THE RESPONSE OF SELECTED LEGUME CROPS TO SOURCES AND RATES OF SULPHUR

by

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DECLARATION

I, JIMMY P. SINGABAPHA, declare that this dissertation represents my own work and that it has not previously been submitted for a degree at this or another University.

Signature: ______________________ Date: 12/12/96

APPROVAL

This dissertation of **Jimmy Primo Singabapha** is approved as fulfilling part of the requirements for the award of the degree of Master of Science in Agronomy by the University of Zambia.

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DEDICATION

I dedicate this work to my late parents, Tumule and Bareki.

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ABSTRACT

There are concerns about increasing incidence of sulphur (S) deficiency in agricultural soils due to increased cropping intensity, development of high yielding crop varieties and the use of S-free fertilizers. Zambia recorded cases of S deficiency in the 1950's and subsequently noticed grain yield responses by maize to S applications. Reductions in crop yields as a result of this deficiency are sometimes mistaken for nitrogen deficiency. A field study was conducted in Lusaka to determine whether cowpea, soyabean and green gram would respond to gypsum and elemental-S as sources of sulphur. Gypsum and elemental-S were each applied at 0, 15, 30 and 45 kg S ha^{-1} rates. The experiment was designed as a split-split plot arranged in a RCBD with four replications.

The average legume grain yield with gypsum was 1410 kg ha^{-1} while it was 1392 kg ha^{-1} with elemental-S. These were not statistically different. The three legumes showed a significant variation in their grain yield. Cowpea produced 2300 kg grain ha^{-1}, soyabean 1327 kg grain ha^{-1} and green gram 575 kg ha^{-1}.

Soyabean and cowpea both had significantly higher protein content in their grains than green gram. Grain yields did not vary significantly with the different S rates applied. The overall mean yield of the control was 2209 kg grains ha^{-1} while the grain yields of 15, 30 and 45 kg S ha^{-1} treatments were 2393 kg ha^{-1}, 2317 kg ha^{-1} and 2282 kg ha^{-1}, respectively. Protein concentrations and contents were not significantly different between the two sources of sulphur.

Gypsum treatments gave 283 mg protein g^{-1} and elemental-S gave 274 mg protein g^{-1}. Soyabean grains contained significantly more protein (375 mg g^{-1}) than both cowpea (230 mg g^{-1}) and green gram (231 mg g^{-1}). However, on a unit area basis, protein contents of soyabean (498 kg ha^{-1}) and cowpea (529 kg ha^{-1}) were not significantly different due to a relatively high yield of cowpea.

Leaf analysis results showed that S uptake from gypsum was 7.1 mg S g^{-1} dry matter (DM) and 7.6 mg S g^{-1} DM from elemental-S. These were not statistically different. Sulphur uptake and assimilation was not different between the legumes, and cowpea had 7.6 mg S g^{-1} DM, soyabean had 6.8 mg S g^{-1} DM and green gram had 7.7 mg S g^{-1} DM. However, cowpea had significantly higher total-N (52 mg N g^{-1} DM) than both soyabean (39 mg N g^{-1} DM) and green gram (37 mg N g^{-1} DM).

The average organic-S : N ratio for gypsum treatments was 1:34 (0.029) whereas it was 1:36 (0.028) for elemental-S, signifying no significant difference. Cowpea had a significantly wider ratio (1:48 or 0.021) than both soyabean (1:32 or 0.031) and green gram (1:30 or 0.033). Soyabean and green gram did not show a significant variation in this ratio. The organic-S : N ratio did not significantly vary with increasing S rates. The 0 kg S ha^{-1} gave a ratio of 1:37 (0.027), while 15 kg S ha^{-1} gave a ratio of 1:45 (0.022) and each of 30 and 45 kg S ha^{-1} gave a ratio of 1:30 (0.033).

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CHAPTER 1

INTRODUCTION

Sulphur (S) is one of the major plant nutrients and it is very vital for protein synthesis (Tisdale & Nelson, 1966). Due to increased cropping intensity, use of high yielding crop varieties and the use of S-free fertilizers, there is growing concern about S deficiency in agricultural soils (Makarim, 1990; Needham, 1983). Makarim (1990) suggested that as a general rule, the higher the grain yield, irrespective of crop, the greater is the rate of soil-S depletion and consequently, the greater the need for S addition.

In the Southern Africa region, cases of S deficiency have been reported in Zambia, Zimbabwe and Malawi (Brady, 1984; Grant & Rowell, 1978; Lungu, 1987). Lungu (1987) reported a five-fold maize yield increase in Northern Zambia when S was applied. Neither soil S concentration values nor soil type were provided in this report. Jansson (1995) reported that S levels of Zambian soils range from as low as 4.3 mg kg^{-1} to 84.5 mg kg^{-1}. Sulphur deficiency cases in Zambia were recorded as far back as in the 1950's (Prior, 1977). He reported that a series of maize trials then carried out throughout Zambia indicated positive yields response to S application. These observations resulted in government enacting a law that required all compound fertilizers to contain at least 10% S. With the introduction of multi-party democracy in Zambia in 1991 that liberalised the economy, there are fears that incidence of S deficiency may be in the increase due to importation of S-free fertilizers.

Food legumes, due to their relatively high protein contents, play a very significant role in human nutrition (Norton *et al*, 1985). These grain legumes are quite relevant to the Southern Africa region for they can supplement the low nutritive values of major food crops like cereals and root tubers which have relatively low protein content. Some of the grain legumes that have great potential in the Southern African region and indeed in Zambia are soyabean, cowpea and green gram. This potential is evident from the yield variations obtained under different environments.

In Zimbabwe, soyabean grain yields of up to 4500 kg ha^{-1} have been recorded under commercial production whereas very few farmers have ever achieved such high production levels in

Zambia (McPhillips, 1982). Javaheri (1982) pointed out that Kaleya soyabean variety has yield potential above 3000 kg ha^{-1} although its yield record from field trials has been similar to those of other varieties, below 2000 kg ha^{-1}. Hill (1980) reported variable cowpea grain yields in Zambia, ranging from 61 kg ha^{-1} at Lusitu to 2600 kg ha^{-1} at Magoye sub-stations. He cited green gram yields which varied from 15 kg ha^{-1} (Lusitu sub-station) to 1438 kg ha^{-1} (Mochipapa research station).

Legumes tolerate moisture stress to a greater extent than maize which is considered the staple crop in Zambia. They have an added advantage of being able to fix N. Therefore, inorganic fertilizer requirements may be reduced. This is important for small-scale farmers with limited resources. However, the growing of legumes without fertilizer application will require caution since they are reported to be particularly sensitive to S deficiency (Needham, 1983).

In recent times, there has been a general lack of research on the S status of African soils as it pertains to the impact it has on the production of grain legumes.

The objectives of this study are:

1. To determine whether soyabean, cowpea and green gram yields and protein content will be improved by S applications.
2. To establish the effect of gypsum and elemental-S as sources of S on the grain yield and protein content of the three legumes.

