions were made in which each element was withheld from the full nutrient suite, so that there was a treatment representing the complete nutrient suite minus one element for as many of the elements as required. Those elements withheld in Subtractive Trial 1 were P, Ca, Mg, S, Mn, Fe, Cu, Zn, B, and Mo. In some instances, where one element was withheld it was necessary to add a new compound to provide the counter ion that was also removed. For example, in the -Ca treatment withholding $CaSO_4 \cdot 2H_2O$ requires another compound to provide S. The substitutions used are listed at the bottom of Table 2.1. The total number of treatments in this trial was 12 including the complete and control; in triplicate this resulted in a total of 52 pots (the minus P and minus Mo treatments were doubled to six pots each to determine the precision of the experiment) (Table 2.2).

The nutrient solutions for each treatment were made up in two separate parts. First basal solutions containing the necessary NPKS salts (Table 2.1) were made. There were four basal solutions: a complete, -Ca (to supply more S), -P and -S treatments. The remaining nutrients were made up into 11 separate solutions, for the one complete and ten subtractive treatments. Both the basal NPKS and subtractive solutions were made up to a concentration such that 20 ml of solution could be applied per pot.

Based on the results of the first subtractive growth trial a second trial was necessary to try to achieve a better balance of nutrients. The rates, chemical forms and substitutions used in the second trial are also presented in Table 2.1. This smaller growth trial consisted of a complete, a control and subtractive treatments for only K, Ca, Mg, Zn and B. This resulted in eight treatments (the -Ca treatment was replicated with a different S source) and, in triplicate, 24 pots in total (Table 2.2).

Table 2.1 Rates of elemental application, forms of chemicals applied and substitutions used in Subtractive Growth Trials 1 and 2.

Element	Application Rate		Chemical Form	
	Trial 1	Trial 2	Trial 1	Trial 2
	mg kg^{-1}			
N	100	100	NH_4NO_3	NH_4NO_3
P	20	20	$NaH_2PO_4 \cdot 2H_2O$	$NaH_2PO_4 \cdot 2H_2O$
K	100	60	K_2SO_4	KCl
S	160	120	K_2SO_4, $CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
Mg	50	25	$MgCl \cdot 6H_2O$	$MgCl \cdot 6H_2O$
Ca	150	150	$CaSO_4 \cdot 2H_2O$	$CaSO_4 \cdot 2H_2O$
B	4	1	$Na_2B_4O_7$	$Na_2B_4O_7$
Mo	2	2	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$
Cu	3	3	$CuNO_3$	$CuNO_3$
Mn	3	3	$MnNO_3$	$MnNO_3$
Zn	3	3	$ZnNO_3$	$ZnNO_3$ & $(CH_3COO)_2Zn \cdot 2H_2O$†
Fe	3	3	$[CH_2N(CH_2COO)_2]FeNa$	$[CH_2N(CH_2COO)_2]FeNa$
Treatment			Substitution	
-S			KCl, $CaCl_2$	
-Ca			$Na_2S_2O_5$	Na_2SO_4
-Ca2				$Na_2S_2O_5$

† This form of Zn was used for the Full treatment only in this trial.

Lower application rates were used in Subtractive Growth Trial 2 for B, K, Mg, and S (Table 2.1). The B rate was found to be excessive in the first growth trial and was accordingly stepped down for the second. Potassium was applied as KCl to keep the S rate from going above the desired application rate. Sulphur was applied in the oxidised form for the -Ca treatment and in the reduced form for the -Ca2 treatment, to determine whether the more reduced form of S applied in the -Ca treatment in Subtractive Trial 1 may have had a detrimental effect on plant growth. It was also necessary to apply the Zn as $(CH_3COO)_2Zn \cdot 2H_2O$ for the Full treatment only. Other than these differences the procedures outlined for the first growth trial were followed for the second growth trial.

Table 2.2 Treatments included in Subtractive Growth Trials 1 and 2.

Trial	Treatments
1	-P, -Ca, -Mg, -S, -Mn, -Fe, -Cu, -Zn, -B, -Mo, Full and Nil
2	-K, -Ca, -Ca2, -Mg, -Zn, -B, Full and Nil

2.2.2.3 Potting

Six hundred grams of soil was weighed into non-draining plastic pots with a soil surface radius of 4.76 cm, and therefore a surface area of 72 cm^2, a basal radius of 4.25 cm and soil depth of 5.25 cm. Each container of soil was transferred to a separate, labelled plastic bag into which the solid gypsum was first added, where applicable, and thoroughly mixed. Next, 20 ml of the appropriate basal solution was added and thoroughly mixed. Twenty millilitres of the subtractive solution was then added in the same manner. Finally, 30 ml of distilled water was added by weight and mixed, to bring the soil up to field capacity (WHC, as described in section 2.2.2.2.1). The soil was then transferred back to the original container. For the Nil treatment with no fertiliser added, the pot was simply brought to field capacity by adding 70 ml distilled water.

Six seeds of commercially available white maize (*Zea mays* L., cultivar PAN 6671) pre-soaked in distilled water for 24 h, were placed on top of the soil, five in a circle one centimetre from the edge of the pot and one in the centre. The seeds were pressed down to a depth of 2.5 cm with a marked glass rod and then covered with soil.

2.2.2.4 Growth conditions and harvesting

The pots were transferred to a growth chamber in the phytotron unit of the Botany Department, University of Cape Town (UCT) and set out in a randomised manner. The conditions of the phytotron were set to be similar to the summer climate in Maputaland. The day length was set at 14 h and the temperature was stepped up in half an hour intervals between 0600 and 0700 h from 19 to 30 °C, and down again between 1900 and 2000 h. Photosynthetic irradiance was set at 600 W m^{-2}, and was stepped up from 0 at the same time as the temperature adjustment, and relative humidity maintained at 50%.

The pots were kept covered with moistened paper towels until germination. Five days after germination the four plants with the best growth were retained in each pot and the other two removed by cutting the stem 1 cm above the soil. The plants were watered to field capacity daily with distilled water. This was done by mass with a balance in the chamber, and pot positions were then randomly rotated to minimise any effect of spatial heterogeneity. Once the plants were big enough to transpire large quantities of water it was necessary to water them twice a day, once in the early morning and again at the end of the day.

The plant growth period was six weeks, after which the plants were harvested by cutting the stem 1 cm above the soil. The harvested plants were placed in brown paper bags with small aeration holes and dried for 72 h in a ventilated oven set at 70 °C. Once oven-dried, the plants were transferred to plastic bags and weighed to determine yield.

2.2.3. Soil Analysis

After harvesting the remaining seeds from the two aborted plants were found and removed by noting the place in the original six seed pattern that had no maize plants. The roots from each pot were then removed by gently pulling and shaking the roots out. The roots were held above the soil and distilled water was used to rinse off any adhering soil. The soil was air dried prior to analysis.

Analyses included pH in deionised water and 1 *M* KCl at a 1:2.5 soil to solution ratio (NASAWC, 1990; McLean, 1982). Chemical analysis of the red and grey soils was performed by an external laboratory at the Institute for Fruit Technology (Infruitec) in Stellenbosch. Organic carbon was determined by the Walkley-Black method (NASAWC, 1990; Nelson and Summers, 1982). Total extractable acidity (H and Al) was determined by a modified version of the 1 *M*, pH 7 Eksteen method (Eksteen, 1969). Extractable P was analysed by the Bray-2 method (NASAWC, 1990; Olsen and Sommers, 1982), extractable major cations (K, Ca, Mg and Na) by extraction with 1 *M*, pH 7 NH_4OAc (NASAWC, 1990; Knudsen *et al.*, 1982), inorganic S by extraction with 0.01 *M* $Ca(H_2PO_4)_2$ (NASAWC, 1990; Tabatabai, 1982), extractable trace elements (Fe, Mn, Cu and Zn) by extraction with 0.02 *M* $(NH_4)_2$-EDTA (NASAWC, 1990) and extractable B by ethanol-0.02 *M* $CaCl_2$ extraction (NASAWC, 1990; Bingham, 1982). The extracted concentrations of elements were measured by inductively coupled plasma atomic emission spectometry (ICP-AES). The methods of soil and plant analysis are included in brief in Appendix 1.

For comparative purposes within this study and also as an indication of the variability of extractable nutrient concentrations when different extraction techniques are used, the grey sand was also sent for analysis at the Cedara Agricultural College, managed by the KwaZulu-Natal Department of Agriculture. The pH in 1 *M* KCl was determined in a 1:2.5 soil to solution ratio (NASAWC, 1990; McLean, 1982). Extractable acidity (H and Al), Ca and Mg were analysed by the 1 *M* KCl extraction method (NASAWC, 1990; Thomas, 1982). The extractable acidity was determined by titration with 0.01 *M* NaOH, while Ca and Mg were determined by atomic absorption spectrometry (AAS). All other extractable elements (P, K, Zn and Mn) were determined by the AMBIC-2 method (Farina *et al.*, 1992) with P being determined colorimetrically and the remaining elements by AAS.

Total element concentration was determined by wavelength dispersive X-ray fluorescence spectroscopy (WDXRFS) in the Department of Geological Sciences, University of Cape Town (Jones, 1982). Fusion discs were prepared for the analysis of major elements (Fe, Mn, Ti, Ca, K, P, Si, Al and Mg) by the method of Norrish and Hutton (1982). Powder briquettes were prepared for the analysis of trace elements (Zn, Cu, Ni, Co, Mn, Cr and V). For particle size analysis the standard Bouycous Hydrometer method was used (Gee and Bauder, 1986).

2.2.4 Plant tissue analysis

Oven-dried plant tissue was sent for analysis at the Institute for Fruit Technology (Infruitec) in Stellenbosch, where it was ground and sieved through a 0.84 mm screen. One gram of this material was ashed at 480 °C for 8 h, to remove organic material. The ashed sample was then digested with dilute HCl and the resulting solution analysed by ICP-AES for P, K, Ca, Mg, S, Mn, Fe, Cu, Zn and B (Jones and Case 1990). For N determination a total combustion procedure was used with determination by a thermal conductivity cell (Jones and Case 1990).

2.3 RESULTS AND DISCUSSION

2.3.1 Soil characterisation

The grey sand was classified as a thermic, uncoated, Typic Quartzipsamment (Soil Survey Staff, 1992), and in terms of local classification was placed in the Waterton family of the Fernwood form (Soil Classification Working Group, 1991). It will henceforth be referred to as the grey sand or Fernwood sand.

Although a full soil profile was not described for the red, sandy soil, from what was observed at the soil sample site it was provisionally classified as a thermic, coated, Typic Quartzipsamment (Soil Survey Staff, 1992) and in the Lillieburn family of the Hutton form (Soil Classification Working Group, 1991). This soil is henceforth referred to as the red sand.

The main distinction between the red and grey sands on a textural level is the significantly greater silt plus clay fraction of the red sand (Table 2.3). The grey sand is strictly classified as a sand while the red "sand" is technically a loamy sand (Soil Survey Staff, 1992). The red colour is due to free drainage allowing iron to have been removed from the silicate structure and precipitated as hydrous oxides on grain surfaces (Beater, 1950). Even without this marked colour distinction it has been shown that there is a relationship between the percentage of fine particles and percent ferric oxide, with an increase in both indicating a more advanced degree of weathering (Beater, 1950).

Table 2.3 Particle size distribution of the red and grey sands.

Sample	Clay	Silt	Fine sand	Medium sand	Coarse sand
	< 0.002 mm	0.002–0.02 mm	0.02–0.2 mm	0.2–2.5 mm	0.5–2.0 mm
			%		
Red sand	7.5	3.8	21.4	65.6	1.7
Grey sand	2.3	1.8	19.2	70.7	6.0

The extremely coarse nature of both soils renders them likely to be highly permeable with low water holding capacities. This was found to be the case by Lonsdale, Croft and Hensley (1970; 1969; and 1969) all of whom looked into the irrigation properties of soils within a portion of Maputaland. Both of these properties are factors that contribute to low agricultural production and which may be overcome with clay amendments, as has been successfully done in Australia (Dellar *et al.*, 1994).

Coarse textured soils generally have inherently low cation exchange capacities (CEC). This has been quantified as the sum of the reversibly adsorbed cations, also known as the effective cation exchange capacity (ECEC), which show low levels of 2.0 $cmol_c\ kg^{-1}$ for the grey sand and 2.8 $cmol_c\ kg^{-1}$ for the red sand (Table 2.4). Below an exchangeable base content of 5 $cmol_c\ kg^{-1}$ clay, soils are considered to be dystrophic, which implies a low base status or poor fertility. Low base status is evidence of marked leaching of exchangeable bases, and a combination of high permeability and low CEC in these sandy soils may result in poor nutrient retention. Leaching studies conducted on a Fernwood sand to determine the effects of irrigation found a high propensity for bases to be leached in these soils (Lonsdale, 1970).

The extractable acidity of the grey sand at 0.01 $cmol_c\ kg^{-1}$ is very low in relation to the ECEC value of 1.5 $cmol_c\ kg^{-1}$ (Table 2.4). This suggests that Al toxicity is unlikely, despite the fact that it has been identified in other, more acidic Fernwood sands of this region (Sumner, 1970). The pH_{H2O} and pH_{KCl} were found to be 7.0 and 6.0 for the grey sand and 6.5 and 4.5 for the red sand, respectively, confirming the anticipation that acidity and Al toxicity problems are likely to be negligible in both soils.

Table 2.4 Effective cation exchange capacity (Σ cations), acidity, pH_{H2O} and pH_{KCl} for the red and grey sands.

Sample	Σ cations	Acidity†	pH_{H2O}	pH_{KCl}
	$cmol_c\ kg^{-1}$			
Red sand‡	2.8	0.83	6.5	4.5
Grey sand‡	2.0	0.21	7.0	6.0
Grey sand§	1.5	0.01		

† Infruitec acidity = total extractable acidity by the Eksteen buffer method; Cedara acidity = exchangeable acidity with 1 *M* KCl extraction.
‡ Infruitec data; Σ cations = Na + K + Ca + Mg (Table 2.6).
§ Cedara data; Σ cations = K + Ca + Mg + H + Al (Table 2.7).

Total elemental analysis confirms that both the red and grey sand are mainly composed of Si and this is the only element with a higher concentration in the grey than the red sand (Table 2.5). Of the major plant nutrients, Mn is the most abundant in the red sand followed by Fe, Mg, Ca and K, whereas in the grey sand K is most abundant followed by Fe, Ca, Mg and Mn. The Mn and Cu concentrations of 31 and 2 mg kg^{-1}, respectively, for the grey sand are both well below the lowest values of 115 and 6 mg kg^{-1} found by Pooley (1997) in twelve similar soils of this region. Although it is difficult to make a comparison between total elemental concentrations and soil fertility levels due to the complex nature of dissolution processes involved (Gilkes, 1997), it can be surmised from the low total concentrations that these soils will have marginal reserves of available nutrients.

The organic C concentration of the grey sand is low, at 1.6%, while the red sand has a slightly higher content at 2.3% (Table 2.6). These are above the ranges established by Pooley (1997) and will help to promote the cation exchange capacity of these soils, as negative charges associated with the dissolution of acidic functional groups in organic matter are known to enhance the cation exchange capacity of soils (McBride, 1994). Most importantly the mineralisation of organic matter can release plant available N, P, S and trace elements.

A common approach when assessing soil fertility is to look at the concentration of extractable nutrients with respect to critical levels that have been derived from a correlation of nutrient concentration and crop growth (Sims and Johnson, 1991). Critical levels have been included in Table 2.6 for the Infruitec data, and Table 2.7 for the Cedara data, with respect to the appropriate extraction techniques employed. A more complete discussion of the behaviour of individual elements in terms of their availability in soils of this region has been presented by Pooley (1997). The analysis of the grey sand by the Cedara laboratory is included in Table 2.7 because a direct comparison is afforded between the present data and those of Pooley (1997) who employed the same extraction techniques.

Table 2.5 Total elemental nutrient concentrations determined by wavelength dispersive X-ray fluorescence spectroscopy for the red and grey sands, on a 100% volatile free basis.

Sample	Si	Ti	Al	Fe	K	Mn	Mg	Ca	P	Zn	Co	V	Cu	Ni	Cr
	%					mg kg^{-1}									
Red sand	42	0.6	1.7	1.9	0.4	2552	469	452	127	12	11	72	7	17	105
Grey sand	46	0.1	0.6	0.2	0.3	31	120	213	17	2	0	6	2	2	19

The grey sand has concentrations below critical levels for P, K, S, Cu, Zn and B (Table 2.6). For the red sand, the elements with concentrations below critical levels are S, Zn and B. Based on these results it can be anticipated that the subtractive growth trials will confirm multiple nutrient deficiencies in the grey sand, some of which may be different from those established by Pooley (1997).

In both the red and grey sands the Ca, Mg and Fe concentrations are all above the critical levels (Table 2.6), indicating an adequate level for plant nutrition, which is contrary to Pooley's finding of a Ca deficiency. In comparison with the red sand, the grey sand has lower extractable nutrient concentrations for all elements except Ca. This is in agreement with previous fertility assessments that have shown slightly higher nutrient concentrations in red sands which have resulted in significantly better crop production on red sands in comparison with grey sands (Croft, 1969). The Ca may be present in the landscape as a relict of the marine-calcareous nature of the soil parent material (Tinley, 1985). This, together with a sustained maritime influence through atmospheric deposition, could possibly account for the adequate Ca levels. Calcium deficiencies are rare in most agricultural crops and when they do occur are associated with very acid soils with low CEC (Lanyon and Heald, 1982). The critical level defined here is thus appropriate to acidic, sandy soils (Melsted, 1953) and has tentatively been used in the absence of any other published critical levels.

Table 2.6 Chemical characteristics including organic carbon and extractable P, K, Ca, Mg, S, Mn, Fe, Cu, Zn and B in the red and grey sands, together with levels considered to be approximately critical for adequate plant nutrition.

Sample	C	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	%	mg kg^{-1}									
Red sand†	2.3	8	83	480	126	1.9	155	54	0.7	0.3	0.1
Grey sand†	1.6	4	14	604	61	1.7	5.7	44	0.1	0.1	bdl‡
Critical level§		7	40	400	25	13	3.5	16	0.6	1.0	0.5

† Infruitec data; 1 *M*, pH 7 NH_4OAc extractable P; 0.01 *M* $Ca(H_2PO_4)_2$ extractable S; 0.02 *M* $(NH_4)_2$-EDTA extractable Mn, Fe, Cu and Zn; and 0.02 *M* ethanol-$CaCl_2$ extractable B.
‡ bdl = below detection limit.
§ Critical levels are from Olsen and Sommers(1982) for P; Haby *et al.* (1990) for K and Mg; Melsted (1953) for Ca; Wild (1988) for S; and Sims and Johnson (1991) for Mn, Fe, Cu, Zn and B.

Extractable nutrient concentrations in the grey sand as analysed by the Cedara laboratory are consistently lower than the average values but within the ranges established for 14 grey Fernwood soils by Pooley (1997) (Table 2.7). In particular, the Mn concentration of 0.7 mg kg^{-1} is extremely low. Due to the fact that AMBIC-2 extractable Mn concentrations are poorly

correlated with plant uptake (Smith and Paterson, 1995) there is no well defined threshold level with which to compare this. The mean value of 4.2 mg kg^{-1} was, however, considered low by Pooley (1997). In general, the results in Table 2.7 suggest that the deficiencies identified by Pooley (1997) for Ca, P, Zn and Cu from soil analysis and of Ca, P, Zn, Cu and B from plant tissue analysis and growth responses are also likely to prevail in the grey sand of the present study. This information will provide a useful backdrop against which to evaluate the results of the plant growth trials presented below.

Table 2.7 Chemical characteristics including organic carbon and extractable P, K, Ca, Mg, Mn, Fe, Cu, Zn and B together with levels considered to be approximately critical for adequate plant nutrition, with averages and ranges from Pooley (1997) for comparison.

Sample	C	P	K	Ca	Mg	Mn	Fe	Cu	Zn	B
	%	mg kg^{-1}								
Grey sand†		1.3	19	239	27	0.7			0.3	
Grey sand average‡	0.46	1.9	29	250	49	4.2	17	0.4	0.4	0.52
Grey sand ranges‡	0.3 – 1.5	0.3 – 15.6	3 – 114	30 – 630	10 – 160	0.4 – 15.3	4 – 36	0.1 – 1.0	0.1 – 1.8	0.25 – 0.91
Critical levels§			40	400	25	0.2 – 4.7	4.5 – 5.0	0.4 – 1.0	0.8 – 1.4	0.1 – 0.3

† Cedara data; AMBIC-2 extractable P, K, Zn, Cu, Fe and Mn; 1 *M* KCl extractable Ca and Mg; and 0.05 *M* ethanol-$CaCl_2$ extractable B.
‡ Average and ranges from Pooley (1997), also analysed at the Cedara laboratory.
§ Critical levels are from Haby *et al.* (1991) for K and Mg; Martens and Lindsay (1990) for Fe and Zn; Melsted (1953) for Ca; Smith and Paterson (1995) for Mn; Sims and Johnson (1991) for Cu; and Kabata-Pendias and Pendias (1985) for B.

2.3.2 Subtractive growth trials

2.3.2.1 Visual deficiency symptoms

Observation of plant growth in the grey sand throughout the six-week period revealed several nutrient deficiency symptoms. The Nil treatment in particular had obvious overall yellowing, interveinal chlorosis and reddish ribs in addition to dead tips and marked shortness in comparison with other plants, indicating multiple deficiencies probably dominated by a lack of N (Fig. 2.3). In the first three weeks of growth the –S and –Ca treatments were noticeably shorter than the other plants and the –S treatment had a general yellowing. Syptoms characteristic of Ca deficiency were evident in the –Ca treatment in the form of stunted growth with laddering and poor unfurling of upper leaves, the tips of which were adhered to the lower leaves. All the treatments except –B and –Mg had tissue necrosis at the tips, which may be

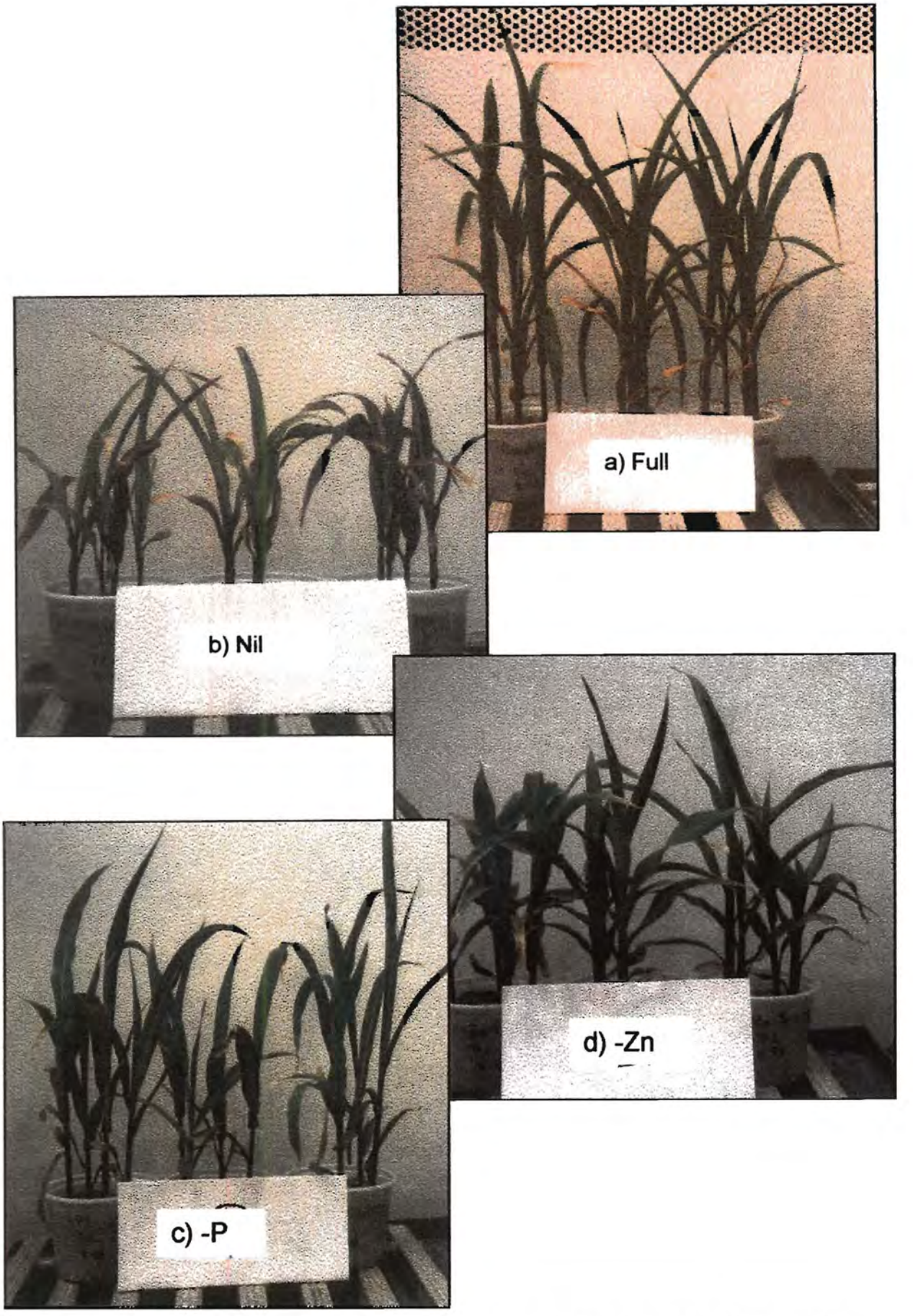

Figure 2.3 Examples of deficiency symptoms in six-week old maize of Subtractive Growth Trial 1 showing; a) Full treatment; b) Nil treatment; c) -P treatment; and d) -Zn treatment.

attributable to either K deficiency or B toxicity. The –P treatment had the typical P deficiency symptom of reddening of the leaf margins as well as die-back of older leaves, while the –Zn treatment had markedly shorted internodal growth indicative of a deficiency of this element (Fig. 2.3). Deficiency symptoms in the second growth trial were generally consistent with those in the first trial except that they were somewhat more pronounced in all treatments after six weeks. All the plants had a yellow appearance and the reddish P deficiency symptoms were more severe. There was no leaf tip necrosis in the second trial, as was present and possibly attributed to K deficiency or B toxicity in the first trial.

2.3.2.2 Yield

The relative yields of the –Zn, –Ca, –P and –S treatments were all below 80%, and the yield of the –S treatment was less than that of the Nil treatment (Fig. 2.4; data in Appendix 3). The relative yield was calculated by dividing each yield by the yield obtained from the Full treatment with a complete supply of nutrients. Theoretically this provides an index of the sufficiency or adequacy of each nutrient. Yields of the –Mg, –B and –Mn treatments were all greater than the Full treatment. The –Mg treatment was significantly so at 127%, while the –Cu and –Fe treatment yields were lower by only 5 and 8%, respectively, than the Full treatment (Fig. 2.5).

In assessing yield response, the purpose of evaluating yield values within the ranges of less than 80%, 80 to 90% and 90 to 110% is that these ranges can be taken to approximately represent the zones of deficiency, hidden hunger and sufficiency, respectively, in a comparison of relative yield versus the availability of an essential element (Dow and Roberts, 1990). It should be emphasised that this conceptual model assumes that all other growth limiting factors, such as moisture, temperature etc., are optimised. According to such an approach Zn, Ca, P and S are all interpreted as bieng deficient while Mo availability lies in the zone of hidden hunger.

