THE RESPONSE OF GREEN BEANS (*Phaseoulus Vulgari*) TO VARYING APPLICATION RATES OF BORON.

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PETER JASTINE MANDA

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ABSTRACT

Green bean (*Phaseolus vulgari*) is a very important crop, feeding a large number of people in the world. However, bean yields are low, hence any method resulting in increased green bean yield may be of great importance. Boron (B) is one of the most important micronutrients necessary for bean growth and yield. A widespread deficiency of boron (B) has been reported in Zambian soils. This is a limitation to the potential yield of green beans, therefore, additions of B to the crop could contribute to higher yields. Currently, the University of Zambia recommends the addition of up to 2 kg /ha B as a way of addressing boron deficiency in most crops grown. It is not well known,however, whether increasing supply rates of B applied would make a difference in yield. A study was carried out to correlate two methods of boron analysis with plant B uptake, and to determine whether B fertilizer application would improve crop performance. The hypothesis of this research was that since B is often deficient in soil, soil and foliar application of B ought to increase green bean yield. In the laboratory, 16 soils that included pairs from cropped and fallow land were extracted for B using hot-water extraction and acid extraction. A parallel study was carried out in the green house. A green bean crop was grown in each of the soils for a six week period. In the field, five rates of B were applied at 0, 2, 4, 6 and 8 kg/ha, to two green beans crops. One foliar application at 0.45g/l was also used as one of the treatments giving a total of 6 treatments. The field experiments were conducted at York Farm in Lusaka Province in Zambia while the pot experiment was conducted in the greenhouse at the University of Zambia. Extractable B values were obtained in the laboratory, and B uptake in the green house. In the field, plant height, pod length, packout rate and yield were obtained. Results indicated that there was no good correlation between each of the two extraction methods with plant uptake. Foliar application of *B* at 0.45 g/l also did not significantly increase bean yield. The results also showed that in both field and green house experiments increasing rates of B did not influence ($p<0.05$) plant height, pod length, yield and quality of green beans. The early crop which was grown purely on drip irrigation did slightly better than the second crop which received some rainfall. During the first crop, the pods were 6 % longer than the control compared to only 1% in the second crop. The length of pod was found to be strongly related to yield increase of green beans. The yields were 28 % more than the control in the first crop and 15.6 % more in the second crop. The fruit quality was not affected by increasing rates of B. However, higher packout rates were obtained in the first crop compared to the second. These preliminary results suggest that green bean yields and quality may be better when grown in winter season. Soil application was more effective than foliar application in the greenhouse while the opposite was true in the field trial.

APPROVAL

This dissertation of PETER JASTINE MANDA is approved, fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy (Soil Science) by the University of Zambia.

Examiner's Names and Signatures	Date
1. Chishala B.H.CHISHALA	05/08/2009
2. O.I. LUNGU	05/08/2009
3. E. PHIRI	1/8/2009

DEDICATION

This work is dedicated to my wife and parents for their unfailing support and love.

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1.0 INTRODUCTION

1.1 Boron in Soil and Plant

Reports out of the University of Zambia Soil Analysis Laboratory indicate a high percentage of Boron deficiency in Zambian soils, yet there has only been limited work on B fertilizer recommendation. It is not clear what the response benefit to increasing B application is. The role of boron in crop production has sometimes remained unknown. However, its importance in crop production is well documented (Epstein, 1972).

The challenge identified in plant-soil boron relationships in Zambia is the fact that many soil test results show low B values. Further it is not well known whether the recommendations are making any difference in the field. Hence it is important to ask whether the soil test methods are detecting the available B and if increasing supply rates of B actually make a difference to crop performance.

The role of B in plant growth is of great significance because it plays an important role in nitrogen and carbohydrate metabolism (Gupta, 1979). Boron is one of the seven essential micronutrient elements required for the growth of most plants. It has a marked effect on plant growth, from the standpoint of both plant nutrition – if boron is deficient in soil, and toxicity – if present in excessive amounts. It has been observed that soils of semi-arid and arid areas are more likely to have excess and toxicity of boron than deficiency incidents (Epstein, 1972). In these soils boron toxicity occurs either due to high levels of B in soils or due to additions of B in irrigation water.

There are several factors which influence B deficiency in the soil. For instance, applications of potassium or calcium to soil favour potential for B deficiency. This is due to competition among the different ion species. Potassium applications aggravate B deficiency through interaction effects while increased calcium concentration decreases B toxicity and increases B deficiency. Soil pH is one of the most important factors affecting B uptake by plants. There is a negative relationship between soil pH and plant boron at pH levels higher than 6.5. Increasing pH enhances boron adsorption on clay minerals, hydroxyl-Al and soils showing a maximum in the alkaline pH range. Alkalinisation of a soil increases its capacity to adsorb B and this adsorbed B could be released by acidification to the original soil pH levels. Therefore, liming of soils to pH 7 and above has often resulted in deficiency due to fixation of B (Kamprath and Foy, 1971). The negative effects of liming are due to boron – calcium carbonate interactions, a phenomenon mostly common in limestone soils. As a result B deficiency symptoms on plants have been noted on limed acid soils. In addition to B adsorption co-precipitation of boron with calcium carbonate in calcareous soils results in similar deficiency symptoms.

The most remarkable factor affecting boron availability in soils is the type of clay minerals present. Boron adsorption isotherms for montmorillonite, illite and kaolinite at constant pH and ionic strength revealed that illite is the most reactive among clay minerals, whilst kaolinite is characterised by the lowest level of B adsorption. Boron adsorption is affected significantly by the particle size of the clay mineral with B adsorption increasing with decreasing clay particle sizes. Although B adsorption by illite is much greater than by montimorillonite, the total surface area of montimorillonite is much greater than that of illite (McLean, 1997).

In addition to clay type, B adsorption is influenced by organic matter. A large part of total B in soils is associated with the organic matter in tightly bound compounds. However this boron can be released to soil solution in forms available to plants, by microbial activities. Oxidation of organic matter also results in significant releases of B in forms available to plants. Humus has affinity for B and it appears to have an important role in the retention of B by soils (Bester and Fey, 1992).

Hydroxyl oxides of Al, Fe, and Mn adsorb large amounts of B but the amount of B combined in the precipitate is also pH dependent. At pH higher than 6, amount of B combined decreased with time. The presence of these hydroxyl oxides has a substantial role in boron adsorption in plants (Bester, 1993).

Plants obtain boron from soil solution. There is an equilibrium between adsorbed and soil solution B although most B is in the adsorbed state. It has been observed that plants positively respond to the concentration of B in soil solution. The species in the soil solution is primarily uncharged boric acid B-(OH)$_{-3}$. Boron uptake has been correlated with the concentration of B-(OH)$^{0}{}_{-3}$ in solution. However, the uptake of B is a physical process, thus soil properties and chemical composition of the soil solution exert little influence on boron uptake by plants. It has been observed that factors which influence transpiration tend to also influence boron uptake and accumulation in foliage.