CHAPTER 2

LITERATURE REVIEW

2.1 CROPS RESPONSES TO SULPHUR APPLICATION

Several studies have been conducted to study the effects of sources and rates of S on crops. Most of the information available on legume studies is focused on S application to pastures rather than grain legumes. This is evident from numerous reports, some of which are presented by the following: Andrew (1975); Bouma (1975); Johnson (1975); Jones (1975); Makarim (1990); Saunders & Cooper (1975) and Spencer (1975). Those who reported some related work on grain legumes include Bell *et al.* (1990), Bewley & Greenwood (1990), Ismunadji (1990), Lawn & Ahn (1985), Lefroy (1990) and Makarim (1990). Since the functions of S in crops are generally the same, its effects on other crops and pastures may be safely inferred to grain legumes.

Lungu (1987) reported dramatic maize response to S application in Northern Zambia. The grain yield was only 890 kg ha^{-1} at Msekera when urea minus S was applied, but urea plus S increased yields up to 5120 kg ha^{-1}. Leaf analysis gave values between 0.6 - 0.7 mg S g^{-1} dry matter (DM) in urea only treatments, but 1.2 - 1.7 mg S g^{-1} DM in urea plus S treatments. The low S concentration in urea minus S treatments was attributed to S deficiency.

Wild (1988) reported that Greenwood (1951) in Northern Nigeria found that approximately 20 kg S ha^{-1} applied as gypsum, improved the yield of groundnuts compared to the control, for two years after it was applied but only had a small effect in the third year. Tisdale & Nelson (1966) reported that when elemental-S is incorporated into the soil, rather than surface broadcast,it can be as effective as sulphate-S in supplying S to crops. This is because when it is left on the surface, a lower fertilizer surface area is in direct contact with the soil which contains S-oxidising micro-organisms. However, its incorporation into the soil ensures more contact between the elemental-S and the oxidising agents, resulting in more S oxidation.

In flooded rice field studies conducted in South East Asia, Blair (1990) reported that elemental-S proved equally effective as a source of S as sulphate-S. This was observed in Thailand

and Indonesia in the 1987 season where a significant grain yield response by rice to S, applied as gypsum and elemental-S, and at rates of 0, 16, 32 and 64 kg ha^{-1} was recorded. Grain yield increased from 1800 kg ha^{-1} at 0 kg S ha^{-1} to 2000 kg ha^{-1} at 64 kg S ha^{-1}. However, he also reported that greenhouse studies have shown that there is slow S release from elemental-S than from sulphate-S. These greenhouse studies revealed that elemental-S, urea-S melt and S-coated triple super phosphate are effective means of supplying S to rice when they are mixed with the soil. Sulphur-coated urea and S-bentonite did not release sufficient S to meet the demands of the growing crops.

Lefroy (1990a) reported the use of S rates similar to those used by Blair (1990), in other experiments conducted to measure the residual effects of fertilizers in Thailand. Gypsum was the source of S. It was observed that, of the three sites studied, all of which were planted with maize followed by either mung beans or cowpea, in only one did maize fail to respond to S application over the three years. One site with light-textured soil considered to be of low fertility, recorded a large and significant response of maize to S from the first crop. On another site which was considered fertile and with good S retention capacity, there was no effect of the applied S to a maize crop. Lefroy (1990a) attributed the absence of a response to S in the latter site to a high use of fertilizers before the experiment, as that was a research station. The absence of response over the three years was also thought of as probably due to other S inputs such as lateral flow of S-containing water, although considered small. The most likely explanation given was that the difference between net input of S and net uptake by crops was accounted for by the soils' S reserves. These reserves differ from soil to soil mainly due to their organic matter content, their sorption capacities and the levels of S-containing minerals.

In a separate report, Lefroy (1990b) indicated that both gypsum and elemental-S, applied at 8 and 32 kg S ha^{-1} to maize in Thailand, increased grain yield. The two sources did not exhibit significant variations. The cowpea crop that was planted after maize did not show significant differences in the grain yield between gypsum and elemental-S.

In other field and pot experiments conducted in Indonesia, Makarim (1990) reported significant yield responses to S application by cowpea, soyabean, rice, maize and *Dolichos lab lab* over a period of three years. There was no response by soyabean at one site and by maize at the other. Maize grain yields increased in the first and third seasons with S applications of 0, 8 and 32 kg S ha^{-1} with most significant increases in the third season. He reported that Yazawa (1985) recorded soyabean grain yield increases from 11.9 g pot^{-1} to 20 g pot^{-1} due to S application.

Ismunadji (1990) reported a high incidence of crops response to S applications in Indonesia. Crops that responded included lowland rice (Ismunadji & Zulkarnaini, 1978), soyabean, maize, potato, cabbage, onion and upland rice (Soepardi, 1985). Spencer (1975) reported that some greenhouse studies have recorded soyabean yield increases as solution concentration of S increased from 0 mg kg^{-1} up to 10 mg kg^{-1}. Protein content, mainly as methionine and lysine, increased up to 20 mg S kg^{-1}. Bewley & Greenwood (1990) also noted that S deficiency decreased protein content of pea seeds by 20 %. Sulphur-containing amino acids were also decreased.

Spencer (1975) observed that initial views were that high oil content crops such as soyabean and groundnuts would require more S than those which had less oil because S is a constituent of oil storage structures. However, subsequent observations did not wholly confirm that, except for rapeseed. He cited work done in Central Africa (Bockelee-Morvan & Martin, 1966) which revealed some moderate response to S occurring in hay yield, pods and protein content, but not in oil content.

2.2 YIELD LEVELS AND PROTEIN CONCENTRATIONS OF COWPEA, SOYABEAN AND GREEN GRAM

Under Zambian conditions, cowpea grain yields of 750 - 1690 kg ha^{-1} were recorded by Hill (1980) at Kaoma Research Sub-Station. He reported other yields recorded at Magoye and Lusitu research stations for several varieties and these ranged from 1115 - 2600 kg ha^{-1} (Magoye) and 61 - 848 kg ha^{-1} (Lusitu).

Soyabean production figures are variable, with some seemingly too high. For example, McPhillips (1982) reported yields by some of Zimbabwe's large-scale farmers of up to 4500 kg ha^{-1}. He admitted that very few Zambian farmers have achieved these high yields, and most even get yields below 1200 kg ha^{-1} in poor seasons. Hume *et al.* (1985) observed that soyabean yields increased over the years from 1,487 kg ha^{-1} in 1969 to 1,751 kg ha^{-1} in 1972. Javaheri (1982) pointed out that soyabean variety Kaleya, had a grain yield potential of over 3000 kg ha^{-1}, and was adapted to all soyabean growing areas of Zambia. In a 1982/83 soyabean test, Kaleya produced 1950 kg ha^{-1} of grains, the highest of all the varieties included in the test (Joshi *et al.*, 1983).

Green gram yields are relatively low. Hill (1980) reported some yield results of trials conducted at three research stations in Zambia. At Lusitu, yields varied from 15 - 475 kg ha^{-1}. At Mochipapa and Siatwinda where N and P fertilizer trials were carried out, the highest yields obtained were 1438 and 1164 kg ha^{-1}, respectively.