Based on soil fertility levels discussed in the previous section (Table 2.6) it was surprising that the –B, –Mn and –Cu treatments all produced relatively high yields, considering the fact that the concentrations of B, Mn and Cu in the soil was assessed to be below critical levels. This might possibly be ascribed to the fact that deficiency thresholds for trace elements in soils will only manifest themselves at a more advanced stage of crop growth when soil supplies are more likely to have become exhausted in relation to plant requirements. The –Mg treatment had the highest yield, which could possibly be ascribed to the relief of a nutrient imbalance, such as the commonly observed cation antagonism between Mg and K (Tisdale *et al.*, 1985). The –Ca treatment exhibited very poor growth even though the soil Ca concentration was assessed as being sufficient. In this instance the poor growth may have been due to the use of sodium metabisulfite as the substitute S source. Although it has been observed that S

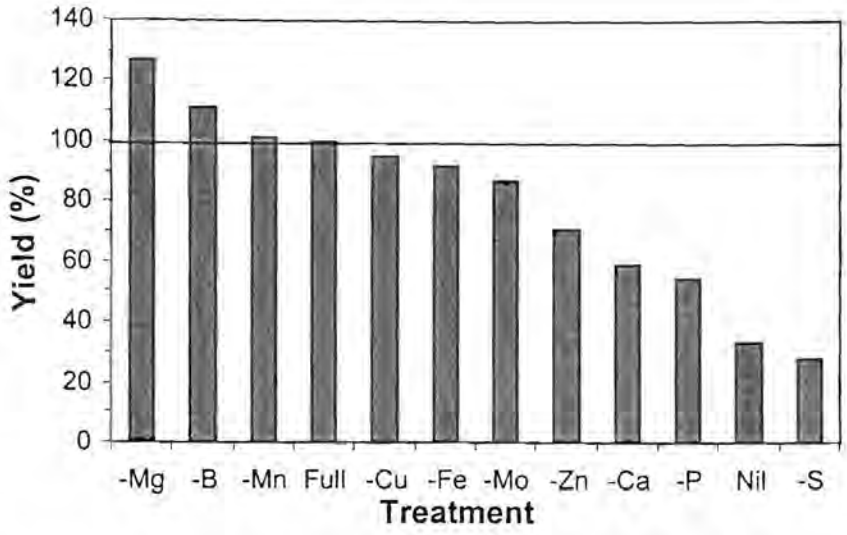

Figure 2.4 Relative dry matter yields for Subtractive Growth Trial 1, with Nil indicating no fertiliser and Full meaning the complete nutrient suite was applied, the other treatments represent a specific element that was withheld from the Full nutrient suite as summarised in Table 2.1.

usually oxidises rapidly in aerated soils (Tisdale *et al.*, 1985) the effect of metabisulfite on plant growth is not documented and this consideration was therefore addressed in the second growth trial. The inconsistent relationship between yield and the levels of nutrients in the soil gives a good illustration of the tentative nature of relying solely on the concentration of soil nutrients as a basis for predicting plant growth (Sims and Johnson, 1991). Ultimately, field trials would be needed not only to verify results of these pot trials but to reveal additional responses which might only become apparent in a mature crop.

The inclusion of a –K treatment in the second trial produced a relative yield of 64% indicating a K deficiency (Fig. 2.5), as predicted by the soil analysis data (Table 2.6). The relative yields of the –Zn and –Ca2 treatments were both 83%, indicating these elements may be deficient (Fig.2.6). The –B, –Ca and Full treatments all produced sufficient relative yields. The –Ca treatment, with a sulfate S source, had a slightly higher relative yield than the –Ca2 treatment, with a sulfite S source, and both were better than the relative yield of –Ca in the first trial, with a sulfite S source. The poor yield of the –Ca treatment in the first trial may be due to factors such as a Ca deficiency or a nutrient imbalance, and was not necessarily caused by the S source. It would be a coincidence if the sulfite caused the same unique plant response of laddering (poor unfurling of young plant leaves in such a manner that the tip of the upper leaf is stuck in the tip of the lower leaf) as a Ca deficiency, which was observed in both trials. The second trial also had significantly higher overall yields, with a yield for the Full treatment of 3.73 g versus 2.95 g (Appendix 3) for the Full treatment in the first trial. Some parameters, such as nutrient application rates, were different in the second trial (Table 2.1), so it is inappropriate to make direct comparisons between the two trials.

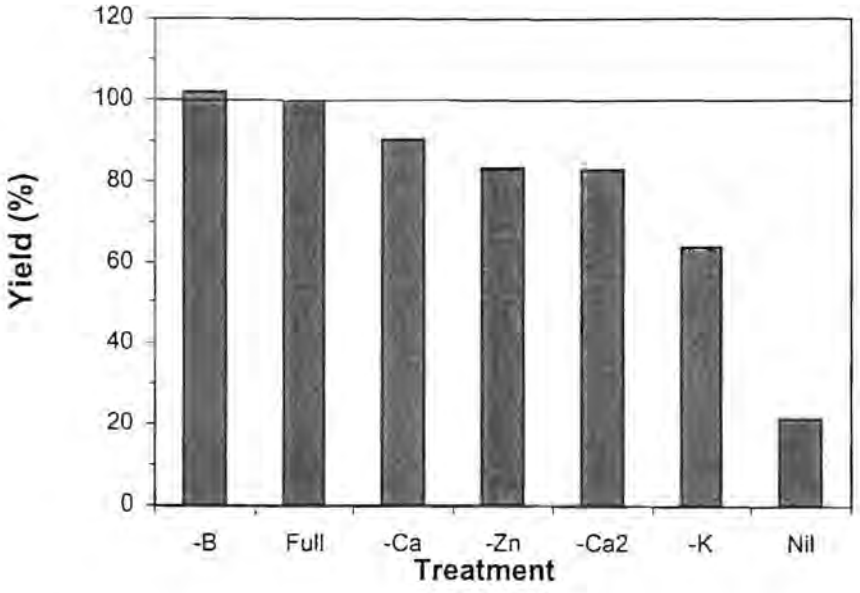

Figure 2.5 Relative dry matter yields for Subtractive Growth Trial 2, with Nil indicating no fertiliser and Full meaning the complete nutrient suite was applied, the other treatments represent a specific element that was withheld from the Full nutrient suite as summarised in Table 2.1.

2.3.2.3 Foliar concentrations

With the subtractive technique an adequacy or deficiency of an element should be indicated by the foliar nutrient concentration for the treatment in which the nutrient was omitted (Lonsdale, 1970). The first subtractive growth trial suggested deficiencies of Ca, P, Mg, Cu and Zn, in relation to critical levels suggested by Bennett (1993) for maize at the three to four leaf stage (Fig. 2.6). (See Appendix 3 for the complete plant tissue data for both trials and all treatments.) For Ca, P, Mg and K an indication is also given (Fig. 2.6 and 2.7) for the critical limit of mature maize (Bennett, 1993), as the relative concentration of these elements is know to decrease with plant growth. All treatments except –P, –S and –Zn were also Ca deficient (Fig. 2.6). Sulphur appeared to be deficient as the –S treatment had the lowest overall yield (Fig. 2.3), but there was not enough plant material for tissue analysis. The Nil treatment had tissue concentrations below the critical level for all elements except Mg, Mn, Fe and B. In conjunction with tissue concentrations above critical levels in the –Mn, –Fe and –B treatments, this suggsts that Mn, Fe and B may be present in the soil in adequate levels. The B tissue concentration in the –B treatment was actually quite high at 63 mg kg^{-1} compared with a critical level of 7 mg kg^{-1}, which was not expected as Fernwood soils of the Natal coast are known to have B deficiencies (Beater, 1950).

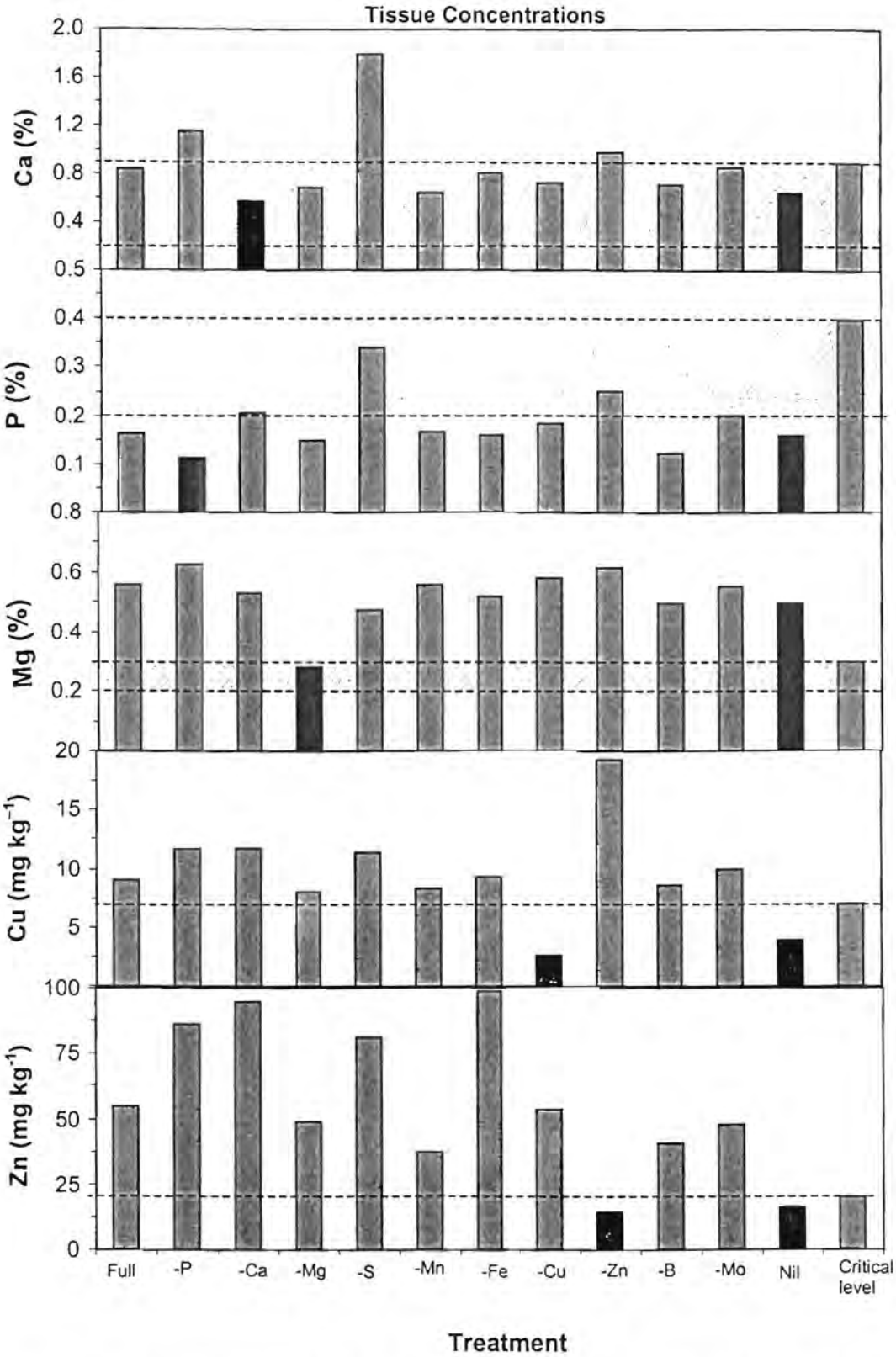

Figure 2.6 Foliar concentrations of Ca, P, Mg, Cu and Zn for treatments in Subtractive Growth Trial 1, showing the critical levels (upper dotted line) of sufficiency for young maize and mature maize where applicable (lower dotted line) in each case (Bennett, 1993), with black shading representing the nutrient concentration for the corresponding treatment in which that nutrient was not applied.

The inclusion of a –K treatment in the second growth trial suggests that K was also deficient, as the K tissue concentration in this treatment was markedly lower than in the other treatments and significantly below the critical level (Fig. 2.7). The repeat treatments of –Ca, –Mg and –Zn in the second growth trial confirmed the Ca, Mg and Zn deficiencies observed in the first trial. The –Ca and –Ca2 treatments had S tissue concentrations of 0.20 and 0.19%, and Ca concentrations of 0.38 and 0.50%, respectively, indicating that the metabisulfite S source was not limiting to plant growth in either trial. The Nil treatment in the second trial also had Mg, Mn, Fe and B tissue concentrations above critical levels, with the B concentration again very high at 85 mg kg^{-1}.

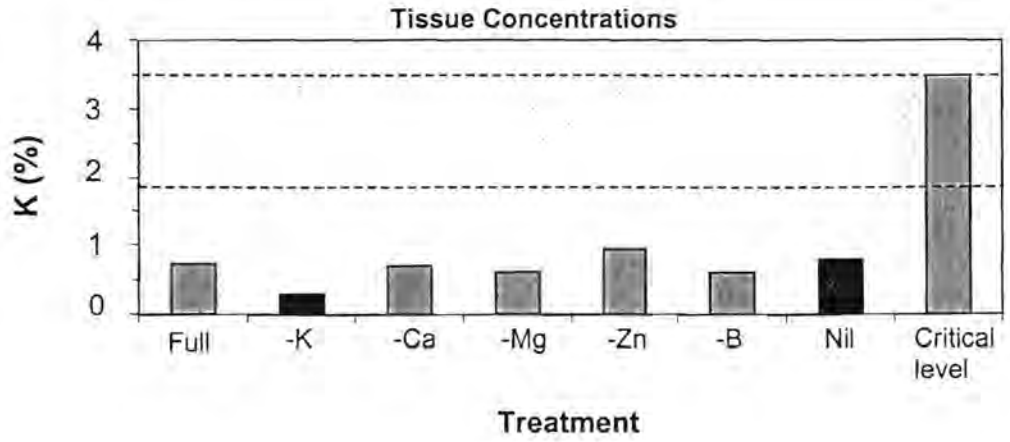

Figure 2.7 Potassium tissue concentrations for treatments in Subtractive Growth Trial 2, showing the range in critical levels (shading) of sufficiency for young maize (upper dotted line) and mature maize (lower dotted line) (Bennett, 1993), with black shading representing the potassium concentration for the corresponding treatment in which potassium was not applied.

Plant tissue concentrations revealed that all treatments from both the first and second growth trials were deficient in N, P and K, in relation to the critical levels of 3.5, 0.4 and 3.5%, respectively. This indicates that the growth trials may have extended beyond the time period for which the applied nutrients were able to provide adequate nutrition for ideal plant growth. All treatments except –K were deficient in Ca and S in the second trial. The higher overall S deficiency in the second trial may have been caused by a decrease in the S application rate from 160 to 20 mg kg^{-1}.

2.3.2.4 Soil concentrations

In the first subtractive trial the respective soil nutrient concentrations (Appendix 2) for the –P, –Ca, –Mg, –S, –Cu, –Zn and –B treatments were all below the critical levels (Table 2.6) for adequate plant growth (Fig. 2.8 and 2.9). The Nil treatment was also deficient in P (7), K (16), Ca (361), S (12), Cu (0.37), Zn (0.7) and B (0.1 mg kg^{-1}). This suggests that all of the elements evaluated except Mn and Fe are deficient in the soil, which includes all of the elements that were deficient in the initial soil characterisation (Table 2.3) plus Ca. Potassium was deficient for almost all treatments which suggests that the K application rate may have been too low (100 mg kg^{-1}) to supply sustained availability. The –S treatment was anomalous in that the concentration of extractable soil K was sufficient at 57 mg kg^{-1}, as opposed to all other treatments in which it was below 27 mg kg^{-1}. This may be accounted for by the low yield of the –S treatment and therefore the inability of these plants to extract as large a quantity of nutrients from the soil as the other plants.

The inclusion of a –K treatment in the second trial confirmed a K deficiency in the soil, with a concentration of only 9 mg kg^{-1} (Fig. 2.10). The second trial also confirmed the soil deficiencies of Ca (235), Mg (7) and Zn (0.3 mg kg^{-1}) in the –Ca, –Mg and –Zn treatments, respectively. The Nil treatment in the second trial had deficiencies of P (4), K (5), Ca (305), Mg (20), Cu (0.1), Zn (0.2) and B (0.1 mg kg^{-1}), with S notably not deficient in this treatment. There were more deficiencies in the second trial with Ca, Mg, and Cu deficient in all treatments in addition to the deficiencies of K, Mn and B, which were also seen in all treatments in the first trial. The Mg deficiency may be due to the decreased application rate from 50 to 25 mg kg^{-1} (Table 2.1). The appearance of the Ca and Cu deficiencies in this trial may be due to the overall increased yield, with plants therefore extracting more nutrients from the soil. An increased extraction of nutrients is evident when the plant tissue data in g m^{-2} is examined. As with the plant tissue data, there was no significant difference between the –Ca and –Ca2 treatments with respect to Ca or S concentrations, at 253 and 275 mg kg^{-1} and 58 and 47 mg kg^{-1}, respectively.

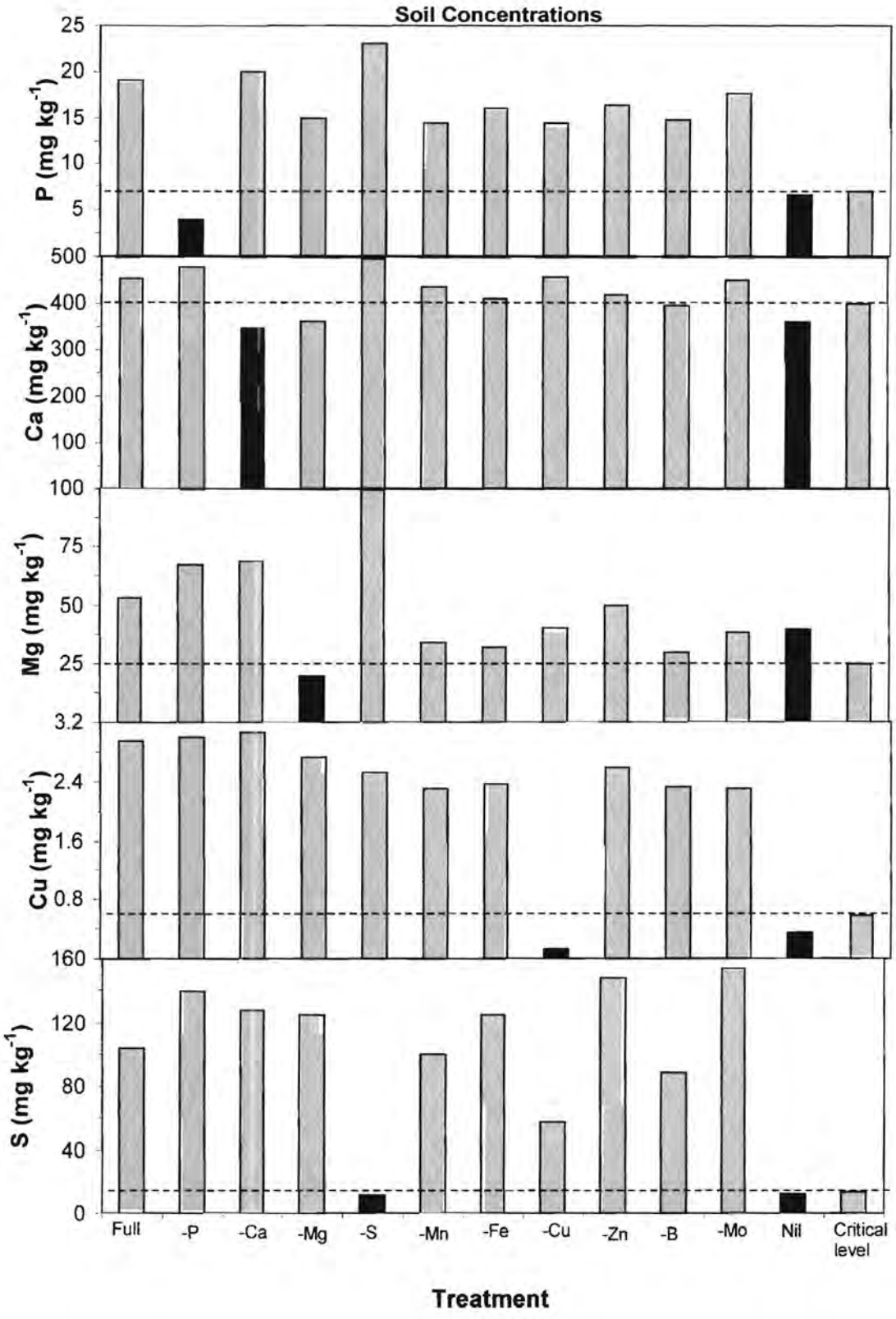

Figure 2.8 Extractable soil concentrations of P, Ca, Mg, Cu and S for treatments in Subtractive Growth Trial 1, showing the critical level (dotted line) for sufficiency, with black shading representing the nutrient concentration for the corresponding treatment in which that nutrient was not applied. Critical levels are from Olsen and Sommers (1982) for P; Melsted (1953) for Ca; Haby *et al.* (1990) for Mg; Sims and Johnson (1991) for Cu; and Wild (1988) for S.

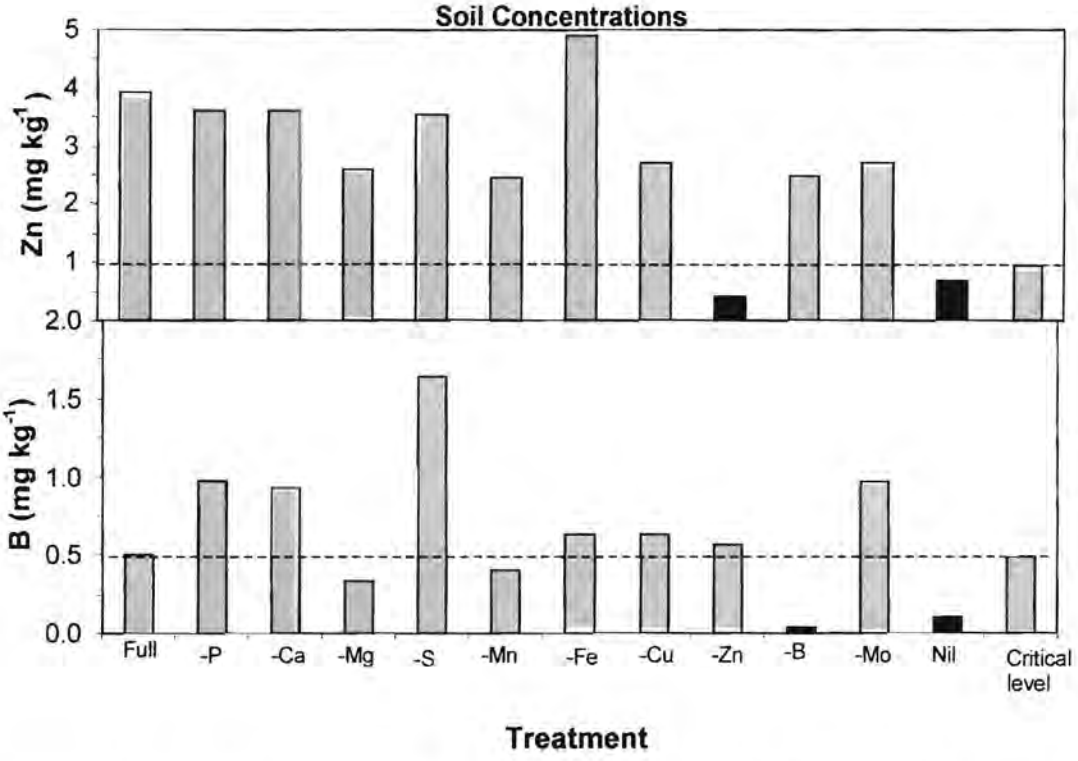

Figure 2.9 Extractable soil nutrient concentrations of Zn and B for treatments in Subtractive Growth Trial 1, showing the critical level (dotted line) for sufficiency (Sims and Johnson, 1991), with black shading representing the nutrient concentration for the corresponding treatment in which that nutrient was not applied.

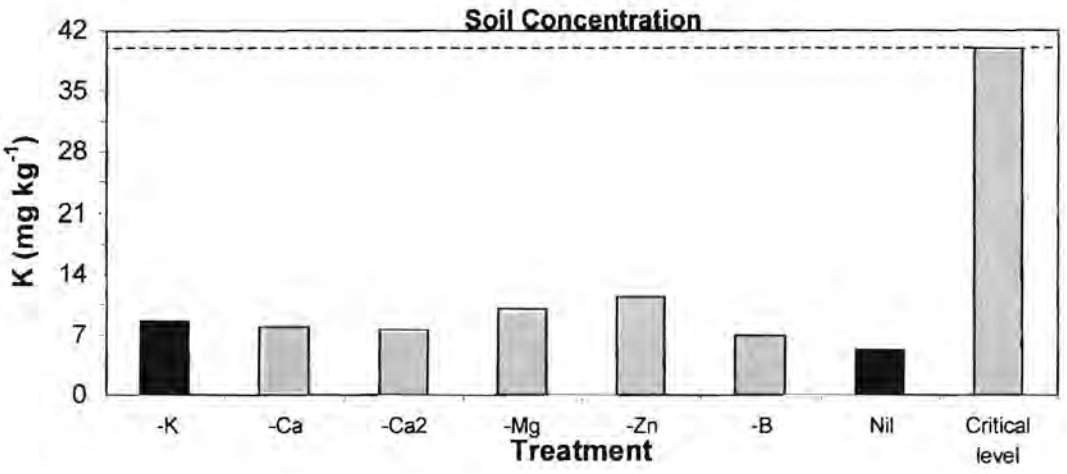

Figure 2.10 Extractable soil potassium concentrations for treatments in Subtractive Growth Trial 2, showing the critical level (dotted line) for sufficiency (Haby *et al.*, 1990), with black shading representing the nutrient concentration for the corresponding treatment in which that nutrient was not applied.

Table 2.8 Summary of laboratory studies conducted with various crops on Fernwood sands of the Maputaland region, indicating the range of elements that are deficient.

Study	Sufficiency category of elements			Elements
	Deficient	Possibly deficient	Sufficient	not studied
Lonsdale (1970)	P, S, Zn	N, Ca, Mo, K	Cu, Mg	Fe, B, Mn
Sumner (1970)	N, P, K, Cu, Zn, B		Mg, S	Fe, Mn, Cu, Zn, Mo
Pooley (1997)	P, Ca, Zn, Cu, B		Fe, Mg, Mn	N, K, S, Mo
Present study	N, P, K, S, Ca, Mg, Cu, Zn	Mo, B	Mn, Fe	

2.4 CONCLUSIONS

Based on soil analysis, the grey Fernwood sand is likely to be deficient in P, K, S, Cu and Zn relative to critical thresholds. Yield and nutrient concentrations of plant tissue established deficiencies in P, K, S, Ca and Zn. Plant tissue and soil analyses for this trial also confirmed Mg and Cu deficiencies. The soil concentration of extractable B indicates it may be deficient, but this were not confirmed by the yield or plant tissue data and the relevant critical level may not be a good indicator for deficiency of maize in sandy soils. A comparison of sulphate and sulphite as a S source in the minus Ca treatments revealed no significant difference between yield, plant tissue or soi nutrient concentrations.

There is sufficient evidence to indicate that the grey sand is deficient in P, K, S, Ca, Mg, Cu and Zn, which is in agreement with findings of other studies, as shown in Table 2.8. There is some evidence that points to Mo and B also requiring increased soil concentrations for adequate plant growth. In the following chapter, amendment growth trials will be conducted to attempt to alleviate these deficiencies, and their success evaluated in terms of their alleviation of multiple deficiencies.

CHAPTER 3

SOIL CHEMICAL AND MAIZE GROWTH RESPONSES TO MINERAL AMENDMENTS IN A FERNWOOD SOIL

3.1 INTRODUCTION

This chapter describes two amendment growth trials that were established with the intention of alleviating the P, K, S, Ca, Mg, Cu and Zn deficiencies established for the grey Fernwood sand in Chapter 2. The trials involve the application of two types of crushed rock and one black clay as amendments, in anticipation that they might increase maize yields through enhanced soil fertility.

No mineral amendment studies of this kind have been carried out on the Fernwood soils of Maputaland, but assessments made of the soil fertility have concluded that the cost of ameliorating fertility would be very high (Lonsdale, 1970). Modern rock crushing techniques are cost effective (R.J. Gilkes, personal communication), while the application of clay obviates the need for this consideration at all. The only plant growth trial that has dealt with improving agricultural production on a grey Fernwood sand was involved with an acidic soil and therefore focused on alleviating Al toxicity and not necessarily increasing extractable soil nutrient concentrations other than as a result of raising the soil pH (Sumner, 1970).

On the other hand, local agriculture practices involve slash-and-burn methods that quickly degrade the fertility status of soil and then move on to clear another plot of indigenous vegetation for its meagre fertility, which ultimately threatens the survival of indigenous plant communities (CORD, 1991). Because of the dystrophic nature of this environment any inputs of traditional water-soluble fertiliser, which can easily be carried into groundwater, threaten to upset the balance that is not yet fully understood in this unique nutrient poor landscape (Reuter, 1994). For these reasons, the choice of amendment material must not only take increasing soil fertility into consideration but acknowledge that having as little an impact on the environment as possible is a priority as well. Studies in Germany have shown clay amendment has long term benefits (Reuter, personal communication), and therefore their use in this ecosystem may be beneficial in halting the destruction of natural habitats.

The objective of this exercise was to obtain rocks with the highest possible fertility potential for use as a ground amendment material. By definition, the doleritic dykes are more basic and therefore may possess higher potential fertility than the rhyolitic mother rock. In other words,

rhyolites have higher Si and correspondingly lower Ca, Mg and Fe concentrations than dolerite. The rhyolitic material, however, has much higher K levels (Armstrong *et al.*, 1984), which may prove to be an important constituent of amendment studies (Gilkes, 1997). For this reason, an attempt was made to sample and compare the fertility of the more common rhyolite and the less common but potentially more fertile basic dolerite.

