Soil Productivity Research Programme
Misamfu Regional Research Centre
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By

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Table of contents

List of Tables

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About this review report

This review covers the period from 1983 to 1993. Two trials: Long Term Fertilizer Trial with Continuous Maize and The National Lime Trial, established in 1965 and 1971, respectively are also reported. Experimental details and results for each trial are covered in detail elsewhere (Appendix 1). The review is arranged according to themes and data for each theme were collected from various sources (Reports) and their means are used for discussion. The picture portrayed represents the expected outcome when the technologies contained herein are used.

1. Introduction contains the mandate research area and the problems associated with it;

2. The Overview examines in general the problems associated with soil productivity;

3. Research findings are grouped according to themes starting with Soil acidity and liming, Screening for tolerance to soil acidity, Single nutrients, Micronutrients, Multi-nutrients, Composts, mulches and green manures, Biological nitrogen fixation, Microbial biomass and litter quality, Cropping systems, and finally, Crop management. All themes are arranged in such a way that they are interconnected, enabling a flow of information from previous section to the next without allowing the reader to get bored with the subject at hand.

3.1. Soil acidity and liming examines the liming methods employed by the pH approach and by the lime equivalent method of aluminum saturation in soil. The short-comings of the pH approach are explained. Liming according to soil texture and judicious use of lime to avoid overliming is stressed. The authorities are also asked to do something about agricultural production in the region and not pay lip service only;

3.2. Screening for tolerance to soil acidity illustrates advances made in this field in collaboration with other commodity research teams. The agricultural potential to be realized is trmendous;

3.3. The major phosphate sources and forms are discussed. The phosphorus intricacies once applied in soil and tips on how to manage this nutrient are presented;

3.4. Sulphur nutrition in soils of the high rainfall area is examplified by studies that stretch three generations. The need for continued use of this nutrient especially, in the high rainfall area is stressed;

3.5. The importance of potassium in plant nutrition and its behaviour with other nutrients, especially with calcium and magnesium is examined. The inadequacies in the research approach are highlighted;

3.6. Micronutrients were reported in many reports as to be in sub-critical levels and recommendations to authorities were presented specifically to address the northern situation. No steps were taken to include these nutrients in the current fertilizers. The request is once more being tabled for appropriate action;

3.7. Muli-nutrients. In this section we examine the current fertilizer recomendations and their management. Continuous cultivation versus the shifting cultivation is reviewed and recomendations are presented;

3.8. Composts, mulches and green manures comprise the much sought low input technology. Tips on preparation of these are provided. Why optimum yields are not obtained when using them is critically reviewed;

3.9. Grain legume production is much dependent on biological nitrogen fixation by *Rhizobium* bacteria either resident in or introduced into the soil. The advances in this field are presented;

3.10 Organic matter breakdown and release of nutrients for plant uptake is dependent on microorganisms resident in soil and the litter quality itself. The contribution from green manures introduced in the region together with potential agroforestry tree species is examined;

3.11. Cropping systems and their merits in the present and future contexts with regards to crop production sustainability are examined. Critical reviews on methodologies used are presented, illustrating the complexity of the problems at hand;

3.12. Finally, without proper crop management in agriculture, starting from the research station itself is futile to the efforts being sought.

This review is intended to stimulate further research. It acts as a basis for future research programmes. Its strength is derived from individual reports cited in Appendix 1.

Acronyms

AN (A/N)	Ammonium nitrate
BNF	Biological nitrogen fixation
C-PAPR	Compacted partially acidulated phosphate rock
C-PR	Compacted phosphate rock
Ca	Calcium
$CaCO_3$	Calcium carbonate
CEC	Cation exchange capacity
CIAT	Centralo instituto agropeculiaro technologico
D,A,X,C,V	Compound fertilizers
FMP	Fused magnesium phosphate
FTE	Fritted (compound) trace elements
GART	Golden valley agricultural research trust
GRP	Ground rock phosphate
ICRAF	International centre for research in agroforestry
ICRISAT	International centre for research in semi arid regions
IITA	International institute of tropical agriculture
ILCA	International livestock centre for Africa
IRRI	International rice research institute
Mg	Magnesium
$MgCO_3$	Magnesium carbonate
MINEX	Minerals exploration Ltd
mm	millimetre
NAB	Nitric acid based
NCZ	Nitrogen chemicals Zambia Ltd
NORAD	Norwagian agency for international development
NORAGRIC	Norwegian centre for international agriculture development
NPK	Nitrogen, phosphorus, potassium
Org-C	organic carbon
PAPR	Partially acidulated phosphate rock
PAS	Percent aluminum saturation
Pdff	Phosphorus derived from fertilizer
pH	Measure of soil acidity or salinity
ppm	Parts per million
PR	Phosphate rock

RAE	Relative agronomic effectiveness
Region III	Agroecological zone (High rainfall area)
SAB	Sulphuric acid based
SMIP	Sorghum and millet improvement programme
SPRP	Soil productivity research programme
SSP	Single super phosphate
TAL-377	Inoculum *Rhizobium* strain
TSP	Triple superphosphate
wks	Weeks
ZAMSEED	Zambia seed company Ltd
Zn, B, Mo	Zinc, boron, molybdenum (Micronutrients)

1 Introduction

The largest reserves of potential arable land still available in Zambia are in the high rainfall area comprising one third of the country's land area. Until 1975 this region was regarded as marginal land unsuited for agricultural production because of the inherent soil related constraints for agricultural production. In spite of this there is now an increasing interest and demand to develop and intensify agricultural production in the high rainfall area, because of an ever-increasing population, erratic rains in the other regions of the country, coupled with the growing food requirements.

Population density in the high rainfall area is at present highest in urbanized areas while in rural areas, on soils that are relatively fertile such as in Mbala, Isoka and Mpika districts. Such soils contain appreciable amounts of weatherable minerals, whose fertility is high enough to make sustained agriculture possible, even with a low level of inputs. In contrast, on the majority of the uplands, acid soils predominate and agriculture at low levels of inputs is only possible through shifting cultivation, in which the land is cropped for a few years in alternation with long periods of fallow. Soil acidity, the aluminum and other toxicities associated with it, low contents of major plant nutrients, trace element deficiencies and disease hazards have all hindered the intensification of agricultural production on these soils. Adequate knowledge of their properties and management requirements is now more than crucial for their further development and for their preservation for use by future generations.

During the last twelve years, the Soil Productivity Research Programme (SPRP) has made significant advances in the characterization and management of these acid soils in the high rainfall area of Zambia. Information on the effects of fertilizer and soil amendments continues to be collected and because of the advances in management practices, use of hybrid varieties and adoption of plant protection measures, potential yields of many important crops are increasing.

It is essential to find out through research by field trials what responses are obtained to nutrients by the different crops, bearing in mind the limitations of soil, climate, insect pest and disease incidence. Fertilizer research in the high rainfall area over the past 12 years has been conducted with major nutrients nitrogen, phosphorus, potassium, sulphur, and calcium and magnesium (through lime). Of the minor elements boron, zinc, molybdenum and copper have been studied.

A substantial effort was put into assessing crop responses to fertilizer across the high rainfall area. This has led to knowledge of severe sulphur and nitrogen deficiencies, phosphorus and potassium deficiencies. It has also led to knowledge of low pH and calcium shortages throughout the whole of the high rainfall area; and to boron and zinc deficiencies especially in groundnut and coffee.

Crops studied included maize, fingermillet, wheat, soybean, groundnut, common bean, sunflower, cassava and coffee. The majority of fertilizer trials used straight fertilizers such as urea, ammonium nitrate, single and triple superphosphate, ground phosphate rock and product alternatives (partially acidulated phosphate rocks, compacted phosphate rocks, fused magnesium phosphate), muriate and sulphate of potash, Solubor, zinc and copper sulphate and sodium molybdate. Compound fertilizers have also been used. Pure nutrients have been employed so as to base fertilizer recommendations in compounds for the farming community.

More research work is now in progress to refine the past research and make the findings more soil and crop specific. It is the aim of this paper to review the experience already acquired and to summarize the research findings so far obtained.

2 Overview

2.1. Soil acidity

Most of the upland soils encountered in the high rainfall area are acid with very poor nutrient and base status. They are well-drained and are still used for shifting cultivation.

Until 1986, all lime research work conducted in ameliorating soil acidity was based on neutralization of pH to some definite level. With the reorganization of our research orientation in 1986 it was realized that the aluminum ion (Al^{3+}) rather than the hydrogen ion (H^+) was the dominant cation in the majority of our soils with pH less than 5.0 (Singh, 1986). In almost all cases crop growth on these soils, by this approach, was found to be directly correlated with aluminum saturation or aluminum concentration in the soil. In contrast, a supposedly high hydrogen concentration (or low pH) *per se* (limed to pH 5 but less than neutrality) did not directly affect crop growth. High hydrogen concentrations in soil solution however, favour weathering of soil minerals, resulting in the release of aluminum and the leaching of ions such as potassium (K^+), magnesium (Mg^{2+}) and calcium (Ca^{2+}). This review concludes that poor crop growth on these acid soils is usually caused by aluminum and/or manganese toxicity and/or by the deficiencies of plant nutrients.

With the exception of very few crops high concentrations of aluminum are very toxic. Tea, coffee, and the indigenous crops (fingermillet and cassava) can tolerate very high concentrations in their tissues. Tea leaves may contain up to 5000 ppm aluminum and appreciable amounts in fingermillet grain were encountered.

Among all crops tested (maize, beans, soybean, fingermillet) the effect of aluminum was apparent on root growth which were found to be swollen, stunted and crooked with very few fine feeder roots. Despite the soil being normally moist the plants failed to utilize soil water and nutrients efficiently due to high aluminum concentrations.

Aluminum concentration in soil solution was usually less than 1 ppm where Al saturation of the cation exchange capacity (CEC) was below 60%. Above 60% saturation, aluminum in the soil solution rose sharply resulting in aluminum toxicity and very poor growth, even of the aluminum tolerant crops (such as tea or coffee). In less tolerant species (groundnuts, maize, beans) a decrease in growth was apparent at 30% aluminum saturation.

2.2. Phosphorus in soils

Most soils in the high rainfall area have low total phosphorus contents. In these highly weathered acid upland soils, up to 80% of all phosphorus could be in the organic form and thus highly concentrated in the top soil layer; this in spite of the fact that the phosphorus content of the organic matter itself was relatively low.

As soil pH decreases the increasing concentrations of iron (Fe) and aluminum (Al), and manganese (Mn) ions in the soil solution combine with phosphate ions to form compounds of very low solubility. In addition, phosphate ions combine with aluminum on the exchange complex to form insoluble compounds. Applied phosphate can thus precipitate aluminum and reduce or eliminate aluminum toxicity. This process is otherwise referred to as "liming with phosphate" but unless an excess of phosphorus is applied, phosphorus may still remain deficient.

In an acid soil it is often difficult to distinguish between aluminum toxicity and phosphorus deficiency. Plant species and cultivars within species differ widely in their abilities to absorb, translocate, and utilize phosphorus for growth, a fact of great practical importance which should be considered when selecting crops for high P-sorbing soils.

2.3. Calcium, magnesium, and potassium in soils

The high rainfall soils generally have a low CEC and very low base saturation. Although poor growth performance on these soils is most frequently caused by aluminum toxicity and phosphorus deficiency, deficiencies of calcium, magnesium and potassium are also often a cause of poor growth. Available soil potassium and magnesium status often become the limiting factors once low pH and phosphorus deficiency have been corrected and yields begin to improve.

2.4. Sulphur in soils

Sulphur deficiency also accounts as a primary constraint in the acid soils of the high rainfall area. It becomes a more serious problem once these soils are brought into permanent cultivation. The reasons for incidence of sulphur deficiency are that the soils are inherently low in total and available sulphur; indiscriminate bush fires and burning on Chitemene depletes soil sulphur reserves by releasing large amounts to the atmosphere; loss of organic matter as a result of cultivation is accompanied by volatile or leaching loss of sulphur; these acid soils contain large amounts of oxides of aluminum and iron which adsorb much of the sulphur. This adsorption is however, temporal and the adsorbed sulphur is readily displaced by phosphates; sulphate is readily lost from the topsoil which has been limed and received dressings of phosphorus fertilizer, and; substitution of fertilizers containing little or no sulphur (as is the case with compound D without sulphur) is likely to lead to serious sulphur depletion in these soils.

About 5 - 7 ppm sulphur is needed in the soil solution of the highly weathered soils of the region to enable most crops have good growth. Grain legumes, maize, and cotton have high sulphur requirements, whereas pineapple, cassava and sweet potato are relatively undemanding.

2.5. Soil nitrogen status

The primary forest at clearing is endowed with a large supply of nitrogen which drastically decreases due to high decomposition rates once the soil is exposed. Nitrogen depletion is further accelerated during burning a Chitemene garden. These factors render these soils to have low yield potential acerbated by low pH, toxicities and nutrient deficiencies. The response to nitrogen input from fertilizer or other sources becomes apparent with good management, including liming, phosphorus application and the correction of other deficiencies.

2.6. Trace elements

The availability of trace elements decreases with pH falling below 5.5 and the acid soils of the high rainfall area suffer seriously from trace element deficiencies. For several trace elements (boron, zinc and molybdenum in particular) total content is often low and applications of lime and some fertilizers can reduce their availability and induce severe deficiencies. Occasional applications of trace elements, careful use of lime and good organic matter management are the most important factors in avoiding or minimizing trace element problems.

2.7. Soil organic matter

The beneficial effects of organic matter diminish rapidly after land clearing in that while there is a continuous supply of organic matter under forest, clearing it and cropping the land interrupts this supply, at the same time accelerating the decomposition of the organic matter already present. In addition the kaolinite clays do not form stable organo-mineral complexes.

The role of organic matter as a key element in the management of poor acid soils in the high rainfall areas is still grossly underestimated and neglected. In too many cases the short-term effect of organic matter as a source of nutrients has been compared with effects of mineral fertilizers, neglecting the direct and indirect effects of organic matter in improving the root environment and thus the potential for plants to make better use of both the inherent soil fertility and applied fertilizers. What makes organic matter so important is that it is the only soil amendment that can be preserved and produced on or around the farm.