The protein concentration of cowpea is estimated at 227 mg g^{-1} at 115 g kg^{-1} moisture content (Norton *et al.*, 1985). They reported soyabean protein concentration of 368 mg g^{-1} (N x 5.71) at 70 g kg^{-1} moisture content. For green gram, they gave a value of 220 mg g^{-1} protein at 120 g kg^{-1} moisture content. Boulter *et al.*, (1973) evaluated 21 varieties of cowpeas and found a range from 230 - 340 mg g^{-1} protein concentration. Lawn & Ahn (1985) reported protein concentrations of green gram between 250 and 280 mg g^{-1} on dry matter basis.

2.3 SULPHUR INPUTS AND TRANSFORMATIONS IN THE SOIL IN RELATION TO CROPS USE

Sulphur in the soil exists in basically two forms - inorganic and organic. The inorganic-S may either be in solution or adsorbed by the soil colloids, and both these forms are readily available to the plants. The inorganic-S can become unavailable to crops when leached beyond the root zone or when in association with calcium carbonate, basic iron and aluminium sulphate, barium sulphate and strontium sulphate (Probert, 1978; Williams, 1975).

The proportions of adsorbed sulphate and that in solution may vary by depth depending on a variety of factors. Chief among these factors are; soil texture, amount and frequency of rainfall, total-S in the soil, rate of S uptake by plants, capacity of soil to adsorb sulphate, rate of S mineralization and presence of other anions such as phosphates (Freney *et al.*, 1975; Freney & Swaby, 1975; Probert, 1978; Williams, 1975). This sulphate-S is eventually converted to organic forms by plants or micro-organisms (Freney & Swaby, 1975).

Although the chemical nature of organic-S in soils is not well understood, it is believed that organic-S can either be S bonded directly to carbon (C-S) or indirectly via oxygen (C-O-S) and nitrogen (C-N-S), the ester sulphates. These ester sulphates have to undergo oxidation in order to convert S into the form utilizable by plants, that is, SO_4^{2-}. Sulphate esters are the prime reservoir of plant available S (Blair *et al.*, 1993; Freney *et al.*, 1975).

Mineralization of S depends on temperature, moisture content (and aeration), pH and availability of food supply for micro-organisms (Bell, 1975; Freney & Swaby, 1975; Janzen & Bettany, 1987). Temperature ranges between 20 and 40 °C, moisture content at or close to field capacity, liming ($CaCO_3$) and increasing pH, all provide a conducive environment for S mineralization.

2.4 GYPSUM AND ELEMENTAL SULPHUR AS SOURCES OF SULPHUR

Gypsum ($CaSO_4.2H_2O$) is the fertilizer which is commonly used to correct S deficiency in soils (Wild, 1988). It has between 130 and 230 g kg^{-1} S depending on its purity and hydration. Upon application to the soil, gypsum ionizes, releasing SO_4^{2-} which is readily absorbed by crops. The other function of gypsum is that of a soil conditioner on clay soils (Bixby & Kilmer, 1975; Loveday, 1975). It flushes out sodium and re-saturates the soil with calcium to promote flocculation and good soil structure (Needham, 1983). Under conditions of low leaching and acidic soils, gypsum can have a rather long lasting residual effect although most likely less than elemental-S (Johnson, 1975).

The fate of elemental-S following its application to the soil is that it undergoes oxidation which culminates in pH reduction (Weir, 1975). This is occasionally used for high-value crops to correct iron and manganese deficiencies induced by over-liming. Wild (1988) noted therefore that, the successful use of elemental-S depends on the presence of S-oxidizing micro-organisms in the soil. It is also believed that the efficiency of these oxidizing organisms depends on the soil pH.

Other factors that determine the rate of oxidation include the particle size of the S-source, phosphate status of the soil, soil temperature, aeration and moisture content of the soil (Weir, 1975). The activity of S-oxidizing micro-organisms is favoured by moisture contents near field capacity. Slow oxidation of elemental-S would result in a long lasting residual effect, especially where there is little loss by leaching.

2.5 SOIL AND PLANT SULPHUR CONCENTRATIONS

Total concentrations of S in soils vary considerably mainly as a result of soil-S dynamics. Zambian soils have S levels from 4.3 - 84.5 mg S kg^{-1} (Jansson, 1995). He also reported that soils from the neighbouring countries of Tanzania and Malawi contain 2.5 - 135.1 mg S kg^{-1} and 2.8 - 616.8 mg S kg^{-1}, respectively. Tabatabai and Bremner (1972) found that the total S concentration of surface soils of Iowa ranged from 57 - 618 mg S kg^{-1}.

Soil analysis results have proved rather difficult to use to predict S requirements of plants (Andrew, 1975; Needham, 1983). However, Spencer (1975) suggested that 3 - 5 mg S kg^{-1} in soils is adequate to supply S for the optimum growth of many plant species. Rape and lucerne have a higher requirement at 8 mg S kg^{-1}. Under Zambian conditions, it is recommended that S be applied when available soil-S value is below 7 mg S kg^{-1} (O. A. Yerokun, Department of Soil Science, University of Zambia, Personal Communication). Crops responses to S in Australia were recorded for soils having S concentrations below 13 mg kg^{-1} (Andrew, 1975).

Analyses of plant materials have been extensively used with a certain degree of success to predict the adequacy of S to plants (Needham, 1983). The only disadvantage is that results cannot be used to take corrective measures for the benefit of the analyzed plants, but subsequent ones (Dijkshoorn & van Wijk, 1967). Total-S in plant leaves has been used by some researchers as an indicator of S sufficiency. Jones (1975) however, acknowledged that total-S values would only give evidence of the S contents of the crops or plants at the time of sampling without indicating future status.

The critical S values provided by different researchers (Bell *et al.*, 1990; Dijkshoorn & van Wijk, 1967; Evans, 1975; Mengel & Kirkby, 1987; Needham, 1983) vary considerably, mainly from one plant species to the other, and from location to location. Bell *et al.* (1990) have proposed leaf analysis standards for diagnosis of nutrient deficiency in Thailand. They suggested critical concentration values of 2.1 mg S g^{-1} in DM of soyabean and 2.0 mg S g^{-1} in DM of black gram when crops produce more than 1500 kg ha^{-1} seed DM. Evans (1975) agreed with this finding of wide S variations, and he cited ranges from less than 1.0 mg S g^{-1} in DM of some cereals and more than 7.0 mg S g^{-1} in DM of rape and kale. Needham (1983) gave critical levels for total-S in many temperate plants of 2.0 mg S g^{-1} in DM with a possibility of concentrations more than 10.0 mg S g^{-1} in DM under conditions of adequate S, part of which is present as sulphate.

Mengel & Kirkby (1987) mentioned that plant tissues can have from 2.0 - 5.0 mg g^{-1} total-S on dry matter basis. They provided data on S concentration in seeds and grains of *gramineae*, *leguminosae* and *cruciferae* which ranged from 1.7 - 17.0 mg S g^{-1} in DM. Wheat and maize had the lowest concentration of 1.7 mg S g^{-1}, *leguminosae* had 2.4 - 3.2 mg S g^{-1}, soyabean had 3.2 mg S g^{-1}, while the *cruciferae* had the highest, 10.0 - 17.0 mg S g^{-1}.