Ultimately, this chapter will attempt to improve on the paucity of information regarding successful agriculture production in this region. This aims to be done in an environmentally sustainable manner so as not to impact the fragile ecosystem, and in an economically feasible manner for the benefit the resource poor farmers living within local communities.

3.2 MATERIALS AND METHODS

The grey Fernwood sand as sampled and described in sections 2.2.1 and 2.2.3 of the previous chapter was utilised for the amendment growth trials. As with the subtractive trials, there were two sets of amendment trials. These were run one after the other in conjunction with the corresponding subtractive trials. The following describes both amendment trials.

3.2.1 Amendment sampling and preparation

Sampling for amendments was carried out on the same field excursion on July 25th 1998, during which the soil samples were obtained.

Two rock samples were obtained from the Lebombo Mountain Range (Fig. 1.2). The first rock sample was from a roadcut exposure on the east side of the north-south Jozini to Ndumo road, about 2 km north of the Pongolapoort dam (Fig. 2.1). The sample was from a partially decomposed section on the left hand side of this exposed dolerite dyke, about 5 m above the road (Fig. 3.1). This sample is henceforth referred to as LS (Lebombo saprolite). The second was from a rhyolite quarry for road building material on the northern side of the east-west Jozini to Makhathini road, about 1 km from Jozini (Fig. 2.1). Rocks that had already been crushed on site were chosen (Fig. 3.2). This sample has been termed LR (Lebombo rhyolite).

Figure 3.1 A north-south striking dolerite dyke in the Lebombo Moutain Range from which the saprolitic material for amendment was obtained (sampling site marked by an X).

Figure 3.2 Rhyolitic material obtained from a crushing plant near Jozini for amendment purposes.

The rocks were milled for two minutes in a carbon steel Seibtechnik swing mill to reduce the grain size to less than 50 μm. The ground material was then passed through a 124 μm brass sieve and this fraction was used for all analyses and amendment trials.

In addition to the rocks sampled from the Lebombo Range, two other crushed rocks were included in the first amendment trial for comparative purposes. One was a basalt from Queensland, Australia which has been used as an ameliorant on a highly weathered Oxisol and is known to improve soil fertility (Gillman, 1980). The other was a phonolite from Kericho, Kenya which had the potential to be applied as an ameliorant there on old, acidic infertile soils. These are henceforth referred to as QB (Queensland basalt) and KR (Kericho rock). Both rocks were milled and sieved to pass a 124 μm brass screen.

Because one of the objectives of the growth trial was to increase soil and plant tissue trace element concentrations, a trace element fertiliser was also applied in the first amendment trial. This was a granulated micronutrient fertiliser (product no. F 683 G) obtained from Ocean Agriculture, Muldersdrift, South Africa, which contained 0.5% B, 2% Cu, 6% Mg, 1.5% Mn, 5% S, 10% Ca, 8% Fe and 20% Zn. This is henceforth referred to as TE (trace element).

A mixture of two black clay samples that were collected and analysed during the exercise described by Pooley (1997) was used in the second amendment trial. The mixture contained 2 parts of Mudpan Sample 2 to 1.5 parts of Mudpan Sample 1. This amendment has the advantage of being locally available and not requiring crushing as the rocks do. In addition, the pans are a low-point for drainage collection in the plain and may act as a sink for cations that have been leached from the surrounding landscape, with the clays therefore exhibiting higher available nutrient concentrations than the surrounding sands. The approximate location of the two adjacent sampling sites is included on Figure 2.1 and an example of mudpans typically found in this area is shown in Figure 3.3. All analytical data presented in this chapter for the clay sample were obtained from Pooley (1997). This amendment was endearingly called M for mud.

3.2.2 Growth trials

The same soil preparation, planting procedures, maize and growth conditions as described in Chapter 2 (sections 2.2.1 and 2.2.2) were used for the amendment trials. The experimental treatments are described in the following sections.

Figure 3.3 A typical Maputaland mud pan, which are found dotted throughout the sandy coastal plain.

3.2.2.1 Nutrient solutions

The first amendment trial used the same basal nutrient NPKS solution as the first subtractive trial (section 2.2.2.2.) with the exception that $Na_2S_2O_5$ was used in Amendment Trial 1 to increase the S rate, because no gypsum was applied in this trial (Table 3.1). In Amendment Trial 2 the S rate was lowered and Na_2SO_4 was used as the S source, with one treatment (NPKS2) including $Na_2S_2O_5$, to determine whether there were any differences in yield and tissue concentrations with an oxidised versus a reduced from of S (Table 3.1). The K rate

Table 3.1 Rates of elemental application and forms of chemicals applied in Amendment Growth Trial 1 and 2.

Element	Application Rate		Chemical Form	
	Trial 1	Trial 2	Trial 1	Trial 2
	mg kg^{-1}			
N	100	100	NH_4NO_3	NH_4NO_3
P	20	20	$NaH_2PO_4 \cdot 2H_2O$	$NaH_2PO_4 \cdot 2H_2O$
K	100	60	K_2SO_4	KCl
S	160	120	K_2SO_4 & $Na_2S_2O_5$	Na_2SO_4 & $Na_2S_2O_5$†

† This form of S was applied to the NPKS2 treatment only in this trial.

was also lowered in the second amendment trial. In addition, in the second amendment trial the components of the basal solution (meaning N, P, K and S) were applied in four different combinations. The applications were N; N and P; N, P and S; and N, P, S and K. The compounds used to make the solutions and the concentrations they were made up to are listed in Table 3.1

3.2.2.2 Amendment application

The first amendment trial involved the application of four different crushed rocks and a micronutrient fertiliser as ameliorants. The application rate for all amendments in this trial was based on the Ca content of the micronutrient fertiliser as a base reference. The Ca content of the micronutrient fertiliser was 10%, therefore to apply the target of 200 mg Ca kg^{-1} it would be necessary to apply 1.2 g per 600 g of soil (or 2 g kg^{-1}). Based on this rate of 1.2 g pot^{-1} for all amendment applications the total elemental concentrations applied are listed in Table 3.2.

The same potting procedure as for the subtractive trials (section 2.2.2.3) was used with the amendment trials. The amendment was mixed in place of gypsum, 20 ml of NPKS basal solution was added by pipette and 50 ml of water was added to bring the soil to field capacity. The amendments were all applied with the basal fertiliser solution, as it was anticipated that these elements might not be supplied by the crushed rocks and plant growth would be poor in the absence of any N, P, K or S. With five amendment treatments (NPKS + LS, NPKS + LR, NPKS + KR, NPKS + QB and NPKS + TE), one NPKS treatment and one Nil treatment, with all treatments in triplicate, this resulted in a total of 21 pots (Table 3.3).

Table 3.2 Total elemental concentrations (XRF) applied in Amendment Trial 1 with an application rate of 2 g kg^{-1} for Lebombo rhyolite (LR), Lebombo dolerite (LS), Queensland basalt (QB), Kericho phonolite (KR) and trace element (TE) amendments.

Element	LS	LR	QB	KR	TE
			mg kg^{-1}		
Fe	124	50	92	41	60
Mn	3.7	3.1	2.7	5	30
Mg	49	7.4	130	10	120
Ca	20	27	135	24	200
K	5	35	15	48	
P	1.3	0.7	3.3	0.5	
Cu	0.43	0.03	0.12	0.10	5
Zn	0.28	0.25	0.26	0.40	60
S					100
B					10

Table 3.3 Treatments that were included, in triplicate, in Amendment Growth Trials 1 and 2, with the amendments Lebombo rhyolite (LR), Lebombo dolerite (LS), Queensland basalt (QB), Kericho phonolite (KR), trace element (TE) and mudpan clay (M).

Trial 1	Trial 2
NPKS	N
NPKS + LR	NP
NPKS + LS	NPS
NPKS + QB	NPKS
NPKS + KR	NPKS2†
NPKS + TE	M
Nil	M + N
	M + NP
	M + NPS
	M + NPKS
	LR + NPS
	LS + NPS
	Nil

† This treatment has a different S source than the others in this trial.

The second amendment trial was quite different. Four different basal nutrient solutions were used. These comprised N; N and P; N, P and S; and N, P, S and K, with each solution applied to the soil either alone or with clay or rock amendment (LR, LS or M). Due to the amount of soil available and limitations on experiment size these were the only permutations considered. The elements were applied in this order because N was assumed to be the most limiting nutrient in this environment and it was unlikely to be supplied by the clay amendment. The other elements were then added in the increasing order of their likelihood of being supplied by the clay amendment. In other words, K was included last because it was anticipated that some K would be supplied by the clay amendment and plant growth might be adequate with just N, P and S.

The main amendment in the second trial was the black clay, which was applied on its own and in conjunction with each of the four different basal solutions. In addition the Lebombo rhyolite and Lebombo dolerite were applied with NPS. Amendment Trial 2, therefore, had five basal treatments (N, NP, NPS, NPKS and NPKS2), six amendment treatments in combination with a basal solution (M+N, M+NP, M+NPS, M+MPKS, LR+NPS and LS+NPS), one amendment only (M) and a Nil treatment. With all treatments being performed in triplicate this resulted in a total of 39 pots (Table 3.3).

The amendment application rate for the second trial was based on the extractable K level of the clay amendment. From analyses presented in Chapter 2, it was known that the Fernwood soil had an extractable K level of 30 mg kg^{-1}. The objective was to raise the K level to 50 mg kg^{-1}. The clay was known to have an extractable K concentration of about 700 mg kg^{-1} (Pooley, 1997), so in order to add an additional 20 mg kg^{-1} of extractable K, 20 g of clay would need to be added per pot (or 33 g kg^{-1}). This application rate was then used not only for the clay but also for the rhyolite and dolerite amendments. The total elemental

concentrations for the dolerite and rhyolite, and the extractable nutrient concentrations for the clay that were applied are presented in Table 3.4. Because substantially more amendment was added in the second trial the water holding capacity of the soil was slightly enhanced and this was taken into consideration for watering purposes.

Table 3.4 Total elemental concentrations (XRF) for dolerite (LS) and rhyolite (LR) and extractable nutrient concentrations for clay (M) applied in Amendment Trial 2 with an application rate of 33 g kg^{-1}.

Element	Amendment		
	LS	LR	Clay†
	g kg^{-1}		mg kg^{-1}
Fe	2.1	0.84	0.9
Ca	2.0	0.45	84
	mg kg^{-1}		
K	82	581	23
Mn	63	52	0.4
Mg	815	123	14
P	23	11	1.3
Zn	4.7	4.1	0.03
Cu	7.1	0.5	0.03

† From Pooley (1997) based on a 2 parts Mudpan 2 to 1.5 parts Mudpan 1.

3.2.3 Analyses

Soil and plant analyses were carried out in the same manner as described for the subtractive growth trials in Chapter 2 sections 2.2.3.1 and 2.2.3.2 and Appendix 1. Mineralogical analyses of rock samples were performed by X-ray diffraction (XRD) at the National Accelerator Centre in Cape Town.

3.3 RESULTS AND DISCUSSION

3.3.1 Geochemical characterisation of amendments

Chemical and mineralogical investigation confirmed the LR sample to be rhyolitic and the LS sample to be doleritic. The rhyolite is comprised of plagioclase, augite and chlorite (Armstrong *et al.*, 1984), while the dolerite has a mineral composition of plagioclase, K-feldspar, ferro-augite and quartz (Cleverly *et al.*, 1984), as is evident from the XRD patterns

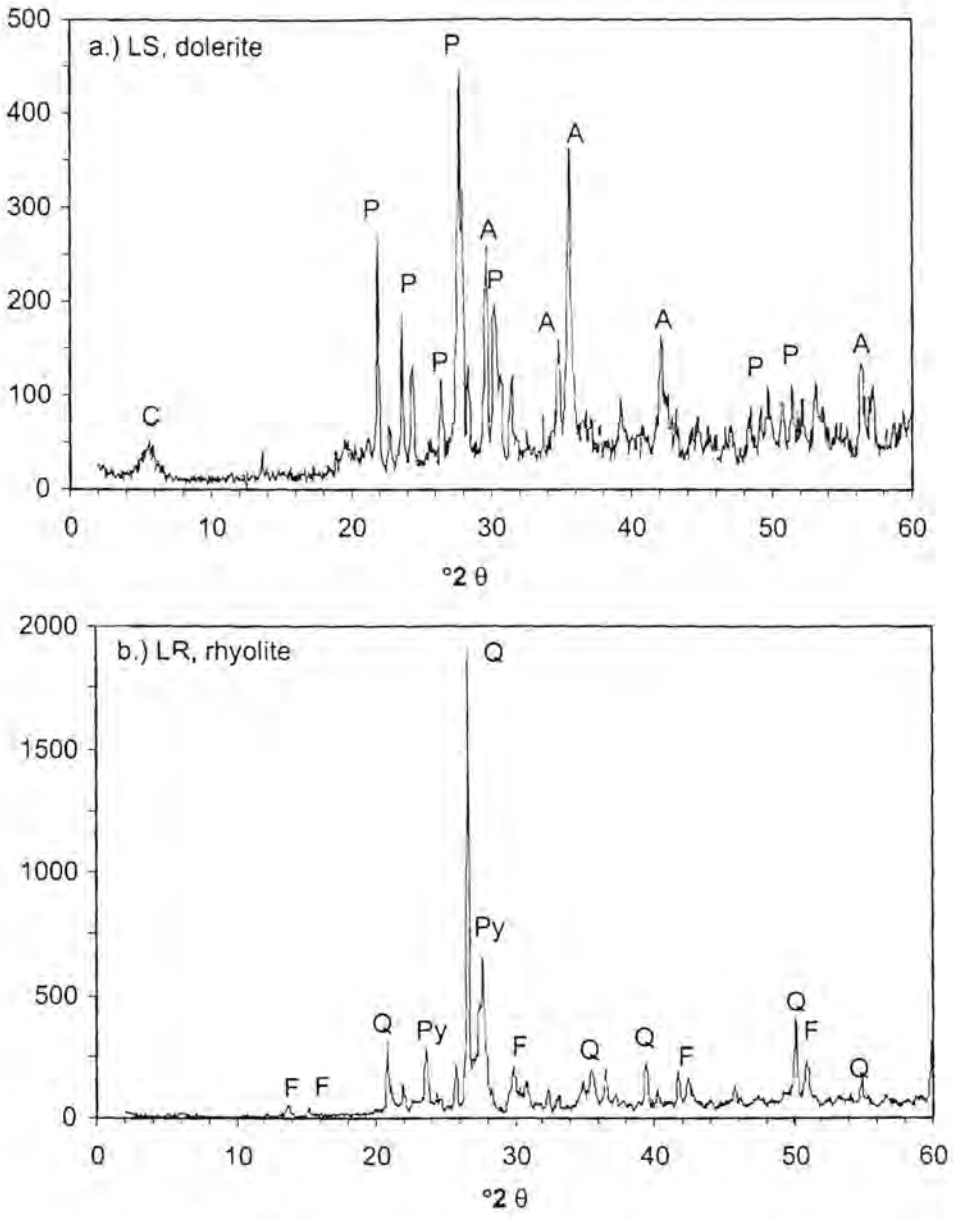

Figure 3.4 X-ray diffraction patterns for a.) the Lebombo dolerite, and b.) the Lebombo rhyolite, with P = plagioclase, A = augite, C = chlorite, Q = quartz, Py = pyroxene and F = feldspar.

(Fig. 3.4). Analysis of total elemental abundance confirmed the rhyolitic nature of the LR sample with 67% SiO_2, 0.6% MgO and 4% K_2O (Table 3.5) relative to classification for Lebombo volcanic rocks (Bristow and Cox, 1984). The dolerite has 48% SiO_2, 3.8% MgO and 0.5% K_2O (Table 3.5), and is therefore a mafic rock and falls within the chemical classification for Lebombo basic volcanics of tholeiitic andesites (Bristow and Cox, 1984).

Examination of the total elemental abundance (Table 3.5) shows the rhyolite has 1.7% K, which is much lower than the 3.8% observed in most Lebombo rhyolites (Eales *et al.*, 1984) The dolerite has 2.4% Mg, 6.0% Ca, 141 mg kg^{-1} Zn and 213 mg kg^{-1} Cu, which are all

Table 3.5 Total elemental concentrations by XRF for dolerite (LS), rhyolite (LR), Queensland basalt (QB) and Kenyan phonolite (KR), including average concentrations for dolerite and rhyolite of the Lebombo monocline (Eales *et al.*, 1984), where all data has been normalised to 100% volatile free.

Element	Sample					
	LS	LR	QB	KR	Dolerite†	Rhyolite†
				%		
Si	23	32	21	26	23	33
Ti	1.6	0.3	1.4	0.4	1.3	0.3
Al	3.3	3.3	3.3	5.1	7.2	6.7
Fe	6.2	2.5	4.6	2.1	10.6	4.4
Mn	0.2	0.2	0.1	0.2	0.2	0.1
Mg	2.4	0.4	6.5	0.5	3.9	0.2
Ca	6.0	1.4	6.8	1.2	7.4	1.1
K	0.2	1.7	0.7	2.4	0.3	3.8
P	0.07	0.03	0.17	0.03	0.1	0.1
				mg kg^{-1}		
Zn	141	124	129	200	110	135
Co	50	6	60	3	53	5.2
V	502	8	195	bdl‡	351	6.2
Cu	213	14	58	4	287	8.8
Ni	60	3	237	3	67	3.8
Cr	99	14	326	16	125	7.5

† Data from

‡ Bdl = below detection limit.

higher than in the rhyolite and may result in the dolerite providing greater benefit as an amendment. The total Zn content of both the rhyolite and dolerite at 141 and 124 mg kg^{-1}, respectively, is much higher than the average total Zn contents of 3.4 and 30 mg kg^{-1} for Fernwood grey sands and mudpan clays, respectively (Pooley, 1997). This greater Zn reserve in the rocks versus mudpan clays may be of benefit as an amendment if it can become plant-available. In terms of fertility assessment, besides the lower K content of the rhyolite the elemental concentrations are what was anticipated with these rock types.

Average available nutrient concentrations in the clay mixture were calculated from the data of Pooley (1997) and are shown in Table 3.6. The clay amendment has extractable soil P, K, Ca, Mg, Mn and Fe that are all above the critical levels presented in Table 2.7. The extractable Cu and Zn content of the clay amendment were both 0.8 mg kg^{-1}, which is below the critical level for sufficiency (Table 2.7). This material may therefore be beneficial in supplying major elements but may not be as successful in supplying micronutrients. The average CEC of 12.7 $cmol_c$ kg^{-1} (Table 3.6) may also be viewed as an overall contribution to fertility of the Fernwood sand, although under the

Table 3.6 Organic C, extractable P, K, Ca, Mg, Mn, Fe, Cu and Zn ranges and averages for two mudpan clays (Pooley, 1997)†.

Sample	C	P	K	Ca	Mg	Mn	Fe	Cu	Zn
	%	mg kg^{-1}							
Mudpan 1	1.2	21	474	1091	181	2	49	0.7	0.6
Mudpan 2	2.7	51	865	3574	613	22	8	0.8	0.9
Clay average‡	2.0	38	697	2506	427	13	26	0.8	0.8

† Cedara data; AMBIC-2 extractable P, K, Zn, Cu, Fe and Mn; and 1 *M* KCl extractable Ca and Mg.
‡ Determined from 1.5 parts Mudpan 1 to 2 parts Mudpan 2.

conditions of experimentation employed here (absence of leaching), the effect of CEC enhancement per se is not expected to be large.

3.3.2 Amendment growth trial

3.3.2.1 Visual deficiency symptoms

At three weeks the first amendment trial showed no deficiency symptoms for the NPKS, LR, LS, QB and KR treatments. The Nil (no fertilisation) treatment had stunted growth, an overall yellowish appearance, reddish midribs and leaf margins and necrosis of leaf tips, while the TE treatment was also stunted and had severe leaf tip necrosis. At six weeks the Nil and TE treatments had the same symptoms. All other treatments had developed slight interveinal chlorosis, dieback of old leaf tips and slight reddening of leaf midribs and margins. These symptoms indicate the possibility of multiple deficiencies of N, P, K and possibly S.

In the second trial all treatments at three weeks, except for the Nil and M treatments, were green with slight dieback of the leaf tips and margins of young and old leaves. The M treatment mimicked the Nil treatment with a general yellowness and reddish leaves, but did not have stunted growth compared with the NPKS treatment. At six weeks all treatments had varying degrees of N deficiency evident as marked yellowness, with most treatments also exhibiting reddish-purple leaves possibly indicative of a P deficiency (Fig. 3.5). These symptoms were more severe than those noted in the first amendment trial and similar to those observed in the second subtractive growth trial, indicating that the decreased K and S application rates for these two trials may have been sub-optimal.

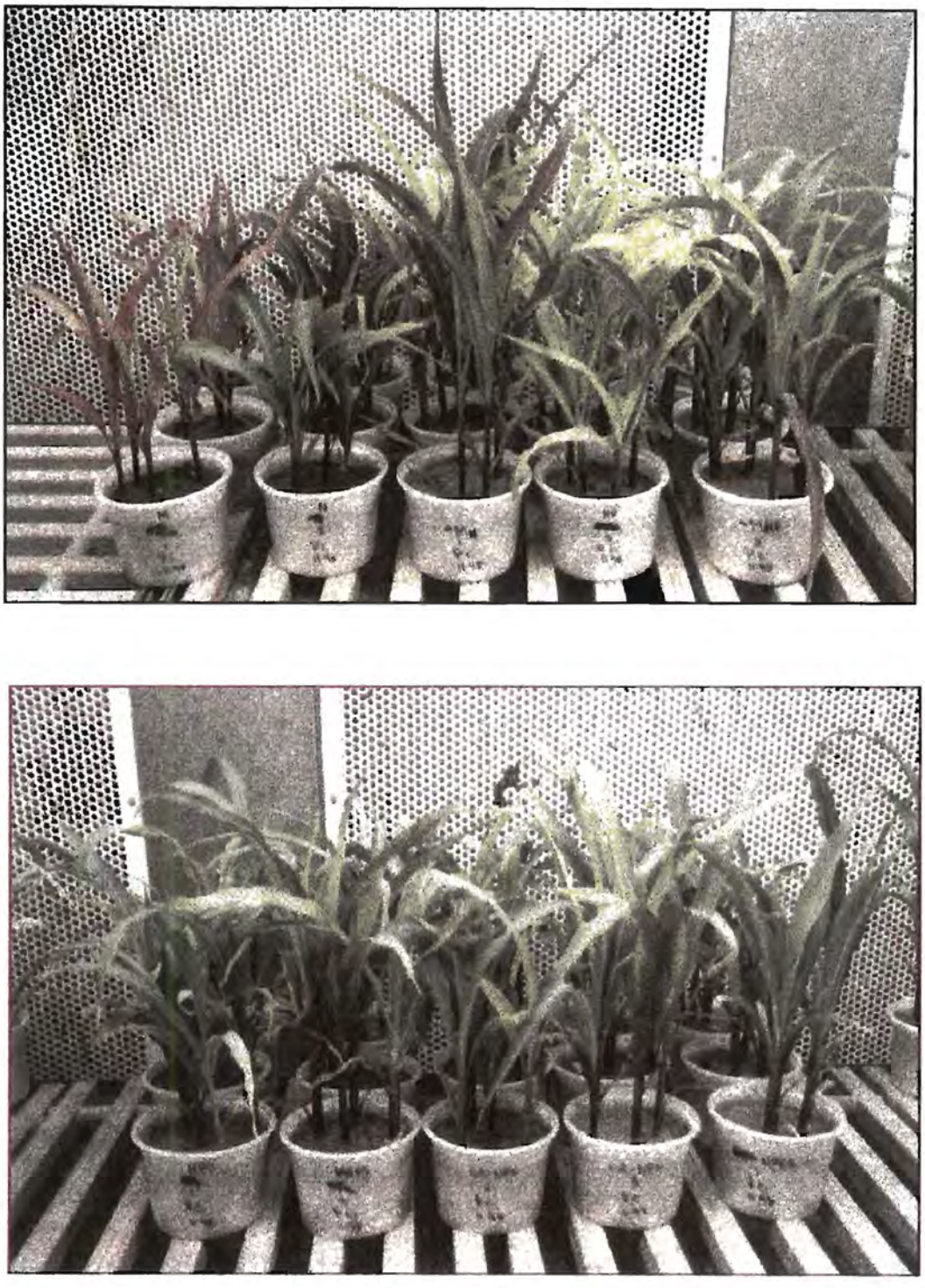

Figure 3.5 Examples of plant growth including deficiency symptoms of N, P and K in six-week old maize of Amendment Growth Trial 2.

3.3.2.2 Yield

The yield results for the first amendment trial are shown in Figure 3.6 as relative yields (data in Appendix 3). From these data it is evident that NPKS alone produced a marked increase in yield, but that none of the amendments in combination with NPKS produced a further yield enhancement. The trace element (TE) application appeared to be counterproductive, with only 60% yield relative to that of NPKS alone. Based on the results of Chapter 2 it is likely that the TE application was excessive, probably giving rise to B toxicity (the symptoms described for this treatment in section 3.3.2.1 tend to support this interpretation).

The results of the second trial are summarised in Figure 3.7, from which it is evident that the M (clay amendment) treatment produces a substantial increase in yield provided that it is applied in combination with nitrogen fertiliser (N). The inclusion of P, S and K in the basal fertiliser along with N does not significantly enhance yield above that obtained with M + N alone, confirming the expectation that the clay amendment might serve as a useful fertiliser substitute. The results for the LR + NPS and LS + NPS treatments suggest that there is a slight benefit from the application of dolerite and a significant benefit from the rhyolite in comparison with the NPS treatment. It is possible that the LR (rhyolite) treatment could serve as a substitute for normal K fertiliser, since the LR + NPS treatment yielded about the same as the NPKS treatment, both of which were substantially greater than that obtained with NPS alone. The LS (doleritic saprolite) amendment was not as effective in this respect. The results in Figure 3.5 for N, M and N + M suggest that the effect of N and M are approximately additive (i.e. not synergistic).

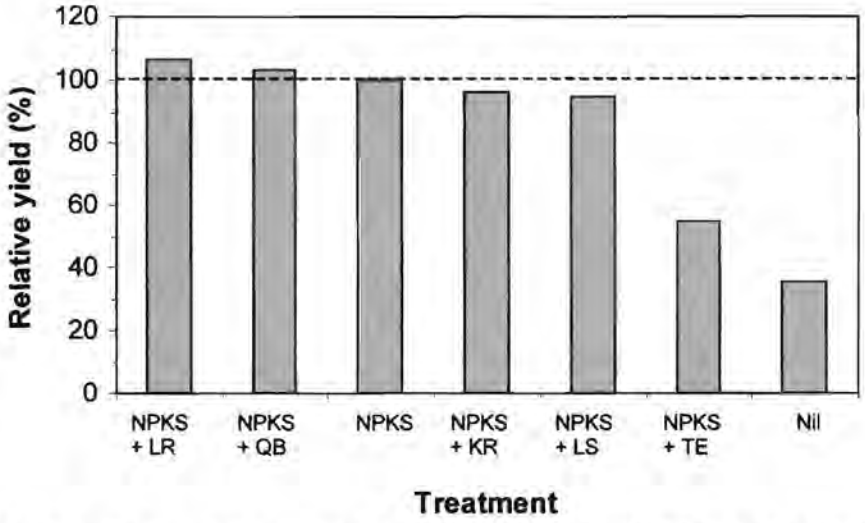

Figure 3.6 Relative dry yield weights for Amendment Growth Trial 1, with Nil indicating no fertilizer was added, NPKS indicating a basal fertilizer solution, LR = Lebombo rhyolite, QB = Queensland basalt, KR = Kenya phenolite, LS = Lebombo saprolite and TE = trace element fertilizer.