Fertilizers are rather ineffective if the physical properties of a soil are poor or are allowed to deteriorate by poor management. Organic matter can play a central role in maintaining, even increasing soil productivity by improving soil temperature, moisture and structure and by reducing the dangers of erosion.

Oxisols are well structured and have excellent internal drainage properties. Plants grown on these soils therefore, may only suffer from severe moisture stress. Excess water in this case is not a problem. On the other hand, plants grown on Ultisols can easily suffer from both moisture excess because of poor drainage, and moisture stress because rooting depth is often limited by aluminum toxicity. Organic matter, especially as mulch, can help to increase water infiltration and reduce evaporative moisture losses. It can also stimulate root growth and thus improve utilization of soil water.

3 Research findings

3.1. Lime and liming

Early liming experiments conducted throughout Zambia and agricultural practices in central and southern provinces all aimed to raise the pH to near neutrality (pH 6.5 to 7.0) involving very large amounts of lime (4 to 12 t ha^{-1} lime). Not only was this expensive but it could also cause deficiencies of potassium, magnesium, zinc, boron, and even iron and manganese. A typical example is shown below where an acid soil from Mbala was incubated at SPRP in 1983 for 14 days and lime requirements were estimated based on pH change:

Table 1. Lime requirements to raise the pH to near neutrality in a Konkola soil series

pH-$CaCl_2$	pH-H_2O	mg Lime	t ha^{-1} lime
3.9	4.7	0	0.0
4.2	5.1	50	1.3
4.3	5.2	75	1.9
4.4	5.3	100	2.5
4.8	5.8	175	4.4
4.9	5.9	200	5.0
5.3	6.0	250	6.1
5.9	6.6	500	12.5

Source: SPRP Annual Report (1983 - 86)

As early as the mid seventies however, it was already recognized that low rates of lime (250 - 500 kg ha^{-1}) were beneficial which often increased yields and uptake of nutrients especially phosphorus, potassium and zinc. Low rates of lime are however, not a cure all as they can depress yield of some crops when grown on soils low in potassium, boron and zinc not supplemented by appropriate applications of these nutrients or if the lime is not thoroughly and evenly incorporated into the soil.

In all benchmark soils tested subsoil pH was not different to that of the top soil, yet even though no physical barriers were encountered the subsoil contained few roots. Such a condition was associated with subsoils high in aluminum and low in calcium. Because of the low negative charge density, such subsoils would adsorb (and thus be able to release) only traces of calcium, potassium and magnesium. Usually when lime is added to the top soil, most of the lime is consumed in generating negative charge, which in turn attracts calcium ions. As a result, little calcium moves into the subsoil, unless subsoiling or anions are provided that helped downward movement as evidenced in the Subsoil Acidity Management trial established in 1987 at Mutanda Regional Research Station where calcium sulphate, sulphate in single superphosphate, and ammonium nitrate and physical subsoiling were employed.

3.1.1. Effects of liming

Liming reduces aluminum and manganese toxicity by precipitating these elements, in turn this increases both soil phosphorus availability and the efficiency of uptake of water soluble fertilizer phosphorus. Overliming to pH 7.0 decreases phosphorus availability because phosphorus is precipitated or fixed in the form of calcium or magnesium phosphates. Liming also stimulates nitrification as the activity of most microorganisms involved in nitrification increases with pH. It also promotes biological N_2-fixation mainly because of the increased availability of phosphorus. The availability of most trace elements is decreased by increases in soil pH, whereas that of molybdenum is increased. For most high rainfall soils a pH between 5.0 and 5.5 is optimal. Liming increases the cation exchange capacity (CEC) and thus decreases leaching losses of the cations (Ca^{2+}, Mg^{2+}, K^+ and NH_4^+). Potassium field experiments conducted in 1985 and a controlled pot experiment carried out in 1987 concluded that liming acid soils usually depressed potassium availability.

3.1.2. Lime experiments conducted

Evidence from experiments conducted in the high rainfall area strongly indicates that if improved agricultural systems are to be developed, the input of mineral fertilizers must be matched by an input of lime so as to alleviate aluminum toxicities, and to avoid a decline in pH and the problems it causes. Lime trials have clearly demonstrated crop responses to lime applications which have corrected and improved pH and calcium supply. The responses have been very notable in legumes, especially groundnut, a crop which performs very poorly in the high rainfall area on the leached sandy soils, due to calcium deficiencies causing "pops".

The direct and residual effects of lime were investigated between 1971 and 1985 on four locations in the high rainfall area at Misamfu on Misamfu yellow soil series and at Mansa, Mbereshi and Samfya on Mufulira soil series. Site histories are not known however, it is assumed that the sites were virgin at initiation as no responses were observed during the first four years of cropping. Initial topsoil pH at all sites was around 4.2. Dolomitic Chilanga limestone was applied at six rates comprising, 0, 0.5, 1.0, 2.0, 4.0 t ha^{-1} applied at establishment and 0.5 t ha^{-1} lime applied annually. These rates were drawn arbitrarily. Test crops were maize grown in rotation with groundnut.

Findings: With the exception of the site at Samfya (where lime responses were evident from the first year itself), inherent soil fertility at initiation plus added NPK nutrients seemed adequate to support good crop growth the first four years after land clearing. With time, liming became inevitable to counteract the fertilizer soil acidification process. In this regard, a maintenance rate of 500 kg ha^{-1} lime each year would be more sustainable for continuous cropping without fallow. Alternatively, applying 4 t ha^{-1} lime initially and realize the beneficial effects in the fifth cropping season would suffice. Who would wait that long with such an initial investment?

Table 2. The effect of lime on maize and groundnut yields (Source: Tveitnes & Svads, 1989)

	Amount of lime applied in kg ha^{-1}					
Mean crop yield†	0	500	1000	2000	4000	500+§
	kg ha^{-1}					
Maize	2600	2500	2870	3080	3480	3480
Groundnut	590	770	890	1050	1100	1030
Due to lime (maize)			270	480	880	880
Due to lime (Groundnut)		180	300	460	510	440

† Crop yield means over 12 years; § Applied every year for 12 years

Notwithstanding, it may be concluded that liming is perhaps as essential part of soil amelioration as fertilizer application to maintain soil productivity under intensive cropping systems on long term basis as may be evidenced from the soil data in Table 3. Organic carbon and calcium were maintained in relatively sufficient quantities while aluminum levels were within tolerable limits when the soil received yearly 500 kg ha^{-1} lime applications or when 4 t ha^{-1} lime was initially applied.

The rate of lime application trial to maize and wheat was conducted between 1978 and 1987 on Katito soil series in Mbala with six rates of lime chosen arbitrarily at 0, 1.0 plus 0.5 added annually, 2.0 plus 0.5 added annually, 4.0, 6.0 and 8.0 t ha^{-1}.

Findings: Again the results show that not more than 2 t ha^{-1} lime plus 0.5 t ha^{-1} yearly maintenance rate was needed. The economic rate however, suggests 1 t ha^{-1} lime plus 0.5 t ha^{-1} added annually. In contrast, given all the fertilizer requirements but without liming both crops failed on this soil.

The evaluation of indigenous liming materials was carried in 1982 to 1988 on Misamfu red soil series with pH = 4.3 and percent aluminum saturation around 55%. The site used was representative of the high rainfall area.

Table 3. Soil chemical properties at beginning (1973), mid (1981) and end of investigations (1986) [Source: SPRP Annual Report 1986; Tveitnes & Svads, 1989]

		Lime rates applied in kg ha^{-1}					
Parameter	Year	0	500	1000	2000	4000	500+
Calcium	1973	0.26	0.46	0.41	0.57	0.92	0.37
	1981	0.42	0.30	0.40	0.70	1.36	1.07
	1986	0.10	0.10	0.20	0.30	0.90	0.80
Magnesium	1973	0.30	0.28	0.28	0.24	0.28	0.27
	1981	0.07	0.13	0.09	0.10	0.14	0.16
	1986	0.10	0.00	0.10	0.10	0.10	0.20
Potassium	1973	0.12	0.08	0.07	0.07	0.06	0.07
	1981	0.05	0.05	0.05	0.05	0.04	0.06
	1986	0.05	0.05	0.07	0.06	0.07	0.05
Organic Carbon	1986	0.62	0.65	0.62	0.55	0.89	0.96
% Al saturation	1986	79	86	72	65	36	27

The materials evaluated for agronomic effectiveness using arbitrarily chosen rates of 2 and 4 t ha^{-1} lime were dolomitic limestones of Chilanga and Nkombwa and a Ndola calcite in conjunction with phosphorus fertilization. Ndola lime contained 98% $CaCO_3$ and traces of $MgCO_3$ with neutralizing value of 98. Both Chilanga and Nkombwa limestone had a neutralizing value of 90% with Chilanga lime containing 75% $CaCO_3$ and 14% $MgCO_3$ and Nkombwa 45% $CaCO_3$ and 25% $MgCO_3$. Other potential deposits exist in Luapula (Matanda) and north-western provinces.

Major findings: All the three materials were found to be agronomically as effective. Other nutrients not limiting (particularly phosphorus) all the three materials increased, on average, maize yields from 1 to 6 t ha^{-1} and groundnut yield from 0.6 to 1.5 t ha^{-1}. They also reduced the aluminum levels to tolerable limits (4 - 14% Al saturation) and maintained the pH at around 5.3 for five years.

Table 4. Agronomic effectiveness of various limestones

	Groundnut yield			Maize yield		
Lime rate	Chilanga	Nkombwa	Ndola	Chilanga	Nkombwa	Ndola
-- t ha^{-1}--			kg ha^{-1}			
0	760	760	760	1100	1100	1100
2	820	1000	890	1500	2000	1900
4	1300	1000	1300	2400	2700	3600
2 with SSP†	1200	1300	1100	5200	5200	5700
4 with SSP	1400	1400	1100	5800	6200	5200

† SSP applied as 33 kg P ha^{-1}

Generally, the results showed no economic benefits to liming at rates higher than 2 t ha^{-1} lime when fertilized. Other trials conducted confirm this finding. The findings further advise to use dolomitic limestone in soils known to be deficient in magnesium.

A multilocational trial on liming needs of selected benchmark soils in the high rainfall area was initiated in 1986, first with soil incubations tests, followed by field experiments at Misamfu on Misamfu yellow sandy loam and Mufulira sandy loam soils; at Lucheche in Mbala on Konkola sandy clay and at Mutanda on Maheba loamy clay soil. Kamprath (1982) suggested that for soils with a low permanent charge and a relatively high pH-dependent charge, lime recommendations should be based on the amount of exchangeable aluminum in the top 15 cm soil depth where about 1.65 tons of lime ($CaCO_3$) or 1.5 milliequivalent calcium should be applied for every milliequivalent of exchangeable aluminum present.

Five levels of lime chemically equivalent to the exchangeable aluminum in the respective soils multiplied by factors of 0, 0.5, 1,0, 1,5 and 2.0 were employed with maize and soybean or maize and groundnut as test crops grown in rotation. Responses across locations and soils varied but it is a general conclusion that lime requirements were met between 0.6 and 1.2 t ha^{-1} lime. These results conclude that for the acid soils and crops in the high rainfall area the pH did not have to be raised above 5.5. An established fact is that in acid soils like those in the high rainfall area, exchangeable aluminum is the cation responsible for buffering in the pH range of 4.0 to 5.5, while hydroxyl aluminum and alumino-organo-complexes controls buffering in pH range of 5.6 to 7.0.

Table 5. Crops response to liming (Source: SPRP Annual Reports 1987 - 90; Goma and Singh, 1993)

	Crop grain yields on soils of differing texture					
	Sandy loam soils				Clayey loam soils	
Lime rate	Maize	Soybean	Groundnut	Lime rate	Maize	Soybean
kg ha^{-1}						
0	3870	950	950	0	4460	1500
400	4820	1350	1300	600	4520	1800
750	5720	1300	1400	1200	5200	1870
1200	5560	1200	1600	2000	4820	2000
1500	5730	1350	1300	2500	5000	1900

Lime trials have been concluded and recommendations have been made for farmers' use which are generally 1.0 and 1.5 t ha^{-1} on sandy and clayey soils, respectively every fourth year. With these rates, overliming is avoided and nutrient disorders are absent.

Management of subsoil acidity was investigated at Katito farm in Mbala on Katito soil series with 3 t ha^{-1} lime, chosen arbitrarily, incorporated either at 0 - 15, 0 - 30 or 0 - 45 cm and using sulphate in gypsum as the calcium-carrier. Between 1986 and 1993 at Mutanda on Maheba soil series 1.5 t ha^{-1} lime, based on aluminum concentration in soil solution, was subjected to four treatments: (1) surface broadcast and mixed in the top 15 cm soil, (2) subsoiled in the 30 cm soil layer; worked in the 15 cm soil layer with (3) sulphate in single superphosphate as calcium-carrier, and (4) with nitrate in ammonium nitrate as calcium-carrier. In both instances, the objectives were to determine the effect of chemical management of subsoil acidity on root development and exploitation of subsoil water and nutrients by plants especially, when there is a chemical barrier of high aluminum concentrations, and/or during drought spells.

Findings: Without liming, most roots were confined within the 15 cm soil depth while very few roots were encountered at 25 cm depth. A prolific root development in all lime treatments was observed. Physical incorporation to 30 and 45 cm resulted in root proliferation of more than 60 cm. The nitrate through ammonium nitrate proved to be the best calcium-carrier as more roots were encountered than in the sulphate calcium-carriers through either gypsum or single superphosphate. In addition, it was found that gypsum could translocate 2 - 5% of calcium and magnesium each year into lower depths.

Implications: With drought spells becoming increasingly common even in the high rainfall area, lime applications and its downward movement seems a mandate. Where lime is available and is in use, the steady supply and common use of ammonium nitrate easily facilitates downward movement of calcium and plants would exploit available moisture and plant nutrients which otherwise are not utilized due to aluminum toxicities. Farmers with ploughs and other implements can exploit deep liming (up to plough depth) and enhance further root development by use of either ammonium nitrate, single superphosphate or gypsum.