There is a marked plant species effect on B uptake. It has been observed that most dicotyledonous crops have a higher B requirement compared to monocotyledons (Mortvedt and Cunningham, 1971). In addition, there is a relationship between plant response (growth and yield) and B content of many plants. Boron deficiency symptoms are a generally restricted growth of terminal buds, necrosis of terminal buds, flower drop, chlorosis and failure to develop mature seeds (e.g. pops in groundnuts). Boron toxicity manifests itself in chlorosis, premature leaf drop and eventual death of the plant. Necrosis of margin and tip portions of leaves is also common (Dell and Huang, 1997).

1.2 Green Beans

Following the liberalisation of the economy by the government, cheap subsidised agricultural products from Zimbabwe and recently from South Africa have offered steep competition to the Zambian food and fruit industry. Hence traditional crops such as maize, cotton, groundnuts, soybeans and wheat are now faced with serious production and marketing challenges. This development has pushed most farmers, both commercial and small scale into diversifying their farming business because it is no longer profitable to produce these traditional cash crops given the high cost of production in terms of agricultural inputs such as fertiliser, labour, machinery, fuel and electric power. There is therefore, need for the government and the farmers in Zambia to find alternative solutions to this problem of agricultural decline. One potential solution is the diversification of the agricultural base in terms of variety of cash crops grown (PRSP,1991). This strategy would involve a deliberate diversification out of but not away from highly mechanised

crops into labour intensive [illegible]
with a great agro-industrial potential is green beans (*Phaseolus vulgaris L.*).

Green beans have importance in the food and feed industry. Green beans is used for human consumption as a green vegetable and is now sold in many leading super markets abroad (Marks Spencer and Sansbury) and locally. As a result, many commercial farmers are increasing production of this crop for these niche markets. In Zambia consumption has also increased among the middle class and green beans is now being sold among the leading national super markets such as Shoprite and Spars. Due to this increased demand of the commodity, there is a growing need to produce more high quality green beans. The crop remains can also be used as fodder for livestock, especially in dairy animal production. In addition, green beans belong to the leguminoceae family and these plants are well known for their ability to fix nitrogen to the soil (Marshcner, 1995). Beans, therefore, have an added advantage of improving soil structure when used as a rotation crop. This is essential in improving soil conditions in the farming system. Due to the high input costs associated with vegetable production, farmers are forced to think innovatively to keep their operations profitable and to meet the demands set upon them. This is also true for green bean farmers as labour costs put profit margins on green beans under pressure.

The promotion of this high value labour intensive non traditional crop has the potential to create jobs for the rural poor, earn the farmer more returns and the government foreign exchange through non traditional exports. Due to the crop being a very good export commodity, the production of green beans is concentrated on large commercial and small holder farms within a radius of 50 km from the Lusaka International Airport for easy reach to export facilities. This production region experiences high rainfall and is situated at high altitude.

Zambian farmers are familiar with new techniques which may be effective in increasing bean yield but still register lower yields than their compatriots in South Africa. Increased quality production is being hindered by lack of adequate micro nutrient fertilisation. In Kenya and South Africa, fine bean producers are getting higher yields (12 tons/ha) as compared to their Zambian counterparts who are only producing 10 ton/ha (Ruaan du Plessis, 2006). The weakest link in the production process will put the entire bean crop at risk. The farmer must, therefore, maintain all production process will put the entire bean crop at risk. The farmer must, therefore, maintain all links in the chain to prevent financial losses. One such element so critical to successful bean production which may limit yields is the micronutrient Boron (B). Commercial producers in Zambia have reported positive response of bean yield even when they have applied boron in excess of the recommended rates of 2 kg /ha (pers.comm. John Anderson, 2007)[1]. There is therefore need to evaluate different boron application rates beyond recommendations to ascertain whether one gets a systematic response in yield at these higher application levels. As agricultural techniques have progressed there has been a steady decline in the use of traditional farm yard manure, organic manure and other crude fertilisers such as basic slag which supplied incidental amounts of B. Fine beans will normally give higher yields in the warm season and responds well to good fertilisation. However, inappropriate micronutrient fertilisation limits the yield potential of most bean crops.

The introduction and promotion of these export crops creates new demands on on-farm agricultural research. Along with this export crop drive, there is need to put in place appropriate research programmes to investigate general and specific factors likely to influence the production potential and profitability of these new crops. One notable aspect in this regard is micronutrient fertilisation. Like other crops, commercial green bean production has benefited a lot from adequate amounts of micronutrient fertilisation (Epstein, 1972).

Although some information is available as regards the use of boron fertilisers in fine beans production at York farm, it is limited. Local agronomic production practice has been limited to the application of NPK fertiliser which may have incidental trace micronutrients in it. However, the green bean yields obtained locally averaging 10 tons ha^{-1} is lower than South African averages of around 12 tons ha^{-1}. The reasons for this trend are not so obvious since production strategies are not different between bean farmers in the two countries. There is no record of fertiliser research done on fine beans locally due to the understanding that bean crops manufacture nitrogen for the soil, therefore fertiliser packages for fine beans have neither been well established nor documented. This is not withstanding the fact that it is well documented

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[1] Mr John Anderson,Farm Manager, York Farm, Lusaka, Zambia.

that micronutrients play a critical role in influencing production of most field crops and especially dicotyledonous crops.

Due to differences in the chemical fertility of most soil types and the varying nutritional demands for boron among different field crops, site and crop specific nutritional research is vital to allow relevant cost effective boron fertiliser recommendations which ensure optimum crop production.

Due to the importance of *B* for green beans production, nutritionally and economically, and the fact that few studies related to soil and foliar application of *B* have been concerned with green bean resistance to diseases (Liang et al., 2005) and not to yield, these experiments were performed.

The main objective of this study was to test the effectiveness of B fertilizer applied to soil, or as foliar on the growth and yield of irrigated green beans. The specific objectives were: 1) to compare the effects of five different *B* concentrations on green bean growth and yield, and 2) to compare effectiveness of two extractants in predicting the level of availability of B for uptake by plants.

2.0 LITERATURE REVIEW

2.1 Introduction

It has been established that of the deficiencies of all the known essential micronutrients, boron deficiency is most widespread (Brown and Shelp, 1997). However, there is a fine line between levels causing toxicity and deficiency of boron in agricultural crop production. This makes practical application of boron to crops, particularly bean, difficult.

It is normal to have B deficiency present long before visual deficiency symptoms occur. The main visual symptoms of boron deficiency are the cessation of terminal growth (plant height), internodes become shorter (length between nodes) and plant has rossetted (bushy) appearance (Keren and Bingham, 1985).