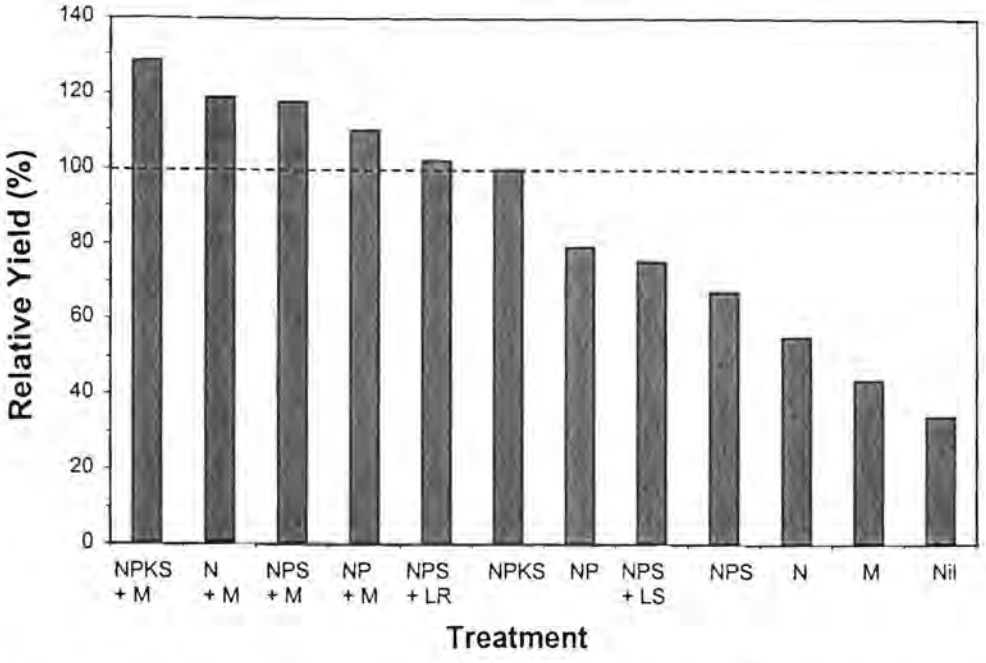

Figure 3.7 Relative dry matter yield for Amendment Growth Trial 2, with Nil indicating no fertilizer was added, N, P, K and S indicating the respective fertilizer combinations added, LR = Lebombo rhyolite, LS = Lebombo saprolite and M = mudpan clay.

3.3.2.3 Foliar concentrations

There was no significant increase in the concentration of foliar nutrients for any amendment treatment in comparison with the NPKS treatment in the first trial (data in Appendix 3). At the N, P, K and S application rates used for all treatments (Table 3.1) only the concentration of S in plant tissue was raised above the critical level. In all treatments except the trace element treatment, foliar Ca, Cu and Zn concentrations were below the critical level, while Mg was present at the critical level. These concentrations are consistent with elemental concentrations in plant tissue found in the subtractive trials, suggesting there was no relief of any deficiencies (Chapter 2). The TE treatment had anomalous K, Mg, S, Cu, Zn and B at concentrations of 3.14, 0.58 and 0.63%, and 14, 152 and 247 mg kg^{-1}, respectively. These are significantly higher than concentrations found in all other treatments, and in particular suggest toxicity of Zn and B at the application rate used.

The M treatment in the second amendment trial did not result in the nutrient concentration of plant tissue being raised above the critical level for any of the deficient elements. Magnesium concentrations were elevated above the critical level in the plant tissue of all treatments with N, but not in treatments with N and K (Fig. 3.8). Calcium concentrations were higher in plant tissue of treatments without S, but lower in the presence of M + N or M + NP than in the N and NP treatments (Fig. 3.8). The only apparent effect of an amendment is the elevated Zn

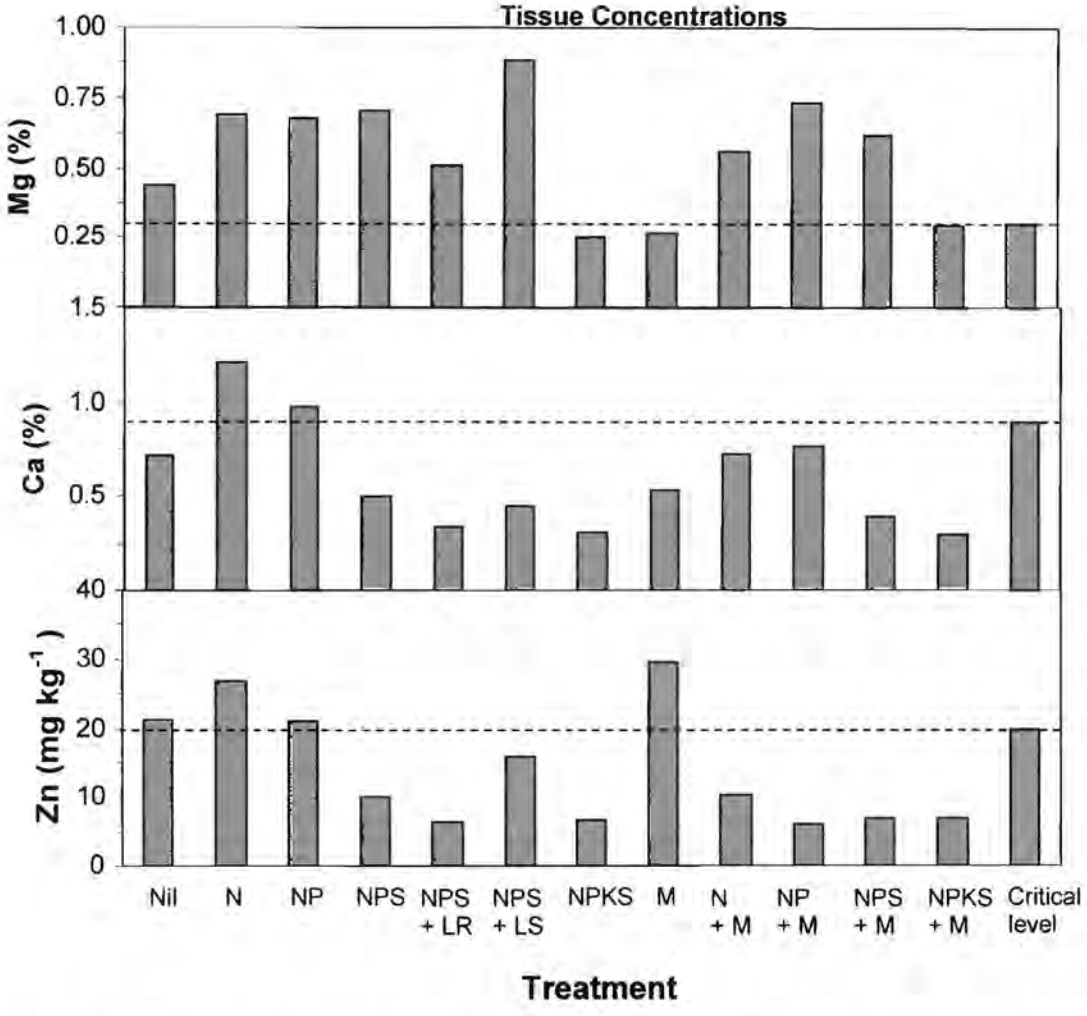

Figure 3.8 Foliar nutrient concentrations of Mg, Ca and Zn for treatments in Amendment Growth Trial 2, showing the critical level (dotted line) for sufficiency for young maize in each case (Bennett, 1993), where LR = Lebombo rhyolite, LS = Lebombo saprolite and M = mudpan clay.

concentration in plant tissue of the LS + NPS trial at 16 mg kg^{-1}, which is still below the critical level of 20 mg kg^{-1} (Fig. 3.8). The Zn concentration was above the critical level in plant tissue of the Nil, M, N and NP treatments, but these treatments did not have high yields and the higher Zn concentrations are probably due to the effect of being more concentrated in relatively less plant material (i.e. the inverse of what is sometimes referred to as dry matter dilution).

Another approach to interpreting foliar concentrations, in order to account for dry matter dilution and to elucidate real concentration differences in element concentrations across treatments, is to express the nutrient uptake data as g m^{-2}, which is the product of foliar concentration and yield. This essentially expresses the uptake of nutrients per pot, which would represent the harvest of elements that would need to be re-supplied in a fertiliser regime in order to maintain the fertility level of the soil. When nutrient uptake is considered

the K, Mg and Mn uptake is greater in plant tissue of all treatments that include M and some basal solution, than in the tissue of their counterparts with only a basal solution of N, P, K or S (Fig. 3.9). In particular, the M treatment has the best K extraction. The Ca uptake is greater in plant tissue of all treatments without S, but it is greater in the M + N and M + NP treatments than the N and NP treatments, contrary to what was revealed when the percent foliar composition was considered (Fig 3.8). When nutrient uptake is considered the LS treatment does not appear to have absorbed a greater quantity of Zn as suggested in Figure 3.7, but rather exhibits the greatest Cu extraction of all the treatments (Fig. 3.9).

3.3.2.4 Soil concentrations

As anticipated from the yield and foliar data, in the first amendment trial there was no significant increase in the concentration of extractable soil nutrients due to the application of any amendments. The soil analyses do show extremely elevated and possibly inhibitory levels of extractable S, Cu, Zn and B at 262, 14, 69 and 4 mg kg^{-1}, respectively, for the TE treatment (data in Appendix 2). The appropriate application rate for a micronutrient fertiliser is extremely important in a sandy soil, particularly in view of the low CEC and low water holding capacity which in combination give rise to a greater concentration of applied nutrients in solution than would be the case in a more clayey soil.

The application of clay in the second amendment trial had a significant effect on the concentration of extractable soil nutrients. In particular, the M treatment raised the P, Ca and Mg concentrations above critical levels to 10, 438 and 58 mg kg^{-1}, respectively, and was the only treatment that raised the Ca content above the critical level (Fig. 3.10). The concentration of extractable soil Mg was raised above the critical level for all treatments with an amendment, but not for treatments with just a basal fertiliser application. Extractable soil K and Mn were also both significantly raised in all M treatments, and this trend is even evident when comparing all the treatments with the NPKS and NPKS + M treatments (Fig. 3.10).

The LS and LR treatments significantly raised concentrations of extractable soil P, Mg and Mn in comparison with all other treatments (Fig. 3.10), while extractable Zn was significantly elevated in soil of the LR treatment and extractable Cu in soil of the LS treatment (Fig. 3.11).

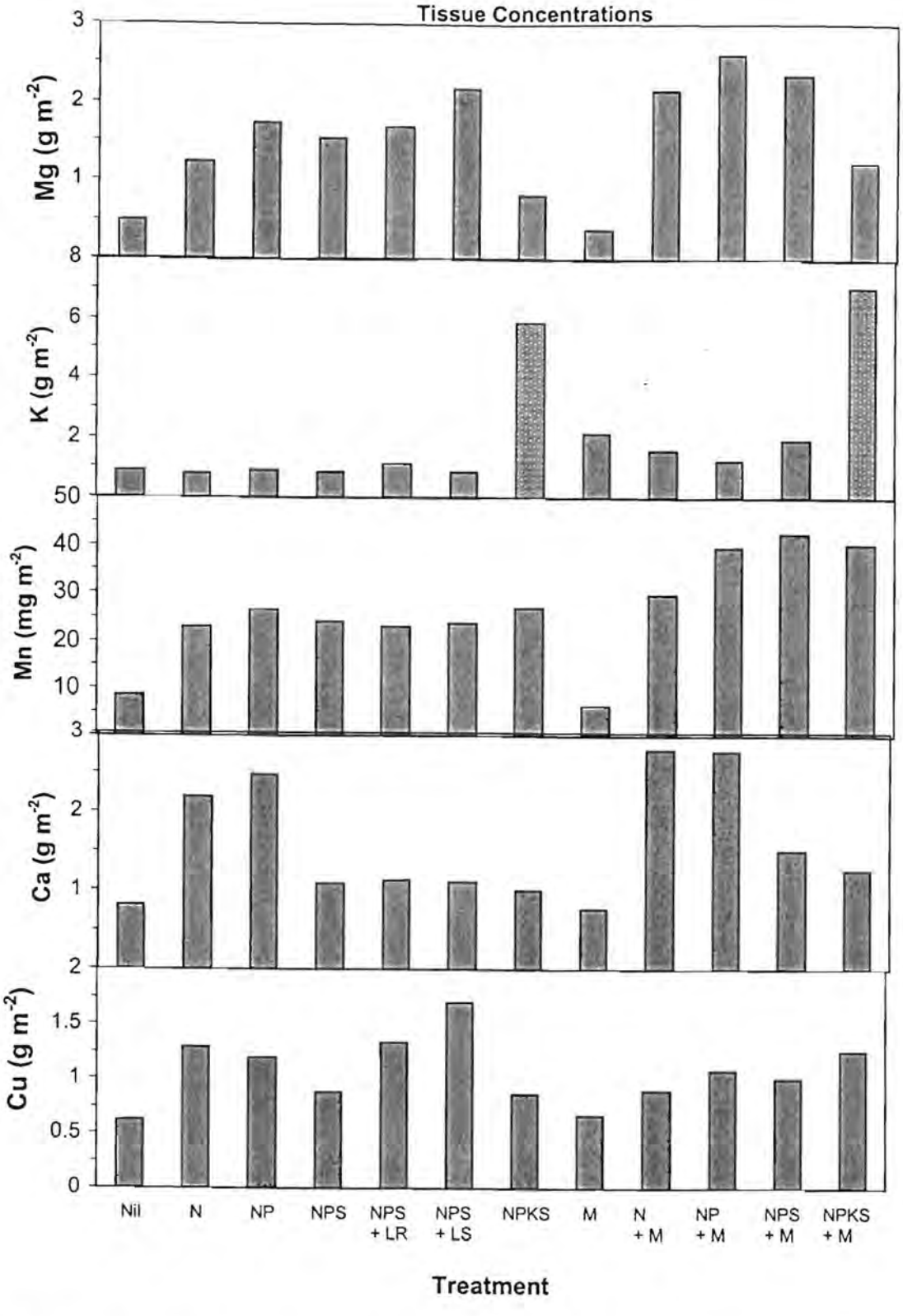

Figure 3.9 Foliar nutrient uptake of Mg, K, Mn, Ca and Cu for treatments in Amendment Growth Trial 2, with speckling representing a treatment in which the corresponding element was applied, where LR = Lebombo rhyolite, LS = Lebombo saprolite and M = mudpan clay.

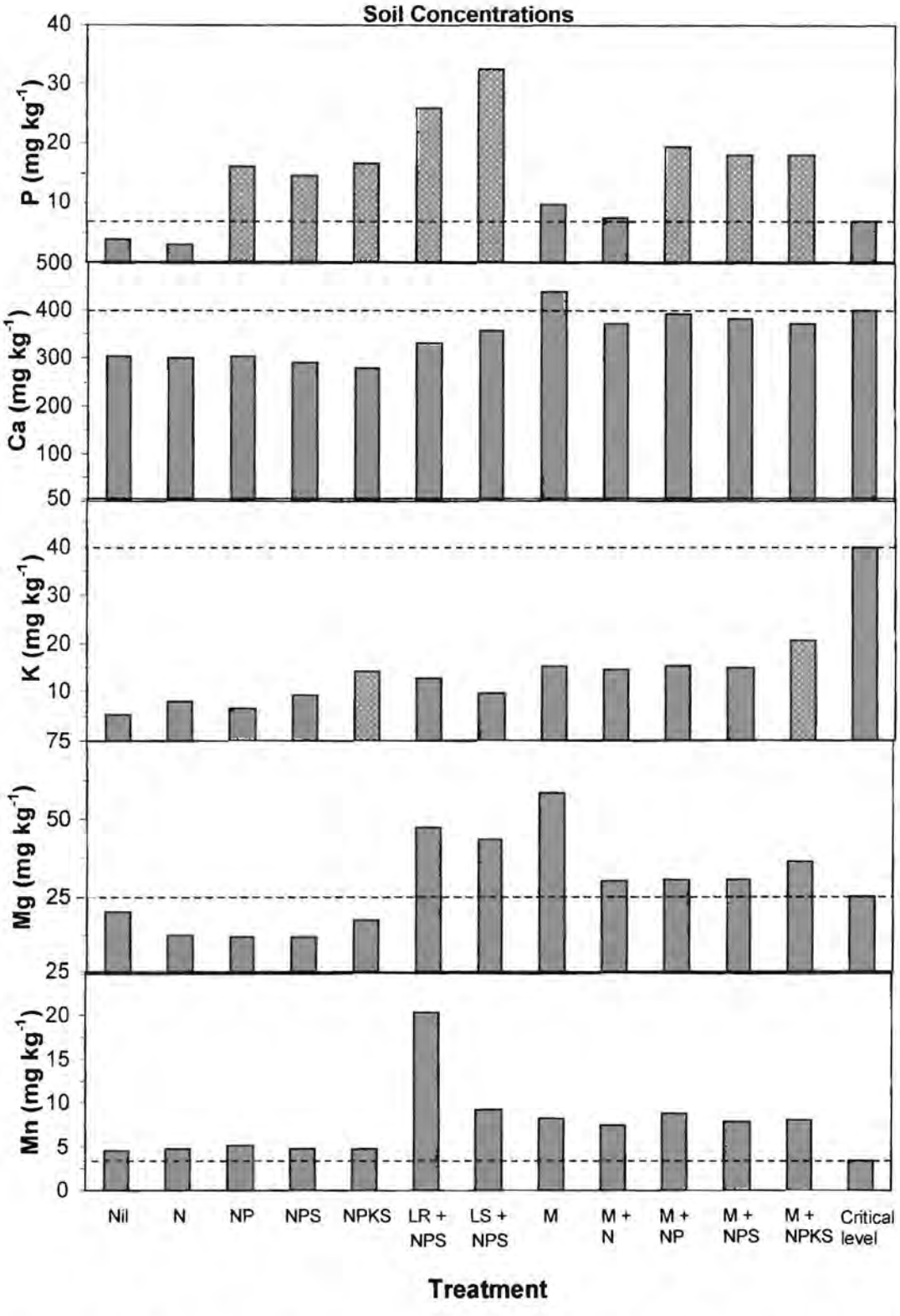

Figure 3.10 Extractable soil concentrations of P, Ca, K, Mg and Mn for treatments in Amendment Growth Trial 2, showing the critical level (dotted line) for sufficiency, with speckling representing a treatment for which the corresponding nutrient was applied, and where LR = Lebombo rhyolite, LS = Lebombo saprolite and M = mudpan clay. Critical levels are from Olsen and Sommers (1982) for P; Melsted (1953) for Ca; Haby *et al.*, (1990) for Mg and K; and Sims and Johnson (1991) for Mn.

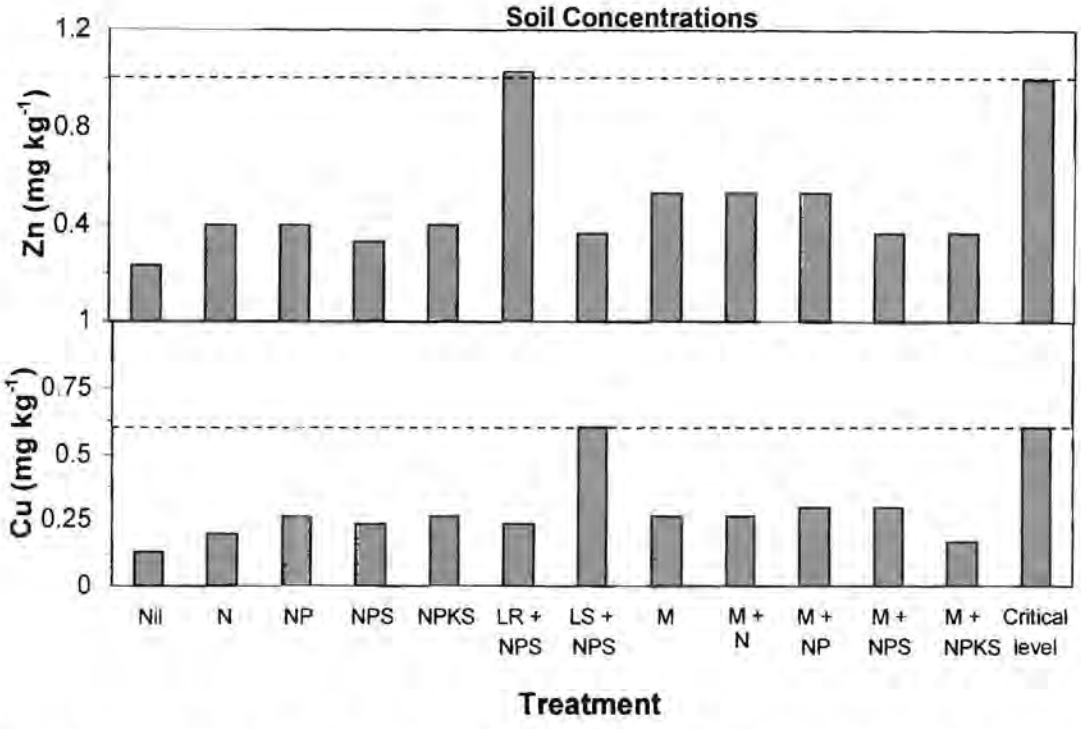

Figure 3.11 Extractable soil concentrations of Zn and Cu for treatments in Amendment Growth Trial 2, showing the critical level (dotted line) for sufficiency (Sims and Johnson, 1991), where LR = Lebombo rhyolite, LS = Lebombo saprolite and M = mudpan clay.

3.4 CONCLUSIONS

Amendment with clay provides significant improvement to crop yield, as long as N is also applied. Clay amendment increases plant nutrient uptake of K, Mg and Mn, while increasing extractable P, K, Ca, Mn and Mg in the soil. Amendment with rhyolite also caused a slight yield increase in the presence of N, P and S in comparison to N, P and S applied on their own. The rhyolitic amendment increased extractable P, Mg, Mn and Zn, while the doleritic material increased extractable P, Mg, Mn and Cu in the soil. In addition, the doleritic material increased plant extraction of Cu.

There is evidence suggesting that amendment with clay in particular and also crushed rock would provide some benefit for crop production on the Fernwood sand. The clay amendment increased concentrations of major cations while the rock material gives some indication of increasing levels of extractable Zn and Cu. A combination of the clay and crushed rock materials may be useful in providing relief from soil deficiencies of major and minor elements.

GENERAL DISCUSSION AND CONCLUSIONS

This study constituted an investigation to improve the soil fertility of a sandy soil by the application of clay or crushed rock. This was done to provide resource poor farmers, living in an area with a high incidence of disease, a locally available and inexpensive means of increasing crop productivity. The application of clay was found to be a feasible option for improving crops as long as adequate N was also applied.

The grey Fernwood sand used in this study was found to be deficient in exchangeable soil P, K, S, Ca, Mg, Cu, and Zn, through a series of plant growth trials with a subtractive technique. There was some indication that Mo and B might also be deficient, but further studies are needed. There are inconsistencies with critical limits for B and the value used may have been inappropriate in these soils.

Amendment with crushed rock and mud was successful in increasing yields and nutrient concentrations as long as the application rate was high enough. A rate of 33 g kg^{-1} was much more successful than 2 g kg^{-1}. There were significant benefits to yield and plant extraction of nutrients from applying clay in the presence of N, which suggests that the clay can supply adequate K. The application of clay caused increased exchangeable concentrations of soil P, Ca, K, Mg and Mn and increased concentrations of plant tissue K, Mg and Mn.

The application of crushed rhyolite resulted in a significant yield increase, suggesting it may also be supplying some K. The rhyolite also caused increased exchangeable P, Mg, Mn and Zn in the soil. The application of dolerite resulted in increased plant tissue concentrations of Cu and Zn, suggesting it may be a good potential supply of trace elements. There was also evidence of increased exchangeable P, Mg, Mn and Cu in soil when dolerite was added.

These results suggest that further research involving a mixture of clay and crushed rock applied to the Fernwood sands may have successful in field results. Other sources of clay material, such as the extensive black smectitic soils along the eastern footslope of the Lebombo Mountain Range, or the organic rich coastal swamp soils, maybe prove to be more successful than the kaolinitic clay used for this study. The organic rich Champagne soils may also provide some N. Alternative sources of N, such as inter-cropping or rotation with legumes, should also be investigated.

Other considerations for future work with clay amendment include determination of the long term sustainability of addition to Fernwood grey sands, with particular emphasis on leaching properties. The feasibility in terms of ease of collection, transport, incorporation and the willingness of local farmers to employ these techniques must also be ascertained.

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APPENDICES

APPENDIX 1

METHODS OF SOIL, ROCK AND PLANT ANALYSES

A1.1 SOIL pH

The standard method for pH_{H_2O} and pH_{KCl} measurement were used, as described by Mc Lean (1982) and NASAWC (1990), at the Department of Geological Sciences, UCT and for pH_{KCl} at the Cedara Agricultural College, Pietermaritzburg.

Ten grams of air-dried and sieved (< 2 mm) soil was weighed into a centrifuge tube and mixed with either 25 ml of MQ water (for pH_{H_2O}) or 25 ml of 1 *M* KCl (for pH_{KCl}), to achieve a 1:2.5 soil to solution ratio. After mixing at 6 000 rpm for five minutes, the solutions were allowed to settle for 30 minutes. Measurements for pH were then taken with a potentiometer that had been calibrated with buffers at pH 7.00 and 4.00. Readings were taken in drift mode after the value settled for 10 seconds, and the internal temperature probe automatically compensated for temperature variations.

Precision of the pH data based on three pH_{H_2O} readings were taken for each sample for, was found to be at 0.3 pH units. The pH_{KCl} data were found to lie within 0.1 pH unit of the corresponding values generated by the Cedara Crop Science Institute for the same soil, indicating a satisfactory level of accuracy. The pH measurements were taken to determine the general acid/base status of this soil and were not an integral part of this study.

A1.2 ORGANIC C

Organic carbon was determined by the Walkley-Black method, as described by Nelson and Sommers (1982), at the Stellenbosch Institute for Fruit Technology, Infruitec.

Organic matter was first oxidised with potassium dichromate and sulphuric acid, and then after completion of the reaction, the remaining dichromate was titrated with iron (II) ammonium sulphate hexahydrate. The reduced dichromate is equivalent to the organic C present and the concentration determined with the appropriate calculation.

Air-dried soil was ground with a porcelain mortal and pestle, where necessary, to pass a 0.35 mm sieve. One gram of soil was placed in a 500 ml Erlenmeyer flask and 10 ml 0.5 *M* $K_2Cr_2O_7$ pipetted into the container and swirled to disperse the soil in the solution. Twenty millilitres of concentrated H_2SO_4 was rapidly added and gently swirled to mix the solutions and then vigorously stirred for one minute. After allowing the mixture to cool on an asbestos surface for 30 minutes,

150 ml de-ionised water and 10 ml ortho-phosphoric acid were pipetted in. About ten drops (1 ml) of barium diphenylamine sulphonate indicator solution were then added and the excess dichromate acid titrated with 0.017 *M* iron (II) ammonium sulphate, the endpoint of which is marked by a colour change from dark violet to green. The percent organic carbon was determined with the following equation:

$$\% C = [(\text{ml } Fe(NH_4)_2(SO_4)_2 \text{ blank} - \text{ml } Fe(NH_4)_2(SO_4)_2 \text{ sample}) \times M \times 0.3 \times 1.3] \div \text{g soil}$$

where M (in *M*) = (10 ml $K_2Cr_2O_7$ x 0.167 x 6) ÷ ml $Fe(NH_4)_2(SO_4)_2$

Methods that use dichromate for rapid oxidation may be subject to interference by chlorides, ferrous iron and manganese oxides which can all undergo oxidation-reduction reactions in chromic acid mixtures, leading to spurious results in organic C values (Nelson and Sommers, 1982). The soils analysed by this method are not expected to have any chlorine present as it is highly mobile, and the oxidised nature of these soils would preclude problems associated with Fe and Mn, which are usually found in reduced environments.

Walkley-Black is a widely used method as it is simple and rapid, however because there is no external heat used to promote the dichromate oxidation, the oxidation of organic carbon is incomplete. Therefore, it is necessary to use a correction factor in the final equation and results are only an approximation of organic carbon and cannot be considered quantitative

No duplicate analyses were carried out as this parameter was only obtained for two soil samples as a general indication of the organic carbon content. The results obtained agreed within a satisfactory range with common literature values for these soils.

A1.3 1 *M* POTASSIUM CHLORIDE EXTRACTABLE ACIDITY (H AND Al), Ca AND Mg

Extractable acidity, Ca and Mg were determined using the standard 1 *M* KCl extraction method (Thomas, 1982; NASAWC, 1990), at the Cedara Agricultural College, Pietermaritzburg.

For the extraction, 2.5 g of air-dried and sieved (< 2 mm) soil and 25 ml of 1 *M* KCl were placed in a 50 ml centrifuge tube and mixed by placing horizontally on a reciprocating shaker set at 180 oscillations per minute for thirty minutes. The mixture was then centrifuged at 6 000 rpm for five minutes and the pH of the supernatant recorded. (The pH is an indication of the extractable acidity of the solution and if it is above 5.0 there is no suspected acidity present.) The solution was then filtered through a Whatman no. 2 filter.