Lime recommendations: Lime is evenly surface broadcast followed by mixing with the soil. Where feasible, lime should be ploughed in or disked in during winter ploughing (if practised), or two weeks prior to planting to allow it to react with the soil before planting. The small-holder farmer without a plough should thoroughly mix it with the soil at least up to 15 cm, which is the effective rooting depth. The soils should be tested every three years and where crops are grown in rotation, it is advised to apply lime during the season when a crop with low aluminum saturation requirements is grown. Dolomitic lime is usually recommended for magnesium deficient soils. The general recommendation is 1.0 and 1.5 t ha^{-1} for sandy and clayey soils, respectively. For tree crops like coffee lime can be applied at any growth stage by surface application as feeder roots are just below the surface. Two hundred to 500 g per tree is recommended.

Conclusions: It is now recommended to apply 1.0 and 1.5 t ha^{-1} lime (preferably dolomitic limestone) on sandy and clayey soils, respectively. Larger amounts would result in overliming and nutrient imbalances. It has been established that below pH-$CaCl_2$ 4.5 the aluminum saturation in the acid soils of the high rainfall area can increase from as low as 12% to about 70%. Liming therefore, may be considered essential to maintain sustainable and economic crop yields on these soils. The current prohibitive costs of lime, its non availability in the region and non exploitation of potential deposits of Matanda in Luapula province and other known deposits in north-western province, all hinder the adoption of liming as a technology. A deliberate government policy should be put in place to supply the liming materials to the farming community of the high rainfall area, even if it would mean subsidy, if farming is to be the mainstay of Zambia's economy.

3.2. Screening of crop varieties for tolerance to soil acidity

Given the high cost of lime and its non availability, screening of crop varieties that are tolerant to soil acidity seems the cheapest and most promising technology for acid soils encountered in the high rainfall area. Most local crop varieties posses some degree of tolerance to soil acidity but they are not high yielding. The search for suitable and acceptable varieties began in 1986 with upland rice varieties acquired from CIAT, IRRI, India and Brazil. Promising lines were screened and were further tested under both on-station and on-farmer conditions (Table 6). However, with the departure of the key agronomist in this area of research no follow up has been possible.

Table 6. Variety screening for acid tolerance (Source: SPRP & SMIP Reports, 1986 & 1993)

Crop	Observations	Agroeconomic potential	Remarks
Upland rice	60 entries tested with 11 selected (1985/86)	Have potential in high uniform rainfall area on fine textured-soil. (Yields: 2 t ha-1)	Kl Pick, IAC47 and Kl Mack screened.
Groundnut	250 entries tested with 25 selected for further testing at Msekera (1989)	Selected lines had a higher degree of tolerance to acidity	Handed to FLIP at Msekera.
Fingermillet	232 entries tested (1986) 30 entries tested in 1994 and 10 lines selected in 1994 for further testing	Many lines proved well adapted to the region. Possess excellent yield potential (6 - 8 t ha^{-1})	SMIP and SPRP are still at work.
Maize	50 lines and pre-release lines tested (1990, 1993) Two selected for further testing.	Show stability across the acidity gradient with high yield potential	S. African variety and GART pre-release.

From 1989 to present germplasma of groundnut, fingermillet, pearlmillet (Bulrush millet) sunflower and maize have been tested and screened (Table 6) in collaboration with other commodity research teams (food legumes improvement programme, sorghum and millet improvement programme, national oilseed development programme and the maize teams, respectively).

Findings: Cumulative data indicate that among all cereals, pearlmillet was the least sensitive crop to aluminum toxicity, followed by fingermillet and maize while sorghum was found to be very sensitive. Two maize lines that hold promise are those from South Africa and a pre-release line bred at Golden Valley Research Trust (Table 6).

Among the fingermillet genotypes good genetic stability for tolerance to aluminum toxicity was observed where one third of the fingermillet lines showed stability across the acid gradient. These lines have a high yield potential and they have been selected and will be tested on a wider scale.

3.3. Phosphorus investigations

The majority of acid soils in the high rainfall area have low contents of total and plant-available phosphorus. These soils can further convert large quantities of applied fertilizer phosphorus to non-available form. Phosphorus is therefore, a key element in these soils and the amount available to plants has to be raised if their productivity is to be improved or sustained.

In these highly weathered acid soils one witnesses a shift in the control of phosphate solubility from calcium to aluminum and iron which form complex phosphate compounds that are precipitated or strongly adsorbed on the clay lattice and amorphous sesquioxides. Adsorption capacity is greatest at pH levels less than 5.5 which is initially rapid and then slows down. It is however, fortunate that high temperatures accelerate both adsorption and release reactions and thus help to maintain the phosphorus concentration in the soil solution. The degree of phosphorus fixation in these soils is that of low to medium and only rarely do we encounter a high phosphorus-fixing soil. The determining factors, in this regard, are quantities of reactive aluminum and iron present, the type and quantities of clay minerals and the nature and amount of organic matter in the soil.

3.3.1. Sources of phosphorus

Phosphorus fertilizers employed in the evaluations were (1) straight fertilizers, single superphosphate (SSP) and triple superphosphate (TSP), (2) ground rock phosphate

(GRP), (3) fused magnesium phosphate (FMP), (4) sulphuric acid based- and nitric acid-based partially acidulated phosphate rock (SAB-PAPR and NAB-PAPR) and (5) compacted phosphate rock (C-PR) with single superphosphate (SSP) to produce compacted partially acidulated phosphate rock (C-PAPR). The characteristics and agronomic properties of these phosphorus fertilizers are described in brief, with particular reference to their suitability for use in the acid soils of the high rainfall area.

Phosphorus is usually applied into the soil through compound mixtures. Only rarely (usually among commercial farmers) are they used as straight fertilizers.

3.4.1.1. Single superphosphate

Single superphosphate is granular, grey or brown in colour. It contains monocalcium phosphate and calcium sulphate (gypsum) with 19% total P_2O_5, of which over 90% is water soluble. In addition, SSP contains 12%S. It has no handling problems in the field.

Uses: Single superphosphate is a suitable phosphorus fertilizer for most crops and soils. In the acid soils of the high rainfall area of Zambia, partially acidulated and compacted rock phosphates are sometimes agronomically superior. Notwithstanding, because of its calcium and sulphur contents, single superphosphate is useful in the high rainfall areas where soils are deficient in these nutrients. Groundnut responds greatly when sulphur is applied through single superphosphate. It is recommended to apply single superphosphate in bands or stations close to the seed (but not directly) to reduce contact with the volume of soil that may render water-soluble phosphate immobile. Single superphosphate is used to produce compound mixtures and compacted partially acidulated phosphate rocks.

3.4.1.2. Triple superphosphate

Triple superphosphate (TSP) contains 44% P_2O_5, almost all of which is water soluble. It is sold commercially as granules which has excellent storage and handling properties and is free-flowing.

Uses: Triple superphosphate has similar uses as SSP, but it is much more concentrated and contains very little sulphur (1%).

3.3.2. Rock phosphates

For direct application, rock phosphate is finely ground to increase contact with and dissolution in the soil (Table 7). It is often light grey or brown and neutral in reaction. The composition varies with the source the phosphorus content being in the range from as little as 5 to as much as 28% P_2O_5 while the calcium content ranges from 18 - 48% but with no apparent liming value. Its phosphate is water-insoluble and only slightly citrate-soluble (Table 8).

Uses: Rock phosphate is essentially a slow-acting phosphorus fertilizer and its efficiency as a direct source of fertilizer phosphorus depends on physical and chemical composition, fineness of grinding (which influences the surface area present for solvent action of the soil acids and hence the rate of phosphorus availability), soil reaction with a pH below 5.5 or in soils containing a high percentage of organic matter and nature of the crop (with the most efficient utilizers being coffee, tea, rubber, and most likely cashew and cassava). On short duration crops ground rock phosphate application was found generally to be agronomically ineffective (Tables 9 & 10).

Table 7. Particle size analysis of fineness of PR used for evaluations

Mesh	Particle size (mm)	% Ore
> 48	> 0.297	14.9
48 - 80	> 0.297 - 0.177	21.9
80 - 100	> 0.177 - 0.150	26.2
< 100	> 0.150	37.0
Total		100.0

Source: MINEX, 1987 (*In*:: Mapiki & Singh, 1990)

3.4.2.1. Partially acidulated phosphate rock

Partial acidulation of phosphate rock represents an alternative means of producing agronomically effective phosphorus fertilizer from present phosphate rocks which may otherwise be unsuited for use as fertilizer. Partially acidulated phosphate rock (PAPR) is produced by using partial quantities of acid normally used in production of SSP or TSP. The acids used for agronomic evaluation in Zambia were sulphuric and nitric acids to produce sulphuric acid based SAB-PAPR and nitric acid based NAB-PAPR.

Table 8. Chemical composition of phosphate rocks from known deposits

Source	Phosphorus (P_2O_5) Total	Citrate†	CaO	SiO_2	Oxides Fe+Al
	%				
Chilembwe	15	1.3	33	27	7
Nkombwa	9	0.3	18	12	20
Kaluwe	3	0.1	48	4	5
Mumbwa	28	1.0	32	20	10
Rufunsa	3	nd§	nd	nd	nd

† Citrate soluble phosphorus; § nd = not determined

Table 9. Agronomic evaluation of phosphate rock derivatives (Source: SPRP Reports, 1986 - 1993)

Fertilizer rate†	Crop grain yield Maize	Gnut	Millet	Bean	Soybean
	kg ha^{-1}				
Control	1820	860	1270	270	420
20 GPR	1610	910	1130	230	650
20 FMP	3220	1020	1900	560	1100
20 PAPR	2550	870	2000	450	550
20 TSP	3110	980	1840	400	1000
20 SSP	2880	nc§	nc	310	650
40 GPR	2130	780	2050	300	600
40 FMP	3790	1280	1700	500	1450
40 PAPR	2850	890	2450	520	680
40 TSP	3910	1100	1870	700	1000
40 SSP	2730	nc	nc	240	540

† Fertilizer rate is expressed in kg P ha^{-1} applied as ground phosphate rock (GPR), fused magnesium phosphate (FMP), partially acidulated phosphate rock (PAPR) and standards triple superphosphate (TSP) and single superphosphate (SSP)

§ nc = evaluation not conducted

Uses: Unlike superphosphates, PAPR provides a portion of phosphorus in a readily plant-available form and the remainder in a form that should enhance residual value. Unlike direct application of phosphate rocks, PAPR increased the concentrations of phosphorus. The quantity of acid required to produce PAPR is greatly reduced unlike in complete acidulation. Ten years data gathered at Misamfu and Mt. Makulu conclude that partial acidulation of PR is agronomically as suited (sometimes superior) to readily soluble SSP or TSP to all crops tested (Tables 9&10). During evaluations phosphorus rates ranged from 10 to 80 kg P ha^{-1} and the data above shows crop responses at two rates only which are commonly encountered among different categories of farmers. Crop yields presented are means of several years and locations and ranged from 800 - 11 000 kg ha^{-1} (maize), 90 - 2000 kg ha^{-1} (groundnut and beans), 300 - 3000 kg ha^{-1} (fingermillet and soybean). For detailed information the reader should refer to reports cited in Appendix 1.

Table 10. Relative agronomic effectiveness of phosphate rock derivatives

P-source and rate	Maize	Groundnut	Millet	Bean	Soybean
	RAE (%)†				
20 GRP	nil	42	nil	nil	40
40 GRP	24	nil	130	7	31
20 FMP	108	133	110	223	117
40 FMP	94	140	72	53	178
20 PAPR	67	8	128	450	56
40 PAPR	113	12	197	58	217

†RAE = relative agronomic effectiveness = $\frac{\text{Yield P source - Yield control}}{\text{Yield P standard - Yield control}} \times 100$

PAPR is applied to the soil prior or at planting. It may be broadcast or be applied in bands. SAB-PAPR possesses good handling and storage qualities while NAB-PAPR is highly hygroscopic. The PAPR can be mixed in the usual manner with other fertilizers to produce compound mixtures.

3.4.2.2. Compacted Partially Acidulated Phosphate Rock (C-PAPR)

Compacting finely ground phosphate rock with finely ground soluble phosphates such as SSP or TSP produces C-PAPR which has shown some agronomic potential in the acid soils of the high rainfall area. The process involves compacting known quantities of phosphate rock in ratio with soluble phosphates. The objective is to utilize the acid present in soluble phosphates to render the insoluble phosphorus in the PR available for plant uptake. The other objective is to eliminate costs of sulphuric and nitric acids usually used in production of soluble phosphates. The ratios of GRP: soluble TSP or SSP may range from 4:1 to 2:1 thereby reducing the importation costs of phosphates by 50 - 80%.

Uses: Though tested on maize only, C-PAPR seems to hold potential. It can be applied either in powder or granular form just as other phosphates. Other fertilizers can be compacted together with C-PAPR, and even organics such as, sunflower and castor oil cakes can be used during compaction. The evaluation was a pot study with ^{32}P. Rigorous evaluation through field and pot experimentation is under way.

Recommendations: The efficiency of water soluble phosphate fertilizers is increased, especially in phosphorus-fixing soils, by minimizing soil contact, so reducing the rate of reaction of phosphorus with iron and aluminum compounds. The presence of organic matter also helps to keep applied water soluble phosphorus in plant available form. When only small quantities of phosphorus fertilizers are available, they should be placed in bands or in stations near the seed (but not in contact with) or plants. The normal recommended phosphorus rate is 17 kg P ha^{-1} or 4 x 50 kg compound D.

On soils extremely low in available phosphorus it is recommended to apply 25 kg P ha^{-1}, or 6 x 50 kg compound D. Band or spot application alone in this instance may be inadequate as it would restrict root development to the limited soil volume enriched with fresh phosphorus fertilizer. This in turn would restrict efficient utilization of other soil nutrients and water. On such soils two bags compound D should be broadcast and worked in the soil to improve overall phosphorus status to be followed with band or station application with the remaining four compound D bags.