The other option for diagnosis of S sufficiency in plant tissue is provided by the ratio of organic-S to organic-N (Dijkshoorn and van Wijk, 1967). This is because of the role of organic forms of S and N in protein synthesis. The ratio of organic-S to organic-N in plants should thus be close to that in their respective protein components. Under conditions of adequate supply of S, it has been shown that on a gram atom basis, organic-S to organic-N ratio ranges from 1:40 (0.025) in legumes to 1:31 (0.032) in graminae (Dijkshoorn & van Wijk, 1967; Wild, 1988). Previous work by Dijkshoorn *et al.* (1960) showed a content of 1:37 (0.027) gram atoms of S per gram atom of N in the foliage of perennial rye grass. Saunders & Cooper (1975) suggested values of between 1:17 (0.059) and 1:19 (0.053) for white clover and 1:15 (0.067) to 1:17 (0.059) for rye grass.

Almost no attempts at using sulphate-S concentrations of plant tissue have proved fruitful in diagnosing S requirements of plants (Andrew, 1975). This is so because sulphate-S would accumulate inside the plant tissues if it is in abundance in the rhizosphere (Evans, 1975). Its high concentration in young plants may therefore not be a good indicator that S will be enough for optimum growth throughout the entire life of the plant (Jones, 1975).

Since most of the freshly absorbed S is found in young leaves (Bell *et al.*, 1990; Wild, 1988), it is these young leaves that are likely to first reveal any marked sulphur deficiency in the soil than the older ones (Bouma, 1975). The best way to assess adequacy of S supply from the soil, and possible response by crops, is to sample young leaves just before flowering when photosynthates are being translocated from vegetative parts for use in flowering and reproduction.

CHAPTER 3

MATERIALS AND METHODS

3.1 LOCATION OF EXPERIMENT

The experiment was conducted at the Natural Resources Development College (NRDC) farm in Lusaka. It is situated on Latitude 15° 23' S and Longitude 28° 22' at an altitude between 1220 and 1260 m above sea level. The farm falls under Zambian Agro-ecological Zone II which receives annual rainfall between 800 - 1000 mm (Agro-meteorological Report No. 9, 1985).

3.2 DESCRIPTION OF SOIL

According to FAO/UNESCO Soil Classification, the soil is classified as Eutric Gleysol (Brammer, 1973). The texture of the soil at the specific site of the experiment was clay loam (Table 1).

TABLE 1. Chemical and physical characteristics of the soil at the experimental site within NRDC farm

1. pH: H_2O = 6.10; $CaCl_2$ = 5.60
2. Phosphorus = 21.5 mg L^{-1}
3. Sulphur = 5.45 mg L^{-1}
4. Total Nitrogen = 0.80 g kg^{-1}
5. Potassium = 6.86 mg l^{-1}
6. Calcium = 58.07 mg l^{-1}
7. Magnesium = 2.31 mg l^{-1}
8. Iron = 4.70 mg l^{-1}
9. Zinc = 0.18 mg l^{-1}
10. Manganese = 5.40 mg l^{-1}
11. Copper = 0.37 mg l^{-1}
12. Boron = Trace
13. Organic Matter = 21.5 g kg^{-1}
14. Sand = 410 g kg^{-1}
15. Silt = 300 g kg^{-1}
16. Clay = 290 g kg^{-1}
17. Texture = Clay loam
18. Exchangeable acidity (H^+ + Al^{3+}) = 0.14 cmol kg^{-1} (all H^+)
19. Electrical Conductivity = 0.33 mS/cm

Available soil S was determined by extraction with 500 mg P L^{-1} as mono-calcium phosphate (Blancher, 1986). Phosphorus was determined by the standard Bray No. 1 method. Total-N was obtained by the regular Kjeldahl method (Bremner & Mulvaney, 1982) and involved digesting samples with concentrated sulphuric acid, distilling with sodium hydroxide and titrating with 0.01 M hydrochloric acid.

Soil organic matter was determined by the Walkley-Black procedure (Nelson & Sommers, 1982). For potassium, calcium and magnesium, the soil was extracted with ammonium acetate plus strontium chloride solution. They were then determined by Atomic Absorption Spectrophotometer (AAS). The AAS was used again to determine iron, copper, zinc and manganese after extraction with DTPA-TEA solution. Boron was extracted with calcium chloride using a reflux condenser. The boron in the filtrate was determined by AAS after adding a buffer solution and azomethine H reagent. Electrical conductivity was determined in a 1:5 soil to water extract. The hydrometer was used to measure the proportions of sand, silt and clay in the soil samples after which the texture of the soil was determined by the use of the soil texture triangle.

3.3 TREATMENTS AND DESIGN

Two sources of S, gypsum and elemental-S were applied, each at four rates, 0, 15, 30 and 45 kg S ha^{-1} to three grain legumes. The legume crops were: soya bean (*Glycine max* L.), variety Kaleya, cowpea (*Vigna unguiculata* L.), variety Lutembwe and green gram/mung beans (*Vigna radiata* L.), variety Kenya 1.

Gypsum($CaSO_4.2H_2O$) was analyzed by the Geological Survey Department (Ministry of Mines and Mineral Development, P.O. Box 50135, Lusaka), and found to contain 180.2 g S kg^{-1}. It was applied in powder form at 83.3, 166.7 and 250.0 kg ha^{-1} to supply 15, 30 and 45 kg S ha^{-1}, respectively. The fourth rate was the control. Calculating the amount of calcium in the gypsum($CaSO_4.2H_2O$) from the chemical formula resulted in 23.28% or 232.8 g kg^{-1} calcium.

Elemental-S obtained from Nampundwe mine contained 800 g S kg^{-1}. It was applied at 18.75, 37.50 and 56.25 kg ha^{-1} to supply 15, 30 and 45 kg S ha^{-1}, respectively. The fourth rate was the control.

Non-gypsum treatments were supplied with Ca ($CaCO_3$) equivalent to that contained in the gypsum application of 45 kg S ha^{-1}. The respective deficit of Ca incurred by gypsum applications lower than 45 kg S ha^{-1} was met from the same source of limestone. All the treatments received 123 kg ha^{-1} of diammonium phosphate to supply 30 kg N ha^{-1} and 33 kg P (75 kg P_2O_5) ha^{-1}. In addition, 33 kg K (40 kg K_2O) ha^{-1} was applied as muriate of potash (KCl).

A 2 x 3 x 4 factorial (split-split-plot) design was used with four replications. The main plot was allocated to S-source, sub-plot to crop and sub-sub-plot to S-rate. Randomization of treatments was done at each level.

3.4 LAND PREPARATION AND PLOT SIZE

The land which had been under fallow for three years was disc-ploughed on 12th December, 1995 and disc-harrowed on 14th December, 1995. Four blocks (replications) 2 m apart, were marked out, each measuring 12.3 m x 24.7 m. Each block comprised two main plots (12.2 m x 12 m) separated by 0.3 m wide border. The main plots were further divided into three sub-plots (4 m x 12.3 m) which were separated by 0.1 m wide borders. Each of the sub-plots was divided into four sub-sub-plots (4 m x 3 m), which were 0.1 m apart.

3.5 CULTURAL PRACTICES AND PLOT MANAGEMENT

All the crops were planted between the 21st and 27th December, 1995. Re-planting to fill in the gaps in poorly established green gram treatments was completed on the 3rd January, 1996. Soyabean seeds were inoculated with *Bradyrhizobium japonicum* strain before planting. The spacing for both soyabean and cowpeas was 50 cm between the rows (which were 4 m long), and 5 cm within, giving a population density of 400,000 plants ha^{-1}. The same population density for green gram was achieved by spacing the 4 m rows 25 cm apart with an intra-row spacing of 10 cm.