For extractable acidity determination, 10 ml of the filtered solution was pipetted into a separate container along with 2 drops of 0.05% phenolphthalein indicator. This was titrated while stirring with 0.01 *M* NaOH, the endpoint of which is evident by a colour change to pink. A blank determination was also run on the 1 *M* KCl solution. Extractable acidity was then determined from the following equation:

$$\text{meq of acidity per ml of soil} = \text{ml } 0.01\ M\ \text{NaOH}$$

For determination of extractable Ca and Mg, 2 ml of the filtered solution was brought up to a dilution of 20 ml with MQ water and transferred to another bottle. Thirty millilitres of 1% lanthanum solution was added to this and the concentrations of Ca and Mg determined using atomic absorption spectroscopy. Then the % acid saturation (in $mmol_c\ kg^{-1}$) can be calculated by the following equation:

$$\%\ \text{Acid Saturation} = 100 \times \text{Acidity} \div (\text{Acidity} + Ca^{2+} + Mg^{2+})$$

Precision and accuracy information pertaining to this technique was not obtained by the author. External laboratories were used for extractable nutrient concentrations because the analyses are laborious and costly and established laboratories have stringent quality control to ensure accurate data. For the initial soil geochemical characterisation the precision of the data was not as important as for the plant growth trials, and duplicates were included for those trials only.

A1.4 1 *M*, pH 7 EKSTEEN TOTAL EXTRACTABLE ACIDITY (H AND Al)

Exchangeable acidity, both H and Al, was determined by a modified version of the Eksteen method at the Stellenbosch Institute for Fruit Technology (Eksteen, 1969). This method was derived as a means of determining the lime requirement of a soil and as such the values obtained cannot be used for determination of percent acid saturation.

A solution containing 435 g K_2SO_4 and 25 g KOAc was brought to 5 L with distilled water. Phenolpthalein indicator was then added until the solution turned pink and a few drops of KH_2O_2 was then added to adjust the solution to pH 7.

Ten grams of air-dried and sieved (< 2 mm) soil was then added to 100 ml of solution and shaken on a reciprocating shaker at 180 oscillations per minute for 15 minutes. The solution was then filtered through Whatman no. 1 filter paper. A few drops of phenolpthalein indicator were added to the filtered solution and this was titrated against 1 *M* NaOH. The result was then plugged into the following equation:

$$\text{me \% titrated acidity} = 10 \times \text{ml NaOH}$$

A1.5 1 *M*, pH 7 AMMONIUM ACETATE EXTRACTABLE K, Ca, Mg AND Na

The available concentrations of pH 7, 1 *M* NH_4OAc extractable major cations and exchangeable acidity were determinec at Infruitec, the Stellenbosch Institute for Fruit Technology, according to the methods of NASAWC (1990) and the general principles of Thomas (1982).

Ten grams of air-dried and sieved (< 2 mm) soil was placed in a 100 ml centrifuge tube, stoppered and weighed. To this, 50 ml of 1 *M* NH_4OAc adjusted to pH 7 was added and the solution shaken on a horizontal shaker at 180 oscillations min^{-1} for 60 min. The samples were removed from the shaker and allowed to stand overnight, after which they were centrifuged for 10 min at 5 000 rpm, or longer if necessary to obtain a clear supernatant. The supernatant was then decanted into a 100 ml volumetric flask. To the soil remaining in the centrifuge tube, 50 ml of 1 mol dm^{-3} NH_4OAc was again added and shaken vigorously by hand to disperse the soil, and then placed on a horizontal shaker for 30 min. This supernatant was added to that already collected in the 100 ml volumetric flask and the solution made up to volume with the NH_4OAc. This solution was filtered through Whatman no. 40 filter paper and put aside for Ca, Mg, Na and K determination.

Simultaneous multi-element analyses of exchangeable bases were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES). The concentration of the cation in solution, C in mg dm^{-3} was then plugged into the following equation:

$$\text{mg cation kg}^{-1}\text{ soil} = C \times 100 \div 10$$

Considerations for this method are poor extraction of Ca and Mg in the presence of free $CaCO_3$ or $CaSO_4$, and the fact that many soils are not completely neutralised at pH 7 (Thomas, 1982). These factors are not deleterious to this determination method in this soil as there is no free lime present and there are no high concentrations of weak acids, Al salts, clay suspensions or organic matter to inhibit the pH parameter.

All analyses pertaining to extractable nutrient concentrations for soils from plant growth trials (i.e. $CaCl_2$, BRAY-2, NH_4OAc, $(NH_4)_2$-EDTA and $Ca(H_2PO_4)_2$ extractions) were carried out by the Infruitec laboratory. This was done because the methods used are complex and require procedures that enable routine determinations to be made on a regular basis. These analyses are both time consuming and costly. Because these results were extremely important within the context of this thesis, a duplicated sample of at least one treatment, in triplicate, for all plant growth trials was included. (Duplicates were submitted for analyses pertaining to plant growth trials, but not for the initial geochemical characterisation.) These results are all included in Appendix 2 along with the mean and standard deviation. There was good precision among all nutrient extraction techniques used. Additionally, these laboratories subscribe to stringent quality control procedure involving regular audits by independent organisations, which assures the accuracy of the data obtained.

A1.6 AMBIC-2 EXTRACTABLE P, K, Zn, Mn, Cu AND Fe

The available concentrations of P, K, Zn, Mn, Cu and Fe were determined using the AMBIC-2 method, which has been shown by Farina *et al.* (1979) to be suitable for a wide range of soils in South Africa. This determination was done at the Cedara Agricultural College, Pietermaritzburg.

Extraction was carried out by adding 25 ml of AMBIC-2 extracting solution [0.25 *M* NH_4HCO_3 + 0.01 *M* $(NH_4)_2$-EDTA + 0.01 *M* NH_4F + Superfloc (N-127)] to 2.5 g of air-dried and sieved (< 2 mm) soil. This was stirred at a low speed (± 400 rpm) for ten minutes and then filtered through Whatman no. 45 filter paper.

Phosphorus determination was performed with a combination diluter-dispenser that took a 2 ml aliquot of the filtrate and added 8 ml of distilled water and 10 ml ammonium molybdate colour reagent B. After allowing the mixture to react for 40 minutes the percent transmission was measured using a spectrophotometer set at 882 nm.

Potassium was determined by using a combination diluter-dispenser to add a 2 ml aliquot of filtrate to 18 ml of distilled water. The K concentration was then determined by atomic absorption methods.

Zinc, Mn, Cu and Fe were measured directly from the filtrate by atomic absorption spectroscopy.

As mentioned previously (section A1.6), precision and accuracy information pertaining to extraction techniques were not obtained by the author. External laboratories were used for extractable nutrient concentrations because the analyses are laborious and costly and established laboratories have stringent quality control to ensure accurate data. For the initial soil geochemical characterisation the precision of the data was not as important as for the plant growth trials, and duplicates were included for plant growth trials only.

A1.7 BRAY-2 EXTRACTABLE P

Extractable P was determined according to the Bray-2 method (NASAWC, 1990; Olsen and Sommers, 1982) at Infruitec, the Stellenbosch Institute for Fruit Technology.

Eight grams of air-dried and sieved (< 2 mm) soil was placed in an extraction bottle and 60 ml of Bray-2 solution (0.03 *M* NH_4F + 0.025 *M* HCl) added, at 20 ±2 °C. The bottle was covered and shaken manually for 40 s and then immediately filtered through Whatman no. 2V filter paper until the filtrate was clear, discarding the first few drop of filtrate. One gram of P free charcoal was then added and the solution again covered and shaken manually for 40 s. Two drops of Superfloc N-127 was added to this and the mixture filtered through Whatman no. 40 filter paper. The P concentration of the filtrate was determined by ICP-AES.

This method provides an availability index for the 1:7 soil to solution ratio of < 3 ppm, very low; 3 to 7 ppm, low; 7 to 20 ppm, medium; and > 20 ppm, high.

Complications may arise with calcareous soil as the acid is rapidly neutralised by $CaCO_3$ and low estimates of available P result. High calcium carbonate concentrations are not a consideration in this soil and accurate fertility assessment can be made with this method. Please see section A1.6 for a brief discussion of precision and accuracy relating to this method.

A1.8 0.02 *M* DI-AMMONIUM EDTA EXTRACTABLE Fe, Mn, Cu, Zn AND Al

The 0.02 *M* $(NH_4)_2$-EDTA extractable trace elements were determined according to the method of NASAWC (1990) at Infruitec, the Stellenbosch Institute for Fruit Technology.

For the extraction of Fe, Cu, Zn and Al, air-dried soil was first crushed with a roller and then with a porcelain mortar and the fraction < 1 mm collected after sieving. Five grams of the sieved soil was placed in a 50 ml centrifuge tube and mixed with 15 ml 0.02 *M* $(NH_4)_2$ EDTA extraction solution. This was stoppered and shaken horizontally on a reciprocating shaker for 60 min at 180 oscillations min^{-1}, with a constant temperature of 20 ±2 °C. The sample was then centrifuged for 5 min at 2 000 rpm and the supernatant immediately filtered through Whatman no. 40 filter paper. For Mn extraction, the above procedure was followed but with 50 ml of extracting solution. Determination of all elements was done on ICP-AES. Please see section A1.6 for a brief discussion of precision and accuracy relating to this method.

A1.9 0.01 *M* CALCIUM PHOSPHATE MONOBASIC EXTRACTABLE INORGANIC S

The 0.01 *M* $Ca(H_2PO_4)_2$ extractable inorganic sulphur was determined at Infruitec, the Stellenbosch Institute for Fruit Technology (Tabatabai, 1982).

Five grams of sieved (< 2 mm) soil was shaken for 30 min with 50 ml of 500 ppm P $Ca(H_2PO_4)_2 \cdot H_2O$. The mixture was then filtered through Whatman no. 42 filter paper. Analysis of S from the filtrate was done with ICP-AES and the concentration of S in solution, C in mg dm^{-3}, was then determined with the following equation:

$$\text{mg S kg}^{-1}\text{ soil} = (C \times 50 \div 5) \div 3$$

Please see section A1.6 for a brief discussion of precision and accuracy relating to this method.

A1.10 0.02 *M* CALCIUM CHLORIDE EXTRACTABLE B

Extractable B concentrations were determined by the 0.02 *M* $CaCl_2$ extraction method (NASAWC, 1990) at Infruitec, the Stellenbosch Institute for Fruit Technology. This is similar to the standard mannitol-calcium chloride method described by Bingham (1982) in that it also removes the soluble plus adsorbed B.

Twenty-five grams of air-dried and sieved (< 2 mm) soil was placed in a low boron quality 500 ml container with 50 ml of 0.02 *M* $CaCl_2$ and boiled under reflux for 15 minutes. After the extraction was complete the solution was filtered through Whatman no. 41 filter paper into a plastic bottle. Determination was then done with ICP-AES.

Please see section A1.6 for a brief discussion of precision and accuracy relating to this method.

A1.11 BOUYOUCOS HYDROMETER PARTICLE SIZE ANALYSIS

The particle size fractionation was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986) at Infruitec, the Stellenbosch Institute for Fruit Technology. This is an adaptation of the standard hydrometer method, with readings only taken at 40 s and 2 h. Because of the sedimentation theory on which this method is based, there can be a discrepancy with readings taken at these times, which can exceed 10 wt% for clay and 5 wt% for sand. The purpose of this analysis was for simple determination of textural class, and, taken in consideration with time and analysis costs, the method was deemed sufficient.

Before chemical separation of the sample, no pre-treatment was necessary due to the sandy nature of the soil. Sodium-hexametaphosphate (HMP) was used for chemical dispersion at a concentration of 5 g L^{-1}. Due to the coarse textured nature of the soil 100 g of soil was used in order to obtain reproducible results. One hundred grams of air-dried soil was placed in a 600 ml beaker with 250 ml distilled water and 100 ml HMP, and soaked overnight. This dispersed mixture was then agitated for the appropriate time and brought to 1 L with distilled water in the sediment cylinder, equilibrated and the temperature recorded. A plunger was then inserted and the solution thoroughly mixed, after which the hydrometer was immediately lowered into the solution and readings were then taken at 40 s and 2 h. A blank containing the dispersing agent was also measured so that the effect of solution viscosity and density could be accounted for. The readings, R in g L^{-1}, were plugged into the following equation to determine the concentration of soil in suspension, with R_L accounting for the blank solution:

$$C = R - R_L$$

A summation percentage curve was then made by plotting C against the log of mean particle diameter (X in μm at time t), which is determined by the following equation, where θ is a sedimentation parameter in μm $min^{½}$:

$$X = \theta t^{-½}$$

Analytical error associated with this method is ± 2 wt% for the clay size fraction.

A1.12 BULK DENSITY

Bulk density was determined according to an unconventional method (Blake and Hartge, 1986) at the Cedara Agricultural College, Pietermaritzburg. The soil was air-dried and milled to pass a 1 mm sieve. The soil was then placed into a container with a known volume of 10 ml and weighed. From this the ratio of the mass of dry solids to the bulk volume of the soil was determined. Considering the coarse texture and weak structure of this soil this method was adequate in reflecting field conditions, and therefore sufficient for the purpose of this study.

A1.13 WATER HOLDING CAPACITY

For watering purposes the water holding capacity (WHC) was determined according to the "sticky point" method, which is based on the preparation method for a saturation extract (Rhoades, 1982). A known quantity and volume of oven dried (100°C for 24 hr) soil was placed in a weighed container, to which water was added until the sticky point was reached. The sticky point is reached when enough water has been added to fill all of the macro- and micro-pores within the soil and no water is standing on the surface after the soil has been thoroughly mixed and left to stand for 6 hours. The surface has a wet glean, and banging the container on a counter does not allow water to be released onto the surface. The quantity of water required to achieve the sticky point is determined by weight and half of this amount is the water holding capacity of the soil.

A1.14 WAVELENGTH DISPERSIVE X-RAY FLUORESCENCE SPECTROSCOPY

The general principle of this technique is the irradiation of the sample with X-rays which generate photoelectrons, or fluorescence, that are characteristic of a specific element. These photoelectrons hit a crystal which separates the different wavelength beams, with the intensity at each wavelength (or the number of secondary electrons) being counted by a step-wise detector (Jones, 1982). Analyses were run by Mrs. F. Pocock at the Department of Geological Sciences, University of Cape Town.

Air-dried and sieved (< 2 mm) soil for wavelength dispersive X-ray fluorescence spectroscopy (WDXRFS) analysis was first milled for 3 minutes in a carbon steel Seibtechnik swing mill to reduce the grain size to less than 50 μm.

Minor Elements:

Powder briquettes for trace element analysis were made by the method of Norrish and Hutton (1969), using 8 g of milled soil and 2 g of Hoechst Wax. These were mixed with 3 plastic balls in a Turbula Mixer Mill for 30 minutes and discs were then made at 10 tons of pressure. The briquettes were placed under vacuum for a day in order to desiccate them and to prevent fracture from occurring in the XRF machine which is under vacuum conditions.

WDXRFS analysis of soil briquettes was done on a Philips PW1480 machine with an Au X-ray tube. Because the sample holder gives backscatter X-ray signals for Al and Mg a Teflon sleeve was fitted. Samples were analysed for Zn, Cu, Ni, Co, Mn, Cr and V with the analytical conditions listed in Table A.1. The lower limits of detection and standard deviations (1 σ counting error) for these determinations are listed in Table A.2.

Table A1.1 Instrumental conditions for determination of trace elements using a Phillips PW1480 WDXRF spectrometer 'Willis, 1996).

Element/		X-ray tube		PHS		Counting		
line	Crystal	Target	KV - mA	LWL	UPL	time (s)	Colllimator	Detector
ZnKα	LiF220	Au	60 45	20	80	200	Fine	FS
CuKα	LiF220	Au	60 45	20	80	200	Fine	FS
MoLα	LiF220	Au	60 45	20	80	200	Fine	FS
Coα	LiF220	Au	50 55	15	75	200	Fine	FL
MnKα	LiF220	Au	50 55	15	75	200	Fine	FL
CrKα	LiF220	Au	50 55	15	75	200	Fine	FL
V Kα	LiF220	Au	50 55	13	67	200	Fine	FL

Table A1.2. Ranges in lower limit of detection and one standard deviation for minor elements analysed.

Parameter	Zn	Cu	Ni	Co	Mn	Cr	V
				mg kg^{-1}			
Lower Limit Detection	0.64-1.38	0.80-1.61	0.86-1.88	1.22-3.37	1.34-2.38	1.32-2.71	1.52-4.59
1 σ Counting Error	0.22-0.72	0.27-0.89	0.29-1.01	0.43-1.25	0.57-3.33	0.53-1.54	0.57-2.36

Major Elements:

Fusion discs were prepared by the method of Norrish and Hutton (1969) for major element analysis. This involved weighing about 1.5 g of sample material and oven drying for four hours at 110°C, cooling for 30 min in a desiccator and then weighing the dried sample to determine H_2O loss. The sample was then oven-dried at 850-1100°C overnight and again cooled and weighed to determine loss due to C, S, CO_3 and molecular H_2O. To 0.28 ± 0.002 g of dried sample material 1.5 ± 0.002 g of 12:22 (LiB_4O_7:$LiBO_3$) flux was added and then 0.02 ± 0.001 g $NaNO_3$. This mixture was then heated in a Pt-Au crucible on a Prometheus Fusion Machine and the molten liquid cast into a mould to create the fusion disc.

Fusion discs were analysed for nine major elements: Fe, Mn, Ti, Ca, K, P, Si, Al and Mg, with Ni and Cr included when their concentrations exceeded 2000 ppm, according to the methods of Norrish and Hutton (1969). WDXRFS analysis of fusion discs was done on a Philips PW1480 machine with a dual target Mo/Sc X-ray tube, with the tube set at 40kV, 65 mA, except for Fe, Mn and Ti which were measured with the tube at 100kV, 25 mA.. The analytical conditions from Willis (1996) in Table A1.3 were used for determination of major elements. The lower limits of detection for the elements analysed for are listed in Table A1.4. Data processing was done with the TRACE software as described by Duncan *et al.* (1984).

Table A1.3 Analytical conditions for determination of major elements using a Philips PW1480 WDXRF spectrometer (Willis, 1996).

Element/ line	Collimator	Crystal	Detector	PHS LWL	PHS UPL	Counting time (s)	Concentration range *	RMS	No. of standards
FeKα	F	LiF(220)	FL	16	70	150	0 - 17	0.118	14
MnKα	F	LiF(220)	FL	15	70	150	0 - 0.22	0.005	14
TiKα	F	LiF(200)	FL	28	70	150	0 - 2.75	0.020	14
CaKα	F	LiF(200)	FL	36	70	20	0 - 12.5	0.037	14
K Kα	F	LiF(200)	FL	36	70	50	0 - 15.5	0.057	14
P Kα	C	GE(111)	FL	25	75	100	0 - 0.36	0.008	14
SiKα	C	PE(002)	FL	32	74	100	0 - 100	0.408	14
AlKα	C	PE(002)	FL	25	75	80	0 - 17.5	0.136	14
MgKα	F	PX-1	FL	30	74	150	0 - 46	0.095	14

* = all concentrations expressed as wt% oxide.

Table A1.4. Lower limits of detection for major elements using WDXRFS.

Element	Lower Limit Detection	Element	Lower Limit Detection
	$mg\ kg^{-1}$		$mg\ kg^{-1}$
Ni2	3.5	Si1	
Al1	65.2	Fe	17.7
Mn2	11.1	Cr1	7.1
Ti	14.2	Ca1	3.9
K1	1.3	S2	22.1
P1	2.9	Mg3	100.0

A1.15 X-RAY DIFFRACTION

X-ray diffraction (XRD) analysis was done at the National Accelerator Centre, Cape Town (Whitting and Allardice, 1982).

Rock samples were crushed for 3 minutes in a carbon steel Seibtechnik swing mill to reduce the grain size to less than 50 μm. This crushed material was then sieved through a 125 μm stainless steel sieve. Powder mounts were prepared from this crushed material by spreading the rock powder inside the opening of a stainless steel metal holder that was placed upside down on Whatman no. 20 filter paper. A hand held press, made to fit the opening in the metal holder, was then used to press down the powder. This created a solid, stable surface for analysis.

XRD analysis was done on a Bruker axs D8advance with a CoKα radiation tube, scanning set from 2 to 60° 2θ, a step size of 0.05°, and readings taken for 1 second at a rotation of 60 revolutions per minute. The DIFFRAC^{PLUS} Basic software package was used and evaluation and peak identification was done with the EVA Version 4.0 software.

A1.16 PLANT TISSUE ANALYSIS

Elemental concentrations of P, K, Ca, Mg, S, Mn, Fe, Cu, Zn and B in the plant tissue were determined by digestion with a dilute acid (Jones and Case, 1990) at Infruitec, the Stellenbosch Institute for Fruit Technology.

Plant tissue was first dried in a ventilated oven at 70 °C for 24 h and then milled to pass a 0.84 mm screen. One gram of the ground plant tissue was placed in a porcelain crucible and ashed in a muffle furnace at 480 °C for 8 h. Once ashed and cooled, dilute HCl was added to dissolve the ash. The remaining material was put into solution and the concentration of elements determined by ICP-AES. Nitrogen was analysed separately with a spectrophotometer set at 410 nm.

All plant tissue data is presented in triplicate in Appendix 3, with relative standard deviation to give an indication of analytical precision.

APPENDIX 2

Soil Data

A2.1 Soil Profile Descriptions

Fernwood Soil Profile Description

Location:	4 km south Phelandaba
Landform:	Plain
Slope:	0-1%
Shape:	Flat
Aspect:	West
Elevation:	50 m
Parent Material:	Quaternary aeolian
Surface Rocks:	< 0.01%
Vegetation:	Palm Veld (*Hyphaene natalensis*, *Karomia speciosa*)
Land Use:	Native vegetation
Watertable:	3 m

A 0 - 10 cm; dry; dark greyish brown (10YR 4/2; 10YR 4/1 when moist); sand; weak, medium, granular; very friable; not sticky and not plastic; many, medium roots; no rock fragments; no effervescence; abrupt boundary.

E 10 - 62 cm; dry; greyish brown (10YR 5/2; 10YR 5/1 when moist); sand; weak, medium, subangular blocky; very friable; not sticky and not plastic; many, medium roots; no rock fragments; no effervescence; clear boundary.

B 62 - 100 cm; dry; brown (10YR 4/3; 10YR 4/2 when moist); sand; single grain; not sticky and not plastic; few, fine roots; no rock fragments; no effervescence.

A photograph of the Fernwood soil profile is presented in section 2.2.1.

Hutton Soil Profile Description

Location:	Lake View, Maputaland
Landform:	Hilltop
Slope:	0 – 1%
Shape:	Convex
Aspect:	West
Elevation:	100 m
Parent Material:	Tertiary Uloa Formation red sand
Surface Rocks:	< 0.01%
Vegetation:	Lebombo Range, with open grass understorey
Land Use:	Native vegetation
Watertable:	10 m

A 0 - 8 cm; dry; dusky red (2.5YR 3/4; 2.5YR 3/3 when moist); sand; weak, medium, granular; not sticky and not plastic; few, fine roots; no rock fragments; no effervescences; clear boundary.

B 8 - 30 cm; dry; dusky red (2.5YR 3/4; 2.5YR 3/3 when moist); sand; weak, coarse, granular; not sticky and not plastic; few, fine roots; no rock fragments; no effervescences.

A photograph of the Hutton soil is presented in section 2.2.1.

A2.1 Soil data for Subtractive Growth Trial 1

The bulk density of the grey sand is 1.5 g cm^{-3}, which is consistent with the average density of 1.54 g cm^{-3} recorded in soil survey results for grey Fernwood sands of Maputaland (Hensley, 1966). This value was used to change between a volume of mass basis for the concentration of extractable soil nutrients.

Table A2.1 Summary of extractable soil nutrient data for Subtractive Growth Trial 1.

Treatment	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
					mg kg^{-1}					
Full	19	22	452	53	104	7.5	50	3.0	3.9	0.5
	0†	4	37	3	20	0.4	2	0.2	0.3	0.0
-P	4‡	17	477	67	140	7.5	42	3.0	3.6	1.0
	1	6	59	11	23	1.0	5	0.3	0.3	0.1
-Ca	20	27	347	68	128	8.5	53	3.1	3.6	0.9
	1	13	45	16	39	0.9	2	0.1	0.3	0.3
-Mg	15	13	359	20	125	4.9	48	2.7	2.6	0.3
	1	6	15	3	10	0.4	2	0.1	0.1	0.1
-S	23	57	503	101	11	9.7	51	2.5	3.5	1.6
	2	23	34	5	2	0.9	2	0.2	0.6	0.1
-Mn	14	10	435	34	99	4.6	42	2.3	2.5	0.4
	1	3	9	6	5	0.5	1	0.2	0.3	0.0
-Fe	16	10	410	32	125	5.0	43	2.4	4.9	0.6
	1	1	14	6	70	0.6	2	0.1	0.5	0.2
-Cu	14	11	459	40	57	6.5	43	0.1	2.7	0.6
	2	2	73	10	34	0.6	3	0.1	0.5	0.2
-Zn	16	24	418	49	148	7.2	52	2.6	0.4	0.6
	1	4	10	5	65	0.6	2	0.1	0.1	0.2
-B	15	7	396	30	88	5.3	43	2.3	2.5	0.1§
	3	2	39	8	22	1.2	1	0.1	0.3	
-Mo	18	14	452	38	154	6.1	42	2.3	2.7	1.0
	2	4	88	9	32	0.6	2	0.2	0.2	0.3
Nil	7	16	361¶	40	12	6.1	44	0.4	0.7	0.1
	3	1	3	2	1	0.6	3	0.2	0.2	0.0

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ Sample size of n = 1, others below detection limit.
¶ Mean and standard deviation are based on a sample size of n=2.

Table A2.2 Complete extractable soil nutrient data for Subtractive Growth Trial 1.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
Full	19	17	441	52	126	7.6	48	2.9	4.2	0.5
	19	24	493	56	93	7.8	49	3.2	4.0	0.5
	19	24	421	51	93	7.0	52	2.8	3.6	0.5
Mean	19	22	452	53	104	7.5	50	3.0	3.9	0.5
StdDev	0	4	37	3	20	0.4	2	0.2	0.3	0.0
Nil	10	17	547†	43	12	6.8	47	0.4	0.6	0.1
	5	17	363	39	11	6.0	44	0.5	0.6	0.1
	5	15	359	39	13	5.6	40	0.2	0.9	0.1
Mean	7	16	423	40	12	6.1	44	0.4	0.7	0.1
StdDev	3	1	108	2	1.0	0.6	3	0.2	0.2	0.0
-P	5	14	445	62	142	8.0	39	3.1	4.0	0.9
	3	24	441	80	161	8.2	41	3.2	3.4	1.0
	4	12	545	60	115	6.4	47	2.7	3.4	1.0
Mean	4	17	477	67	140	7.5	42	3.0	3.6	1.0
StdDev	1	6	59	11	23	1.0	5	0.3	0.3	0.1
-P2‡	5	13	457	67	140	8.7	39	3.3	3.9	1.0
	4	14	437	67	137	8.1	34	2.9	3.5	1.0
	5	8	373	49	114	7.0	40	2.9	3.4	0.8
Mean	5	12	422	61	130	7.9	38	3.0	3.60	0.9
StdDev	1	3	44	11	14	0.86	3	0.2	0.26	0.1
-Ca	20	22	349	64	91	8.4	52	3.0	3.2	0.8
	21	42	301	86	169	9.4	52	3.2	3.8	1.3
	19	18	391	55	122	7.6	55	3.0	3.8	0.7
Mean	20	27	347	68	128	8.5	53	3.2	3.6	0.9
StdDev	1	13	45	16	39	0.9	2	0.1	0.3	0.3
-Mg	16	6	377	17	119	5.0	47	2.7	2.7	0.4
	15	18	351	23	136	5.3	48	2.7	2.5	0.3
	14	15	351	19	120	4.5	50	2.8	2.6	0.3
Mean	15	13	359	20	125	4.9	48	2.7	2.6	0.3
StdDev	1	6	15	3	10	0.4	2	0.1	0.1	0.1
-S	25	83	465	97	11	8.7	52	2.7	4.2	1.7
	22	49	531	107	12	10.3	49	2.4	3.2	1.6
	22	38	513	98	9	10.1	53	2.5	3.2	1.6
Mean	23	57	503	101	11	9.7	51	2.5	3.5	1.6
StdDev	2	23	34	5	2	0.9	2	0.2	0.6	0.1
-Mn	15	10	431	29	94	4.9	42	2.1	2.2	0.4
	14	13	445	41	104	4.9	41	2.3	2.5	0.4
	14	8	429	32	99	4.1	43	2.5	2.7	0.4
Mean	14	10	435	34	99	4.6	42	2.3	2.5	0.4
StdDev	1	3	9	6	5	0.5	1	0.2	0.3	0.0

(continued on next page)

Table A2.2 Continued.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
-Fe	15	9	395	28	93	4.4	41	2.3	4.7	0.8
	16	11	413	39	75	5.5	42	2.5	4.5	0.6
	17	10	423	28	205	5.2	45	2.3	5.5	0.5
Mean	16	10	410	32	125	5.0	43	2.4	4.9	0.6
StdDev	1	1	14	6	70	0.6	2	0.1	0.5	0.2
-Cu	16	11	433	44	22	6.9	40	0.1	2.6	0.6
	15	13	541	47	88	6.8	46	0.1	3.2	0.8
	12	9	403	29	61	5.8	43	0.2	2.3	0.5
Mean	14	11	459	40	57	6.5	43	0.1	2.7	0.6
StdDev	2	2	73	10	34	0.6	3	0.1	0.5	0.2
-Zn	16	21	407	44	74	6.7	51	2.5	0.5	0.4
	16	23	419	50	170	6.9	54	2.6	0.3	0.6
	17	29	427	55	199	7.9	52	2.7	0.5	0.7
Mean	16	24	418	49	148	7.2	52	2.6	0.4	0.6
StdDev	1	4	10	5	65	0.6	2	0.1	0.1	0.2
-B	12	6	381	27	100	4.9	44	2.3	2.6	bdl‡
	18	10	441	39	101	6.6	42	2.3	2.7	0.1
	14	6	367	24	63	4.3	42	2.4	2.2	bdl
Mean	15	7	396	30	88	5.3	43	2.3	2.5	0.1
StdDev	3	2	39	8	22	1.2	1	0.1	0.3	
-Mo	16	9	395	28	118	5.4	40	2.1	2.5	0.7
	19	17	407	45	165	6.6	42	2.4	2.8	1.2
	18	16	553	43	179	6.3	43	2.4	2.8	1.0
Mean	18	14	452	38	154	6.1	42	2.3	2.7	1.0
StdDev	2	4	88	9	32	0.6	2	0.2	0.2	0.3
-Mo2§	16	10	421	47	121	6.5	48	2.5	2.6	0.7
	14	12	407	38	149	5.7	42	2.4	2.5	0.6
	13	7	389	23	106	4.9	41	2.3	2.2	0.3
Mean	14	10	405	36	125	5.7	44	2.4	2.4	0.5
StdDev	2	3	16	12	22	0.8	4	0.1	0.1	0.2

† Excluded as an outlier from final data interpretation, see summary table A2.1.
‡ bdl = Below detection limits.
§ The number 2 indicates a different S source in this treatment only.