3.3.1.2. Fate of phosphorus applied in soils

(This section awaits completed works of S. Phiri and Mai Guldberg)

Table 11. Selected chemical properties of the studied soils

Soil series	pH	Al	Al Sat	CEC	Org-C	Avail P†	Ads-P§
	($CaCl_2$)	(me¶)	(%)	(me)	(%)	(ppm)	($\mu g g^{-1}$)
Konkola	4.4	1.11	48	2.2	0.9	4	180
Maheba	4.3	1.39	61	2.3	1.6	5	290
Misamfu R	4.7	0.17	nd	nd	0.8	3	80
Malashi	5.4	0.06	3	5.2	1.8	16	288

† Available phosphorus determined by Bray 1 method

§ Adsorbed phosphorus in soil at 200 μg P l^{-1}

¶ me = milliequivalent 100 g^{-1} soil

Table 12. Fate of phosphorus in maize production on Misamfu red soil series

	Available P				
P application rate	Soil†	Plant§	Total	Pdff¶	P-sorbed
			kg ha^{-1}		
0	32	14	46	0	0
20	38	17	55	9	11
40	38	21	59	13	27
80	57	22	79	33	47
160	74	21	95	49	111

† Available soil phosphorus by Bray 1 method determined after two cropping seasons

§ Determined plant phosphorus taken up in two maize crops

¶ Phosphorus derived from fertilizer = P treatment available P - Check Total available P

Table 13. Fate of phosphorus in maize production on Konkola soil series

P application rate	Available P Soil†	Plant§	Total	Pdff¶	P-sorbed
			kg ha^{-1}		
0	8	6	14	0	0
20	11	14	25	9	11
40	11	20	31	17	23
80	32	26	58	44	36
160	56	30	86	72	88

† Available soil phosphorus by Bray 1 method determined after two cropping seasons

§ Determined plant phosphorus taken up in two maize crops

¶ Phosphorus derived from fertilizer = P treatment available P - Check Total available P

Table 14. Fate of phosphorus in maize production on Maheba soil series

P application rate	Available P Soil†	Plant§	Total	Pdff¶	P-sorbed
			kg ha^{-1}		
0	6	10	16	0	0
20	9	15	24	8	12
40	15	20	35	17	21
80	32	19	51	44	45
160	53	25	78	72	58

† Available soil phosphorus by Bray 1 method determined after two cropping seasons

§ Determined plant phosphorus taken up in two maize crops

¶ Phosphorus derived from fertilizer = P treatment available P - Check Total available P

Table 15. Direct phosphorus application and maize yields on various soils (1987)

Phosphorus yield	Soil series				
	Konkola	Misamfu	Mutanda	Malashi	Mean
(kg ha^{-1})	kg ha^{-1}				
0	550	2700	1070	3830	2040
20	3110	3930	2850	4380	3570
40	3830	5130	3400	5550	4480
80	4060	4980	4030	4320	4350
160	3890	4330	4640	5000	3720

Table 16. Residual phosphorus and maize yields on various soils (1988)

Phosphorus yield	Soil series				
	Konkola	Misamfu	Mutanda	Malashi	Mean
(kg ha^{-1})	kg ha^{-1}				
0	790	3650	2960	8500	3980
20	2490	4190	3890	8570	4790
40	4000	5510	4620	8580	5680
80	5880	5130	4340	8690	6010
160	6740	5980	5590	9170	6800

3.4. Sulphur nutrition

In highly weathered acid soils about 5 to 7 ppm sulphur is needed for good growth of most crops. Crops however, differ widely in their sulphur requirements with oilseeds, grain legumes, coffee, tea, tobacco, millets, sorghum and cotton having high requirements while pineapple, cassava and sweet potato are undemanding. Crop responses to sulphur are also soil-dependent.

The first sulphur response fertilizer trials were conducted by Pawson between 1950 and 1953 which showed crop responses to sulphate applied through ammonium sulphate. These trials were confined to southern, eastern and central provinces, on heavy textured soils where intensive commercial production of maize was recommended. A pot experiment conducted in 1958 with soil from Mansa followed, in the consequent years, by extensive field studies in northern, Luapula, north-western and eastern provinces revealed that sulphur shortage in many Zambian soils severely limited crop yields. The following (Table 17) were the findings from sites in northern (Mungwi and Malashi), Luapula (Kawambwa) and north-western (Zambezi and Kabompo) provinces:

Table 17. Multi-site maize response to sulphur nutrition (Source: McPhilips, 1986)

	Maize yields on various sites in the high rainfall area				
Treatment†	Mungwi	Malashi	Kawambwa	Zambezi	Kabompo
	------------ kg ha^{-1} ------------				
0	340	938	788	nd§	1260
N	1121	1019	1508	2138	2205
S	2608	3832	7133	2768	3263
Yield due to N	781	81	720	nd	945
Yield due to S	487	2813	5625	630	1058

† the treatments and corresponding yields illustrate possible crop response when other factors are not limiting; § results not determined or not available.

Response of soybean to sulphur and lime was investigated for two years in 1987 and 1988 on a newly cleared Misamfu yellow sandy loam (SPRP Research Reports, 1987 & 1988). The findings confirm that sulphur nutrition is necessary in soils of the high rainfall area. Other nutrients not limiting, soybean yields could be increased by 250 to 500 kg ha^{-1} when sulphur is added.

Of late concern has been raised as to whether continuous application of compound D with 12%S was still justified considering possible sulphur build-up over years. The concern has been two front, (1) possible acidification of the soils under intensive cultivation with sulphur additions; (2) possible savings in the manufacture of compound D which requires pyrite sources and escalating energy costs. The following are findings conducted in 1994 by SPRP in collaboration with the fertilizer company, Nitrogen Chemicals of Zambia (NCZ). The investigations were carried out on virgin land cleared of primary forest and on a site which was under continuous cultivation for more than ten years with well known fertilizer history. The need for sulphur nutrition was again confirmed by this investigation (Table 18).

Table 18. Maize response to sulphur through compound D (Source: Kanyamina & Mapiki, 1994)

	Location and site history	
Treatment	Misamfu (cultivated)†	Chipelepele (virgin)
	---------- kg ha^{-1} ----------	
0	524	3201
250 comp-D without S§	1206	11000
250 comp-D with sulphur¶	1586	13520
Yield contribution due to S	380	2520

† yields were low at Misamfu due to late planting (31/12/1993)

§ contains, in percentages, 10N: $20P_2O_5$: $10K_2O$, without S, imported by government

¶ contains, in percentages, 10N: $20P_2O_5$: $10K_2O$: 12S, manufactured by NCZ

Although there is no established correlation between soil sulphur-content and crop yields, maize leaf analysis with sulphur values of 0.12 to 0.15%S were found to be adequate. Groundnut would require up to 0.25% tissue sulphur content. Quantitatively, a maize grain yield of 5 t ha^{-1} can remove 20 to 25 kg S ha^{-1} in aboveground plant parts, most of which is lost as economic grain yield. The findings to date conclude that sulphur nutrition is as important as other nutrients as it was found to be a major limiting nutrient (even to a greater extent than nitrogen) in the soils of the high rainfall area. Sulphur dressings of about 24 kg S ha^{-1} appear to correct even the most severe deficiency and it has since been a requirement that all compound fertilizers contain a minimum of 10% sulphur.

Recommendations: The use of concentrated fertilizers containing little or no sulphur (urea, triple superphosphate) and importation of compounds without sulphur (as the case with imported compound D) is eventually likely to lead to serious sulphur depletion and deficiencies in these soils. A rate of 24 kg S ha^{-1} was found optimal even for the most severe deficiency. Applying 200 kg ha^{-1} compound D containing 12%S (4 x 50 bags) meets the above requirement. Where and when severe deficiencies occur (especially in tree crops) foliar sprays as flowers of sulphur using the same rate is recommended. Flowers of sulphur should not be incorporated into the soil as elemental sulphur has a strong acidifying effect. Where incorporation is the choice, it should be accompanied by liming.

Groundnut responds highly to sulphur nutrition. To enhance its growth and yield it is usually recommended to topdress the crop with gypsum at flowering stage at a rate of 4 to 6 x 50 kg ha^{-1} gypsum. The residual sulphur would greatly benefit a cereal crop grown in rotation.

3.5. Potassium nutrition evaluation

The soils in the high rainfall area are relatively low in potassium. Response to potassium in these soils is generally expected especially when they are subjected to intensive cultivation. Under Chitemene cultivation system large quantities of potash are added to the soil through ash. The potassium level however, decreases quite rapidly after three to four years of cultivation that the system permits. The decline in potassium is mainly due to leaching losses under high rainfall conditions and luxury consumption of the nutrient by the crops. Rapid deterioration in soil productivity under shifting cultivation is most likely due to decrease in potassium availability acerbated by deficiencies of other nutrients.

Assessing potassium availability in soils involves measuring exchangeable potassium plus the labile potassium in soil solution by ammonium acetate procedure adjusted to pH 7.0. A suggested classification of ammonium acetate extractable potassium values by von Uexkull (1986) in Oxisols and Ultisols of different textural classes seems applicable even to our soil conditions (Tveitnes, 1983) and is given below (Table 19):

Table 19. Critical values for ammonium acetate extractable K in Oxisols and Ultisols

	Soil texture		
Potassium status	Sandy/silt sands	Loamy sands/sandy loams	Clay loams
	me K 100 g^{-1} soil		
Deficient†	0.08	0.08 - 0.15	< 0.15
Low§	0.08 - 0.15	0.16 - 0.25	< 0.25
Adequate¶	0.15 - 0.25	0.25 - 0.35	< 0.35
High‡	> 0.25	> 0.35	< 0.50

† *deficient*: expected crop response to potassium very high

§ *low*: response to potassium likely; potassium requirements increase with yield

¶ *adequate*: potassium application needed for maintenance only

‡ *high*: no potassium required for some years

3.5.1. Potassium and liming

Although the acid soils encountered in the high rainfall area are generally low in total and available potassium this nutrient rarely limits crop yields in virgin soils. In cultivated lands however, potassium becomes limiting due to plant uptake and leaching which is promoted by predominance of kaolinite which does not fix significant quantities of potassium. Potassium also becomes a very important factor once acid soils are improved by liming. The increase in effective cation exchange capacity brought about by liming increases the capacity of such soils to adsorb potassium thereby reducing leaching losses. In this regard, liming increases potassium selective sorption sites which at low pH would otherwise be occupied by aluminum hydroxyl polymers. If no additional potassium is applied then the potassium concentration in the soil solution decreases. Since diffusion in the soil solution is the major mechanism by which potassium reaches plant roots, the decrease in concentration may adversely affects potassium uptake. Furthermore, liming increases calcium and magnesium concentrations in the soil solution, which also may depress potassium uptake. This is supported by a pot study (Mapiki, 1988) and field evaluations (Singh and Goma, 1986; Singh *et al.*., 1987) where there was a general tendency of potassium to improve crop yields in the absence of lime application and to decrease them at high potassium rates and when 1.5 t ha^{-1} dolomitic limestone was employed (Table 20).

Table 20. The effect of liming and potassium on crop yield (Source SPRP Annual Reports)

	Maize yield				Groundnut yield			
Lime rate	0	40	80	120	0	40	80	120
				t ha^{-1}				
0.0	3.7	4.7	4.4	5.3	0.8	1.0	0.8	0.8
1.5	4.7	4.6	5.4	4.3	1.2	1.3	1.0	1.0
Due to lime	1.0				0.4			
Due to K		1.0	0.7	1.6		0.2	0.0	0.0
Due to K x Lime		-0.1	1.0	-1.0		0.3	0.2	0.2

Liming to correct soil acidity can thus decrease availability and uptake of potassium. Small quantities of lime (up to 500 kg ha^{-1}) however, often stimulate root growth, especially where calcium is deficient, and thus increase potassium uptake.

3.5.2. Crop response to potassium

Most of the acid soils in the region have a very low effective cation exchange capacity and kaolinite, the predominant clay mineral, fixes only small amounts of potassium. The availability of potassium applied on such soils is usually good but leaching losses can also be very high. Leaching losses can be minimized if potassium is broadcast, whereas banding of potassium or application in pockets can result in severe losses.

The current fertilizer recommendations for the region advises to apply potassium through compounds of D or X which contain 10 and 5% K_2O, respectively. In this regard 200 kg ha^{-1} compound D recommended for small-holders would supply 16 kg K ha^{-1} or 20 kg K_2O ha^{-1} and half the potassium amounts if compound X is used. With the commercial farmers the fertilizer recommendation is 300 kg ha^{-1} compound D or X where 25 kg K ha^{-1} or 30 kg K_2O ha^{-1} through compound D or half the amount when compound X is used.

The potassium experiments conducted at SPRP (Singh & Goma, 1986; Singh *et al.*, 1987) had used potassium rates of 40, 80, 120 and 160 kg K ha^{-1} which translates to 48, 96, 144 and 192 K_2O ha^{-1} or 480, 960, 1440 and 1920 kg ha^{-1} compound D. Some of the rates unfortunately would be un affordable by any farmer category. The deficiency in the experiments was non appreciation of baseline information contained in the fertilizer/crop recommendations handbook. The investigations conducted however, indicate strong responses to potassium (Table 21) especially after three to four years of continuous maize cultivation.

Table 21. Maize and soybean response to K expressed as means over years and soils

Potassium rate	Maize yield	Due to K	Soybean yield	Due to K
		kg ha^{-1}		
No potassium added	2900		1230	
40 all as basal dress	3850	950	1390	160
20 basal + 20 topdress	4200	1300	1370	140
80 all as basal dress	4020	1120	1550	320
40 basal + 40 topdress	4660	1760	1490	260
120 all as basal dress	3670	770	1480	250
160 all as basal dress	4040	1140	1540	310

Soybean followed maize in rotation and did not receive direct fertilization

Major findings:: (1) soils in the region are low in potassium content (0.12 to 0.15 me K per 100 g^{-1} soil) but responses are usually absent, especially if the soil was virgin. With the expected high yields obtainable and the all too common practice of monoculture the potassium position should be constantly reviewed. Maintenance applications should continue to be applied through fertilizer compounds; (2) split application of K as initial basal dressing and later as sidedress seemed to have advantages as it increased yields than when single application was employed; (3) liming could adversely affect potassium availability and uptake.

Inadequacies:: (1) baseline information was ignored. It would have been necessary to ascertain the cut-off point in potassium nutrition starting with the lowest recommended potassium rate , i.e. 8 kg K ha^{-1} applied through compound X, rising through to 16, 24, 32, 40, 48, 56 kg K ha^{-1} and so on; (2) potassium was in all cases confined in ridges (banded), which would have accelerated leaching losses.