First weeding was done on the 12th January, 1996. It was repeated on the 1st and 28th February, 1996. Supplementary irrigation with 60 mm of water was carried out on the 11th January, 1996 when a drought spell was experienced.

Green gram was the first crop to mature. It was first harvested on the 6th March, 1996 and last on the 29th March, 1996. This sort of harvesting was adopted because of the crop's indeterminate nature that permitted continuous flushes of flowers to arise. The next crop to mature was cowpeas which was harvested on the 18th and 27th March, 1996. Soyabean matured last and was harvested on the 11th April, 1996. Due to its high shattering characteristics, plants were cut near the base when about 60 - 70 % of the pods had turned yellow and before they started shattering. The plants were allowed to dry before threshing was done.

3.6 DATA COLLECTION

The following data were collected: leaf total-N, total-S, sulphate-S, organic-S and organic-S : organic-N ratio. Grain yield data was also collected as well as data on total crude protein (N x 6.25) of the grains.

Fully expanded young leaves were randomly sampled from fifteen plants in each experimental unit at the beginning of flowering. Sampling was done only on those plants which constituted the harvest area as described below. The leaves were dried at 105 °C for 24 hours and ground prior to analysis following Dijkshoorn *et al.* (1960) methodology.

They were analyzed for total-S by wet digestion with nitric and perchloric acid (Blanchar, 1986). The SO_4-S was extracted with 20 % HCl (Dijkshoorn *et al.*, 1960). In both cases (total-S and SO_4-S), the S was precipitated with barium chloride and the resultant S concentration in barium sulphate determined turbidimetrically. Organic-S in the leaves was obtained by the difference between total-S and SO_4-S. Total-N values which exclude inorganic forms of nitrogen (Egan *et al.*, (1981), were obtained in the leaves by the standard Kjeldahl method. These values were subsequently used as organic-N values.

The concentrations of organic-S and organic-N in the plant samples were divided by their respective atomic weights to obtain an atomic ratio of S to N (Dijkshoorn *et al.*, 1960). This ratio is subsequently referred to here in this document as organic-S : organic-N ratio or only as organic-S : N ratio.

Yields of soyabean and cowpea treatments were obtained by harvesting the four inner rows leaving one row on each side of the plots. An area of 300 cm x 17.5 cm at each end of the rows was left for discard. This gave a harvest area of 7.3 m^2. For green gram, eight inner rows were harvested leaving two rows on each side of the plots. An area 300 cm by 15 cm wide was left at both ends of the rows, resulting in a harvest area of 7.4 m^2. Grain weight was determined at moisture contents of 100 mg g^{-1} for soyabean, 120 mg g^{-1} for cowpea and 140 mg g^{-1} for green gram.

3.7 STATISTICAL ANALYSIS

All the data collected were subjected to statistical analysis as a split-split plot arrangement using MSTAT-C computer programme. The statistical analyses done were analysis of variance (ANOVA), least significance difference (LSD), only where ANOVA showed significant differences, and simple linear correlation analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GRAIN YIELD RESPONSE TO SULPHUR

The source of S did not influence grain yield of the three legumes at $P \leq 0.05$ (Table 2 and Appendix 1). The overall mean yield for gypsum treatments was 1410 kg ha^{-1} whereas that for elemental-S was 1392 kg ha^{-1}. These results agree with those reported by Blair (1990) who found out that elemental-S was as effective a S-source as sulphate-S in supplying S to flooded rice in field studies conducted in South East Asia. Lefroy (1990b) reported similar results in Thailand when gypsum and elemental-S did not differently affect the yield of maize in the first year and cowpeas in the second year.

The yields of legumes obtained in this study were not significantly ($P \leq 0.05$) influenced by the application of increasing S rates. The overall mean yield of the control was 2209 kg ha^{-1}, and the yields of 15, 30 and 45 kg S ha^{-1} treatments were 2393, 2317 and 2282 kg ha^{-1}, respectively. These results are in contrast with those obtained by Blair (1990)

Table 2. Mean grain yield (kg ha^{-1}) of the three legume crops: average of over two sources and four rates of sulphur applied

Sulphur-Rate (kg ha^{-1})	GYPSUM CP	SB	GG	ELEMENTAL SULPHUR CP	SB	GG
0	2104	1460	424	2314	1182	407
15	2394	1255	315	2391	1188	515
30	2328	1507	902	2305	1254	708
45	2180	1341	704	2383	1431	624

LSD ($P \leq 0.05$): S-sources = Not Signifacant
Legumes = 347.6
S-rates = Not Signifacant
Interactions : Not Signifacant

CP = cowpea; SB = soyabean; GG = green gram

which indicated that S rates at 0, 8, 16, 32 and 64 kg S ha^{-1} applied to a dry season rice crop of 1987 in Thailand and Indonesia caused a significant grain yield response to S. However, these results are in agreement with those obtained at one site in Thailand and reported again by Lefroy (1990a). He reported that grain yield of maize did not respond to S application over a period of three years where similar rates as those reported by Blair (1990) were used. The soil that did not show S response was believed to be fertile and had a high sorption capacity.

There was no grain yield and protein concentration response to S application by the three legumes under study. This is in spite of the fact that the soil had 5.45 mg kg^{-1} of available-S which is lower than the critical S level of 7 mg kg^{-1} applied by the University of Zambia (UNZA) Soil Testing Laboratory (O.A. Yerokun, Department of Soil Science, UNZA, Personal Communication). This may be an indication that the soil at the experimental site had high sorption capacity. The texture of that soil which was clay loam, supports this view. The clay in the soil may have enhanced the anion exchange capacity of this slightly acidic soil (pH 5.6, $CaCl_2$). Acidic soils with iron and aluminum oxide clays have positive charges that attract

SO_4^{2-} ions. Since SO_4^{2-} ions are more prone to leaching, particularly under humid conditions (Brady, 1983), a potentially highly adsorbing soil may have played a crucial role of ensuring SO_4^{2-} ion retention and availability to the growing crops. The rainfall (843.40 mm) received during the growing season (Appendix 8) was not too high to have greatly accelerated leaching rate. This might then have resulted in most of the measured S (5.45 mg kg^{-1}), plus residual S in the sub-soil being made available to the legume crops.

The crops' failure to respond to added S may be further explained by the possibility that organic-S met some of the crops' S requirements. In fact, it has been established that soil organic matter, of which organic-S is a major constituent (Freney *et al.*, 1975; Probert, 1978), plays a very prominent role in providing S to growing plants (Freney *et al.*, 1975; Trudinger, 1975). This may be supported by Lefroy's (1990a) suggestion that the lack of response by crops to S at one of the experimental sites in Thailand might have been due to the contribution of organic-S.

The tap root system of the grain legumes possibly enabled them to access the residual-S in both the top soil and sub-soil.

Actually, Williams (1975) reported some studies by Lichtenwalner (1923) which established that sub-soil sulphate also plays an important role in providing available S to deep rooted crops. This view is shared by Probert (1978).