A2.2 Soil data for Subtractive Growth Trial 2

Table A2.3 Summary of extractable soil data for Subtractive Growth Trial 2.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
Full	13	10	304	20	102	5.0	47	2.3	3.1	0.1
	1†	3	5	1	34	0.8	18	0.3	0.4	0.0
-K	11	9‡	355	9	88	4.7	42	2.1	2.0	0.1
	1	1	9	2	11	0.3	3	0.3	0.3	0.0
-Ca	10	8	253	16	58	4.4	33	2.0	2.1	0.2
	1	2	7	6	22	0.5	3	0.1	0.1	0.1
-Ca2§	14	8	275	20	47	5.5	31	2.1	2.4	0.1
	2	1	20	6	3	0.7	1	0.2	0.2	0.1
-Mg	11	10	347	7	101	4.3	44	2.0	2.2	0.1
	2	2	23	1	27	0.6	5	0.0	0.2	0.0
-Zn	11	11	327	15	58	4.6	32	2.4	0.3	0.1
	2	2	13	2	11	0.7	1	0.3	0.1	0.0
-B	13	7	347	15	86	4.0	38	2.2	2.3	bdl¶
	3	2	52	6	24	0.7	5	0.3	0.2	
Nil	4	5	304	20	15	4.7	37	0.1	0.2	0.1
	1	1	5	1	3	0.3	5	0.1	0.1	0.0

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ The number 2 indicates a different S source for this treatment only.
¶ bdl = Below detection limits.

Table A2.4 Complete extractable soil nutrient data for Subtractive Growth Trial 2.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
Nil	4	6	299	21	12	4.6	67	0.2	0.3	0.1
	3	5	305	19	16	5.0	39	0.2	0.2	0.1
	4	5	309	21	17	4.4	34	0.0	0.2	0.1
Mean	4	5	304	20	15	4.7	47	0.1	0.2	0.1
StdDev	1	1	5	1	3	0.3	18	0.1	0.1	0.0
Full	13	10	383	16	142	4.5	43	2.7	2.8	0.1
	14	13	401	23	82	5.9	44	2.2	3.5	0.1
	13	7	337	12	82	4.5	39	2.1	2.9	0.1
Mean	13	10	373	17	102	5.0	42	2.3	3.1	0.1
StdDev	1	3	33	6	35	0.8	3	0.3	0.4	0.0
-K	12	8	347	11	81	4.9	34	2.3	2.2	0.1
	10	10	355	7	82	4.3	35	2.3	2.0	0.1
	10	8	365	7	101	4.9	29	1.7	1.7	0.1
Mean	11	9	355	9	88	4.7	33	2.1	2.0	0.1
StdDev	1	1	9	2	11	0.3	3	0.3	0.3	0.0
-Ca	10	6	246	10	33	3.9	30	2.0	2.1	0.1
	11	8	253	22	72	4.6	30	2.1	2.2	0.2
	9	10	261	16	70	4.8	32	2.0	2.0	0.2
Mean	10	8	253	16	58	4.4	31	2.0	2.1	0.2
StdDev	1	2	7	6	22	0.5	1	0.1	0.1	0.1
-Ca2†	15	8	281	23	50	5.5	47	2.3	2.6	0.2
	12	8	253	13	43	4.9	38	2.0	2.2	0.1
	15	7	291	23	48	6.2	46	2.1	2.5	0.1
Mean	14	8	275	20	47	5.5	44	2.1	2.4	0.1
StdDev	2	1	20	6	3	0.7	5	0.2	0.2	0.1
-Mg	13	8	357	7	91	4.2	32	2.0	2.3	0.1
	11	11	365	9	132	4.9	31	2.0	2.3	0.1
	10	11	321	6	80	3.7	32	2.0	1.9	0.1
Mean	11	10	347	7	101	4.3	32	2.0	2.2	0.1
StdDev	2	2	23	1	27	0.6	1	0.0	0.2	0.0
-Zn	11	13	341	17	45	4.7	43	2.8	0.4	0.1
	9	11	315	13	64	3.8	33	2.2	0.2	0.1
	12	10	327	15	65	5.2	39	2.2	0.4	0.1
Mean	11	11	327	15	58	4.6	38	2.4	0.3	0.1
StdDev	2	2	13	2	11	0.7	5	0.3	0.1	0.0
-B	10	8	293	9	59	3.3	32	2.0	2.1	bdl‡
	14	5	353	18	92	4.6	38	2.1	2.4	bdl
	15	8	397	18	107	4.0	42	2.5	2.4	bdl
Mean	13	7	347	15	86	4.0	37	2.2	2.3	bdl
StdDev	3	2	52	6	24	0.7	5	0.3	0.2	

† The number 2 indicates a different S source for this treatment only.
‡ bdl = Below detection limits.

A2.3 Soil data for Amendment Growth Trial 1

Table A2.5 Summary of extractable soil nutrient data for Amendment Growth Trial 1.

Treatment	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
					mg kg^{-1}					
NPKS†	13	17	332	53	74	5.1	44	0.3	0.6	0.1
	1‡	1	13	3	7	0.2	5	0.1	0.1	0.0
NPKS + LS	14	29	346	33	79	6.3	54	0.5	0.6	bdl§
	1	19	23	1	21	0.3	2	0.1	0.2	
NPKS + LR	14	23	339	36	90	6.5	39	0.3	0.6	bdl
	2	12	23	4	23	0.7	4	0.2	0.1	
NPKS + QB	19	31	377	59	77	6.4	79	0.1	0.7	bdl
	1	4	14	5	11	0.3	12	0.1	0.2	
NPKS + KR	17	22	377	39	95	8.2	50	0.3	0.7	0.1¶
	1	1	17	4	12	0.2	6	0.1	0.1	
NPKS + TE	27	23	522	98	262	19.8	54	13.8	68.0	3.7
	3	6	49	7	43	0.5	4	0.2	1.7	0.4
Nil	7	16	361#	40	12	6.1	44	0.4	0.7	0.1
	3	1	3	2	1	0.6	3	0.2	0.2	0.0

† NPKS indicates a basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.
‡ The standard deviation is shown below the mean for each treatment.
§ bdl = Below detection limits.
¶ Sample size of n = 1, others below detection limit.
# Mean and standard deviation are based on a sample size of n=2.

Table A2.6 Complete extractable soil nutrient data for Amendment Growth Trial 1.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
NPKS†	12	17	339	34	66	4.9	38	0.4	0.6	0.1
	13	17	317	29	80	5.1	46	0.2	0.6	0.1
	14	16	341	30	76	5.3	46	0.2	0.7	0.1
Mean	13	17	332	31	74	5.1	44	0.3	0.6	0.1
StdDev	1	1	13	3	7	0.2	5	0.1	0.1	0.0
Nil	10	17	547‡	43	12	6.8	47	0.4	0.6	0.1
	5	17	363	39	11	6.0	44	0.5	0.6	0.1
	5	15	359	39	13	5.6	40	0.2	0.9	0.1
Mean	7	16	423	40	12	6.1	44	0.4	0.7	0.1
StdDev	3	1	108	2	1	0.6	3	0.2	0.2	0.0
NPKS + LS	15	51	365	34	57	6.1	52	0.5	0.8	bdl§
	14	17	353	32	79	6.1	54	0.4	0.6	bdl
	13	18	321	34	100	6.6	54	0.5	0.5	bdl
Mean	14	29	346	33	79	6.3	54	0.5	0.6	bdl
StdDev	1	19	23	1	21	0.3	2	0.1	0.2	
NPKS + LR	15	36	357	40	115	7.3	34	0.1	0.6	bdl
	14	18	349	32	70	6.2	41	0.4	0.6	bdl
	12	14	313	35	84	6.1	42	0.5	0.5	bdl
Mean	14	23	339	36	90	6.5	39	0.3	0.6	bdl
StdDev	2	12	23	4	23	0.7	4	0.2	0.1	
NPKS + QB	18	27	361	53	88	6.0	88	0.2	0.6	bdl
	19	32	385	61	78	6.6	65	0.0	0.9	bdl
	20	34	385	63	66	6.5	83	0.0	0.7	bdl
Mean	19	31	377	59	77	6.4	79	0.1	0.7	bdl
StdDev	1	4	14	5	11	0.3	12	0.1	0.2	
NPKS + KR	17	21	377	39	99	8.4	54	0.4	0.80	0.1
	18	21	361	44	105	8.1	53	0.4	0.60	bdl
	17	23	395	35	82	8.0	44	0.2	0.70	bdl
Mean	17	22	377	39	95	8.2	50	0.3	0.70	0.1
StdDev	1	1	17	4	12	0.2	6	0.1	0.10	
NPKS + TE	29	30	465	97	302	20.2	55	13.8	68.6	4.1
	27	21	551	106	216	19.8	57	14.0	69.3	3.6
	24	19	549	92	269	19.3	50	13.6	66.1	3.3
Mean	27	23	522	98	262	19.8	54	13.8	68.0	3.7
StdDev	3	6	49	7	43	0.5	4	0.2	1.7	0.4

† NPKS indicates a basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.

‡ Excluded as an outlier from final data interpretation, see summary table A2.5.

§ bdl = Below detection limits.

A2.4 Soil data for Amendment Growth Trial 2

Table A2.5 Summary of extractable soil nutrient data for Amendment Growth Trial 2.

Treatment	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
					mg kg^{-1}					
Nil	4	5	304	20	15	4.7	47	0.1	0.2	0.1
	1†	1	5	1	3	0.3	18	0.1	0.1	0.0
M‡	10	15	438	58	16	8.3	64	0.3	0.5	bdl§
	1	2	25	5	4	0.4	3	0.1	0.1	
N	3	8	303	13	14	4.7	27	0.2	0.4	bdl
	1	1	21	3	3	0.8	1	0.0	0.2	
N + M	7	15	374	30	8	7.5	53	0.3	0.5	bdl
	1	3	20	8	2	1.4	12	0.1	0.2	
NP	16	7	307	12	10	5.2	38	0.3	0.4	bdl
	2	1	11	4	2	0.3	3	0.1	0.1	
NP + M	19	15	395	30	8	8.8	66	0.3	0.5	bdl
	1	1	7	1	1	0.3	2	0.0	0.1	
NPS	15	9	289	12	152	4.8	39	0.2	0.3	bdl
	1	1	15	1	10	0.2	3	0.1	0.1	
NPS + M	18	15	383	30	110	7.9	66	0.3	0.4	bdl
	1	1	3	4	5	0.1	2	0.1	0.1	
NPS + LR	26	13	333	47	99	20.4	151	0.2	1.0	bdl
	2	3	9	7	23	3.6	24	0.1	0.3	
NPS + LS	33	10	358	43	137	9.2	107	0.6	0.4	bdl
	6	3	11	9	20	2.0	32	0.2	0.1	
NPKS	17	14	279	17	141	4.7	43	0.3	0.4	bdl
	1	3	26	1	0	0.3	2	0.1	0.0	
NPKS2¶	18	10	261	12	108	3.9	44	0.2	0.3	bdl
	1	2	14	1	38	0.1	3	0.0	0.0	
NPKS + M	18	21	373	36	119	8.0	68	0.2	0.4	bdl
	0	1	12	4	22	0.4	2	0.1	0.1	

† The standard deviation is shown below the mean for each treatment.
‡ N, NP, NPS and NPKS indicate basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.
§ bdl = Below detectior limits.
¶ The number 2 indicates a different S source in this treatment only.

Table A2.6 Complete extractable soil nutrient data for Amendment Growth Trial 2.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
Nil	4	6	299	21	12	4.6	67	0.2	0.3	0.1
	3	5	305	19	16	5.0	39	0.2	0.2	0.1
	4	5	309	21	17	4.4	34	0.0	0.2	0.1
Mean	4	5	304	20	15	4.7	47	0.1	0.2	0.1
StdDev	1	1	5	1	3	0.3	18	0.1	0.1	0.0
M†	9	14	445	58	14	7.9	61	0.3	0.6	bdl‡
	11	17	459	63	13	8.6	67	0.3	0.6	bdl
	9	15	411	52	21	8.3	64	0.2	0.4	bdl
Mean	10	15	438	58	16	8.3	64	0.3	0.5	bdl
StdDev	1	2	25	5	4	0.4	3	0.1	0.1	
N	4	9	327	16	17	5.5	27	0.2	0.6	bdl
	2	7	293	12	10	4.7	27	0.2	0.3	bdl
	3	8	289	10	15	4.0	26	0.2	0.3	bdl
Mean	3	8	303	13	14	4.7	27	0.2	0.4	bdl
StdDev	1	1	21	3	3	0.8	1	0.0	0.2	
N + M	8	18	383	34	6	8.5	63	0.3	0.5	bdl
	6	12	351	21	9	5.9	40	0.2	0.4	bdl
	8	14	389	35	9	8.0	56	0.3	0.7	bdl
Mean	7	15	374	30	8	7.5	53	0.3	0.5	bdl
StdDev	1	3	20	8	2	1.4	12	0.1	0.2	
NP	14	6	295	9	10	5.2	40	0.2	0.3	bdl
	17	6	315	17	12	4.9	40	0.3	0.5	bdl
	17	8	311	11	8	5.5	35	0.3	0.4	bdl
Mean	16	7	307	12	10	5.2	38	0.3	0.4	bdl
StdDev	2	1	11	4	2	0.3	3	0.1	0.1	
NP + M	19	15	387	30	8	8.6	67	0.3	0.4	bdl
	19	16	401	29	8	8.6	67	0.3	0.6	bdl
	20	15	397	32	9	9.1	63	0.3	0.6	bdl
Mean	19	15	395	30	8	8.8	66	0.3	0.5	bdl
StdDev	1	1	7	1	1	0.3	2	0.0	0.1	
NPS	15	10	283	11	164	5.0	41	0.2	0.3	bdl
	14	8	307	12	149	4.6	35	0.3	0.3	bdl
	15	10	279	13	144	4.8	41	0.2	0.4	bdl
Mean	15	9	289	12	152	4.8	39	0.2	0.3	bdl
StdDev	1	1	15	1	10	0.2	3	0.1	0.1	

(continued on next page)

Table A2.6 Continued.

Treatment	Nutrient concentrations									
	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	mg kg^{-1}									
NPS + M	18	15	381	30	106	8.0	64	0.4	0.4	bdl
	19	14	383	34	116	8.0	67	0.3	0.3	bdl
	17	16	387	27	109	7.8	67	0.2	0.4	bdl
Mean	18	15	383	30	110	7.9	66	0.3	0.4	bdl
Std Dev	1	1	3	4	5	0.1	2	0.1	0.1	
NPS + LR	24	15	343	47	124	18.2	135	0.3	1.0	bdl
	28	9	333	55	79	24.5	179	0.2	1.3	bdl
	26	15	325	40	96	18.4	140	0.2	0.8	bdl
Mean	26	13	333	47	99	20.4	151	0.2	1.0	bdl
Std Dev	2	3	9	7	23	3.6	24	0.1	0.3	
NPS + LS	38	10	347	35	114	10.1	109	0.7	0.3	bdl
	27	12	359	43	152	6.9	75	0.4	0.4	bdl
	33	7	369	52	146	10.7	138	0.7	0.4	bdl
Mean	33	10	358	43	137	9.2	107	0.6	0.4	bdl
Std Dev	6	3	11	9	20	2.0	32	0.2	0.1	
NPKS	16	15	248	16	142	4.7	42	0.2	0.4	bdl
	17	17	297	18	141	5.0	45	0.3	0.4	bdl
	17	11	291	18	142	4.5	41	0.3	0.4	bdl
Mean	17	14	279	17	142	4.7	43	0.3	0.4	bdl
Std Dev	1	3	26	1	1	0.3	2	0.1	0.0	
NPKS2§	17	11	257	13	74	3.8	44	0.2	0.3	bdl
	19	12	251	12	149	4.0	47	0.2	0.3	bdl
	18	8	277	11	102	4.0	42	0.2	0.3	bdl
Mean	18	10	261	12	108	3.9	44	0.2	0.3	bdl
Std Dev	1	2	14	1	38	0.1	3	0.0	0.0	
NPKS + M	18	20	359	33	105	7.6	66	0.2	0.5	bdl
	18	21	379	36	145	8.1	69	0.2	0.3	bdl
	18	21	381	40	107	8.3	68	0.1	0.3	bdl
Mean	18	21	373	36	119	8.0	68	0.2	0.4	bdl
Std Dev	0	1	12	4	23	0.4	2	0.1	0.1	

† N, NP, NPS and NPKS indicate basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.

‡ bdl = Below detection limits.

§ The number 2 indicates a different S source in this treatment only.

APPENDIX 3

Plant Tissue Data

A3.1 Dry Yield Data

Table A3.1 Dry yield data for Subtractive Growth Trials 1 and 2.

Treatment	Dry Yield			Average	Standard Deviation
	g				
Trial 1					
Nil	0.94	0.95	1.06	0.98	0.07
Full	3.12	2.92	2.80	2.95	0.16
-B	3.28	2.87	3.73	3.29	0.43
-Ca	1.86	1.20	2.20	1.75	0.51
-Cu	2.40	2.73	3.31	2.81	0.46
-Fe	2.60	2.97	2.55	2.71	0.23
-Mo	3.33	1.95	2.42	2.57	0.70
-Mo2†	2.84	3.50	2.37	2.90	0.57
-Mn	2.68	3.21	3.06	2.98	0.27
-Mg	3.57	3.81	3.86	3.75	0.16
-P	1.78	1.38	1.65	1.60	0.20
-P2†	1.34	0.93	1.67	1.31	0.37
-S	0.63	0.60	1.22	0.82	0.35
-Zn	2.29	1.93	2.05	2.09	0.18
Trial 2					
-K	2.56	2.25	2.35	2.39	0.16
-B	3.83	3.86	3.72	3.80	0.07
-Zn	3.10	3.11	3.10	3.10	0.01
-Ca	3.43	3.17	3.52	3.37	0.18
-Ca2‡	3.16	3.07	3.03	3.09	0.07
Full	3.68	3.29	4.23	3.73	0.47
Nil	0.90	0.68	0.81	0.80	0.11
-Mg	3.53	4.03	3.41	3.66	0.33

† The number 2 in trial1 indicates a replicated treatment.
‡ The number 2 in trial 2 indicates a different S source in this treatment only.

Table A3.2 Dry yield data for Amendment Growth Trials 1 and 2.

Treatmen	Dry Yield			Average	Standard Deviation
	g				
Trial 1					
NPKS + LR†	2.98	3.02	2.80	2.93	0.12
NPKS + LS	2.90	2.73	2.18	2.60	0.38
NPKS + QR	2.62	3.02	2.87	2.84	0.20
NPKS + KR	2.84	2.59	2.50	2.64	0.18
NPKS + TE	1.19	1.69	1.62	1.50	0.27
NPKS	2.68	2.73	2.85	2.75	0.09
Trial 2					
M‡	1.11	1.06	0.93	1.03	0.09
N	1.44	1.25	1.20	1.30	0.13
N + M	3.01	2.51	2.82	2.78	0.25
NP	1.75	2.14	1.69	1.86	0.24
NP + M	2.62	2.70	2.41	2.58	0.15
NPS	1.67	1.46	1.61	1.58	0.11
NPS + M	2.50	2.67	3.08	2.75	0.30
NPS + LR	2.40	2.36	2.41	2.39	0.03
NPS + LS	1.92	1.58	1.79	1.76	0.17
NPKS2	2.53	3.14	2.95	2.87	0.31
NPKS	2.51	2.06	2.44	2.34	0.24
NPKS + M	2.89	3.01	3.11	3.00	0.11
Nil	0.94	0.95	1.06	0.98	0.07

† NPKS = basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.

‡ N, NP, NPS and NPKS = basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.

A3.2 Plant tissue data for Subtractive Growth Trial 1

Table A3.3 Summary of maize foliar concentrations and yield data for Subtractive Growth Trial 1.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
Full	2.95	28.8	1.6	17.5	8.5	5.6	2.2	487	113	9	55	395
	0.16†	1.7	0.1	1.5	0.6	0.1	0	39	14	2	7	69
-P	1.60	32.7	1.1‡	20.5	11.6	6.3	2.1§	710§	153	12	86	530§
	0.20	3.2	0.1	1.4	1.4	0.6	1.1	113	13	2	7	48
-Ca	1.75	36.7	2.1	24.5	5.7	5.3	2.0§	658	159	12	95	586§
	0.51	1.2	0.2	4.2	0.4	0.6	0.1	51	29	2	19	59
-Mg	3.57	23.1	1.5	13.4	6.9	2.8	2.6	450	133	8	49	215
	3.57	1.2	0.1	1.2	0.7	0.1	0.3	1	6	0	1	13
-S	0.82	43.7	3.4	31.1	17.9	4.7	ND¶	542	160	11	81	861
	0.35	2.1	0.3	0.6	2.1	0.6	0	28	31	3	10	24
-Mn	2.98	21.0	1.7	16.2	6.5	5.6	2.5	173	106	8	37	275
	0.27	0.9	0.1	2.1	0.5	0.4	0.2	16	8	1	4	12
-Fe	2.60	28.4	1.6	17.1	8.1	5.2	2.4	459	116	9	99	462
	2.60	1.8	0.2	1.1	0.1	0.2	0.2	22	10	1	7	61
-Cu	2.81	26.4	1.8	19.6	7.3	5.8	2.8	322	136	3	53	508
	0.46	2.5	0.1	2.4	0.9	0.7	0.3	33	4	1	1	79
-Zn	2.09	28.4	2.5	23.4	9.9	6.1	3.5	375	212	19	14	445§
	0.18	3.3	0.2	3.1	1	0.4	0.4	62	20	2	1	23
-B	3.29	22.0	1.2	13.8	7.2	4.9	2.1	375	93	9	40	28
	0.43	1.9	0.1	1.8	0.5	0.4	0.3	18	8	2	2	6
-Mo	2.57	32.5	2.0	21.8	8.6	5.5	3.1	397	135	10	48	916
	0.70	1.6	0.2	2.4	1.3	0.8	0.3	72	10	1	5	86
Nil	0.98	11.0	1.6	6.3	6.4	4.9	ND	54	106	4	16	63
	0.07	0.8	0.1	1.3	0.9	0.8	0	10	5	2	3	5
Critical level#		35	4	35	9	3	2	50	50	7	20	7

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ Mean and standard deviation are based on a sample size of n=2.
¶ ND = Not determined; too little sample.
# Critical levels are from Bennett (1993) for young maize.

Table A3.4 Complete maize foliar concentrations and yield data for Subtractive Growth Trial 1.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
Full	3.12	26.8	1.5	16.2	7.9	5.6	2.2	456	106	8	53	325
	2.92	29.8	1.7	17.3	8.5	5.6	2.2	473	104	8	49	398
	2.80	29.8	1.7	19.1	9.1	5.5	2.2	531	130	11	62	462
Mean	2.95	28.8	1.6	17.5	8.5	5.6	2.2	487	113	9	55	395
StdDev	0.16	1.7	0.1	1.5	0.6	0.1	0.0	39	14	2	7	69
Nil	0.94	11.6	1.7	7.8	7.5	5.8	ND†	66	107	6	20	60
	0.95	11.3	1.5	5.2	6.1	4.5	ND	48	100	3	15	69
	1.06	10.1	1.6	5.9	5.7	4.5	ND	49	110	3	14	61
Mean	0.98	11.0	1.6	6.3	6.4	4.9	ND	54	106	4	16	63
StdDev	0.07	0.8	0.1	1.3	0.9	0.8		10	5	2	3	5
-P	1.78	30.3	1.0	18.9	12.0	7.0	2.8	627	148	12	85	496
	1.38	36.3	1.2	21.4	12.7	5.9	ND	787	168	13	93	823‡
	1.65	31.5	1.2	21.2	10.0	5.9	1.3	176‡	143	10	80	564
Mean	1.60	32.7	1.1	20.5	11.6	6.3	2.1	530	153	12	86	628
StdDev	0.20	3.2	0.1	1.4	1.4	0.6	1.1	317	13	2	7	173
-P2§	1.34	33.4	1.2	22.1	11.1	5.8	ND	676	146	12	87	519
	0.93	38.3	1.2	22.2	10.6	5.4	ND	669	166	8	81	790
	1.67	28.6	0.9	17.0	9.7	7.1	2.8	604	135	9	72	433
Mean	1.31	33.4	1.1	20.4	10.5	6.1	2.8	650	149	10	80	581
StdDev	0.37	4.9	0.2	3.0	0.7	0.9		40	16	2	8	186
-Ca	1.86	36.8	2.1	23.6	5.3	5.0	3.1	602	142	10	81	627
	1.20	37.9	2.2	29.1	6.0	4.8	ND	702	192	14	117	866‡
	2.20	35.5	1.9	20.8	5.8	6.0	3.0	670	143	11	87	544
Mean	1.75	36.7	2.1	24.5	5.7	5.3	2.0	658	159	12	95	679
StdDev	0.51	1.2	0.2	4.2	0.4	0.6	0.1	51	29	2	19	167
-Mg	3.57	24.4	1.6	14.8	6.6	2.9	2.4	450	130	8	48	213
	3.81	22.9	1.5	13.1	6.3	2.7	2.4	450	139	8	49	203
	3.86	22.1	1.4	12.4	7.7	2.9	2.9	449	129	8	50	228
Mean	3.57	23.1	1.5	13.4	6.9	2.8	2.6	450	133	8	49	215
StdDev	3.57	1.2	0.1	1.2	0.7	0.1	0.3	1	6	0	1	13
-S	0.63	43.6	3.7	30.4	20.3	5.4	ND	529	194	14	91	865
	0.60	41.7	3.4	31.4	17.3	4.6	ND	574	153	11	80	835
	1.22	45.9	3.1	31.6	16.2	4.2	ND	522	134	9	72	883
Mean	0.82	43.7	3.4	31.1	17.9	4.7	ND	542	160	11	81	861
StdDev	0.35	2.1	0.3	0.6	2.1	0.6		28	31	3	10	24

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Table A3.4 Continued.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
-Mn	2.68	20.1	1.6	15.7	7.0	6.0	2.3	189	106	8	39	269
	3.21	21.1	1.6	18.5	6.2	5.3	2.4	157	99	8	33	288
	3.06	21.9	1.8	14.5	6.2	5.5	2.7	173	114	9	40	267
Mean	2.98	21.0	1.7	16.2	6.5	5.6	2.5	173	106	8	37	275
StdDev	0.27	0.9	0.1	2.1	0.5	0.4	0.2	16	8	1	4	12
-Fe	2.60	28.9	1.7	17.4	8.2	5.4	2.7	456	127	10	101	525
	2.97	26.4	1.4	15.9	8.1	5.0	2.3	439	115	8	91	403
	2.55	29.9	1.7	18.0	8.1	5.2	2.3	482	107	10	104	458
Mean	2.60	28.4	1.6	17.1	8.1	5.2	2.4	459	116	9	99	462
StdDev	2.60	1.8	0.2	1.1	0.1	0.2	0.2	22	10	1	7	61
-Cu	2.40	28.1	1.9	21.6	8.1	6.6	3.2	352	140	3	54	595
	2.73	27.7	1.9	20.2	6.4	5.2	2.6	287	133	2	52	487
	3.31	23.5	1.7	17.0	7.4	5.7	2.6	327	136	3	54	442
Mean	2.81	26.4	1.8	19.6	7.3	5.8	2.8	322	136	3	53	508
StdDev	0.46	2.5	0.1	2.4	0.9	0.7	0.3	33	4	1	1	79
-Zn	2.29	24.8	2.3	19.8	8.8	5.9	3.2	358	190	19	13	428
	1.93	28.9	2.7	25.3	10.7	6.6	3.9	443	216	18	15	704‡
	2.05	31.4	2.6	25.1	10.1	5.9	3.5	323	230	21	15	461
Mean	2.09	28.4	2.5	23.4	9.9	6.1	3.5	375	212	19	14	531
StdDev	0.18	3.3	0.2	3.1	1.0	0.4	0.4	62	20	2	1	151
-B	3.28	21.0	1.2	13.2	6.7	5.0	1.8	391	89	7	39	35
	2.87	24.1	1.3	15.8	7.2	4.5	2.4	377	89	11	40	25
	3.73	20.8	1.2	12.4	7.6	5.3	2.1	356	102	8	42	25
Mean	3.29	22.0	1.2	13.8	7.2	4.9	2.1	375	93	9	40	28
StdDev	0.43	1.9	0.1	1.8	0.5	0.4	0.3	18	8	2	2	6
-Mo	3.33	30.9	2.0	19.5	10.0	6.2	3.3	470	142	10	52	950
	1.95	34.1	2.2	24.2	7.7	4.7	2.8	327	139	11	50	980
	2.42	32.6	1.9	21.7	8.0	5.6	3.2	395	124	9	42	819
Mean	2.57	32.5	2.0	21.8	8.6	5.5	3.1	397	135	10	48	916
StdDev	0.70	1.6	0.2	2.4	1.3	0.8	0.3	72	10	1	5	86
-Mo2§	2.84	24.5	11.5	17.7	7.8	5.6	2.1	352	92	9	38	331
	3.50	21.7	1.4	13.2	7.3	6.2	2.9	409	92	9	45	257
	2.37	28.4	1.6	18.8	7.9	5.5	2.5	334	114	10	45	350
Mean	2.90	24.9	4.8	16.6	7.7	5.8	2.5	365	99	9	43	313
StdDev	0.57	3.4	5.8	3.0	0.3	0.4	0.4	39	13	1	4	49

† ND = Not determined; too little sample.
‡ Excluded as an outlier from final data interpretation, see summary table A2.1.
§ The number 2 indicates a replicated treatment.