2.2 Micronutrients – An Overview

In addition to carbon, hydrogen, and oxygen, plants also require some thirteen other mineral nutrients for normal functions and growth. These elements are conveniently divided into two groups. The six macronutrients – nitrogen, phosphorous, potassium, calcium, magnesium and sulphur- and the seven generally recognised micronutrients which are iron, manganese, copper, zinc, boron, chlorine and molybdenum. According to Thompson and Troeh (1973), the terms macro and micro are perhaps misleading because they do not refer to importance of the specific groups of nutrients but rather to the relative amounts required by plants.

Although needed in small amounts, micronutrients are essential for almost every biological process within the plant. Therefore, when deficiencies occur, crop yield and quality will inevitably suffer. Intensive crop husbandry that aims at increasing crop yields tends to induce nutrient deficiency in subsequent crop when the nutrients removed by the previous crop are not returned to the soil in full measure (Purvis, 1995).

In traditional cropping methods where the use of organic manures was rampant, incidences of B deficiency was lower than now when the use of inorganic fertilizers is on the increase. These organic materials were rich sources of micro elements and therefore tended to maintain adequate levels of nutrients in the soil. As a direct result of these changes in farming practices, micronutrient deficiency problems are now widespread and increasing in severity. The newer high analysis fertilisers contain fewer impurities and no longer contain micronutrients as incidental components unless they are specially added (FAO, 1972)

Whereas micronutrient deficiencies can seriously adversely affect plant growth, these can easily be controlled. However, before new developments in technology and methods, it was difficult to predict the potential for micronutrient limitations and these are widely uncovered by trial and error plus "educated guesses" (Wallace, 1961). The only reliable method of identifying micronutrient deficiencies is by accurate soil and plant tissue analysis.

Agriculture production in the tropics, and arid and semi arid regions still focuses on the supply of the macro nutrients, nitrogen, phosphorous and potassium, with little attention to micronutrients. This is so even when it has been demonstrated that several crops respond to lower doses of N, P, and K compared to the high amounts supplied. Hence the role of micronutrient deficiencies as a challenge to soil fertility in the tropics seems clear (Magar and Babikir, 1965).

2.3 Boron in Plant Physiology

Boron (B) was shown to be essential to plant growth in 1923 (Warington, 1923). Among the micronutrients, deficiency of B is the most frequently encountered in the field (Gupta, 1979) and it has been observed that in general cereals have lower B requirements compared to legumes (Marten and Westermann, 1991).

There is general agreement that boron (B) is essential for higher plants although its essential biochemical role has not yet been well established (Dugger, 1983). Hewitt (1996) also suggested that no specific physiological role has been identified for boron although the capacity of the element to complex with phenolic and polysaccharide hydroxyl groups may be a clue to one of its functions. Boron is different from the other micronutrients because it is a non metal and does not form a direct part in any enzyme system (Batey, 1971). Boron is a microelement absorbed through the root as boric acid and its uptake depends on pH and soil boron content (Tabrizi et al., 2008). The mechanism of Boron transport from plant roots via the xylem, is by water potential gradient created by transpiration. Therefore, factors which reduce the transpiration rate of plants also adversely affect boron transport through the plants.

Boron may be considered a typical metalloid having properties intermediate between metals and the electronegative non metals. B has a tendency to form anions rather than cationic complexes. It has been established that boron chemistry is of a covalent boron compound always combined and not in ionic form. Therefore, in soils boron exists as three boron ions namely boric acid, mono borate ions and poly borate ions. The equilibrium between these ion species in aqueous solutions is rapidly reversible (Rerkasem and Jamjod, 2004).

It has been suggested that Boron plays an essential part in carbohydrate and nitrogen metabolism (Ortlie et al., 1991 as reported by Fageria et al., 1991). This is confirmed by the later observation of Bailey and Mc Hargue (1994) that increasing the concentration of B in lucern had a marked effect in raising sucrase activity.

Gauch and Duger (1972) as reported by Price et al. (1972) proposed that B functions by facilitating the transport of sugars through membranes. The borate ion reacts with hydroxyl rich substances, such as sugars, to produce complexes which are then translocated more rapidly across membranes than the undissociated free sugars. To account for this, Gauch and Duger (1972) suggested that B is a constituent of the membranes through which sugars pass, and that the sugar combined with borate in a reversible reaction, which would result in the rapid transference of sugars across the membranes. Hewitt (1966) reported that tomato plants suffering from boron deficiency, accumulated sugars in the leaves with a corresponding stunting of the stems. Mc Iirath and Palser (1956) had earlier reported an observation similar to Batey (1971) that the translocation of sugars in tomatoes and turnips was reduced in boron deficient plants. They suggested that the deficiency of B resulted in necrosis of phloem.

Boron has favourable influence on absorption of cations especially calcium while it has a negative effect on anion absorption. Boron is relatively immobile in plants and that affects the rate of cell division and/or elongation especially when the plant is B deficient. This was demonstrated by Albert and Wilson (1961) who observed that the elongation of tomato root tips stopped within 6 hours of transferring intact plants into B free nutrient solution. Such characteristic reduction in elongation of roots observed in B deficient plants can be shown by the use of supra-optimal levels of indoleacetic acid (IAA). Consequently Coke and Whittengton (1968) proposed the hypothesis that along with the transfer of sugars, boron is also involved in auxin metabolism.

2.4 Factors Affecting B Deficiency in Soils

A variety of soil properties have been identified as affecting behaviour of B in soils, thereby influencing boron distribution between the liquid and the solid phase. Soil adsorption sites may act as pool from which boron is supplied to solution or where boron is adsorbed depending on changes in solution B concentration and the affinity of soil for B. Adsorbed B may buffer fluctuations in solution B concentrations and B concentration in soil solution may change insignificantly by changing the soil water content. According to Rerkasem and Jamjod (2004) the soil properties which mainly influence boron concentration in soils are clay mineral type and content, specific surface area, presence of sesquioxides, organic matter content, soil pH and soil salinity. In seasons that are dry, B deficiency is observed more than in wet seasons. In addition, soil types may affect B deficiency with serious problems observed on very light soils, loamy sands and sandy soils (Hewitt, 1966). Such light soils are invariably free draining and in many areas are excessively drained such that B is lost by leaching. Under acid conditions, boron occurs in solution as uncharged H_3BO_3 molecule, it becomes strongly adsorbed in soil containing sesquioxides, organic matter and soluble Al as the pH is raised. Thus availability is increased with decreasing pH (Goma and Singh, 1993). Boron deficiency also occurs more frequently on soils that have been limed just prior to growing crops susceptible to B deficiency. In an experiment carried out in Eire, England, to determine the effect of ground limestone on boron deficiency in tomatoes, Woods (1994) reported that when soil was treated with 5.6 and 13.44

tons ha^{-1} of limestone, B content in the leaves were 25 and 17 mg kg^{-1} in the dry matter compared to 55 mg kg^{-1} when no limestone was added.