As expected, the three legumes showed significant variations among their grain yield ($P \leq 0.05$) irrespective of S-source and S-rate. Cowpea gave the highest mean grain yield of 2300 kg ha^{-1} as compared to 1327 and 575 kg ha^{-1} by soyabean and green gram, respectively. These yields are consistent with those obtained in the past in some research stations in Zambia. Hill (1980) recorded cowpea yields of up to 2600 kg ha^{-1} at Magoye sub-station and yield figures of up to 1438 kg ha^{-1} for green gram at Mochipapa. Joshi *et al.* (1983) recorded an average of 1950 kg ha^{-1} soyabean yield for three locations (Magoye, Mt. Makulu and Mufulira).

These grain yield values obtained in this study just manifest the potential genotypic differences among the three legumes as dictated by the strength of their respective source - sink relationship. Under optimum conditions, cowpea yields will be higher on a per unit area basis than both soyabean and green gram.

4.2 CRUDE PROTEIN CONCENTRATIONS AND CONTENT OF THE GRAINS

The protein concentrations of the grains as affected by the S-source were not significantly different at $P \leq 0.05$ (Table 3 and Appendix 2). Gypsum treatments had 283 mg g^{-1} protein whereas elemental-S treatments produced 274 mg g^{-1}.

The four S-rates, irrespective of the source, did not cause significant variations ($P \leq 0.05$) in the protein concentrations of each of the three legume crops. The protein concentrations of cowpea were 218, 229, 235 and 236 mg g^{-1} at 0, 15, 30 and 45 kg S ha^{-1}, respectively. The soyabean grain protein concentrations were 373, 375, 377 and 375 mg g^{-1} at 0, 15, 30 and 45 kg S ha^{-1}, respectively. As for green gram, the protein concentrations were 232, 224, 235 and 231 mg g^{-1} for the respective rates of 0, 15, 30 and 45 kg S ha^{-1}. These results showed that the protein concentration in the three legumes was not affected by S application. Disregarding the individual crop's performance, the protein concentration of the control treatment was 274 mg g^{-1}, while those treated with 15, 30 and 45 kg S ha^{-1} were 276, 283 and 281 mg g^{-1}, respectively. The trend of these four rates is showing a non significant quadratic function.

Table 3. Protein concentrations and contents of the three legume crops averaged over two sources and four rates of sulphur applied

	S-RATE (Kg ha^{-1})	Concentrations (mg g^{-1})			Protein content (kg ha^{-1})		
		CP	SB	GG	CP	SB	GG
GYPSUM	0	221	376	240	465	549	102
	15	223	373	233	534	468	73
	30	235	384	238	547	579	215
	45	248	386	237	541	518	167
ELEMENTAL-S							
	0	215	369	223	498	436	91
	15	234	378	215	559	449	111
	30	235	370	232	542	464	164
	45	225	365	225	536	522	140

LSD:	Concentrations	Protein content
($P \leq 0.05$)	S-sources = not signifacant	not signifacant
	Legumes = 11.48	107
	S-rates = not signifacant	not signifacant
	Interactions : not signifacant	not signifacant

NOTE: Average values for three replications were used
CP = cowpea; SB = soyabean; GG = green gram

Although the data was not significant, the trend for each crop seemed to differ with increasing S. Protein concentration tended to increase linearly in cowpea, quadratically in soyabean and that for green gram showed no definite trend. Under controlled conditions, there is an indication that protein concentrations may be increased in both cowpea and soyabean with an increasing amount of S. Table 3 seems to support this view because the mean protein concentrations values for both soyabean and cowpea were slightly greater than the values at 0 kg S ha^{-1} application whereas, the mean protein concentration for green gram was slightly lower than the value obtained at the zero rate of S application.

Irrespective of S sources and rates, a comparison among the legume crops, as expected, indicated that soyabean grains had significantly ($P \leq 0.05$) higher protein concentration than both cowpea and green gram. Cowpea and green gram grains did not have significantly different contents of protein. Irrespective of S supply, soyabean is expected to produce grain with higher protein concentration than the other two crops (Boulter *et al.*, 1973; Lawn & Ahn, 1985; Norton *et al.*, 1985). The mean protein concentration of each of the three crops falls within the ranges established by some earlier researchers. For example, the 375 mg g^{-1} contained in soyabean grain is just slightly above the 368 mg g^{-1} cited by Norton *et al.*(1985). The figure 230 mg g^{-1} in cowpea grain is very close to the 227 mg g^{-1} also reported by the same author. The 231 mg g^{-1} protein concentration in green gram is below the 290 mg g^{-1} reported by Lawn & Ahn (1985) from the data of Boulter *et al.* (1970) and Yohe & Poehlman (1972).

When the protein concentrations of these three crops are converted to protein content on a unit area basis, it becomes obvious that cowpea, which had less protein concentration than soyabean, compensated that by producing relatively high grain yield. Cowpea was not significantly different from soyabean in protein content, and also was not significantly different from green gram in protein concentration, but in protein content (Table 3). As for green gram, its inherently low grain yield will almost always guarantee that its protein content per unit area remains low.

4.3 CONCENTRATIONS OF SULPHUR AND NITROGEN IN LEAVES AS THEY RELATE TO GRAIN YIELD AND PROTEIN CONCENTRATION

There was no significant difference ($P \leq 0.05$) in plant leaf total-S concentration when either source of S was used. Gypsum treatments averaged 7.1 mg S g^{-1} in DM whereas elemental-S averaged 7.6 mg S g^{-1} in DM. The three crops were also not significantly different from each other in their leaf total-S concentrations (Table 4). The overall mean values for cowpea, soyabean and green gram were 7.6, 6.8 and 7.7 mg S g^{-1} in DM, respectively. These values confirm the adequacy of S from both sources for all the crops. All these values are greater than the critical values cited by Bell *et al.* (1990) which were 2.1 mg S g^{-1} in DM of soyabean and 2.0 mg S g^{-1} in DM of green gram. Bell *et al.* (1990) in Thailand concluded that 81.5 % of soyabean leaf samples from farmers fields, which all had total-S values above 3.0 mg g^{-1}, indicated that the crops were adequately supplied with S. These figures show that these three legume crops had the same ability to absorb S under the prevailing experimental conditions.

The three crops exhibited significant variations ($P \leq 0.05$) in their total-N concentrations at the four S rates (Table 4). Cowpea leaves had an overall mean of 52 mg N g^{-1} DM which was significantly higher than soyabean with 39 mg N g^{-1} DM and green gram with 37 mg N g^{-1} DM. However, neither one of the three crops showed any definite trend in N concentration with increasing S rates. The analysis of variance (Appendix 4) showed that there was no significant difference in leaves' N concentration between gypsum and elemental-S treatments as sources of S. The four S rates averaged over two S sources and over the three crops did not show significant variation with respect to the leaves' N concentrations.