Table A3.5 Summary of maize foliar concentrations and yield data for Subtractive Growth Trial 1.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
Full	2.95	11.8	0.67	7.15	3.47	2.28	0.90	199	46	4	22	161
	0.16†	0.28	0.02	0.24	0.06	0.14	0.05	7	4	1	2	19
-P	1.60	7.2	0.25‡	4.54	2.56	1.40	0.50§	115	34	3	19	137
	0.20	0.27	0.02	0.39	0.36	0.30	0.28	65	2	0	2	19
-Ca	1.75	8.9	0.50	5.77	1.38	1.31	0.86§	159	37	3	22	158
	0.51	2.33	0.11	0.80	0.39	0.52	0.08	44	6	1	4	12
-Mg	3.57	12.0	0.78	6.97	3.58	1.47	1.34	234	69	4	26	112
	3.57	0.15	0.02	0.35	0.48	0.07	0.19	9	5	0	2	9
-S	0.82	5.0	0.38	3.50	1.99	0.52	ND¶	61	17	1	9	98
	0.35	2.39	0.13	1.57	0.68	0.17		24	5	0	3	45
-Mn	2.98	8.7	0.69	6.80	2.67	2.31	1.02	71	44	3	15	114
	0.27	1.08	0.09	1.31	0.08	0.07	0.15	2	4	0	1	14
-Fe	2.60	10.6	0.60	6.41	3.06	1.95	0.91	172	44	3	37	173
	2.60	0.23	0.02	0.14	0.25	0.11	0.09	8	5	0	1	15
-Cu	2.81	10.2	0.71	7.56	2.84	2.26	1.08	125	53	1	21	195
	0.46	0.76	0.07	0.32	0.50	0.33	0.11	22	8	0	4	10
-Zn	2.09	8.2	0.73	6.74	2.85	1.78	1.02	108	61	6	4	152
	0.18	0.65	0.01	0.43	0.04	0.10	0.02	14	4	1	0	32
-B	3.29	10.0	0.56	6.25	3.29	2.27	0.95	171	43	4	18	13
	0.43	0.69	0.05	0.21	0.57	0.48	0.13	18	9	1	3	3
-Mo	2.57	11.5	0.72	7.60	3.10	2.01	1.12	146	48	4	17	327
	0.70	2.57	0.18	1.26	1.33	0.80	0.39	65	15	1	6	98
Nil	0.98	1.5	0.22	0.86	0.87	0.67	ND	7	14	0.5	2	9
	0.07	0.01	0.02	0.17	0.09	0.08		1	2	0	0	1

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ Mean and standard deviation are based on a sample size of n=2.
¶ ND = Not determined; too little sample.

Table A3.6 Complete maize foliar concentrations and yield data for Subtractive Growth Trial 1.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
Full	3.12	11.6	0.65	7.02	3.42	2.43	0.95	198	46	4	23	141
	2.92	12.1	0.69	7.02	3.45	2.27	0.89	192	42	3	20	161
	2.80	11.6	0.66	7.43	3.54	2.14	0.86	207	51	4	24	180
Mean	2.95	11.8	0.67	7.15	3.47	2.28	0.90	199	46	4	22	161
StdDev	0.16	0.28	0.02	0.24	0.06	0.14	0.05	7	4	1	2	19
Nil	0.94	1.51	0.22	1.02	0.98	0.76	ND†	9	14	1	3	8
	0.95	1.49	0.20	0.69	0.80	0.59	ND	6	13	0	2	9
	1.06	1.49	0.24	0.87	0.84	0.66	ND	7	16	0	2	9
Mean	0.98	1.50	0.22	0.86	0.87	0.67	ND	7	14	1	2	9
StdDev	0.07	0.01	0.02	0.17	0.09	0.08		1	2	0	0	1
-P	1.78	7.49	0.25	4.67	2.97	1.73	0.69	155	37	3	21	123
	1.38	6.96	0.23	4.10	2.43	1.13	ND	151	32	2	18	158
	1.65	7.22	0.28	4.86	2.29	1.35	0.30	40	33	2	18	129
Mean	1.60	7.22	0.25	4.54	2.56	1.40	0.50	115	34	3	19	137
StdDev	0.20	0.27	0.02	0.39	0.36	0.30	0.28	65	2	0	2	19
-P2‡	1.34	6.22	0.22	4.11	2.07	1.08	ND	126	27	2	16	97
	0.93	4.95	0.16	2.87	1.37	0.70	ND	86	21	1	10	102
	1.67	6.63	0.21	3.94	2.25	1.65	0.65	140	31	2	17	100
Mean	1.31	5.93	0.20	3.64	1.89	1.14	0.51	117	27	2	14	100
StdDev	0.37	0.88	0.04	0.68	0.46	0.48		28	5	1	3	3
-Ca	1.86	9.51	0.54	6.10	1.37	1.29	0.80	156	37	3	21	162
	1.20	6.32	0.37	4.85	1.00	0.80	ND	117	32	2	20	144
	2.20	10.9	0.58	6.36	1.77	1.83	0.92	205	44	3	27	166
Mean	1.75	8.89	0.50	5.77	1.38	1.31	0.86	159	37	3	22	158
StdDev	0.51	2.33	0.11	0.80	0.39	0.52	0.08	44	6	1	4	12
-Mg	3.57	12.1	0.79	7.34	3.27	1.44	1.19	223	64	4	24	106
	3.81	12.1	0.79	6.93	3.33	1.43	1.27	238	74	4	26	107
	3.86	11.9	0.75	6.65	4.13	1.55	1.55	241	69	4	27	122
Mean	3.57	12.0	0.78	6.97	3.58	1.47	1.34	234	69	4	26	112
StdDev	3.57	0.15	0.02	0.35	0.48	0.07	0.19	9	5	0	2	9
-S	0.63	3.82	0.32	2.66	1.78	0.47	ND	46	17	1	8	76
	0.60	3.48	0.28	2.62	1.44	0.38	ND	48	13	1	7	70
	1.22	7.78	0.53	5.35	2.75	0.71	ND	88	23	2	12	150
Mean	0.82	5.02	0.38	3.54	1.99	0.52	ND	61	17	1	9	98
StdDev	0.35	2.39	0.13	1.57	0.68	0.17		24	5	0	3	45

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Table A3.6 Continued.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
-Mn	2.68	7.48	0.60	5.84	2.61	2.23	0.86	70	39	3	15	100
	3.21	9.41	0.71	8.25	2.76	2.36	1.07	70	44	4	15	128
	3.06	9.31	0.77	6.16	2.64	2.34	1.15	74	48	4	17	113
Mean	2.98	8.73	0.69	6.75	2.67	2.31	1.02	71	44	3	15	114
StdDev	0.27	1.08	0.09	1.31	0.08	0.07	0.15	2	4	0	1	14
-Fe	2.60	10.4	0.61	6.28	2.96	1.95	0.98	165	46	4	36	190
	2.97	10.9	0.58	6.56	3.34	2.06	0.95	181	47	3	38	166
	2.55	10.6	0.60	6.38	2.87	1.84	0.81	171	38	4	37	162
Mean	2.60	10.6	0.60	6.41	3.06	1.95	0.91	172	44	3	37	173
StdDev	2.60	0.23	0.02	0.14	0.25	0.11	0.09	8	5	0	1	15
-Cu	2.40	9.37	0.63	7.20	2.70	2.20	1.07	117	47	1	18	198
	2.73	10.5	0.72	7.66	2.43	1.97	0.99	109	50	1	20	185
	3.31	10.8	0.78	7.82	3.40	2.62	1.20	150	63	1	25	203
Mean	2.81	10.2	0.71	7.56	2.84	2.26	1.08	125	53	1	21	195
StdDev	0.46	0.76	0.07	0.32	0.50	0.33	0.11	22	8	0	4	10
-Zn	2.29	7.89	0.73	6.30	2.80	1.88	1.02	114	60	6	4	136
	1.93	7.75	0.72	6.78	2.87	1.77	1.05	119	58	5	4	189
	2.05	8.94	0.74	7.15	2.88	1.68	1.00	92	65	6	4	131
Mean	2.09	8.19	0.73	6.74	2.85	1.78	1.02	108	61	6	4	152
StdDev	0.18	0.65	0.01	0.43	0.04	0.10	0.02	14	4	1	0	32
-B	3.28	9.57	0.55	6.01	3.05	2.28	0.82	178	41	3	18	16
	2.87	9.61	0.52	6.30	2.87	1.79	0.96	150	35	4	16	10
	3.73	10.9	0.62	6.42	3.94	2.75	1.09	184	53	4	22	13
Mean	3.29	9.98	0.56	6.25	3.29	2.27	0.95	171	43	4	18	13
StdDev	0.43	0.69	0.05	0.21	0.57	0.48	0.13	18	9	1	3	3
-Mo	3.33	14.3	0.93	9.02	4.63	2.87	1.53	217	66	5	24	439
	1.95	9.24	0.60	6.55	2.09	1.27	0.76	89	38	3	14	265
	2.42	11.0	0.64	7.29	2.69	1.88	1.08	133	42	3	14	275
Mean	2.57	11.5	0.72	7.62	3.13	2.01	1.12	146	48	4	17	327
StdDev	0.70	2.57	0.18	1.26	1.33	0.80	0.39	65	15	1	6	98
-Mo2‡	2.84	9.66	4.54	6.98	3.08	2.21	0.83	139	36	4	15	131
	3.50	10.6	0.68	6.42	3.55	3.01	1.41	199	45	4	22	125
	2.37	9.35	0.53	6.19	2.60	1.81	0.82	110	38	3	15	115
Mean	2.90	9.85	1.91	6.53	3.08	2.34	1.02	149	40	4	17	124
StdDev	0.57	0.62	2.27	0.41	0.47	0.61	0.34	45	5	1	4	8

† ND = Not determined; too little sample.
‡ The number 2 indicates a replicated treatment.

A3.3 Plant tissue data for Subtractive Growth Trial 2

Table A3.7 Summary of maize foliar concentrations and yield data for Subtractive Growth Trial 2.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
Full	3.73	14.4	1.2	7.5	7.1	4.0	1.9	190	57	8	46	50
	0.47†	2.3	0.1	1.5	0.4	0.3	0.3	11	3	1	3	5
-K	2.39	21.0	1.7	3.1‡	11.3	7.7	2.7	324	82	15	52	58
	0.16	0.3	0.3	0.1	0.4	0.6	0.1	66	9	0	12	11
-Ca	3.37	15.5	1.1	7.2	3.8	4.4	2.0	178	54	7	37	56
	0.18	4.2	0	1.9	0.3	0.1	0.1	9	6	1	9	14
-Ca2§	3.09	16.5	1.1	8.2	5.0	4.3	1.9	320	62¶	8	52¶	44
	0.07	2.6	0.1	0.8	0.1	0.4	0.1	46	4	1	11	6
-Mg	3.66	13.8	1.1	6.3	6.9	2.7	1.7	211	54	8	35	47
	0.33	2	0.1	0.8	1.1	0.1	0.3	22	2	1	4	12
-Zn	3.10	14.7	1.5	9.5	8.3	5.8	1.9	244	87	15	8	54
	0.01	0.3	0.1	0.3	0.5	1.9	0.3	26	8	2	1	7
-B	3.80	12.7	1.0	6.3	7.1	3.6	1.7	221	62¶	8	37¶	18
	0.07	1.7	0.1	0.7	0.6	0.2	0.2	21	10	1	8	1
Nil	0.80	9.3	1.7	8.0	7.2	4.4	1.7#	78	70	6	21	85
	0.11	0.3	0.1	1.1	0.6	0.6		7	4	1	3	28
Critical level††		35	4	35	9	3	2	50	50	7	20	7

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ The number 2 indicates a different S source for this treatment only.
¶ Mean and standard deviation are based on a sample size of n=2.
# Based on a sample size of n=1.
†† Critical levels are from Bennett (1993) for six-week old maize plants.

Table A3.8 Complete maize foliar concentrations and yield data for Subtractive Growth Trial 2.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
Nil	0.90	9.3	1.7	7.7	7.4	5.0	1.7	70	67	6	21	117
	0.68	9.5	1.7	9.2	6.5	3.8	ND†	84	74	6	24	67
	0.81	9.0	1.6	7.1	7.7	4.4	ND	80	69	5	19	70
Mean	0.80	9.3	1.7	8.0	7.2	4.4	1.7	78	70	6	21	85
StdDev	0.11	0.3	0.1	1.1	0.6	0.6	0.0	7	4	1	3	28
Full	3.68	13.9	1.2	7.9	6.9	3.9	2.0	180	58	8	46	45
	3.29	17.0	1.3	8.7	7.6	4.3	2.1	201	59	8	49	51
	4.23	12.4	1.1	5.8	6.8	3.7	1.6	188	53	7	44	55
Mean	3.73	14.4	1.2	7.5	7.1	4.0	1.9	190	57	8	46	50
StdDev	0.47	2.3	0.1	1.5	0.4	0.3	0.3	11	3	1	3	5
-K	2.56	21.1	1.4	3.0	11.1	7.1	2.7	280	80	15	54	49
	2.25	21.2	2.0	3.0	11.8	8.2	2.7	400	92	15	63	70
	2.35	20.6	1.6	3.2	11.1	7.9	2.6	292	74	15	40	54
Mean	2.39	21.0	1.7	3.1	11.3	7.7	2.7	324	82	15	52	58
StdDev	0.16	0.3	0.3	0.1	0.4	0.6	0.1	66	9	0	12	11
-Ca	3.43	10.7	1.1	5.0	3.6	4.4	1.9	168	49	6	28	39
	3.17	17.7	1.1	8.5	3.8	4.3	2.1	181	60	8	37	63
	3.52	18.2	1.1	8.1	4.1	4.5	2.1	186	52	7	46	65
Mean	3.37	15.5	1.1	7.2	3.8	4.4	2.0	178	54	7	37	56
StdDev	0.18	4.2	0.0	1.9	0.3	0.1	0.1	9	6	1	9	14
-Ca2‡	3.16	19.4	1.0	9.0	5.0	4.1	1.8	278	64	7	44	50
	3.07	14.4	1.1	7.4	5.1	4.8	1.9	369	59	8	59	41
	3.03	15.6	1.2	8.2	5.0	4.1	1.9	314	719§	9	129§	40
Mean	3.09	16.5	1.1	8.2	5.0	4.3	1.9	320	281	8	77	44
StdDev	0.07	2.6	0.1	0.8	0.1	0.4	0.1	46	380	1	45	6
-Mg	3.53	16.0	1.1	6.7	6.3	2.6	1.8	189	51	7	32	36
	4.03	12.0	1.0	5.4	6.2	2.6	1.3	212	55	7	34	45
	3.41	13.3	1.1	6.7	8.2	2.8	1.9	232	55	9	40	59
Mean	3.66	13.8	1.1	6.3	6.9	2.7	1.7	211	54	8	35	47
StdDev	0.33	2.0	0.1	0.8	1.1	0.1	0.3	22	2	1	4	12
-Zn	3.10	14.9	1.5	9.1	7.9	4.6	1.6	230	95	13	8	61
	3.11	14.7	1.4	9.7	8.8	4.8	2.1	274	79	16	9	54
	3.10	14.4	1.5	9.7	8.3	8.0	1.9	229	88	15	8	48
Mean	3.10	14.7	1.5	9.5	8.3	5.8	1.9	244	87	15	8	54
StdDev	0.01	0.3	0.1	0.3	0.5	1.9	0.3	26	8	2	1	7
-B	3.83	10.8	0.9	5.6	6.5	3.8	1.5	197	55	7	31	19
	3.86	13.8	1.1	6.9	7.6	3.6	1.8	237	147§	9	59§	17
	3.72	13.6	1.1	6.3	7.2	3.5	1.8	229	69	7	42	18
Mean	3.80	12.7	1.0	6.3	7.1	3.6	1.7	221	90	8	44	18
StdDev	0.07	1.7	0.1	0.7	0.6	0.2	0.2	21	50	1	14	1

† ND = Not determined; too little sample.
‡ The number 2 indicates a different S source for this treatment only.
§ Excluded as an outlier from final data interpretation, see summary table A3.5.

Table A3.9 Summary of maize foliar concentrations and yield data for Subtractive Growth Trial 2.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
Complete	3.73	7.39	0.62	3.81	3.66	2.04	0.97	98	29	4	24	26
	0.47†	0.34	0.03	0.35	0.29	0.11	0.04	11	2	0	2	5
-K	2.39	6.95	0.55	1.02‡	3.75	2.56	0.88	107	27	5	17	19
	0.16	0.48	0.07	0.07	0.17	0.03	0.07	16	3	0	4	3
-Ca	3.37	7.3	0.52	3.36	1.80	2.06	0.95	84	25	3	17	26
	0.18	1.95	0.03	0.86	0.18	0.16	0.07	6	2	0	5	7
-Ca2§	3.09	7.1	0.47	3.52	2.16	1.86	0.80	137	27¶	3	22¶	19
	0.07	1.27	0.03	0.40	0.05	0.17	0.01	18	2	0	4	3
-Mg	3.66	6.95	0.54	3.16	3.48	1.35	0.84	107	27	4	18	24
	0.33	0.80	0.02	0.13	0.40	0.09	0.09	13	3	0	2	5
-Zn	3.10	6.32	0.63	4.09	3.59	2.50	0.80	105	38	6	4	23
	0.01	0.11	0.02	0.15	0.20	0.82	0.11	11	3	1	0	3
-B	3.80	6.72	0.55	3.31	3.75	1.92	0.90	112	48¶	3.7	23¶	10
	0.07	0.87	0.06	0.36	0.31	0.11	0.09	10	27	0	8	1
Nil	0.80	1.02	0.18	0.88	0.80	0.49	0.21#	9	8	1	2	10
	0.11	0.13	0.03	0.08	0.17	0.13		1	1	0	0	4

† The standard deviation is shown below the mean for each treatment.
‡ Grey shading represents the concentration of the element that was withheld for each treatment.
§ The number 2 indicates a different S source for this treatment only.
¶ Mean and standard deviation are based on a sample size of n=2.
# Based on a sample size of n=1.

Table A3.10 Complete maize foliar concentrations and yield data for Subtractive Growth Trial 2.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
Nil	0.90	1.16	0.21	0.96	0.93	0.63	0.21	9	8	1	3	15
	0.68	0.90	0.16	0.87	0.61	0.36	ND†	8	7	1	2	6
	0.81	1.01	0.18	0.80	0.87	0.50	ND	9	8	1	2	8
Mean	0.80	1.02	0.18	0.88	0.80	0.49	0.21	9	8	1	2	10
StdDev	0.11	0.13	0.03	0.08	0.17	0.13		1	1	0	0	4
Full	3.68	7.10	0.61	4.04	3.53	1.99	1.02	92	30	4	24	23
	3.29	7.77	0.59	3.98	3.47	1.96	0.96	92	27	4	22	23
	4.23	7.29	0.65	3.41	4.00	2.17	0.94	110	31	4	26	32
Mean	3.73	7.39	0.62	3.81	3.66	2.04	0.97	98	29	4	24	26
StdDev	0.47	0.34	0.03	0.35	0.29	0.11	0.04	11	2	0	2	5
-K	2.56	7.50	0.50	1.07	3.95	2.52	0.96	100	28	5	19	17
	2.25	6.63	0.63	0.94	3.69	2.56	0.84	125	29	5	20	22
	2.35	6.72	0.52	1.04	3.62	2.58	0.85	95	24	5	13	18
Mean	2.39	6.95	0.55	1.02	3.75	2.56	0.88	107	27	5	17	19
StdDev	0.16	0.48	0.07	0.07	0.17	0.03	0.07	16	3	0	4	3
-Ca	3.43	5.10	0.52	2.38	1.72	2.10	0.91	80	23	3	13	19
	3.17	7.79	0.48	3.74	1.67	1.89	0.92	80	26	4	16	28
	3.52	8.90	0.54	3.96	2.00	2.20	1.03	91	25	3	22	32
Mean	3.37	7.26	0.52	3.36	1.80	2.06	0.95	84	25	3	17	26
StdDev	0.18	1.95	0.03	0.86	0.18	0.16	0.07	6	2	0	5	7
-Ca2‡	3.16	8.51	0.44	3.95	2.19	1.80	0.79	122	28	3	19	22
	3.07	6.14	0.47	3.16	2.17	2.05	0.81	157	25	3	25	17
	3.03	6.57	0.51	3.45	2.10	1.73	0.80	132	303§	4	54§	17
Mean	3.09	7.07	0.47	3.52	2.16	1.86	0.80	137	119	3	33	19
StdDev	0.07	1.27	0.03	0.40	0.05	0.17	0.01	18	159	0	19	3
-Mg	3.53	7.84	0.54	3.28	3.09	1.27	0.88	93	25	3	16	18
	4.03	6.72	0.56	3.02	3.47	1.46	0.73	119	31	4	19	25
	3.41	6.30	0.52	3.17	3.88	1.33	0.90	110	26	4	19	28
Mean	3.66	6.95	0.54	3.16	3.48	1.35	0.84	107	27	4	18	24
StdDev	0.33	0.80	0.02	0.13	0.40	0.09	0.09	13	3	0	2	5
-Zn	3.10	6.42	0.65	3.92	3.40	1.98	0.69	99	41	6	3	26
	3.11	6.35	0.60	4.19	3.80	2.07	0.91	118	34	7	4	23
	3.10	6.20	0.65	4.18	3.57	3.44	0.82	99	38	6	3	21
Mean	3.10	6.32	0.63	4.09	3.59	2.50	0.80	105	38	6	4	23
StdDev	0.01	0.11	0.02	0.15	0.20	0.82	0.11	11	3	1	0	3
-B	3.83	5.75	0.48	2.98	3.46	2.02	0.80	105	29	4	16	10
	3.86	7.40	0.59	3.70	4.07	1.93	0.97	127	79§	5	32§	9
	3.72	7.03	0.57	3.26	3.72	1.81	0.93	118	36	4	22	9
Mean	3.80	6.72	0.55	3.31	3.75	1.92	0.90	112	48	4	23	10
StdDev	0.07	0.87	0.06	0.36	0.31	0.11	0.09	10	27	0	8	1

† ND = Not determined; too little sample.
‡ The number 2 indicates a different S source was used in this treatment only.
§ Excluded as an outlier from final data interpretation, see summary table A3.7.

A3.4 Plant tissue data for Amendment Growth Trial 1

Table A3.11 Summary of maize foliar concentraions and yield data for Amendment Growth Trial 1.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g				g kg^{-1}					mg kg^{-1}		
NPKS†	2.75	17.3	1.9	13	3.3	3	4	283	98	2	9	42
	0.09‡	0.7	0.2	1.3	0	0.1	0.1	12	17	1	0	11
NPKS + LS	2.60	16.5	1.9	12.9	3.4	3.5	4.7	348	98	3	9	44
	0.38	2.4	0.1	1.6	0.3	0.2	0.9	21	18	1	2	10
NPKS + LR	2.93	15	1.8	13.9	2.6	2.9	3.9	270	78	2	9	36
	0.12	0.6	0.1	1.3	0.1	0.3	0.2	24	12	1	1	6
NPKS + QB	2.84	13.7	1.6	11.4	2.7	3.9	2.4	228	87	2	8	37
	0.20	0.7	0.1	1.1	0.1	0.2	0.3	13	2	1	1	14
NPKS + KR	2.64	14.4	1.5	14	3.1	2.8	3.5	179	89	3	9	42
	0.18	1.3	0.1	2.2	0.2	0.6	0.4	47	7	1	1	7
NPKS + TE	1.50	27	2.3	31.4	4.4	5.8	6.3	167	94	14	152	247
	0.27	3	0.2	5.4	0.3	0.5	1	17	7	0	22	35
Nil	0.98	11	1.6	6.3	6.4	4.9	ND§	54	106	4	16	63
	0.07	0.8	0.1	1.3	0.9	0.8	0	10	5	2	3	5
Critical level¶		35	4	35	9	3	2	50	50	7	20	7

† NPKS = basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.
‡ The standard deviation is shown below the mean for each treatment.
§ ND = Not determined, too little sample.
¶ Critical level from Bennett (1993) for young maize.