Zambian soils are usually deficient in plant available boron. According to Shorrocks (1997), Zambia is among the countries where B deficiency has been reported and plant response to B application observed. In high rainfall areas of the Northern Province, this is exacerbated by the high leaching losses. Purvis (1951) as cited by Phiri (1986) suggests that during drought periods when microbial activity is slow and there is less break down of organic matter, boron deficiency has been observed more frequently than during periods of adequate moisture supply.

2.5 Soil and Foliar Application of Boron

Like other nutrients, the solubility of B is pH-dependent, and hence any changes in soil pH may affect B availability to the plant. Especially in calcareous soils, including 30% of agricultural soils in the world (Mori, 1999), and containing B as oxides and hydroxide compounds with little solubility (Lindsay and Schawb, 1982). In such soils B uptake considerably diminishes and signs of chlorosis appear on plant, resulting in substantial yield reduction (Marschner, 1995a). Therefore B uptake when spraying B onto plant leaf may be greater compared to the soil application of B. Marschner and Crowley (1998) found that foliar application of B could provide barley stressed plants with adequate B. Also according to Eichert and Burhardt (2001) most parts of the solutes, sprayed onto the leaves are absorbed through the stomatal pathway.

A source of error in B response trials is contamination in other fertilisers' especially basal applications. Large amounts of B have been found in common NPK fertilisers and could sometimes be responsible for the lack of response in B fertiliser trials.

2.5.1 Extraction and Test Methods

The critical soil test levels for B have been established using hot water extraction techniques. Beans, peas, and soya beans need to have at least 0.009 mol B/mg soil for optimum crop yields.

If the extraction value is less, B fertilisation is needed. On the other hand 0.28 – 0.46 mol B /mg soil have been shown to be phototoxic to plants (Chadwick and Chorover, 2001).

2.6 Crops Responses to B Deficiency

The most rapid response to B deficiency in higher plants is the cessation of root elongation (Marschner, 1995). The range of crops susceptible to boron deficiency is fewer than for most of the other micronutrients. Cereals do not appear to show symptoms of B deficiency, while horticultural crops such as cauliflower, cabbage and carrots are particularly sensitive. However, grain set failure associated with male sterility has been observed in wheat crop. Boron deficiency was observed to be the cause of almost complete crop failure in some 40 000 hectares of wheat in North China (Li et al., 1978). A key to understanding B deficiency in wheat appears to be the relative sensitivity of its reproductive process. Boron deficiency negatively affects male fertility, grain set and grain yield resulting in depressed dry weights. In respect of physiological development, it has been observed that there is a lower requirement for B for vegetative than reproductive growth. In Bangladesh, B application increased wheat yield in farmer's field by 8.5 - 14% (Rerkasan and Jamjod, 2004). Yang et al. (1993) showed that boron application increased photosynthesis rate and nitrate reductase activity in rape seed, plant height, yield quality and quantity.

It has been reported that in Sudan, despite the high inputs of nitrogenous fertilisers used in the production of irrigated cotton in the Gezira scheme, yields have declined by 30% since the implementation of the intensification and diversification program in 1975 (Ishag,1987). This decline has been attributed to micronutrient deficiencies. According to Ellis and Knezek (1974) deficiencies of manganese, iron, and zinc are commonly associated with calcareous soils. High pH found in calcareous soils, results in low availability of these micronutrients. However, when acid forming N fertiliser such as urea is applied frequently, the low soil pH makes the micronutrient more soluble and available for plant uptake. Ishag (1992) reporting from a study conducted by Jewitt (1956) indicated that when rotations of varying intensities were compared, it was observed that cotton yield was not improved by application of iron, manganese, copper, zinc and molybdenum nor was the appearance of the crop affected in less intensive rotations. This was probably because the soil pH did not decrease as fast as in the more intensive rotations.

Knight and Hailey (1969) concluded that boron deficiency is known to limit cotton yields over a wide range of soils in Zambia. In order to determine the amount required in the soils of Southern Zambia and a satisfactory application method, an experiment was designed to compare soil and foliar application of boron alone and in combination with other nutrients on cotton. The levels of B used were 0, 2.25, 4.50, 6.75 and 9.00 kg ha^{-1} using borate fertiliser (Solubor). Soil applications were side banded along with basal dressing fertilisers before sowing while foliar treatment was applied at 0.9 kg B ha^{-1} in each of eight weekly sprays commencing nine weeks after sowing. From this experiment, it was observed that, in general, there were non significant differences between high and low levels of boron, nor was there a difference between application methods. In addition, highest levels of B caused reduction in stand counts and also resulted in stunted growth of the crop, showing that there was little advantage in applying more than 1.1 kg B ha^{-1}. There was a reduction in cotton yields at application rates above 4.5 kg ha^{-1}. It was concluded that foliar applications of B (0.9 kg ha^{-1} in each of the 8 weekly sprays), as a standard recommendation appeared to have been effective in preventing reduction in yield due to boron deficiency.

Information obtained from literature suggests that monocotyledons generally need less than half the boron requirement of dicotyledons. Most dicotyledons such as sunflower (*Helianthus annus*) and marri show more sensitivity to B deficiency than monocotyledons (Farajzadeh et al., 2008). The lower B requirements in graminaceous species than dicotyledons species is related to their different cell wall composition (Marschner, 1995). Boron deficiency causes flower buds to shed in some species, e.g. in apple (*Malus domestica*), black gram (*Vigna Mungo L*) and sunflower (Blamey et al., 1987).

Brussels sprouts, cauliflower, cabbage, carrot and sweet corn are particularly sensitive to boron deficiency. Deficiency causes the various tissues of the affected plants to become brittle resulting in cracking of leaf petioles, stems and roots. Common disorders associated with boron deficiency include "brown heart" in swede and turnip, "five o'clock shadow" in carrots and "brown curd" in cauliflower. In apples boron deficiency causes corkiness of the fruit and is linked, along with calcium, to the "bitter pit" disorder (Marschner, 1995).

Phiri (1986) investigated the effect of boron on pops in groundnuts and found that application of boron reduced the number of pops significantly. Boron also reduced the number of immature pods and increased the number of mature pods. The decrease of immature pods and number of pops could have led to the increase in sound mature pods which were recorded with increasing content of leaf boron. Levels of boron in the leaf were found to be negatively correlated to percentage pops, immature pods and dry matter yield. It was positively correlated to mature pods, shelling percentage and shelled weight.

Some of the most severe disorders caused by boron deficiency include brown spot of sweet potatoes (*Ipomea batatas L*). Boron deficiency has also been observed in glasshouse tomatoes and carnations (Ruann du Plessis, 2006).