TABLE 4. Concentrations of Sulphur and Nitrogen in leaves of the three legumes at four rates of sulphur averaged over two sulphur sources

	S-RATE ($kg\ ha^{-1}$)	N concentrations ($mg\ g^{-1}$)			S concentrations ($mg\ g^{-1}$)		
		CP	SB	GG	CP	SB	GG
GYPSUM	0	51.8	38.8	36.3	8.7	5.4	5.5
	15	52.9	38.0	36.9	7.9	4.9	5.6
	30	51.0	39.8	37.7	8.1	9.2	9.2
	45	51.8	42.2	37.3	6.0	7.3	7.3
ELEMENTAL-S							
	0	51.5	37.0	33.5	8.5	7.6	6.5
	15	53.4	39.7	37.3	5.2	4.9	8.4
	30	47.5	36.7	38.8	8.2	6.9	9.9
	45	53.3	39.0	37.4	7.8	8.2	8.8

LSD: ($P \leq 0.05$)	N concentrations	S concentrations
S-sources	= not signifacant	not signifacant
Legumes	= 4.67	not significant
S-rates	= not signifacant	not signifacant
Interactions	: not signifacant	not signifacant

CP = cowpea; SB = soyabean; GG = green gram

The organic S:N ratio in the leaves of the three legumes showed that there was no significant difference ($P \leq 0.05$) between the two sources of S. The overall mean ratio of S:N for gypsum treatments was 1:34 (0.029) and elemental-S was 1:36 (0.028). This signifies that gypsum and elemental-S were not different in influencing the uptake and assimilation of sulphate-S by the crops under study.

This observation is consistent with the grain yield and protein concentrations of the three legumes which revealed that they were not influenced differently by the two S sources. Cowpea had a significantly higher ratio (1:48 or 0.021) than soyabean with 1:32 (0.031) and green gram which had 1:30 (0.033). The LSD value ($P \leq 0.05$) was 0.005. However, neither of the three crops experienced S deficiency as evidenced by the grain yields and protein concentrations. These ratios mean that at the time of sampling, all the crops were adequately supplied with S. The ratios agree with those cited by Dijkshoorn *et al.* (1960), which were 1:40 (0.025) in legumes. Dijkshoorn & van Wijk (1967) noticed S deficiency in maize when the ratio was 1:200 (0.005) under conditions of S deficiency, while a ratio of 1:100 (0.010) signified S adequacy.

The S-rates did not show significantly different effects on the ratios. The control treatment had an overall organic-S:N ratio of 1:37 (0.027) while those for 15, 30 and 45 kg S ha^{-1} were 1:45 (0.022), 1:30 (0.033) and 1:30 (0.033), respectively.

The fact that grain yield and protein concentration were not affected by S application means that, under conditions of sufficient S and N, cowpea would have a significantly wider difference in values between organic-S and organic-N in its young leaves than both soyabean and green gram. It assimilated more N than the other two legumes. This may explain why Dijkshoorn & van Wijk (1967) found more non-protein nitrogenous compounds in its grains.

The dry matter of soyabean and green gram leaves on the other hand, had similar composition with respect to the proportions of organic-S to organic-N. However, the fact that the soyabean and green gram grain protein concentrations were significantly different ($P \leq 0.05$) suggested that, soyabean is genetically more efficient at converting metabolites to oil and protein than green gram. This explains why soyabean has less quantities of other seed components such as carbohydrates and water than cowpea and green gram (Norton *et al.*, 1985). Cowpea was reported to have 115 mg g^{-1} water and as high as 610 mg g^{-1} carbohydrates whereas green gram has 120 mg g^{-1} water and between 620 and 650 mg g^{-1} carbohydrates. Soyabean has 70 mg g^{-1} water and only 235 mg g^{-1} carbohydrates which is equivalent to the amount of oil in it. Cowpea and green gram grains have only 16 mg g^{-1} and between 10 and 15 mg g^{-1} oil, respectively.

Correlation analyses among grain yields and protein content as well as other variables are presented below (Tables 5-7).

Table 5. Simple linear correlation coefficients of some measured parameters of cowpea

	GY	PC	N	S_t	Org.S	S:N
GY	1	-0.15	0.23	-0.18	0.21	-0.22
PC		1	-0.25	-0.64	0.19	-0.05
N			1	-0.39	-0.57	0.45
S_t				1	0.39	-0.48
Org.S					1	-0.98*
S:N						1

* Significant at $P \leq 0.05$

GY = grain yield (kg ha^{-1}); PC = protein concentration (mg g^{-1}); N = nitrogen (mg g^{-1});

S_t = total sulphur (mg g^{-1}); Org.S = organic sulphur (mg g^{-1})

Table 6. Simple linear correlation coefficients of some measured parameters of soyabean

	GY	PC	N	S_t	Org.S	S:N
GY	1	0.28	0.38	0.48	0.53	-0.43
PC		1	0.77*	0.06	0.11	0.15
N			1	0.13	0.09	0.15
S_t				1	0.87*	-0.64
Org.S					1	-0.78*
S:N						1

* Significant at $P \leq 0.05$

GY = grain yield (kg ha^{-1}); PC = protein concentration (mg g^{-1}); N = nitrogen (mg g^{-1});

S_t = total sulphur (mg g^{-1}); Org.S = organic sulphur (mg g^{-1})

Table 7. Simple linear correlation coefficients of some measured parameters of green gram

	GY	PC	N	S_t	Org.S	S:N
GY	1	0.28	0.58	0.80*	0.53	-0.26
PC		1	0.24	-0.22	-0.22	0.29
N			1	0.63	0.26	0.30
S_t				1	0.67	-0.21
Org.S					1	-0.67
S:N						1

* Significant at $P \leq 0.05$

GY = grain yield (kg ha^{-1}); PC = protein concentration (mg g^{-1}); N = nitrogen (mg g^{-1});

S_t = total sulphur (mg g^{-1}); Org.S = organic sulphur (mg g^{-1})

Grain yield of cowpea was weakly (not significant) and negatively (r = -0.15) correlated with grain protein concentration. This shows that grain protein concentration of cowpea is not likely to be increased by an increase in this crop's grain yield. The two parameters were weakly and positively correlated in the cases of soyabean and green gram, both with r = 0.28. This may be an indication that although the correlation is small, possibilities of increasing these crops' protein concentrations by increasing their grain yield are there.

Grain yield of cowpea was negatively, but not significantly correlated with total-S (r = -0.18) and organic-S:N ratio (r = -0.22). The cowpea's organic-S:N ratio indicates that when it increases, the yield is likely to be low, although the correlation is weak. For soyabean, grain yield was positively correlated with total-S (0.48), but not significant, whereas it was negatively correlated with organic-S:N ratio (r = -0.43), but not significantly. Soyabean yield is likely to be high with an increasing value of total-S concentrations and low with high values of organic-S:N ratio. The correlation of yield with total-S was positive and strong or significant (r = 0.80) in the case of green gram. This suggests that increasing S concentrations in the leaves of green gram will be accompanied by an increase in its grain yield. The green gram's negative, but insignificant correlation with organic-S:N ratio (r = -0.26) may be suggestive of lower grain yields attainment with higher ratios.

The S:N ratio generally showed no clear relationship with protein concentration of the three crops. There was very weak correlation between the protein concentration of cowpeas and S:N ratio which was r = -0.05. It was also very weak, but positive, for both soyabean (r = 0.15) and green gram (r = 0.29). This means that green gram's protein concentration is more, although not significant, and positively associated with the organic-S:N ratio than both soyabean and cowpea.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The major findings of this study were that cowpea, soyabean and green gram showed no response to the application of S under experimental conditions. Grain yields and protein concentrations were not improved with increasing S-rates nor showed any significant difference between gypsum and elemental S as sources of S. The absence of S effects on the crops was also apparent as early as at flowering when the leaf samples of the three legumes did not show any significant variations in their total-S concentrations.