Table A3.12 Complete maize foliar concentrations and yield data for Amendment Growth Trial 1.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g kg^{-1}						mg kg^{-1}				
NPKS†	2.68	18.0	1.7	11.8	3.3	2.9	4.0	297	87	2	9	54
	2.73	16.7	2.1	14.3	3.3	3.1	4.1	273	90	3	9	37
	2.85	17.3	2.0	13.0	3.3	2.9	4.0	279	118	2	9	34
Mean	2.75	17.3	1.9	13.0	3.3	3.0	4.0	283	98	2	9	42
StdDev	0.09	0.7	0.2	1.3	0.0	0.1	0.1	12	17	1	0	11
Nil	0.94	11.6	1.7	7.8	7.5	5.8	ND‡	66	107	6	20	60
	0.95	11.3	1.5	5.2	6.1	4.5	ND	48	100	3	15	69
	1.06	10.1	1.6	5.9	5.7	4.5	ND	49	110	3	14	61
Mean	0.98	11.0	1.6	6.3	6.4	4.9	ND	54	106	4	16	63
StdDev	0.07	0.8	0.1	1.3	0.9	0.8		10	5	2	3	5
NPKS + LS	2.90	13.8	1.8	11.2	3.1	3.4	3.7	332	80	2	7	33
	2.73	17.5	1.9	13.0	3.7	3.5	5.0	371	115	3	10	50
	2.18	18.3	2.0	14.4	3.4	3.7	5.4	340	100	3	9	50
Mean	2.60	16.5	1.9	12.9	3.4	3.5	4.7	348	98	3	9	44
StdDev	0.38	2.4	0.1	1.6	0.3	0.2	0.9	21	18	1	2	10
NPKS + LR	2.98	15.3	1.9	15.4	2.6	2.9	3.8	285	90	2	8	31
	3.02	14.4	1.8	12.9	2.7	2.6	4.1	243	67	1	9	42
	2.80	15.4	1.8	13.4	2.6	3.1	3.8	283	76	2	10	36
Mean	2.93	15.0	1.8	13.9	2.6	2.9	3.9	270	78	2	9	36
StdDev	0.12	0.6	0.1	1.3	0.1	0.3	0.2	24	12	1	1	6
NPKS + QB	2.62	13.8	1.5	11.1	2.7	4.0	3.4	216	89	2	8	52
	3.02	13.0	1.6	10.5	2.8	4.0	3.7	241	86	2	7	33
	2.87	14.4	1.6	12.6	2.7	3.7	3.9	228	87	3	8	25
Mean	2.84	13.7	1.6	11.4	2.7	3.9	2.4	228	87	2	8	37
StdDev	0.20	0.7	0.1	1.1	0.1	0.2	0.3	13	2	1	1	14
NPKS + KR	2.84	12.9	1.4	12.5	3.1	2.5	3.1	173	94	3	9	39
	2.59	15.4	1.5	16.6	2.9	2.4	3.4	136	92	2	9	50
	2.50	15.0	1.5	13.0	3.3	3.5	3.9	229	81	3	10	37
Mean	2.64	14.4	1.5	14.0	3.1	2.8	3.5	179	89	3	9	42
StdDev	0.18	1.3	0.1	2.2	0.2	0.6	0.4	47	7	1	1	7
NPKS + TE	1.19	30.0	2.4	37.6	4.2	5.5	7.2	185	99	14	170	288
	1.69	24.1	2.0	27.8	4.2	5.5	5.2	164	86	14	127	226
	1.62	26.8	2.4	28.7	4.7	6.4	6.4	152	97	14	159	228
Mean	1.50	27.0	2.3	31.4	4.4	5.8	6.3	167	94	14	152	247
StdDev	0.27	3.0	0.2	5.4	0.3	0.5	1.0	17	7	0	22	35

† NPKS = basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.
‡ ND = Not determined; too little sample.

Table A3.13 Summary of maize foliar concentrations and yield data for Amendment Growth Trial 1.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g			g m^{-2}						mg m^{-2}		
NPKS†	2.75	6.63	0.74	4.99	1.26	1.13	1.54	108	38	1	3	16
	0.09‡	0.27	0.09	0.53	0.04	0.05	0.05	4	8	0	0	4
NPKS + LS	2.60	5.91	0.68	4.60	1.23	1.27	1.67	126	35	1	3	16
	0.38	0.63	0.07	0.29	0.19	0.13	0.21	20	7	0	1	3
NPKS + LR	2.93	6.12	0.75	5.67	1.07	1.17	1.59	110	32	7	4	15
	0.12	0.19	0.04	0.62	0.06	0.06	0.12	8	5	0	0	2
NPKS + QB	2.84	5.40	0.62	4.49	1.08	1.54	1.45	90	34	1	3	14
	0.20	0.36	0.06	0.50	0.10	0.12	0.18	11	2	0	0	4
NPKS + KR	2.64	5.28	0.54	5.14	1.14	1.02	1.27	66	33	1	3	15
	0.18	0.23	0.02	0.75	0.09	0.18	0.08	15	4	0	0	3
NPKS + TE	1.50	5.55	0.47	6.40	0.91	1.21	1.28	34	19	3	31	51
	0.27	0.54	0.07	0.16	0.19	0.27	0.14	4	3	1	4	3
Nil	0.98	1.50	0.22	0.86	0.87	0.67	ND§	7	14	1	2	9
	0.07	0.01	0.02	0.17	0.09	0.08		1	2	0	0	1

† NPKS = basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.
‡ The standard deviation is shown below the mean for each treatment.
§ ND = Not determined; too little sample.

Table A3.14 Complete maize foliar concentrations and yield data for Amendment Growth Trial 1.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
NPKS†	2.68	6.70	0.63	4.39	1.23	1.08	1.49	111	32	1	4	20
	2.73	6.33	0.80	5.42	1.25	1.18	1.55	104	34	1	3	14
	2.85	6.85	0.79	5.15	1.31	1.15	1.58	110	47	1	4	13
Mean	2.75	6.63	0.74	4.99	1.26	1.13	1.54	108	38	1	3	16
StdDev	0.09	0.27	0.09	0.53	0.04	0.05	0.05	4	8	0	0	4
Nil	0.94	1.51	0.22	1.02	0.98	0.76	ND‡	9	14	1	3	8
	0.95	1.49	0.20	0.69	0.80	0.59	ND	6	13	0	2	9
	1.06	1.49	0.24	0.87	0.84	0.66	ND	7	16	0	2	9
Mean	0.98	1.50	0.22	0.86	0.87	0.67	ND	7	14	1	2	9
StdDev	0.07	0.01	0.02	0.17	0.09	0.08		1	2	0	0	1
NPKS + LS	2.90	5.56	0.73	4.51	1.25	1.37	1.49	134	32	1	3	13
	2.73	6.64	0.72	4.93	1.40	1.33	1.90	141	44	1	4	19
	2.18	5.54	0.61	4.36	1.03	1.12	1.64	103	30	1	3	15
Mean	2.60	5.91	0.68	4.60	1.23	1.27	1.67	126	35	1	3	16
StdDev	0.38	0.63	0.07	0.29	0.19	0.13	0.21	20	7	0	1	3
NPKS + LR	2.98	6.33	0.79	6.37	1.08	1.20	1.57	118	37	1	3	13
	3.02	6.04	0.76	5.41	1.13	1.09	1.72	102	28	0	4	18
	2.80	5.99	0.70	5.21	1.01	1.21	1.48	110	30	1	4	14
Mean	2.93	6.12	0.75	5.67	1.07	1.17	1.59	110	32	1	4	15
StdDev	0.12	0.19	0.04	0.62	0.06	0.06	0.12	8	5	0	0	2
NPKS + QB	2.62	5.02	0.55	4.04	0.98	1.46	1.24	79	32	1	3	19
	3.02	5.45	0.67	4.40	1.17	1.68	1.55	101	36	1	3	14
	2.87	5.74	0.64	5.02	1.08	1.47	1.55	91	35	1	3	10
Mean	2.84	5.40	0.62	4.49	1.08	1.54	1.45	90	34	1	3	14
StdDev	0.20	0.36	0.06	0.50	0.10	0.12	0.18	11	2	0	0	4
NPKS + KR	2.84	5.09	0.55	4.93	1.22	0.99	1.22	68	37	1	4	15
	2.59	5.54	0.54	5.97	1.04	0.86	1.22	49	33	1	3	18
	2.50	5.21	0.52	4.51	1.15	1.22	1.35	80	28	1	3	13
Mean	2.64	5.28	0.54	5.14	1.14	1.02	1.27	66	33	1	3	15
StdDev	0.18	0.23	0.02	0.75	0.09	0.18	0.08	15	4	0	0	3
NPKS + TE	1.19	4.96	0.40	6.21	0.69	0.91	1.19	31	16	2	28	48
	1.69	5.66	0.47	6.53	0.99	1.29	1.22	38	20	3	30	53
	1.62	6.03	0.54	6.46	1.06	1.44	1.44	34	22	3	36	51
Mean	1.50	5.55	0.47	6.40	0.91	1.21	1.28	34	19	3	31	51
StdDev	0.27	0.54	0.07	0.16	0.19	0.27	0.14	4	3	1	4	3

† NPKS = basal fertiliser solution, LS = Lebombo saprolite, LR = Lebombo rock, QB = Queensland basalt, KR = Kenya rock, and TE = trace element.
‡ ND = Not determined; too little sample.

A3.5 Plant tissue data for Amendment Growth Trial 2

Table A3.14 Summary of maize foliar concentrations and yield data for Amendment Growth Trial 2.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g				g kg^{-1}					mg kg^{-1}		
Nil	0.80	9.3	1.7	8.0	7.2	4.4	1.7‡	78	70	6	21	85
	0.11†	0.3	0.1	1.1	0.6	0.6		7	4	1	3	28
M§	1.03	8.4	2.1	15.2	5.4	2.6	1.3	45	100	5	30	25
	0.09	2.4	0.1	1.8	1.1	0.3	0.3	26	8	1	6	7
N	1.30	29.1	0.9	4.4	12.1	6.9	2.3	127	129¶	7	27¶	44
	0.13	4.6	0.2	0.9	1.3	0.3	0.6	34	28	2	1	6
N + M	2.78	15.0	0.9	4.1	7.2	5.6	1.6	77	116	2	10	39
	0.25	3.6	0.1	1.1	1.2	0.4	0.2	9	18	1	2	9
NP	1.86	28.3	7.6	3.6	9.7	6.7	2.5	103	238¶	5	21¶	59
	0.24	3.8	0.7	0.5	1.3	0.6	0.5	11	83	1	4	9
NP + M	2.58	16.6	4.5	3.5	7.8	7.3	2.0	111	191	3	6	35
	0.15	1.8	0.3	0.3	0.6	0.5	0.2	2	16	0	0	4
NPS	1.58	36.9	7.6	4.0	5.0	7.1	7.4	110	141	4	10	77
	0.11	2.1	0.3	0.6	0.7	0.3	1	11	8	0	1	20
NPS + M	2.75	16.6	3.8	5.0	3.9	6.2	4.9	111	135	3	7	51
	0.30	4.3	0.4	0.7	0.2	0.6	0.3	21	28	1	0	18
NPS + LR	2.39	14.0	1.8	3.3	3.4	5.1	4.2	70	79	4	6	43
	0.03	0.5	0.2	0.4	0.6	0.9	0.2	13	12	3	1	21
NPS + LS	1.76	26.0	4.1	3.4	4.5	8.9	6.8	97	214¶	7	16¶	48
	0.17	8.1	0.3	0.5	0.6	0.7	1.1	7	21	1	4	11
NPKS	2.34	20.4	3.5	18	3.1	2.5	5.1	84	142¶	3	7	47
	0.24	3.6	0.4	1.2	0.4	0.3	1	12	30	1	1	18
NPKS2#	2.87	20.2	2.9	13.3	3.5	2.5	3.8	259	116	2	7	31
	0.31	3.3	0.2	2.8	0.3	0.1	0.5	31	25	1	1	3
NPKS + M	3.00	15.0	2.9	16.9	3	3	6.7	97	154¶	3	7	31
	0.11	1.2	0.1	0.7	0.7	0.5	0.5	4	20	0	2	5
Critical level††		35	4	35	9	3	2	50	50	7	20	7

† The standard deviation is shown below the mean for each treatment.
‡ Based on a sample size of n=1.
§ N, NP, NPS and NPKS = basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.
¶ Mean and standard deviations are based on a sample size of n=2.
# The number 2 indicates a different S source was used in this treatment only.
†† Critical values are from Bennett (1993) for six-week old maize plants.

Table A3.16 Complete maize foliar concentrations and yield data for Amendment Growth Trial 2.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	%						mg kg^{-1}				
Nil	0.90	9.3	1.7	7.7	7.4	5.0	1.7	70	67	6	21	117
	0.68	9.5	1.7	9.2	6.5	3.8	ND†	84	74	6	24	67
	0.81	9.0	1.6	7.1	7.7	4.4	ND	80	69	5	19	70
Mean	0.80	9.3	1.7	8.0	7.2	4.4	1.7	78	70	6	21	85
StdDev	0.11	0.3	0.1	1.1	0.6	0.6	0.0	7	4	1	3	28
M‡	1.11	7.1	2.0	15.3	4.7	2.3	1.5	34	94	4	26	27
	1.06	7.0	2.1	13.3	4.8	2.7	1.0	26	109	4	36	17
	0.93	11.2	2.1	16.9	6.7	2.9	1.5	74	97	6	27	31
Mean	1.03	8.4	2.1	15.2	5.4	2.6	1.3	45	100	5	30	25
StdDev	0.09	2.4	0.1	1.8	1.1	0.3	0.3	26	8	1	6	7
N	1.44	24.1	1.1	3.5	13.4	6.7	1.8	143	422§	9	57§	41
	1.25	33.2	0.9	4.5	12.0	7.2	2.9	88	148	6	27	39
	1.20	30.0	0.8	5.3	10.8	6.9	2.2	149	109	6	26	51
Mean	1.30	29.1	0.9	4.4	12.1	6.9	2.3	127	226	7	37	44
StdDev	0.13	4.6	0.2	0.9	1.3	0.3	0.6	34	171	2	18	6
N + M	3.01	15.3	0.9	4.0	7.4	5.4	1.6	82	113	2	9	36
	2.51	18.4	0.8	5.2	8.3	6.1	1.7	82	135	3	13	49
	2.82	11.2	0.9	3.1	6.0	5.4	1.4	67	99	2	9	33
Mean	2.78	15.0	0.9	4.1	7.2	5.6	1.6	77	116	2	10	39
StdDev	0.25	3.6	0.1	1.1	1.2	0.4	0.2	9	18	1	2	9
NP	1.75	32.7	8.3	4.1	10.1	7.1	3.7	114	7760§	5	83§	51
	2.14	25.6	6.9	3.1	8.2	6.0	2.9	102	296	4	18	69
	1.69	26.7	7.5	3.5	10.8	7.1	3.7	92	179	5	23	58
Mean	1.86	28.3	7.6	3.6	9.7	6.7	2.5	103	2745	5	41	59
StdDev	0.24	3.8	0.7	0.5	1.3	0.6	0.5	11	4344	1	36	9
NP + M	2.62	14.9	4.5	3.5	7.9	7.1	1.8	109	174	3	6	37
	2.70	16.5	4.3	3.8	7.1	7.0	2.0	112	205	3	6	37
	2.41	18.4	4.8	3.2	8.3	7.9	2.1	113	195	3	6	30
Mean	2.58	16.6	4.5	3.5	7.8	7.3	2.0	111	191	3	6	35
StdDev	0.15	1.8	0.3	0.3	0.6	0.5	0.2	2	16	0	0	4
NPS	1.67	36.6	7.3	3.7	4.7	6.8	6.3	100	137	4	10	99
	1.46	39.1	7.9	4.7	5.8	7.3	7.6	122	150	4	11	74
	1.61	35.0	7.6	3.6	4.5	7.1	8.3	108	135	4	9	59
Mean	1.58	36.9	7.6	4.0	5.0	7.1	7.4	110	141	4	10	77
StdDev	0.11	2.1	0.3	0.6	0.7	0.3	1.0	11	8	0	1	20

(continued on next page)

Table A3.16 Continuec.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	%						mg kg^{-1}				
NPS + M	2.50	20.3	4.2	4.9	3.8	6.8	5.0	123	165	4	7	54
	2.67	17.7	3.8	5.8	4.1	5.6	5.1	87	132	2	7	32
	3.08	11.9	3.5	4.4	3.9	6.2	4.5	124	109	2	7	68
Mean	2.75	16.6	3.8	5.0	3.9	6.2	4.9	111	135	3	7	51
Std Dev	0.30	4.3	0.4	0.7	0.2	0.6	0.3	21	28	1	0	18
NPS + LR	2.40	14.5	1.7	3.7	2.7	4.1	4.0	55	90	2	6	20
	2.36	13.5	1.8	3.4	3.8	5.7	4.4	78	80	3	6	59
	2.41	14.1	2.0	2.9	3.7	5.5	4.3	77	67	7	7	51
Mean	2.39	14.0	1.8	3.3	3.4	5.1	4.2	70	79	4	6	43
Std Dev	0.03	0.5	0.2	0.4	0.6	0.9	0.2	13	12	3	1	21
NPS + LS	1.92	16.7	3.8	3.0	4.5	9.5	5.6	100	327§	6	60§	35
	1.58	30.8	4.2	4.0	4.0	8.1	6.9	89	228	8	19	52
	1.79	30.6	4.4	3.3	5.1	9.0	7.8	102	199	7	13	56
Mean	1.76	26.0	4.1	3.4	4.5	8.9	6.8	97	251	7	31	48
Std Dev	0.17	8.1	0.3	0.5	0.6	0.7	1.1	7	67	1	26	11
NPKS	2.51	16.4	3.1	16.9	2.9	2.5	4.1	78	163	2	7	28
	2.06	21.8	3.6	18.0	3.6	2.8	6.0	98	224§	3	6	64
	2.44	23.1	3.8	19.2	2.9	2.3	5.1	76	120	3	7	48
Mean	2.34	20.4	3.5	18.0	3.1	2.5	5.1	84	169	3	7	47
Std Dev	0.24	3.6	0.4	1.2	0.4	0.3	1.0	12	52	1	1	18
NPKS2¶	2.53	23.5	3.1	15.8	3.8	2.6	4.3	293	142	3	7	33
	3.14	20.2	3.0	13.7	3.3	2.5	3.7	234	93	2	7	28
	2.95	16.9	2.7	10.3	3.5	2.5	3.3	249	112	2	6	31
Mean	2.87	20.2	2.9	13.3	3.5	2.5	3.8	259	116	2	7	31
Std Dev	0.31	3.3	0.2	2.8	0.3	0.1	0.5	31	25	1	1	3
NPKS + M	2.89	13.7	2.8	16.2	3.7	3.4	6.2	100	252§	3	9	26
	3.01	15.2	2.8	16.9	2.9	3.0	7.1	98	168	3	6	32
	3.11	16.0	3.0	17.5	2.4	2.5	6.9	92	140	3	6	36
Mean	3.00	15.0	2.9	16.9	3.0	3.0	6.7	97	187	3	7	31
Std Dev	0.11	1.2	0.1	0.7	0.7	0.5	0.5	4	58	0	2	5

† ND = Not determined; too little sample.

‡ N, NP, NPS, and NPKS = basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.

§ Excluded as an outlier from final data interpretation, see summary table A3.13.

¶ The number 2 indicates a different S source was used in this treatment only.

Table A3.17 Summary of maize foliar concentrations and yield data for Amendment Growth Trial 2.

Treatment	Yield	N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g			g m^{-2}						mg m^{-2}		
Nil	0.80	1.02	0.18	0.88	0.80	0.49	0.21‡	9	8	1	2	10
	0.11†	0.13	0.03	0.08	0.17	0.13		1	1	0	0	4
M§	1.03	1.19	0.30	2.17	0.77	0.38	0.19	6	14	1	4	4
	0.09	0.22	0.02	0.20	0.09	0.02	0.04	3	2	0	1	1
N	1.30	5.19	0.17	0.79	2.19	1.25	0.41	23	22¶	1	5¶	8
	0.13	0.50	0.04	0.09	0.45	0.10	0.08	7	5	1	0	1
N + M	2.78	5.73	0.34	1.57	2.78	2.17	0.60	30	44	1	4	15
	0.25	1.17	0.05	0.31	0.38	0.08	0.06	4	5	0	1	2
NP	1.86	7.27	1.94	0.91	2.48	1.73	0.88	27	70¶	1	5¶	16
	0.24	0.89	0.16	0.09	0.05	0.06	0.02	4	33	0	0	4
NP + M	2.58	5.92	1.62	1.26	2.77	2.62	0.70	40	68	1	2	12
	0.15	0.43	0.02	0.18	0.11	0.03	0.05	2	7	0	0	2
NPS	1.58	8.08	1.66	0.87	1.09	1.55	1.62	24	31	1	2	17
	0.11	0.36	0.05	0.07	0.08	0.06	0.21	1	1	0	0	5
NPS + M	2.75	6.23	1.45	1.91	1.50	2.36	1.85	43	51	1	3	20
	0.30	1.02	0.04	0.23	0.18	0.29	0.10	10	6	0	0	9
NPS + LR	2.39	4.66	0.61	1.11	1.13	1.69	1.40	23	26	1	2	14
	0.03	0.21	0.05	0.13	0.20	0.28	0.06	4	4	1	0	7
NPS + LS	1.76	6.27	1.01	0.83	1.12	2.18	1.65	24	50¶	2	4¶	12
	0.17	1.63	0.09	0.04	0.21	0.38	0.25	4	0	0	1	2
NPKS	2.34	6.59	1.13	5.85	1.01	0.82	1.62	27	50¶	1	2	15
	0.24	1.10	0.14	0.68	0.02	0.05	0.17	1	12	0	0	4
NPKS2#	2.87	8.00	1.17	5.25	1.40	1.01	1.49	102	45	1	3	12
	0.31	0.97	0.12	0.92	0.06	0.09	0.13	1	5	0	0	1
NPKS + M	3.00	6.25	1.20	7.04	1.24	1.23	2.81	40	65¶	1	3	13
	0.11	0.71	0.09	0.53	0.23	0.14	0.28	1	7	0	1	3

† The standard deviation is shown below the mean for each treatment.
‡ Based on a sample size of n=1.
§ N, NP, NPS, and NPKS = basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.
¶ Mean and standard deviations are based on a sample size of n=2.
# The number 2 indicates a different S source was used in this treatment only.

Table A3.18 Complete maize foliar concentrations and yield data for Amendment Growth Trial 2.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	g	g m^{-2}						mg m^{-2}				
Nil	0.90	1.16	0.21	0.96	0.93	0.63	0.21	9	8	1	3	15
	0.68	0.90	0.16	0.87	0.61	0.36	ND[T]	8	7	1	2	6
	0.81	1.01	0.18	0.80	0.87	0.50	ND	9	8	1	2	8
Mean	0.80	1.02	0.18	0.88	0.80	0.49	0.21	9	8	1	2	10
StdDev	0.11	0.13	0.03	0.08	0.17	0.13		1	1	0	0	4
M‡	1.11	1.09	0.31	2.36	0.72	0.35	0.23	5	14	1	4	4
	1.06	1.03	0.31	1.96	0.71	0.40	0.15	4	16	1	5	3
	0.93	1.45	0.27	2.18	0.87	0.37	0.19	10	13	1	3	4
Mean	1.03	1.19	0.30	2.17	0.77	0.38	0.19	6	14	1	4	4
StdDev	0.09	0.22	0.02	0.20	0.09	0.02	0.04	3	2	0	1	1
N	1.44	4.82	0.22	0.70	2.68	1.34	0.36	29	84§	2	11§	8
	1.25	5.76	0.16	0.78	2.08	1.25	0.50	15	26	1	5	7
	1.20	5.00	0.13	0.88	1.80	1.15	0.37	25	18	1	4	9
Mean	1.30	5.19	0.17	0.79	2.19	1.25	0.41	23	43	1	7	8
StdDev	0.13	0.50	0.04	0.09	0.45	0.10	0.08	7	36	1	4	1
N + M	3.01	6.40	0.38	1.67	3.09	2.26	0.67	34	47	1	4	15
	2.51	6.41	0.28	1.81	2.89	2.13	0.59	29	47	1	5	17
	2.82	4.39	0.35	1.21	2.35	2.12	0.55	26	39	1	4	13
Mean	2.78	5.73	0.34	1.57	2.78	2.17	0.60	30	44	1	4	15
StdDev	0.25	1.17	0.05	0.31	0.38	0.08	0.06	4	5	0	1	2
NP	1.75	7.95	2.02	1.00	2.45	1.73	0.90	28	1886§	1	20§	12
	2.14	7.61	2.05	0.92	2.44	1.78	0.86	30	88	1	5	21
	1.69	6.27	1.76	0.82	2.54	1.67	0.87	22	42	1	5	14
Mean	1.86	7.27	1.94	0.91	2.48	1.73	0.88	27	672	1	10	16
StdDev	0.24	0.89	0.16	0.09	0.05	0.06	0.02	4	1052	0	9	4
NP + M	2.62	5.42	1.64	1.27	2.87	2.58	0.66	40	63	1	2	13
	2.70	6.19	1.61	1.43	2.66	2.63	0.75	42	77	1	2	14
	2.41	6.16	1.61	1.07	2.78	2.64	0.70	38	65	1	2	10
Mean	2.58	5.92	1.62	1.26	2.77	2.62	0.70	40	68	1	2	12
StdDev	0.15	0.43	0.02	0.18	0.11	0.03	0.05	2	7	0	0	2
NPS	1.67	8.49	1.69	0.86	1.09	1.58	1.46	23	32	1	2	23
	1.46	7.93	1.60	0.95	1.18	1.48	1.54	25	30	1	2	15
	1.61	7.83	1.70	0.81	1.01	1.59	1.86	24	30	1	2	13
Mean	1.58	8.08	1.66	0.87	1.09	1.55	1.62	24	31	1	2	17
StdDev	0.11	0.36	0.05	0.07	0.08	0.06	0.21	1	1	0	0	5

(continued on next page)

Table A3.18 Continuec.

Treatment	Yield	Nutrient concentrations										
		N	P	K	Ca	Mg	S	Mn	Fe	Cu	Zn	B
	G	g m^{-2}						mg m^{-2}				
NPS + M	2.50	7.05	1.46	1.70	1.32	2.36	1.74	43	57	1	2	19
	2.67	6.56	1.41	2.15	1.52	2.08	1.89	32	49	1	3	12
	3.08	5.09	1.50	1.88	1.67	2.65	1.93	53	47	1	3	29
Mean	2.75	6.23	1.45	1.91	1.50	2.36	1.85	43	51	1	3	20
Std Dev	0.30	1.02	0.04	0.23	0.18	0.29	0.10	10	6	0	0	9
NPS + LR	2.40	4.83	0.57	1.23	0.90	1.37	1.33	18	30	1	2	7
	2.36	4.43	0.59	1.11	1.25	1.87	1.44	26	26	1	2	19
	2.41	4.72	0.67	0.97	1.24	1.84	1.44	26	22	2	2	17
Mean	2.39	4.66	0.61	1.11	1.13	1.69	1.40	23	26	1	2	14
Std Dev	0.03	0.21	0.05	0.13	0.20	0.28	0.06	4	4	1	0	7
NPS + LS	1.92	4.45	1.01	0.80	1.20	2.53	1.49	27	87§	2	16§	9
	1.58	6.76	0.92	0.88	0.88	1.78	1.51	20	50	2	4	11
	1.79	7.61	1.09	0.82	1.27	2.24	1.94	25	49	2	3	14
Mean	1.76	6.27	1.01	0.83	1.12	2.18	1.65	24	62	2	8	12
Std Dev	0.17	1.63	0.09	0.04	0.21	0.38	0.25	4	22	0	7	2
NPKS	2.51	5.72	1.08	5.89	1.01	0.87	1.43	27	57	1	2	10
	2.06	6.24	1.03	5.15	1.03	0.80	1.72	28	64	1	2	18
	2.44	7.83	1.29	6.51	0.98	0.78	1.73	26	41	1	2	16
Mean	2.34	6.59	1.13	5.85	1.01	0.82	1.62	27	54	1	2	15
Std Dev	0.24	1.10	0.14	0.68	0.02	0.05	0.17	1	12	0	0	4
NPKS2¶	2.53	8.26	1.09	5.55	1.34	0.91	1.51	103	50	1	2	12
	3.14	8.81	1.31	5.97	1.44	1.09	1.61	102	41	1	3	12
	2.95	6.92	1.11	4.22	1.43	1.02	1.35	102	46	1	2	13
Mean	2.87	8.00	1.17	5.25	1.40	1.01	1.49	102	45	1	3	12
Std Dev	0.31	0.97	0.12	0.92	0.06	0.09	0.13	1	5	0	0	1
NPKS + M	2.89	5.50	1.12	6.50	1.49	1.36	2.49	40	101§	1	4	10
	3.01	6.35	1.17	7.07	1.21	1.25	2.97	41	70	1	3	13
	3.11	6.91	1.30	7.56	1.04	1.08	2.98	40	60	1	3	16
Mean	3.00	6.25	1.20	7.04	1.24	1.23	2.81	40	77	1	3	13
Std Dev	0.11	0.71	0.09	0.53	0.23	0.14	0.28	1	12	0	1	3

† ND = Not determined; too little sample.

‡ N, NP, NPS and NPKS = basal fertiliser solutions, M = clay, LS = Lebombo saprolite, and LR = Lebombo rock.

§ Excluded as an outlier from final data interpretation, see summary table A3.15.

¶ The number 2 indicates a different S source was used in this treatment only.