3.0 MATERIALS AND METHODS

3.1 Locations

The field experiments were carried out at York Farm, South of Lusaka while the pot experiments were conducted in the greenhouse located at the School of Agricultural Sciences at the University of Zambia, Great East Road Campus.

3.1.1 York Farm

A field experiment was carried out at York farm, Lusaka. This farm is located 15 km south of Lusaka city centre, at longitude 28^0 15' E , latitude 15^0 25' S – and elevation 1154 m above sea level. York Farm is a commercial farm that grows baby corn in rotations with green beans. The soil here is described as a fine mixed Isohyperthemic paleustalf (Soil Survey Staff, 1999).

3.1.2 University of Zambia

A laboratory and greenhouse study was conducted at the School of Agricultural Sciences, University of Zambia, Great East Road Campus. The soils used in this study were obtained from various locations and some of them have not been described.

3.2 Climate

The meteorological data were collected from Mt Makulu Research Station which is the nearest meteorological station to York Farm (Table 1). In 2008 rainfall total was 843.6 mm. Annual temperatures ranged from an average low of 18.2 ^{0}C to an average high of 25.4^{0}C. The area is characterized by a short growing season (October to March) and a low occurrence of drought.

3.3 Soil Characteristics at the Site of the Field Experiment

Twenty random soil samples were collected from a depth of 0 - 30 cm from the field experimental site using a soil auger. These soil samples were thoroughly mixed to make a composite sample for the trial site. This composite sample was air dried and passed through a 2 mm sieve. The sample was analysed to determine some of the physical and chemical properties of the soil at the experimental site. Laboratory analysis for soil texture, soil organic matter

(SOM), phosphorus (Bray P1), sulphur, B extracted with dicalcium hydrogen phosphate Ca $(HPO_4)_2$, calcium, potassium and manganese extracted with ammonium acetate (NH_4OAc), Al in potassium chloride (KCl), Mn, Fe, Cu and Zn extracted in diethlene triamine pentaacetic acid (DTPA) was done using standard methods employed by the University of Zambia Soil Analysis Laboratory (Songolo and Pauwelyn, 1992). The soil analysis results are shown in Table 2 and Table 3. In addition, 16 bulk soil samples were collected from top soil at different locations of Zambia (including one sample from the trial area) and analysed for soil boron in order to compare the abilities of extraction solution to predict plant B uptake in some Zambian soils (Table 5).

Table 1. Average monthly climatological data for Mt Makulu (Nearest to York Farm) Research Station (1998 - 2008).

Month	Avg. Temp. -------- (^{0}C)	2008 ------------	Mean Rel. Humidity(%)	Mean Mon. Evpt (mm).	Monthly Rainfall (mm)
July	18.3	18.6	56.5	4.0	0
Aug	18.1	18.2	50.4	5.0	0
Sep	21.5	21.7	42.1	6.1	0
Oct	24.9	25.4	38.2	7.1	9.9
Nov	25.3	21.2	51.7	5.6	41.8
Dec	24.2	24.2	76.1	4.8	196.3
Jan	23.7	22.8	78.2	2.0	305.8
Feb	23.8	21.4	75.9	3.6	240.8
Mar	22.5	21.7	70.8	3.4	49.0
Apr	22.3	19.8	59.5	3.8	0
May	20.2	20.3	49.1	4.3	0
Jun	18.9	20.0	53.0	4.2	0
Mean	22.0	21.3	58.5	4.5	-

Table 2a. Selected physical and chemical characteristics of some soils (0 – 30 cm) used in the study

Soil Name	pH (H_2O)	Sand	Silt	Clay	Texture	OM	CEC	Ca	Mg	Exch. Al^{3+}
			%			-- cmols (+) --		cmol kg^{-1}		
York Farm[a]	5.60	83.60	7.60	8.80	Loamy Sand	1.20	4.75	0.43	0.31	1.13
Misamfu Cultivated[b]	5.12	86.60	8.80	7.60	Loamy Sand	1.20	4.73	0.06	0.04	0.10
Misamfu Fallow[b]	5.25	73.60	17.60	8.80	Sandy Loam	1.76	5.00	0.34	0.86	0.32
Gene Bank Fallow[b]	5.70	83.60	7.60	8.80	Loamy Sand	1.45	3.50	13.57	1.02	0.25
Gene Bank Cultivated[b]	5.40	75.60	11.60	12.80	Sandy Loam	1.40	4.00	14.90	1.38	0.21
Mufulira Fallow[b]	5.25	73.60	17.60	8.80	Loamy Sand	1.25	4.75	12.50	0.78	0.45
Mufulira cultivated[b]	5.00	81.60	11.60	13.80	Loamy Sand	1.45	4.55	8.50	3.55	0.30
Kabwe Research Station[b]	5.75	73.60	17.60	8.80	Loamy Sand	1.00	4.25	7.09	3.35	0.24
Mpongwe Farm[b]	5.65	76.00	10.60	13.40	Loamy Sand	1.25	3.85	26.45	6.64	0.11
Kashima Farm[b]	5.45	80.70	11.70	7.60	Loamy Sand	1.50	5.50	33.43	6.64	0.09
Liempe Farm[b]	5.60	85.00	9.00	6.00	Loamy Sand	1.35	4.35	35.29	6.14	0.23
Syringa Farm[b]	5.85	82.00	10.40	7.60	Loamy Sand	1.50	4.55	33.41	6.31	0.11
Chiawa Farm[b]	5.40	77.40	6.20	16.40	Sandy Loam	1.40	4.48	4.40	1.50	0.90
UNZA Field Station[b]	7.80	78.00	17.00	95.00	Loamy Sand	1.15	3.75	22.08	5.60	0.23
Kalundu Cultivated[b]	5.60	84.50	10.75	4.75	Loamy Sand	1.20	4.25	18.06	6.39	0.12
Kalundu Fallow[b]	5.70	82.30	11.75	5.95	Loamy Sand	1.25	4.00	19.45	6.22	0.13

[a] This soil was used for field study

[b] All the soils were included in the Laboratory and Greenhouse Study

Table 2b. Selected physical and chemical characteristics of some soils (0 – 30 cm) used in the study