Under prevailing conditions of the experiment, cowpea had a significantly wider organic-S : organic-N ratio in the young leaves than soyabean and green gram. It also had significantly higher N concentration than both soyabean and green gram under conditions of S adequacy. However, cowpea did not contain significantly higher grain protein than green gram, and both had significantly lower protein concentration than soyabean.

The difficulties with studying S-dynamics, especially through plant uptake were obvious in this experiment, and demonstrated by an absence of grain yield or protein concentration increase in response to inorganic S additions to the soil. It is therefore, recommended that;

1. More studies should be done on various soils, here in Zambia and in the whole Southern Africa region, to try and understand better, the role of all fractions of soil sulphur pools in supplying S to crops.
2. Comparative studies in Zambia of major crops be done on their response (yield, protein concentration and quality) to S application, especially in highly leached soils.

CHAPTER 6

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APPENDICES

Appendix 1. Analysis of variance (ANOVA) table for the grain yield (kg ha^{-1}) of the legumes supplied with two sources of sulphur applied at four rates

Source	Degrees of freedom	Sum of squares	Mean square	F value
Rep	3	2649470.17	883156.72	3.83ns
S-Source(S)	1	7632.67	7632.67	0.03ns
Error	3	4691147.50	230382.50	
Legume (L)	2	47863618.90	23931809.45	58.76*
S x L	2	200057.52	100028.76	0.25ns
Error	12	4887769.58	407314.13	
S-Rate (R)	3	540629.25	180209.75	2.04ns
S x R	3	185863.25	61954.42	0.70ns
L x R	6	634521.94	105753.66	1.20ns
S x L x R	6	252648.31	42108.05	0.48ns
Error	54	4765134.25	88243.23	
CV = 21.21 %				

* Significant at $P \leq 0.05$

ns = not significant at $P \leq 0.05$

Appendix 2. ANOVA table for grain crude protein concentration (mg g^{-1}) in the legumes supplied with two sources of sulphur applied at four rates

Source	Degrees of freedom	Sum of squares	Mean square	F value
Rep	2	558.11	279.06	1.98ns
S-Source(S)	1	1431.13	1431.13	10.17ns
Error	2	281.33	140.67	
Legume (L)	2	336507.69	168253.85	567.97*
S x L	2	259.75	129.88	0.44ns
Error	8	2369.89	296.24	
S-Rate (R)	3	865.38	288.46	1.44ns
S x L	3	748.71	249.57	1.24
L x R	6	864.75	144.13	0.72ns
S x L x R	6	910.92	151.82	0.76ns
Error	36	7226.00	200.72	
CV = 5.09 %				

* Significant at $P \leq 0.05$

ns = not significant at $P \leq 0.05$

endix 3. ANOVA table for total sulphur (mg g^{-1}) in the leaves of legumes supplied with two sources of sulphur applied at four rates

Source	Degrees of freedom	Sum of squares	Mean square	F value
Rep	3	21.652	7.217	0.55ns
S-Source(S)	1	5.368	5.368	0.41ns
Error	3	39.603	13.201	
Legume (L)	2	14.224	7.112	1.15ns
S x L	2	13.013	6.506	1.06ns
Error	12	73.993	6.166	
S-Rate (R)	3	74.566	24.855	1.81ns
S x L	3	14.577	4.859	0.35ns
L x R	6	54.124	9.021	0.66ns
S x L x R	6	33.396	5.566	0.41ns
Error	54	739.754	13.699	
CV = 50.48 %				

ns = not significant at $P \leq 0.05$

endix 4. ANOVA table for total nitrogen (mg g^{-1}) in the leaves of legumes supplied with two sources of sulphur applied at four rates

Source	Degrees of freedom	Sum of squares	Mean square	F value
Rep	3	685.840	228.613	3.54ns
S-Source(S)	1	5.950	5.950	0.09ns
Error	3	193.563	64.521	
Legume (L)	2	4231.932	2115.966	28.78*
S x L	2	9.254	4.627	0.06ns
Error	12	882.138	73.511	
S-Rate (R)	3	47.598	15.866	1.12ns
S x L	3	45.352	15.117	1.07ns
L x R	6	97.106	16.184	1.14ns
S x L x R	6	41.505	6.918	0.49ns
Error	54	765.217	14.171	
CV = 8.89 %				

* Significant at $P \leq 0.05$

ns = not significant at $P \leq 0.05$

endix 5. ANOVA table for organic S:N ratio in the young leaves of legumes supplied with two sources of sulphur applied at four rates

Source	Degrees of freedom	Sum of squares	Mean square	F value
Rep	3	0.001	0.000	0.87ns
S-Source(S)	1	0.000	0.000	0.04ns
Error	3	0.001	0.000	
Legume (L)	2	0.003	0.001	4.34*
S x L	2	0.001	0.000	1.17ns
Error	12	0.004	0.000	
S-Rate (R)	3	0.002	0.001	2.01ns
S x L	3	0.003	0.001	2.37ns
L x R	6	0.003	0.000	1.28ns
S x L x R	6	0.002	0.000	1.05ns
Error	54	0.020	0.000	
CV = .93 %				

* Significant at $P \leq 0.05$

ns = not significant at $P \leq 0.05$

pendix 6. Mean organic sulphur concentrations (mg g^{-1}) in young leaves of the three crops grown under two sources of sulphur at four rates

	GYPSUM			ELEMENTAL SULPHUR		
lphur-Rate (kg ha^{-1})	CP	SB	GG	CP	SB	GG
	2.4	1.6	2.7	1.8	3.4	2.7
	2.9	2.6	1.8	2.1	0.6	2.8
	3.9	5.3	3.1	3.6	2.1	3.1
	1.9	2.9	2.6	2.4	3.6	4.1

= cowpeas; SB = soyabean; GG = green gram

pendix 7. Mean sulphate sulphur concentrations (mg g^{-1}) in young leaves of the three crops grown under two sources of sulphur at four rates

	GYPSUM			ELEMENTAL SULPHUR		
lphur-Rate (kg ha^{-1})	CP	SB	GG	CP	SB	GG
	6.3	3.9	2.8	6.7	4.2	3.8
5	5.0	2.3	3.8	3.2	4.3	5.6
0	4.2	4.0	6.1	4.7	4.8	6.8
5	4.2	4.5	4.7	5.4	4.6	4.7

P = cowpeas; SB = soyabean; GG = green gram

Appendix 8. Summary of annual rainfall at the Natural Resources Development College farm (1995 / 1996)

Month	Total rainfall (mm)	Number of days of rain (1 mm plus)
Jul., 1995	0	-
Aug., 1995	0	-
Sept., 1995	0	-
Oct., 1995	20.8	2
Nov., 1995	56.6	9
Dec., 1995	115.1	11
Jan., 1996	180.6	14
Feb., 1996	328.4	16
Mar., 1996	141.9	11
Apr., 1996	0	-
May, 1996	0	-
Jun., 1996	0	-
Total	843.4	63