3.6. Micronutrient studies

Although micronutrients are found and needed by plants in relatively small quantities, they should be present in adequate amounts for optimum plant growth and maximum yield. A deficiency in any one of them will obstruct normal growth while a severe deficiency may result in complete crop failure. Investigations conducted at SPRP focused mainly on zinc, boron and molybdenum, availability of which are considered to be in sub-optimal amounts. A soil analysis conducted for the 23 major soils encountered in the high rainfall area confirmed this. Zinc levels ranged from 0.10 - 0.32 ppm while those of boron ranged from 0.01 - 0.58 all considered to be sub-critical (Tables 22 & 23)

Table 22. Extractable zinc and boron (in ppm) status of selected soil series before cropping and after harvest of maize at 8 weeks (Zn) and sunflower at maturity(B)

		Zinc†		Boron§	
Soil series	Classification	Initial	Harvest	Initial	Harvest
Malashi	Oxic Rhodustalf	0.32	1.88	0.16	0.32
Katito	Oxic Paleustult	0.26	2.20	0.11	0.14
Misamfu red	Oxic Paleustult	0.18	1.39	0.10	0.16
Mufulira	Oxic Paleustult	0.26	1.25	0.10	0.01
Mpongwe	Ustox Palehumult	0.16	1.06	0.58	0.16
Konkola	Rhodic Haplustox	0.10	1.13	0.01	0.04
Maheba	Rhodic Haplustox	0.12	1.52	0.07	0.18
Kasempa	Typic Haplustox	0.20	1.12	0.01	0.10
Chinsali	Ustox Dystropept	0.14	2.14	0.08	0.01

† 0.005*M* DTPA extractable zinc before and after applying 10 kg Zn ha^{-1} (Source: Banda, 1987)

§ HWS: Hot water extractable boron before and after applying 2 B kg ha^{-1} (Source· Lubinda, 1987)

3.6.1. Zinc deficiency

Crop species vary markedly in their susceptibility to zinc deficiency. Sensitive crops include coffee, citrus, beans, soybean and maize while sorghum is mildly sensitive. Experiments conducted showed very high responses to zinc amendments (Table 24). It increased maize leaf contents from 8 to 23 ppm. For several crops zinc concentration less than 20 ppm suggests the probability of zinc deficiency and values less than 15 ppm indicate sure deficiency. Zinc deficiency may depress plant yields by as much as 50%. The investigations conducted at Misamfu show that zinc can increase maize yields by up to 1000 kg grain ha^{-1} (Table 24). Zinc deficiency in maize is manifested on leaves having yellow streaks or chlorotic striping between veins. Unfolding young leaves may be white or yellow.

Recommendations: Soil application of zinc is the most satisfactory to cure zinc deficiency. It is either broadcast or sidedressed. When broadcast zinc should be incorporated into the soil as surface application without mixing is inefficient since zinc moves little from the point of placement. Preplant or presowing zinc application represents the most effective time of application. The zinc rate ranges between 5 to 20 kg Zn ha^{-1}. Once applied, residual zinc lasts for several seasons as the efficiency of inorganic zinc carriers applied to soil seldom exceed 2% (Table 22). Continuous soil application of zinc may thus lead to its accumulation to toxic levels, therefore, treatment with zinc should be regulated according to the crop needs and soil tests. For the high rainfall area where zinc deficiencies are severe, zinc should be coated on, or incorporated into compounds. This achieves uniform distribution of micronutrients in the field and cuts down the application costs.

Overliming brings about severe zinc deficiencies. Organic manuring increases zinc availability in soils. Thus soils low in organic matter are prone to zinc deficiencies. Light textured soils are generally zinc deficient.

3.6.2. Boron deficiency

Boron in the soil is present in adsorbed form with soil colloids and in association with soil organic matter. However, sandy soils, soils derived from acid igneous rocks and those that are low in organic matter have strikingly low available boron levels since it is likely to leach down the soil profile. Hot water soluble boron is regarded as plant available and its content generally lies between 1.0 - 3.0 ppm. Soils with less than 0.1 -

0.5 ppm hot water soluble boron are considered incapable of supplying sufficient boron to support normal plant growth (Table 23).

Table 23. Critical levels of micronutrients in soil and plants (Source: Katyal & Randhawa, 1983)

Nutrient	Crop	Critical levels		Adequate level
		Soil	Plant	Plant
		ppm		
Zinc	Maize	< 0.6	0 - 20	21 - 70
	Soybean	< 0.6	0.- 20	21 - 70
	Rice	< 0.6	0 - 20	21 - 70
Boron	Maize	0.1 - 0.5	1 - 2	5 - 10
	Cotton	0.1 - 0.5	16	30 - 50
	Groundnut	0.1 - 0.5	< 25	> 25
Molybdenum	Beans	< 0.2	< 0.1	0.4
	Cotton	< 0.2	< 0.1	113
Copper	Maize	6	< 5	5 - 30
	Soybean	6	10	11 - 30
	Cotton	6	>8	8 - 20

Maize, beans, soybean, rice, sorghum and wheat are least sensitive to boron deficiency while sunflower, cotton groundnut and vegetables are. Boron deficiencies have been found to be limiting on most soils throughout the high rainfall area especially in groundnut, sunflower and coffee. Experiments conducted showed good responses to boron applications.

It increased sunflower leaf content from 62 to 102 ppm and yields by 250 kg ha^{-1} (Table 24). Small applications of boron to groundnut (0.5 kg B ha^{-1}) was found to reduce "pops" (pod filling failure) to as much as 37% and thus increase shelling percentage (Phiri, 1989: *In* SPRP Report, 1989).

Table 24. Average leaf tissue contents of zinc and boron and yields of maize and sunflower

Maize crop			Sunflower crop		
Zinc rate	Leaf Zn	Yield	B rate	Leaf B	Yield
kg ha^{-1}	ppm	kg ha^{-1}	kg ha^{-1}	ppm	kg ha^{-1}
0	8.58	4860	0	61.94	190
5	13.66	4860	1	69.39	307
10	15.11	5550	2	78.94	446
20	22.92	5834	3	102.28	328

Source: SPRP Annual Reports, 1987 & 1988

Zinc and boron determined in 0.005*M* DTPA and hot water, respectively.

Recommendations: Boron may be applied to soil either broadcast or banded prior or at planting. Top dressings may also be successful. Boron usually applied as Solubor or borax ranges in application rate from 1.2 - 3.2 kg B ha^{-1} for legumes and root crops and 0.6 - 1.2 kg B ha^{-1} for other crops. Foliar applications are quite successful for tree crops. In annual crops boron sprays are used if boron deficiency is noticed during the growing season. Solubor is used widely for foliar application with a concentration for majority of the crops being 0.2 - 0.5% Solubor in water.

3.6.3. Molybdenum deficiency

Molybdenum is intimately involved in nitrogen metabolism therefore its deficiency resembles nitrogen deficiency. In legumes molybdenum deficiency adversely affects nitrogen fixation. Molybdenum is considered an antidote to excessive copper, boron, manganese and zinc in plants. Concentrations are highly variable with plants containing as little as 0.1 ppm to as much as 300 ppm Mo. Notwithstanding, crops will usually respond to molybdenum if they contain less than 0.1 ppm Mo. Molybdenum in soils is found in association with sesquioxides of iron and aluminum whose binding is firm and the molybdenum so retained is largely unavailable for plant uptake. Molybdenum is also found in organic combination and it is from this important fraction that plants draw their requirement. Therefore, treatment of soils with organic manures enhances inherent molybdenum availability. A soil is classified deficient if it tests less than 0.2 ppm molybdenum by the ammonium oxalate method.

Molybdenum deficiency can be a problem among field crops, especially on very acid soils. Since it is an essential element for nitrogen fixation, legumes are the most affected crops. Molybdenum treatment not only enhances crop yields but also helps in nitrogen economy. In Mbala on Katito soil series foliar sprays with 0.5 kg Mo ha^{-1} as ammonium molybdenum on average increased soybean grain yields from 1341 to 1506 kg ha^{-1} (SPRP Reports, 1987 & 1988).

Recommendations: Molybdenum deficiencies can be corrected by soil, foliar or seed applications. Alternatively molybdenum deficiency may be effectively prevented by liming. Applications of lime however, should be used judiciously as overliming can reduce micronutrient availability and induce severe deficiencies. Molybdenum can either be broadcast or band applied with soil application of 70 - 200 g Mo ha^{-1}. One application may produce a residual effect for several years. Pre-bloom foliar applications on legumes with a spray solution containing 0.1 - 0.3% soluble molybdenum salt is equally effective. The most common method of molybdenum application is seed treatment of 50 - 100 g Mo ha^{-1}. It is more efficient because it ensures uniform distribution and it avoids waste of molybdenum through soil fixation. Molybdenum salts are applied to seed in liquid or slurry form. Merely dusting is less effective.

Among the current fertilizers commercially produced in Zambia or marketed in the region only three compounds (A, V and C) contain traces of boron (0.1%) while none contain zinc or molybdenum. For fetilizers destined for use in the high rainfall area they should have inclusions of at least 5% Zn and 2% B. Legumes require small amounts of molybdenum and seed dressings of this can be achieved by ZAMSEED at very little cost.

3.7. Multi-nutrient investigations

3.7.1. Continuous cultivation and monocropped maize

Considering the low inherent fertility and fragility of the soils in the high rainfall areas it has been argued that intensive use of commercial fertilizers and continuous cropping on these soils could lead to soil degradation and decline in productivity. The sharp decrease in organic matter content following clearing and decrease in other soil parameters as a result of continuous cultivation suggest that a careful soil management policy has to be followed if long term cultivation on these soils is envisaged to avoid mining and rapid degradation of the soil inherent fertility. Remedial measures include an adequate liming programme, organic matter management, subsoiling plough pans and balanced nutrient management. The general fertility of the soil under continuous cultivation could further be maintained by use of fertilizers provided that care was taken to supply both secondary and micronutrients.

In 1965 it was felt necessary to initiate a long term fertilizer trial with continuous monocropped maize with the objectives being (1) assessing the capability of soils in the high rainfall area to support continuous maize cultivation under commercial farming conditions; (2) finding a balanced mixture and economic amounts of fertilizer for maize cultivation over an indefinite period of time.

The investigations were conducted on Misamfu red and Chinsali soils that were strongly leached and derived from non-basic rocks. Three levels of nitrogen (80, 135 and 190 kg N ha^{-1}), two phosphorus levels (0 and 30 kg P ha^{-1}), two levels of potassium (0 and 40 kg K ha^{-1}) and two levels of zinc (0 and 10 kg Zn ha^{-1}) were employed. Nitrogen was applied initially as sulphate of ammonia, later as calcium ammonium nitrate and later still substituted to ammonium nitrate and urea. Phosphorus was applied through single superphosphate while potassium was through muriate of potash and zinc as zinc sulphate. About 2 t ha^{-1} dolomitic lime was applied every fifth successive year.

In spite of adequate fertilization maize yield levels declined continuously over the years indicating that sustained high yields of monoculture maize on such soils would not be expected (Table 25). Towards the 24th year (1989) yields declined to non-economical levels with no cob formation in some cases. This has been attributed to build up of soil acidity, especially during the period when sulphate of ammonia was in use. The organic matter in the soil rapidly declined from about 60 t ha^{-1} to a steady equilibrium state of about 30 t ha^{-1}, representing an annual average loss of 1.5 t ha^{-1} $year^{-1}$. The total soil nitrogen content very rapidly declined with no observed effect from applications of inorganic nitrogen. It probably would mean added nitrogen was either taken up by the crop or much of it was leached down the soil profile.

In spite of successive liming attempts, calcium and magnesium levels by the year 1989 dropped to 0.6 and 0.3 me 100 g^{-1} soil, respectively suggesting nutrient imbalances were at play and could not be corrected even through liming. Even potassium levels fell to sub-critical levels (0.06 me 100 g^{-1} soil). It would seem therefore, that the physical parameters were the most limiting constraints to continuous cultivation.

Table 25. Long term fertilization with monocropped maize

	Mean maize yield		Selected chemical properties with time				
Year	Control	Fertilized	pH	Org-C	K	Ca	Mg
1965-69	2720	3720	5.1	1.3	0.16	1.6	0.7
1970-73	1300	1800	4.4	1.1	0.08	0.8	0.4
1974-79	630	1400	4.3	0.5	0.07	n.d	n.d
1980-81	350	750	4.3	0.7	0.08	0.8	0.3
1986-89	0	1500	4.5	0.6	0.06	0.6	0.3

The most important effect of cultivation on physical soil properties was manifested by the reduction in infiltration rates and the resultant water logging encountered. The reduction in infiltration rates was due to breakdown of topsoil structural units brought about by mechanical cultivation followed by differential illuviation of the silt and clay fractions. Also, a hard plough pan was witnessed at 20 cm depth which affected infiltration rates. This in turn resulted in a reduction in crop rooting depth.

It seems therefore, that for continuous cultivation to take place, the breakdown of a hard plough pan is necessary. Also continuous cultivation should be translated as inclusion of fallows, preferably, improved fallows so as to promote organic matter build up. Crop rotations also must be encouraged so as to maintain/build up organic matter reserves.

3.7.2. Crop production: Traditional Chitemene vs fertilizers and lime

Chitemene involves lopping and collection of wood followed by burning in the field. The burning helps control weeds and the ash provides both the needed plant nutrients and the liming effect. The beneficial effects of wood burning and ash addition to the soil are however short-lived, lasting for a few seasons only. Recuperation of soil fertility is accomplished by bush fallowing during which period the land remains out of cultivation. Due to increasing population pressure and demand for food however, in many areas the period of bush fallow has been curtailed drastically leading to soil exhaustion and deterioration sometimes to its limits.

Table 26. Wood burning versus compost, fertilizers and lime

Treatment	Crops grown in sequence F/millet	Maize	S/Beans	G/nuts	Cassava
	kg ha^{-1}				
Burned	2040	1170	480	1270	45800
Unburned	660	180	80	770	20800
Unburned + X	2240	2260	380	660	30300
Unburned + X + FTE	2280	1440	280	900	29200
Unburned + X + lime	2410	1560	490	1770	33900
Benefits to burning	1380	990	400	500	25000
Benefits to fertilizer	1580	2080	300	nil	9500
Benefits to lime	170	nil	110	1110	3600
Benefits to FTE	40	nil	nil	240	nil

Fingermillet, groundnut and maize received 750 kg compound X ha^{-1}. Soybean received 200 kg compound D ha^{-1}. FTE = fritted (compound) trace elements applied at 50 kg ha^{-1} annually. Cassava was grown on residual fertilizers.