Soil Name	P	Fe	Mn	Cu	Zn	B
	--------------------	mg	kg^{-1}	------	------	------
York Farm[a]	1.20	5.08	5.00	6.27	0.36	T[c]
Misamfu Cultivated[b]	4.20	86.60	9.50	0.79	0.95	T
Misamfu Fallow[b]	1.26	80.70	7.05	0.30	0.36	T
Gene Bank Fallow[b]	0.03	6.08	6.44	0.23	T	T
Gene Bank Cultivated[b]	0.33	3.50	4.18	0.21	0.07	T
Mufulira Fallow[b]	3.40	4.70	9.50	0.79	0.85	T
Mufulira cultivated[b]	3.6	3.80	6.70	0.60	0.75	T
Kabwe Research Station[b]	0.05	8.90	8.58	0.06	0.34	T
Mpongwe Farm[b]	0.81	3.17	6.52	0.41	3.86	T
Kashima Farm[b]	0.41	2.30	3.50	1.14	1.37	T
Liempe Farm[b]	0.21	15.82	5.38	0.10	T	T
Syringa Farm[b]	0.06	15.27	9.96	0.79	0.71	T
Chiawa Farm[b]	5.00	5.78	3.76	0.74	0.50	0.15
UNZA Field Station[b]	2.10	1.93	9.93	0.27	0.24	T
Kalundu Cultivated[b]	0.08	4.68	4.48	0.17	0.56	T
Kalundu Fallow[b]	0.06	4.76	4.87	0.18	0.62	T

[a] This soil was used for field study

[b] All the soils were included in the Laboratory and Greenhouse Study

[c] T = Trace

3.4 Field Experiment

A field experiment was done in order to compare the response of green beans to five B rates applied as a soil and foliar application. Two crops were planted, the first in July 2008 (under irrigation) and the second in November 2008 (rain fed crop).

3.4.1 Land Preparation

The field was ploughed twice and ridged using a tractor. A pre-planting herbicide was incorporated to control grass weeds and selected broad leaf weeds.

3.4.2 Field Marking

Twenty four plots measuring 3m x 3m (9 m^2) were marked out. Seven (7) shallow planting furrows 50 cm apart and 3.0 m long were made in each treatment plot.

3.4.3 Fertilizer Application

A pre-plant fertilizer application of 600kg/ha of D compound (10:20:10) was applied to the planting furrows. A total of 6 treatments (4 soil rates, 1 foliar and a control) were used in this trial (Table 4).

Table 4. Different rates and application methods used in the boron trial.

Method	B Rates**				
	-------------------- kg ha^{-1} ---------------------------				
Soil application (kg ha^{-1})	0	2.00	4.00	6.00	8.00
Foliar application (g/L)	-	0.45	-	-	-

** solubor rates used = (x 5)

One soil treatment was the recommended rate (4.0kg/ha) of boron application at York farm (personal comm., J Anderson, 2008), one treatment was at a lower rate (2.0 kg/ha) than currently applied while the other two treatments were incrementally higher than the current application levels (6.0 and 8.0 kg/ha). These together with a foliar rate of 0.45 g/L made the six treatments used in the trial. The different treatments were replicated four times in a randomised complete block design (RCBD). Boron rate treatments were mixed in with the D compound as Solubor to supply 0,2,4,6 and 8 kg/ha B. The fertilizer was lightly mixed with the soil. Green beans seed (variety Amy 1) was hand sown in the same planting farrows at a seed rate of 50.0 kg ha^{-1}. Commencing from the fourth week after planting, 0.45 g /L of B was foliar applied to the green beans, four times at weekly intervals using a hand-held Knapsack sprayer fitted with wind shield. Two weeks after planting, 20 kg N ha^{-1} was supplied to the plots as urea (46%) in irrigation water. This practice continued over the following nine weeks until a total of 200 kg N had been supplied.

3.4.4 Field Management

The trial plots were planted to an irrigated winter crop in July 2008 and the same trial repeated as a rain fed summer crop in November 2008. Weeding was done by hand hoeing three and six weeks after planting. All treatments received standard supplementary irrigation. Standard pest control sprays were also applied to all the treatments.

Green beans from the net plots (6.25m^2) were harvested in split harvests for 4 weeks. The weight of the 4 harvests was totalled to give the yield (kg/ha) for the different treatments. In addition, other agronomic data namely pod length and plant height were collected. The pod length (cm) was an average of 10 randomly selected pods at every harvest while the plant height was the average of 10 randomly selected plants measured at final harvest. The packout percentage (an indicator of quality) was calculated as the weight of all exportable (first grade) beans as a percentage of total harvested bean weight from each treatment.

3.5 Pot Experiment

The objective of the study was to select a test method better correlated to plant B uptake. In this study, 16 soil samples from different parts of Zambia were used in pot experiments. The 16 soil samples were analysed for inherent boron content. This was done in order to have an understanding of the occurrence of B deficiency or toxicity in several Zambian soils. Each soil type was then mixed with D compound fertiliser (NPK) and filled into 4 experimental pots giving a total of 64 pots. Two bean seeds (var Amy 1) were planted in each pot. The pots were watered three times per week until the fourth week after planting when the plants were at full vegetative stage. At 6 weeks, plant tissue B was analysed in each pot using strong nitric acid extraction method. In this regard, three sets of data were obtained namely acid soluble soil B, Hot Water Soluble B and Acid Soluble plant tissue B. A correlation analysis was done between the two soil boron values and those found in the plant tissue analysis to ascertain whether there was a relationship between soil B and plant tissue B. This study helped to answer several questions as regards B chemistry such as the fate of B and the various responses when B is applied to different soil types. In addition, the efficacy of the two B extraction methods was also compared.

3.6 Statistical Analysis

Using SAS (1988) the data were subjected to statistical analysis to obtain the analysis of variance (ANOVA). The significant differences between different treatments were determined (Gomez and Gomez, 1983). Treatment means were compared using the Least Square Difference (LSD) test (Steel and Torrie, 1980). Correlation analysis was done.

4.0 RESULTS AND DISCUSSIONS

4.1 Soil Test and Soil B

The soil test values for York Farm (Table 2 and Table 3) indicate that while other micronutrients namely Cu, Mn and Zn tested above the critical values (Viets and Lindsay, 1973), soluble B was below the critical level (Reisenauer et al., 1973). In addition, the soil B analysis of 16 other soil samples from different locations (Table 5) also revealed that most (80%) Zambian soils show only trace amounts available for plant growth. Most of the soils reviewed showed deficiency of B. This observation is in agreement with Gupta, (1979) who also observed that among the micronutrients, deficiency of B is the most frequently encountered in the field. These results, according to soil test interpretation would suggest a wide spread deficiency of B in most Zambian soils and a likely positive crop response to any B applications. In this study, a combination of methods including plant symptoms, soil and plant analysis and plant response to applied B was employed for diagnosing B deficiency. However, inference from vegetative symptoms was not very useful as deficiency symptoms were hardly ever seen in the field.

4.2 Boron Application Method

Although not as effective as B applied to the soil (11.3 ton/ha), foliar B also increased bean yield (10.29 ton/ha) over the control (8.7 ton/ha) so this can be quiet significant for the purpose of ameliorating B deficiency. A source of error in B response trials is "contamination" from other fertilisers. Large amounts of B have been found in common N, P, and K fertilisers and could sometimes be responsible for lack of response in B fertiliser trials (Rerkasem and Jamjod, 2004). Particularly in those trials on low B soils in which any sign or symptom of B deficiency was no longer evident in the nil B treatment, such contamination should be suspected.

Application of B in foliar spray or to the soil increased green bean yield over the control by 20% or more (Table 6 and 7). However, it was observed that application of boron as a foliar spray was not as effective as soil application in raising green bean yield. Foliar application gave crop yield that was 4.7 % less than that from soil application.

Table 5. Plant available boron in sixteen Zambian soils extracted using hot water soluble and nitric acid extraction methods.

Location	Soil B (mg/Kg)	
	HWS	Acid
Misamfu Cultivated	T	5.50
Misamfu Furrow	T	5.50
Gene Bank Fallow	0.15	25.00
Gene Bank cultivated	0.15	22.00
Mufulira Fallow	T	12.40
Mufulira cultivated	T	22.50
Kabwe Research Station	0.65	33.40
Mpongwe farm	0.50	35.00
Kashima farm	0.20	45.00
York Farm	0.30	55.00
Liempe farm	1.50	32.80
Syringa farm	5.25	47.30
Chiawa farm	0.15	33.70
Unza Field Station	0.65	25.90
Kalundu cultivated	0.45	42.30
Kalundu fallow	0.45	40.80
Critical Value	1.50	-

According to these results, foliar application of B at 0.45 mg/kg may be the appropriate concentration to increase green bean growth and hence yield in the field. Foliar application of nutrients, especially micronutrients such as B may be an effective way to provide the crop with necessary nutrients, especially at areas where soil pH is a limiting factor for soil B solubility and uptake. The foliar method may be economically important compared to soil fertilization of B, because foliar B may highly be absorbed through plant stomata (Eichert and Burkhardt, 2001). In addition, soil fertilisation may not be very efficient since Boron compounds are very much subjected to precipitation and hence highly reduced uptake, especially in calcerous soils.

Boron applications rates of 0.25 to 3kg/ha are generally recommended for most crops (Fey and Manson, 2004). The lower rates are for more sensitive crops such as cotton and corn (maize), while higher rates are used on more tolerant perennial crops such as lucerne. In this trial, application rates slightly higher than these (4kg/ha) were used and proved just as effective.

4.3 Plant Height

The variable nature of plant responses to B is well known and evidence of B deficiency being accentuated by sub optimal environmental conditions such as temperature, water stress and water logging is well documented. Evidence of adverse effects of low B on vegetative parameters is rare. However, it has been well established that B deficiency causes flower shedding in most plants (Maschner, 1991)

The final average plant height and pod length measurements were used to compare the effect of B applications to growth of green beans (Table 6 and 7). Generally, green bean plants were shorter in the summer (second) crops (40.0 cm) than the winter (first) planting (53.3cm). However, there was no consistent pattern by treatment between the two crops. The plant height of both the first and second crop was not influenced ($p<0.05$) by application of B or its increasing supplemental amounts. However, when height was averaged among soil applied treatments, the first crop was taller than the second crop. The second crop received some rain which promoted plant diseases and insect attacks. Thus, according to Smit and Combrink (2004) it would have been expected that the increased humidity would have promoted leaf blight attack therefore adversely affecting plant growth. On the other hand, the first (winter) crop did not suffer from blight attack. In the case of foliar treatment, the average plant height was not different between the first and second crop. The amount of B did not affect average plant height for the two crops.

4.4 Pod Length

The pod length ranged from 5.7 to 6.3 cm (Table 6). Pod length was not significantly ($P<0.05$) different between the treatments although the second crop had slightly longer pods (Table 7). As the pod length increased, bean yield also increased. This was expected as pods give rise to yield.

Table 6. Effects of boron fertiliser on green bean (Irrigated crop)

Boron Treatment*	Plant Height cm	Pod length cm	Yield (ton/ha)	Packout rate %
Nil	54.0	5.7	8.5	94
Foliar	48.9	5.9	10.5	98
Soil -1	52.6	6.1	11.8	97
Soil – 2	54.6	6.3	12.5	98
Soil – 3	57.2	6.0	9.1	98
Soil – 4	52.6	5.9	10.6	96
LSD ($p < 0.05$)	ns	ns	ns	ns
Cv	**7.6**	**12.6**	**20.5**	**8.5**

* 1, 2, 3 and 4 represents 2, 4, 6 and 8 kg B/ha respectively, foliar application was 0.45 g/L

Table 7. Effects of boron fertiliser on green bean (Rainfed crop)

Boron Treatment	Plant Height cm	Pod length cm	Yield (ton/ha)	Packout rate %
Nil	40.8	7.1	8.95	87
Foliar	40.2	6.5	10.60	80
Soil -1	40.8	7.1	12.35	85
Soil – 2	39.1	7.3	10.10	87
Soil – 3	40.7	7.0	9.70	78
Soil – 4	38.4	7.2	9.00	88
LSD ($p<0.05$)	ns	ns	ns	ns
Cv	8.4	9.8	21.00	14.50

4.5 Yield

The yield of green beans obtained from applying four rates of soil B and one rate of foliar B are given in Table 6 and Table 7. In the first crop, the maximum bean yield (12.5 ton /ha) in soil application was obtained when B was applied at the rate of 2.0 kg/ha. This was an increase of 47.1 % over the control (nil B) which yielded only 8.5 tons /ha. This trend was repeated in the second crop when the highest bean yield (12.35 kg/ha) was recorded when 2.0 kg /ha B was applied. In general additional application of soil or foliar B increased yields by between 7 and 47 % in the winter crop. As the rate of soil applied B increased beyond the recommended rate (2.0 kg/ha) there was a reduction in green bean yield although the difference was not significant. Yield reduction at these higher boron rates indicate that caution must be used with supplying supplemental B. These observed effects of B are in agreement with Knight and Hailey (1969) who observed that high levels of B caused reduction in the plant stand and stunted the growth of cotton. In addition, they concluded that there was no advantage in applying more than 2.25 kg B/ha and that there was a yield reduction of cotton with the application of over 4.5 kg B/ha. The results in this trial also suggest that application rates beyond 4.0 kg /ha appear to be too high for optimal green bean production. In contrast, although the B source and rates used in this trial are consistent with what other researchers recommend for correction of B deficiency, Wallace (1961) recommends the use of higher boron rates (4.5 kg/ha) for the correction of deficiencies. The lower rates observed in this study are not in agreement with what Wallace recommends. Lancaster et al. (1962) applied powdered $Na_2B_4O_7$ as a pre-plant application (0.5kg/ha) and as 5 foliar applications of 0.1kg/ha and increased the yield of seed cotton by 15 %.