An investigation was conducted for seven years (1983 - 89) with an objective of finding an alternative to the non sustainable Chitemene system. It was argued that perhaps an alternative to Chitemene could be found by use of both organic and inorganic fertilizer and lime inputs. Under low soil fertility and highly acidic conditions there is an immediate need to ameliorate soil conditions for optimum plant nutrient availability and supply of deficient nutrients in adequate quantities.

The experiment involved burned and unburned Chitemene plots to which 0 and 2 t ha^{-1} dolomitic lime, 0 and 750 kg ha^{-1} compound X and 50 kg ha^{-1} trace element compound were added annually (except lime which was applied only once). The crops were fingermillet, maize, soybean, groundnut and cassava, grown in succession. Maize and fingermillet received 200 kg ha^{-1} ammonium nitrate as top dressing. Soybean received 200 kg ha^{-1} compound D as basal dress.

Findings: Cumulative data concludes that Chitemene burning coupled with rotations employed supports crop production throughout the study period (Table 26). The yield increase in relation to unamended soil was quite substantial to warrant its merits. The benefits of fertilizing groundnut with 750 kg ha^{-1} were negative if not minimal due to high nitrogen levels added (150 kg N ha^{-1}). At this rate vegetative growth at the expense of pod formation was manifested. A balanced nutrient supply in form of inorganic fertilizers in conjunction with lime out-performed the Chitemene method suggesting that agricultural production on these soils can be intensified once rotations and other management practices are followed.

3.7.3. Delayed fertilization and fertilizer rates in maize production

While compound fertilizers are recommended to be applied as basal dressings during the time of planting, it has become common practice, especially among small-holders to apply these compounds after germination. This method not only localizes plant nutrients (for maximum plant uptake) but also economizes their use (broadcast or band application would benefit weeds in the intra spacings). Fertilizer distribution and supply can also be erratic. It has not been rare that fertilizer inputs arrived late and that the supply of ammonical fertilizers sometimes preceded the supply of compounds which did not arrive before the planting period was already in progress. In both circumstances therefore, it is of utmost importance to determine when it is economic to spend this resource with minimum risk. This information gathered needs to be disseminated through extension messages.

The investigation was conducted for four planting seasons (1987 - 90) on two sites at Misamfu on Misamfu red and at Mpika on Malashi soil series. The Misamfu site and soil were representative of the high rainfall area (1490 mm) with highly leached soils. The Malashi site and soil resembled those of region III's southern fringes (Serenje/Mkushi) with rainfall of 900 - 1000 mm and soils rich in weatherable minerals. Two recommended fertilizer rates were used (4 and 6 bags compound D and 4 and 6 bags ammonium nitrate). The times when these fertilizers were applied are presented in Table 27 together with respective 4-year mean yields.

Findings: The agronomic practice of applying compound fertilizers after maize emergence seems to be paying some dividends. The data repeated over four growing seasons (Table 27) indicate that applying basal fertilizers two weeks after emergence produces best results in terms of yields for both categories of farmers, i.e. the small-holder (5.5 tonnes grain with 4 x 50 kg D ha^{-1}) and the commercial farmer (6.8 tonnes grain with 6 x 50 kg D ha^{-1}). Although good maize yields were obtained by applying all fertilizers in one operation at two weeks after emergence the practice should be used with caution as most nutrients may be lost through leaching and/or through fixation. Labour saving as this may seem, it may not be recommended unless circumstances do not permit split applications. It may still be practical and desirable for commercial farmers to apply basal dressing at planting. Yields obtained by this method are comparable to those cited earlier (6.4 tonnes ha^{-1} grain).

Table 27. Effect of time, rate and methods of fertilizer application on maize yield

Fertilizer application method	Added nutrients				
	N	P	K	S	Yield
	kg ha^{-1}				
Control (no fertilizer added)	0	0	0	0	2300
4x50kg D at planting; 4x50kg AN at 4 weeks†	88	17	16	20	5000
4x50kg D at 2 weeks; 4x50kg AN at 8 weeks	88	17	16	20	5500
2x50kg D+2x50kgAN at 2 weeks; Repeat at 8 weeks	88	17	16	20	5200
4x50kg D+4x50kg AN all applied at 2 weeks	88	17	16	20	5200
6x50kg D at planting; 6x50kg AN at 4 weeks	132	26	25	30	6400
6x50kg D at 2 weeks; 6x50kg AN at 8 weeks	132	26	25	30	6800
3x50kg D+3x50kg AN at 2 weeks; Repeat at 8 weeks	132	26	25	30	6600
6x50kg D+6x50kg AN all applied at 2 weeks	132	26	25	30	6700

† weeks in all cases mean weeks after emergency; D = compound D mixture; AN = ammonium nitrate

Recommendations: Where it is the preference of the farmer to apply compound fertilizer as post-emergence dressing, it should be applied at three-leaf stage. This is especially true for compound D. When fertilizer application is delayed (up to knee high), maize should be dressed with compound X to give it a boost. Compound D would not provide similar effects. Once the maize has past the knee-high stage fertilization is not recommended. Fertilizer is better stored for the following season. Depending on cash outlay the following guide shows the amounts of major nutrients applied (Table 28):

With good management, any combinations as illustrated below would result into a good maize harvest. Caution however should be taken not to apply too much nitrogen in a single application as most of it would not be taken up by plants and it will be lost through leaching. Split application of nitrogen is recommended, at grand growth period and at tassling stage. All nitrogenous fertilizers should be covered immediately after application as surface application may result into considerable ammonia losses by volatilization. Urea sometimes contains small quantities of biuret (1%) which may inhibit the unfolding of maize leaves. Ammonia may damage young seedlings if urea is placed in contact with them. It should not therefore be applied to young maize seedlings.

Table 28. Fertilizer recommendations and major nutrients supplied for plant uptake

			Major nutrients supplied			
Farmer category	Compound	Nitrogen	N	P	K	S
	amounts ha^{-1}		kg ha^{-1}			
Small-holder	4 x 50 kg D	4 x 50 kg A/N	88	17	16	24
	4 x 50 kg D	4 x 50 kg Urea	112	17	16	24
	4 x 50 kg X	4 x 50 kg A/N	108	8.5	8	24
	4 x 50 kg X	4 x 50 kg Urea	160	8.5	8	24
Commercial	6 x 50 kg D	6 x 50 kg A/N	132	26	25	36
	6 x 50 kg D	6 x 50 kg Urea	168	26	25	36
	6 x 50 kg X	6 x 50 kg A/N	162	13	12.5	36
	6 x 50 kg X	6 x 50 kg Urea	198	13	12.5	36

3.7.4. Fertilizer requirements for upland rice

The agroecological conditions of the high rainfall area have great potential for upland rice production. This is favoured by reliable rainfall with only minor dry spells. Rice also to some degree is tolerant to acidity and can withstand water logging. Out of the 60 entries tested by the third year four varieties (K1 Pick, K1 Mack Fey, IAC-47 and Kalembwe) had reached the advanced screening stage. Tolerance to soil acidity, yield potential and drought resistance were some of the favourable agronomic attributes used during selection. The fertilizer requirements of these varieties were investigated at Misamfu on Misamfu red upland soil. One month after planting all varieties received 15 kg nitrogen, 14 kg phosphorus and 12 kg potassium per hactre. Four weeks later the crop was topdressed with 30 kg N ha^{-1} through urea. Results show that upland rice production is feasible in northern Zambia and the introduced varieties out yielded the local Kalembwe variety (Table 29). Paddy rice yields rarely exceed 1000 kg ha^{-1} under present circumstances even with higher fertilization.

Table 29. Rice in response to fertilization

Varieties			
Kalembwe	K1 Pick	K1 Mack Fey	IAC-47
kg ha^{-1}			
1510	2700	2120	2060

The phosphorus threshold level encountered through further investigations (SPRP, 1989) confirm that a rate of 15 kg P ha^{-1} was the optimum for upland rice. Further additions did not increase grain yield significantly. It would seem therefore that 4 x 50 kg ha^{-1} compound D and 2 x 50 ha^{-1} ammonium nitrate are adequate for upland rice production.

3.8. Composts, mulches and green manures

Organic sources of plant nutrients comprise plant and animal residues most important of which are farmyard manure, compost, green manure, and various animal wastes. Organic manures are bulky in nature usually containing small amounts of nutrients. Their main value, therefore lies in the supply and restoration of organic matter to the soil. Unless applied in large amounts, they do not contribute much to the nutrient supply to plants. Organic matter promotes microbial activity in the soil, it improves soil structure, aeration and water holding capacity. In addition it supplies micronutrients and helps to make phosphorus in the soil more available to plants.

3.8.1. Farmyard manures

Farmyard manure is a decomposed mixture of the dung and urine of confined cattle or other livestock with the straw and litter used as bedding and residues from the fodder fed to them. Litter, dung and urine accumulate in livestock housing for several weeks, followed by removal and storage in a compacted heap thereby reducing the rate of breakdown and the loss of ammonia. One to two weeks before planting farmyard manure is spread evenly over the field and immediately incorporated in the soil so as to realize maximum nutrient efficiency.

Poultry manure has a higher nutrient content than other livestock manures, but as with all farmyard manures it is variable in composition depending on management, storage and amount of litter used. The nitrogen content ranges from 1.5%N in a poor weathered sample to more than 4%N for kiln-dried manure.

Cow dung and pig manure constitute the major component of kraal manure which can be used in both field crops and vegetable crops. While in some parts of the country these manures are used in various degrees of maturity, in the high rainfall area they are hardly used. The non use of kraal manure in northern Zambia is contained in surveys conducted by SPRP in 1981 and 1988 which concluded that due to bulkiness manures needed labour and carts to transport the manures to the fields. These were not readily available to most farmers; farmers using these manures encountered weed infestation problems which they could not handle due to labour constraints which usually coincided with peak periods; the manures were usually not adequate to cover the whole field resulting in low yields than anticipated; the manures were also usually not uniformly spread resulting in uneven growth of crops.

Recommendations: Manures should not be used when they are fresh (usually greenish-colour). They should be allowed to mature until they obtain a dark to black colour. This is achieved by kraal rotations usually done in February. Only the manures from the abandoned February kraal should be used in the following season. Why? With the rains on the wane, the slurry manure forms a sealed surface crust which encourages decomposition of manures to maturity by October when it is ready for application.

Construction of kraals should be done on a slope (by an anthill) thereby the manure will be collecting at the lower end where a pit or trench is dug and layers of dung and soil/grass are added as in farmyard manure or composts. The pit or trench should accommodate all manure throughout the rainy season. Once the pit is full, it is covered with soil. Composting this way the weed seed in manure may be killed.

In Israel (Ashri, 1993, personal communications) manures and composts are covered with white plastic sheeting after periodic watering trapping the heat and thereby killing all the weed-seed and accelerating decomposition rate within 60 days. This is worth trying in Zambia.

In circumstances where manures are not treated as above, the manure should be watered to field capacity before field application, allow weeds to sprout which eventually wither under the scotching November heat. The manure is then ready for application. This method however, allows the nutrients to leach out or volatilize. Once transported into the field manures are usually placed in heaps (hillocks) spaced at even distances which are later spread to cover evenly the in-between spaces using spades or shovels.

3.8.2. Compost

Large quantities of waste materials (sweepings, vegetable wastes, slashed grasses, litter) can be converted into useful compost manures by conserving them and subjecting them to a controlled process of decomposition. Farm refuse like crop residues, stubble, weeds can be collected and stored in pits. The accumulated refuse is thoroughly mixed and spread in a layer 30 cm thick, well moistened and sprinkled with dung and water or soil and water to break it down. The layers are repeated to a height of 50 cm above ground level. After turning and storage for about six months, the compost is mature and ready for application into the field. It is used like farmyard manures on all soils and almost all crops.

In a maize experiment the crop received 10 t ha^{-1} crop residue of groundnut shells and soybean residue which were evenly spread on the soil surface before being buried in ridges. A 3-cm thick mulch of same plant material was evenly spread after crop germination (Table 30). In another experiment with beans 17 t ha^{-1} dry *Hyperrhenia* grass and compost were used (Table 30). In both cases no follow up was done as the experiments were one year investigations only.

Table 30. The effects of composts and mulches on crop yields

	Crop					
	Maize with crop residue			Common bean with *Hyperrhenia*		
Fertilizer	Control	Mulch	Compost	Control	Mulch	Compost
	--------- kg ha^{-1} ----------------			-------------- kg ha^{-1} ---------------		
Nil	400	500	2200	300	200	480
Lima rec	1100	1800	2000	300	840	720

When applied alone mulches of both plant origin did not improve yields (Table 30). Fertilizer additions helped breakdown the mulch left on the soil surface and hence nutrient release from the mulch was realized. Together with improved moisture retention, comparably better yields were obtained than when used alone. Composts are likely to improve yields especially when used in conjunction with fertilizers. They do not only provide extra nutrients but also improve soil physical conditions

3.8.3. Green manures

Green manuring is one way of adding organic matter to the soil. A leafy crop, usually a legume grown in the field itself or cut and carried from elsewhere, is incorporated in the soil at flowering. Some of the most important green manures evaluated at Misamfu are *Crotalaria zanzibaricum, C. juncea, Stylosanthes* spp. and *Cajanus cajan*. In the cut and carry the following agroforestry tree species seem to hold potential: *Calliandra calothyrsus, Gliricidia sepium,* and *Tephrosia vogelii*. The green manure crop supplies organic matter and, if a legume, fixes and supplies nitrogen. The amount of nitrogen fixed varies and may average about 30 - 40 kg N ha^{-1}. Green manuring is effective when large quantities of biomass can be realized, when there is sufficient water supply for green manure decomposition in the soil whose nutrients will be utilized by the subsequent food crop.

In alley cropping prunings from hedgerows of trees are used to provide organic manure and mulch to improve the soil fertility and thus sustain crop yields. It has however, been difficult to determine the contribution of prunings to a maize crop because of large variations in soils and biomass realized from these agroforestry trees. An evaluation in which a known quantity of biomass and farmyard manure applied to the soil would help discern the nutrient dynamics and crop response. The hypothesis is that organic matter so added would complex aluminum and thus reduce its toxicity which is one of the major limiting factors to crop production.