In general, the winter crop performed better in terms of yield (10.9 tons/ha) than the summer crop (10.1tons/ha) because the rain crop suffered from an attack of bacteria blight. As a result this crop showed lesser plant height and slightly poor quality of harvested pods. However, using increasing supplemental rates of B did not significantly ($p<0.05$) affect green bean yield during growth of the two crops. Similar to these observations, Smit and Combrink (2004) did not obtain increasing tomatoe yield response to increasing B in solution. It would, therefore, be expected that there was less humidity during the first crop and, therefore, less diseases and insect burden. A similar observation was reported for tomatoe (Smit and Combrink, 2004)

In this study, the difference in yield that was obtained between the recommended foliar (0.45g/kg) and soil (4 kg B/ ha) application rates and the control (nil B), which amounted to between 18 % and 30 % would appear rather important when considering commercial production of green beans. The elimination of B (control) did not significantly ($p<0.05$) adversely affect yield potential of green beans. This can be explained by either the fact that B could be present in adequate amounts in the soil, irrigation water or as incidental components of the basal fertilisers.

4.6 Bean Quality (Pack out Percentage, POP)

Using the packout percentage as an indicator of quality, the POP was not significantly ($p<0.05$) affected by increasing rates of soil B nor the different application methods(Table 5 and Table 6). The packout percentage values ranged from 94 to 98 % in the first crop and from 78 to 88 % in the second crop. These values appear to be generally good when compared to local and regional trends on most commercial farms or a rate of 88 % reported by Ruann du Plessis (2006) to be the highest in most genotypes of green beans germplasm in South Africa. However, since the POP is only a ratio which depends on yield, higher yields are critical to obtaining satisfactory POP values.

4.7 Pot Experiment

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In this trial, due to the fact that most soils showed trace amounts of B, it was only possible to conduct a meaningful soil – plant correlation analysis on a few number of paired entries (n=9). Correlation analyses was done between HWS B and plant tissue B ($r = 0.65$) as well as between acid soluble B with plant tissue B ($r = 0.45$). Incidences of B in bean tissue were highly correlated with the level of HWS B in the soil and lowly correlated with acid soluble soil B. Therefore, the soil B may or may not correlate well with whole green bean plant response, a phenomenon which needs more experiments to confirm. However, from experiments conducted by other researchers it has been generally observed that correlation tests are the best in selecting the best soil test for B (Fey and Manson, 2004). Fey and Manson (2004) found that available soil B levels associated with B deficiency ranged from 0.1 mg HWS B/kg to 0.3 – 0.4 mg. Matoh (1997) found that critical B concentration for early vegetative growth in wheat was 1 mg B/kg dry weight while tissue analysis of other graminaceous species contained between 4 and 7 mg B/kg compared to 20 and 40 mg/kg in dicotyledonous plants.

4.7.1 Soil and Plant Boron

There was no relationship between soil B and that found in plant tissue because of the B adsorption – desorption hysteresis. B applied to the soil goes into two pools, available and the other locked up. The easily available B can be determined by hot water extraction while the locked up pool requires acid extraction. There was no response to increasing rates of B because some of the applied B was immediately locked up into unavailable forms. This observation supports the need for foliar application which minimises the risk of B being locked up in unavailable forms.

Table 8. Boron concentration in green beans tissue grown in 16 different Zambian soil types

Soil Type	Acid Soluble Plant Tissue B (mg/kg)
York Farm	39.20
Misamfu Red	52.20
Misamfu Fallow	35.00
Mufulira	<0.05
Mufulira Fallow	25.45
UNZA	<0.05
Kalundu	31.50
Mpongwe	56.00
Liempe Farm	2.70
Genebank Cultiv	<0.05
Genebank fallow	<0.05
Syringa farm	21.40
Kabwe fallow 2	<0.05
Chiawa	<0.05
Kabwe Fallow	<0.05
Kashima farm	5.00

Each number is mean of samples from four replicates of pot-grown green beans

<0.05 = trace amounts

4.8 Boron Extraction Methods

Two methods comparing strong acid extraction and hot water method were used in soil B analysis while acid digestion was used to determine plant tissue B. In general, it was observed that in soil analysis, B extracted by acid was more than that extracted by water. However, the water extraction is a good indicator of soil B because it has a lower extraction threshold that best simulates the plant available B. When extracted with hot water, most soil samples revealed only trace amounts of soil B (<0.05 g /kg). However, when the same soils were extracted with strong acid, the readings of available B substantially increased. This observation indicates that Boron was locked up in unavailable forms and could only be unlocked using acid extraction. Therefore, there is a possibility of unlocking B and its remobilisation in small scale farming using humic acids derived from the addition of organic matter such as manures. Other methods in which locked up soil B could be made available to plants is by use of genotypic variation (nutrient efficiency) in which specific types are bred for adaptation to low B soils. Correlation analysis between HWS B, acid soble B and plant tissue B showed that there was a better relationship between HWS B with plant tissue B (r = 0.65) than there was between Acid solube B and plant tissue B (r = 0.45).

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Results from this study indicate that, in Zambia on soils similar to those used in the trial, for one to obtain increased total yields of green beans, B additions are beneficial in addition to the NPK fertilisers. Although not as effective as B applied to the soil, foliar B significantly increases bean yield so it can be quite sufficient for the purpose of confirming B deficiency.

From this experiment, responses to B applied both in the toxic range as well as in low B soils have been observed. In this trial, diagnosis of B deficiency was confirmed by positive responses to B application both foliar and soil-applied. This observation confirms the principle that the final verification of B deficiency in soils is plant response to soil applied B.

The amount of soil B extracted by boiling water method correlated well with crop response to applied B and is, therefore, recommended being a simple and cost effective method of determining boron requirements. The acid extracted B does not seem to be a good indicator because it shows that it over-extracts the amount of B available for plant use and can, therefore, lead to over estimation.

In addition, seasonal effects on green bean yield have been observed with winter (July) planted crops growing better than summer (November) crops. It can, therefore, be concluded that in order to achieve higher yields of green beans in Zambia, winter crops fertilised with NPK fertilisers plus a micronutrient addition of B is best.

5.2 Recommendations

In Zambia, deficiency of the micronutrient boron is very common. The crop diversification drive being pursued by the government and private farming enterprises will require a corresponding deliberate policy by researchers to come up with crop production guides similar to the cotton production pack which will put emphasis on vital boron for the production of these export-oriented crops in order to increase yield and enhance quality. The realisation of this will require a two way approach. Firstly, there should be a nation-wide soil survey and the mapping of all productive soils to determine their boron status. Secondly, boron specific research on all potential crops in these areas should be carried out in order to determine their respective responses to its applications. Further, multi-location research in green beans is recommended to consolidate the findings of this study.

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