Cut-and-carry prunings from three tree species (*Cassia spectabilis* , *Calliandra calothyrsus* and *Leucaena leucocephala*) applied at 2, 4 and 6 t ha^{-1} dry weight were evaluated in comparison with inorganic fertilizers applied at recommended rates and with 2 t ha^{-1} kraal manure (Table 31). The yields obtained were lower than those with recommended fertilization (Table 31). Supplemental fertilization with lower inorganic rates and top dressing with nitrogen would not only have been a better comparison but more realistic. Maize is a heavy feeder and therefore would require nutrient supplements. It is difficult to draw conclusions about which tree species or rate of biomass performs best since the trial site was subjected to wood burning (Chitemene) prior to planting. Such investigations and comparisons need be properly planned and conducted where responses are expected.

Table 31. Maize response to inorganic fertilizers, tree prunings and kraal manure

Treatment†	Organic matter added in t ha^{-1}			
	0	2	4	6
	kg ha^{-1}			
Control (no fertilizer)	2840			
4 x 50kg comp X + 4 x 50kg urea	4270			
Kraal manure	2440			
Cassia spectabilis prunings		2480	5000	3700
Calliandra calothyrsus prunings		3060	2180	4310
Leucaena leucocephala prunings		1860	2850	3440

† Whole trial area was burned as Chitemene prior to introduction of treatments

The high rainfall area is the main producer of common bean. The crop is predominantly grown by the Fundikila method of cropping with *Hyperrhenia* residues as the main source of nutrients. *Crotalaria zanzibaricum* and *Sesbania sesban* were evaluated as possible alternatives to natural grass. Preliminary investigations indicate that these and other green manures have potential to improve bean crop production if used as soil inputs in the traditional grass mound system. The optimum seed rate of these green manures, the time of establishment and incorporation and their performance with inorganic fertilizers were investigated.

Crotalaria zanzibaricum has a rapid initial growth and gives appreciable amounts of biomass within three months and therefore may be utilized for relay bean production the same season it is planted. The yield from bean planted in the mounds made in February, three months after green manure planting, without fertilization is presented in Table (32). The optimum seed rate for both green manures was found to be 20 kg ha^{-1}. Seed rates lower or higher than this seed rate did not provide extra green manure biomass or bean yield.

Table 32. Bean yield as affected by population density of green manures in Fundikila

Seed rate	Bean yield *Hyperrhenia grass*	*C. zanzibaricum*	*S. sesban*
(kg ha^{-1})	---------- kg ha^{-1} ----------		
Control	900		
20		1430	960
40		1410	1050

Once the seed rate had been established, investigations on green manure planting dates and incorporation to be in synchrony with crop demand were conducted with *Crotalaria zanzibaricum*. The experiments were conducted at Misamfu and Mansa on Mufulira soil series. The sites in both cases were newly cleared lands of regenerated Miombo woodland. Maize received the fertilizer recommended rates while soybean was grown in rotation without additional fertilizers. The green manure crop was relay planted in the maize plant intra spaces and incorporated when it flowered.

Table 33. Green manure planting and incorporation synchrony with plant demand

Green manure planting date†	Crop yield Maize§	Soybean¶
	---------- kg ha^{-1} ----------	
Control	3210	1950
Late December	3520	1760
Mid January	3750	1990
Late January	3710	1890

† The green manure was *Crotalaria zanzibaricum*

§ The maize crop received in addition 200 kg D and 200 kg A/N ha^{-1}

¶ Soybean depended on residual organo-inorganic fertilizers.

Results (Table 33) indicate no additional benefits to green manuring. The reasons could be that inherent soil fertility, supplemented with fertilization was adequate. Furthermore, despite evidence from previous investigations that green manures (especially *Crotalaria*) are serious competitors for plant nutrients, this investigation was conducted in this manner. The objectives and design of the experiment remain obscure.

3.8.3.1. Degraded lands-soil fertility restoration

With population pressure and as land becomes scarce the fallow period practised under Chitemene is drastically reduced. Meanwhile the lands converted into semi-permanent fields decline in soil fertility producing low crop yields. A two to four year improved fallow with leguminous grasses and shrubs may improve or even restore soil fertility and reduce the fallow period. To investigate the ability of leguminous plant species to restoring soil fertility on abandoned lands, *Desmodium distortium*, pigeon pea, and mixed grass of *Stylosanthes gracilis* with Rhodes grass were planted and allowed to establish for four years. The investigation was an on-farm experiment conducted at Chilongoshi village (Mporokoso). After four years the grasses were buried in mounds while *Desmodium distortium* and pigeon pea were burned *in situ*. Maize was planted the first season and was followed by soybean.

Table 34. The effect of a 3-year fallow with perennial legumes on crop growth

	Yield		Chemical data at experiment's end					
Treatment	Maize	Soybean	PAS†	Org-C	Ca	Mg	K	P
	--- kg ha^{-1} ---		--- (%) ----		- (me 100 g^{-1} soil) -			ppm
Natural regrowth	500	900	26	1.12	0.5	0.3	0.24	13
Lima Rec	7500	1900	24	1.28	0.5	0.3	0.28	19
D. distortium	4200	1750	31	1.18	0.4	0.3	0.12	15
Pigeon pea	3800	1650	37	0.64	0.5	0.3	0.24	13
Stylo + Rhodes grass	4000	2150	23	1.32	0.6	0.3	0.23	15

† PAS = Percent aluminum saturation

The results (Table 34) show that utilization of perennial legumes in improved fallows help restore soil fertility and therefore may have potential in shortening the fallow period. The good yields obtained with legumes compared with natural regrowth confirm the resting periods soils need when subjected to continuous cultivation. These leguminous plant species need further on-farm testing on a wider scale.

3.8.3.2. Observations and comments

The compost and mulch experiments were inconclusive. It is difficult to draw conclusions from one year data. Composts and mulches incorporated the following season normally do work. It is apparent that the trial objectives were not stated clearly at the inception of these experiments. In the same experiments (not presented) there were treatments of burning *Hyperrhenia* and *Stylosanthes* grasses with a view of saving the forests during Chitemene practices. Hypothetical reasoning as this would be, it becomes a waste of time and resources if no workable investigations are conducted as to whether the client would adapt such a technology.

The green manure investigations were haphazardly executed without clearly defined objectives and proper planning. Crop response from tree prunings, kraal manure and fertilizer effects were being expected on land already rich in nutrients from ash. Another site would have been chosen. The test crop maize requires substantial nitrogen. The crop was chlorotic and yet no nitrogen was planned or applied. Planting green manures together with a crop (maize) did earlier reveal the competition existing between the crop and the green manure. Yet later investigations continued to modify the experiments but principally getting the same results and responses. Green manure seed rates continued to be changed from year to year and from site to site. This makes it difficult to draw conclusions. In another experiment (not reported herein) the benefits of green manuring were investigated with inorganic fertilizers. In 1992 fertilizer P added was 40 kg P or 480 kg SSP ha^{-1} while in 1993 only 12 kg P or 150 kg SSP ha^{-1} was added. No explanation for rate change was given. In the same experiment the bean yields reported in 1992 are reproduced to represent 1993 yields. In the soil fertility restoration of degraded lands, pigeon pea and *Desmodium* were burned while the grasses were incorporated in mounds. Burning would have facilitated nutrient loss especially that of sulphur, nitrogen and organic matter. Cutting the shrubs at root collar well before the rains would have facilitated shading of litter while the root mass would have undergone slow decomposition. Stems could have been used for other purposes.

Recommendations: Green manure experiments should as much as possible be pure stands (not planted together with the main crop). They should be allowed to establish to desired growth stage and then be manipulated as required. Green manures alone would not supply crop nutrient requirements in sufficient quantities. Where supplements in form of inorganic fertilizers are added, the quantities should be such that they produce optimum yields, but with savings from normal fertilizer recommendations.

3.9. Biological nitrogen fixation

Biological nitrogen fixation is realized by growing legumes such as groundnut, common bean, soybean, pigeon pea, bambara nut and cowpea, in whose root nodules nitrogen from the atmosphere is fixed by rhizobial bacteria living in symbiotic association with these plants. A number of other microorganisms in the soil also do fix atmospheric nitrogen though in insufficient amounts required by high yielding crops. Nitrogen fixation is an energy-consuming process and the symbiotic nitrogen fixers obtain this energy from the crop in association, in principle resulting in some loss of crop production.

3.9.1. *Rhizobium* bacteria

Bacteria of various *Rhizobium* species live symbiotically in the root nodules of leguminous plants, use the carbohydrates of the host plant as an energy source and pass a proportion of the fixed nitrogen to the host plant. The amounts of nitrogen fixed by legume-*Rhizobium* associations can be very large (up to 200 kg N ha^{-1}). Thus legumes may obtain their total nitrogen requirement from this source, or may need a combination of symbiotic and fertilizer nitrogen for a good yield harvest. Also, there may be a residual effect to the extent of 20 - 30 kg N ha^{-1} on the succeeding cereal crop from mineralized bacteria and root nodules.

3.9.2. Free-living bacteria

Many soils, especially the acid soils of the high rainfall area, do not have active populations of Azotobacter and related free-living bacterial species. Where soil conditions permit, as in Makeni and other related soil series, the amount of nitrogen that may be fixed may be 10 - 20 kg N ha^{-1} which would be available for plant uptake.

3.9.3. *Azospirillum*

The bacterium *Azospirillum* is widespread in Zambian soils and grows on and inside the roots of grasses such as millets, barley, Rhodes grass and other graminaceous pastures where it is able to fix atmospheric nitrogen. It may therefore, be particularly useful where barley and millets receive little nitrogen fertilizer, and may thus have potential for small and marginal farmers in Zambia.

3.9.4. Research conducted and findings

Soil microbes are the only organisms that can fix atmospheric nitrogen, ultimately making it available for plant uptake and growth. Many tropical soils contain rhizobia that belongs to the cowpea type (*Bradyrhizobium* species) which in Zambia have been reported to also nodulate soybean. Cowpea and soybean belong to different cross inoculation groups, but reports from region II have revealed that high soybean yields (up to 1000 kg ha^{-1}) of Magoye and Hernon-147 varieties have been obtained.

The efficiency with which the cowpea type rhizobia fix nitrogen in the high rainfall area was not known and needed to be investigated. Nodules from various legumes were collected for isolation of presumptive cultures of local *Rhizobium* strains. There seemed to be no *Rhizobium* strains that nodulate bean as it was not possible to get isolates from these cultivars. Groundnut and cowpea, in contrast had an abundance of isolates which were effective in biological nitrogen fixation. The strains so isolated were further screened and those selected were found to have an ability to effectively infect and fix atmospheric nitrogen under acid conditions. The most promising, among these, were SPRP 3, SPRP 36 and SPRP 42.

3.9.4.1. Soybean

Trials were initiated in 1988 - 1990 to determine nodulation, plant growth and yield responses of three soybean varieties when inoculated with local isolates and imported American strains. Magoye, Hernon-147 and Kaleya varieties were tested on Misamfu yellow at Misamfu and on Konkola soil at Lucheche, Mbala. The contribution of local *Rhizobium* isolates to soybean yield was less than that of the introduced American strains (Table 35). Notwithstanding, their contribution to soybean yield, especially that of SPRP 3, was similar to that of the inorganic fertilizer source. When Hernon-147 and Magoye varieties were planted without application of inoculum, they successfully picked up rhizobia from the soil and fixed appreciable amounts of nitrogen to give economical yields (Table 35). When inoculated with a proven effective strain, the three varieties responded differently. Kaleya variety exhibited a dramatic response to inoculation compared to the other two varieties.

Table 35. Dinitrogen fixation: Indigenous and exotic *Rhizobium* strains effect on soybean yield

	Soybean varieties and yield					
Inoculum	Kaleya	Due to	Hernon	Due to	Magoye	Due to
	kg ha^{-1}					
Control	760		1130		1960	
120 N ha^{-1}	1580	820	1220	90	2120	160
SPRP 3	1490	730	1330	200	1950	nil
SPRP 36	1225	465	1270	140	1630	nil
SPRP 42	1060	300	1240	110	1940	nil
TAL 377	2040	1280	1890	760	2250	290
TAL 379	2410	1650	1990	860	2110	150

The findings at SPRP conclude that Kaleya variety performs poorly without inoculation or fertilizer application. Magoye and Hernon-147, on the other hand are compatible with the resident strains in the soil and can be grown successfully without inoculation. These two varieties therefore, should be recommended for resource-poor farmers.

3.9.4.2. Bean

Common bean is widely grown in the high rainfall area either intercropped with or as a rotation with other crops in Chitemene and Fundikila farming systems. Bean yields rarely exceed 500 kg ha^{-1} as farmers rarely apply fertilizer dependent mainly on low quality organic inputs and/or ash culture. For these cash-strapped farmers one way in which bean yield may be improved is by inoculation.

Trials were conducted in 1988 at Misamfu and Mbala on Misamfu yellow and Konkola soil series to assess the response of common bean to inoculation with local *Rhizobium* isolates (SPRP series) and with imported *Rhizobium leguminosarium* biovar *phaseoli* (CIAT series). Carioca and Mbala local mixture varieties were tested. Common bean responded to inoculation with introduced *Rhizobium* strains and to fertilizer with resultant yield increases (Table 36).

Table 36. Common bean response to inoculation and fertilizer application

Inoculum	Bean yield Carioca	Due to	Local mix	Due to
	kg ha^{-1}			
Control	600		560	
100 kg N ha^{-1}	1790	1190	1370	810
SPRP 28	na†	na	1200	640
CIAT 274	1150	550	550	nil
CIAT 632	1000	400	520	nil
CIAT 899	1200	600	800	240
CIAT 652	890	290	590	30
TAL 1797	650	50	950	390

† Data not available

The response to inoculation was however, varied with varieties. The local common bean mixture, widely used by subsistence farmers, yielded less and was less responsive when compared to Carioca variety (Table 36). Generally the response varied from year to year and was very much dependent on rainfall and soil type. The local isolate SPRP 28 seems to hold potential as it out yielded the imported strains (Table 36).

3.9.4.3. Groundnut

Groundnut is an important crop in northern Zambia as it compliments the dietary needs of the rural population. As with other legumes, groundnut requires starter nitrogen (20 - 30 kg N ha^{-1}) and a cheap nitrogen source would be through inoculation with effective strains of *Rhizobium*. Among all legumes, groundnut has the greatest affinity to calcium nutrition. The ability of lime to reduce pod filling failure and enhancing microbial activity was also investigated by applying 1.8 t ha^{-1} dolomitic limestone. Inoculating groundnut with TAL 1000 without liming increased groundnut yield by as much as 100%. With liming however, inoculation becomes less important. Lime acting as an ameliorator of soil acidity, as well a principal source of calcium for groundnut nutrition contributed greatly to groundnut yield with increases up to 300% (Table 37).

Table 37. Liming and biological nitrogen fixation (BNF) in groundnut

	Groundnut yield		Yield due to
	---------- kg ha^{-1} ----------		
Treatment	Unlimed	Limed†	Lime
Control	400	1300	900
20 N	420	1340	920
TAL 1000	830	1470	640
Yield due to inoculum	430	170	

† Lime applied at about 2 t ha^{-1} dolomitic limestone

It would seem that liming also facilitated suitable environment for nitrogen-fixing bacteria and it also rendered micronutrients (molybdenum and boron) available for groundnut nutrition. Lime also helped reduce pod filling failure in groundnut from as much as 97% in control plots to 21% when limed.

3.10. Microbial biomass and litter quality

3.10.1. Microbial biomass

Soil microorganisms are the main decomposers of organic matter and are therefore, important in the release of nutrients otherwise locked up in undecomposed organic residues. Studies in microbial ecology was conducted to estimate microbial populations in various environments (Dambo, pasture, Miombo woodland, improved fallows and cultivated lands). The evaluation was conducted both in dry and wet conditions to investigate changes in microbial populations with seasons and when lands are put under various management systems. The fungi were found to exhibit higher microbial biomass than bacteria (Table 38). The Miombo woodland and Dambos had more fungi and bacteria than the cultivated areas. The microbial populations in a second year Chitemene were not fully established after destruction by burning.

Seasonal variations in abundance of bacterial and fungal populations seems to occur. In the rainy season more colony forming units per gramme soil were encountered (10^7) than in the dry season (10^4). The fungal biomass was found to be the primary decomposers while bacterial populations were secondary. The dominance of the fungi was attributed to the tolerance exhibited by fungi to soil acidity as opposed to the susceptibility of a large proportion of bacterial species under the same environment.

Table 38. Microbial biomass in forested and cultivated soils

		Microbial biomass		
		Fungal		Bacterial
Landuse†	Treatment	Total	Active	Total
		(Meter g^{-1} soil)		(x 10^8 g^{-1} soil)
Dambo	Natural grass	111.7	11.1	12.0
Pasture	mixed grasses	45.5	8.9	5.9
Forest	Miombo woodland	58.2	6.6	9.2
Improved fallow	*L. leucocephala*	46.3	5.9	8.2
Fundikila mounds	*Hyperrhenia*	45.8	5.0	7.3
Fundikila mounds	*C. zanzibaricum*	48.9	4.4	7.0
Maize cropping	No fertilizer	40.5	4.3	6.5
Maize cropping	120 kg N ha^{-1}	47.8	3.5	7.1
2nd-year Chitemene	Groundnut	39.3	1.6	4.1

† The representative upland soil used was Misamfu yellow soil series

In a separate study nitrification in soils of the Miombo woodland and the cultivated areas was assessed. Undisturbed sites support a higher microbial biomass but keep the soil nutrients locked up and unavailable for other processes. When the soil is put under cultivation, the microorganisms are destroyed releasing nutrients as they decompose. This is supported by higher levels of nitrate nitrogen found in the 20 - 40 cm soil layer in cultivated soils than in the undisturbed Miombo woodland, signifying higher rates of nitrification when land is cleared and cultivated. It would appear that nitrification is accelerated when land is cleared and when ammonium nitrogen is oxidized to nitrate nitrogen. Due to high rainfall the formed nitrate nitrogen is likely to be leached down the soil profile to still lower soil levels.

3.10.2. Litter quality and decomposition

The decomposition of plant residues (litter) is carried out mainly by soil microorganisms. The rate of decomposition depends mainly on climate (rainfall) and the quality of litter (contents of lignin, polyphenolics, carbohydrates, protein). If the litter is poor in nitrogen, the microbes have to take nitrogen from the soil to speed up the decomposition process. If enough nitrogen is not available in the soil, the process slows down and may even stop. This may lead to a slow release or immobilization of existing plant available nitrogen. In tropical agriculture, a lot of research efforts are being made to use biological means such as biological nitrogen fixation, agroforestry and improved fallows for developing low input farming systems.

Table 39. Organic matter quality: nutrient content

	Nutrient content							
Litter type	N	P	K	Ca	Mg	S	Mo	Zn
	---------- kg t^{-1} ----------						------ ppm -----	
Sesbania sesban	46	3.4	18.4	9.5	2.0	3.1	0.5	24.2
Cassia spectabilis	38	2.5	16.1	8.4	2.7	2.3	0.7	14.4
Tephrosia vogelii	36	2.3	7.5	8.6	3.1	1.9	0.4	15.3
Albizia guachepele	34	2.4	5.5	13.7	4.4	1.9	2.5	16.4
Stylosanthes zanzibaricum	17	1.1	13.5	12.1	3.3	0.9	0.9	19.0
Flemingia congesta	29	2.2	12.4	6.8	1.7	1.6	0.6	21.1
Panicum maximum	8	1.5	19.5	2.0	1.4	0.7	0.8	15.8
Jubernardia paniculata	20	3.2	6.7	8.6	4.0	1.3	0.3	13.5
Hyperrhenia	8	1.7	5.2	4.5	1.5	0.8	7.6	14.4
Baphia berquertii	30	1.4	4.3	3.8	1.6	1.3	0.7	14.4
Brachystegia longifolia	18	1.5	2.6	10.5	1.5	1.0	0.5	14.7

To be able to recommend a suitable plant species for an improved nutrient cycling, it is of utmost importance to study the kinetics of decomposition of potential biological materials, so as to reduce inorganic fertilizer input. The objective of the study was to evaluate the kinetics of mass loss and nutrient cycling from eleven litter types comprising eight tree and three grass species (Table 39). The nutrient content of various litter types show that *Sesbania sesban* followed by *Cassia spectabilis* and *Albizia* *guachepele* had highest initial nutrient composition while grasses had the least. The chemical analysis further suggest that only nitrogen levels are adequate to substitute inorganic fertilizer inputs.

Litter decomposition measured as rate of mass loss over time was determined by placing 3 g dried litter at room temperature into litter bags which were later placed in the field during the wet season. In general the litter types with high nutritional levels had the highest mass loss with *Flemingia congesta* and *Stylosanthes zanzibaricum* decomposing the fastest. (Table 40). Exceptions were *Baphia berquertii* and *Brachystegia longifolia* which have high nutritional status but had lower mass loss rates than the grasses. Different lignin contents, allelopathic effects, or non-availability of existing nutrients could account for the lower mass loss rates.

Table 40. Organic matter quality: litter decomposition

	Mass loss in days					
Litter type	10	20	30	60	90	120
	------------------ Mass loss (%) ------------------					
Sesbania sesban	56	70	77	91	98	96
Cassia spectabilis	38	55	66	84	92	96
Tephrosia vogelii	40	53	58	88	92	88
Albizia guachepele	40	53	63	81	94	94
Stylosanthes zanzibaricum	26	38	57	89	96	95
Flemingia congesta	14	21	49	59	78	73
Panicum maximum	14	26	35	49	73	77
Jubernardia paniculata	13	22	28	47	60	63
Hyperrhenia	12	23	43	52	80	81
Baphia berquertii	7	19	29	46	54	69
Brachystegia longifolia	8	10	13	22	40	38

The change in nutrient content with time was also evaluated by periodic sampling. The potassium and phosphorus contained in the litters had an initial quick release while calcium, magnesium and sulphur had a slower but more steady release with time (Table 41). Nitrogen had a less unpredictable release pattern. Generally the nitrogen fixing plants had a faster nitrogen release than the non-fixing ones. *Cassia spectabilis* however, a non-fixing plant, resembled *Tephrosia vogelii* (not presented) in release pattern and had a faster release than the nitrogen fixing *Flemingia congesta* and *Baphia berquertii*. *Brachystegia longifolia* and *Hyperrhenia* released minute amounts of nitrogen initially and after 30 days there was hardly any nitrogen release.

Table 41. Organic matter quality: change in nutrient content with time

Litter type	Days	N	P	K	Ca	Mg	S
		Nutrient content					
		---------------- mg g^{-1} ----------------------					
Sesbania sesban	0	35.7	2.7	14.3	7.4	1.5	2.4
	10	13.0	0.8	1.5	4.2	0.7	1.1
	30	6.0	0.2	0.3	2.5	0.4	0.4
Cassia spectabilis	0	29.7	1.9	12.5	6.5	2.1	1.8
	10	20.7	0.5	1.0	4.7	0.7	1.4
	30	10.7	0.2	3.8	2.8	0.3	0.9
Flemingia congesta	0	27.2	2.0	11.6	6.4	1.6	1.5
	10	23.2	1.0	3.1	5.2	1.0	1.3
	30	13.6	0.5	1.0	4.1	0.8	0.9
S. zanzibaricum	0	12.7	0.9	10.5	9.4	2.5	0.7
	10	8.0	0.3	1.3	6.5	1.4	0.5
	30	4.7	0.2	0.4	3.3	0.5	0.3
Hyperrhenia	0	6.3	1.3	0.7	3.5	1.2	0.6
	10	4.3	0.6	2.1	2.1	0.7	0.5
	30	4.7	0.3	0.6	1.8	0.5	0.4

3.11. Cropping systems

3.11.1. Agroforestry

Initiated in 1983 at SPRP agroforestry research became the first project to undertake such research work in Zambia. The objectives were to develop alternative technologies to prevailing shifting cultivation with agroforestry to form permanent farming systems. Agroforestry systems in other parts of the world generally have proved to be sustainable by increasing overall productivity of the land. This is attributed to combined productivity of food crops and trees and/or animals in a unit area.

Agroforestry research involves several stages of implementation. The diagnosis and design exercise which identifies the constraints and possible solutions to crop production was conducted by ICRAF at the request of SPRP in March 1985. The second stage was acquisition of seed of various tree and shrub species to be used in agroforestry. Local seed collection and requests to various international institutions were extended. The seed so collected underwent rigorous screening after which the promising species were selected. Selected species were raised in the nursery before transplanting for evaluation in the field.

3.11.1.1. Mass screening of exotic and indigenous species

An important part of SPRP's research was to test and screen new tree species with potential for agroforestry research in northern Zambia. The research material was requested from the Commonwealth Forestry Institute at Oxford which supplied a seed-lot of 26 species. Seed from thirty indigenous species was collected. The seedlings were raised in the nursery four to six months prior to transplanting in the arboretum.

Table 42. Exotic tree species screening four (4) years after establishment

Tree species	Survival	Height	Biomass Wood	Biomass Prunings	Biomass Total drymatter
	(%)	(m)	------------ g plant^{-1}		----------------
Leucaena leucocephala	86	1.4	300	80	380
Gliricidia sepium	84	1.0	350	70	420
Ateleia herbert-smithii	100	1.4	740	250	990
Acacia farnesiana	89	1.0	220	190	410
Albizia guachepele	98	1.9	1070	50	1120
Haematoxylon brasiletto	100	1.3	580	460	1040
Leucaena diversifolia	91	1.8	440	120	560
Acacia pennatula	63	1.0	1230	670	1900
Enterolobium cyclocarpum	97	1.7	640	80	720
Sena atomaria	97	1.7	770	230	1000
Calliandra calothyrsus	70	4.0	4230	450	4680
Flemingia congesta	88	2.6	1430	600	2030

The results (Table 42) indicated that *Calliandra calothyrsus* and *Flemingia congesta* could be recommended for field evaluations. *Albizia guachepele, Enterolobium cyclocarpum* and *Ateleia herbert-smithii* showed promise but still required establishment and lopping management observations. A more critical examination of *Acacia pennatula* and *Gliricidia sepium* was found wanting.

Table 43. Indigenous tree and shrub screening

				Drymatter weight				
Plant species	Age	Height	Root	Root	Stem	Leaves	Fruit	Total
	Days	cm	cm	g $plant^{-1}$				
Sesbania macrantha	202	315	196	135.7	289.6	69.2	77.0	571.5
Tephrosia vogelii	236	104	135	55.8	120.0	163.8	14.6	354.2
Cassia obtusifolia	220	38	148	39.4	8.2	39.0		86.6
Crotalaria spp.	157	70	145	8.5	16.6	27.2		52.3
Cassia petersiana	215	28	160	21.3	6.7	21.1		49.1
Cassia singuena	219	38	104	21.0	6.0	21.3		48.3
Acacia polyacantha	160	33	95	11.0	4.0	6.8		21.8
Entada abyssinica	156	25	68	11.7	1.6	7.0		20.3
Bahinia petersinia	148	39	100	7.5	3.1	5.7		16.3
Baphia bequaertii	171	5	111	0.8	0.1	0.3		1.1

Survival rate among the indigenous species was more than 80% with growth rate of saplings varying according to species. Except for *Baphia bequaertii* and *Entada abyssinica* (in Table 43), the rest showed better growth rates than *Leucaena leucocephala*. In addition the growth rates of *Sesbania macrantha* and *Tephrosia vogelii* were more than that of *Flemingia congesta*. The *Cassia* species and *Tephrosia vogelii* produced more leaf biomass and to some extent were taller than *Leucaena leucocephala*. *Sesbania macrantha*, *Crotalaria* species, *Entada abyssinica* and *Tephrosia vogelii* were found to be heavy nodulators but with poor taproot system. Most of the roots were found to spread laterally with root tips coming close to the soil surface. It is feared competitive biological interaction with food crops for water and nutrients would take place.

The screening exercise eventually selected *Cassia spectabilis, Calliandra calothyrsus, Cajanus cajan, Tephrosia vogelii, Gliricidia sepium* and *Flemingia congesta* as plant species having potential in agroforestry systems. *Leucaena leucocephala* was maintained, though it performed poorly under acid conditions. A search for acid tolerant species continued through acquisition of more cultivars.

3.11.1.2. Investigations on seedling handling

Presowing seed treatments and seed zone conditions were investigated as germination requirements for majority of acquired species were not known. The seed was subjected to acid and mechanical scarification, hot water treatment and direct sowing. Seed zone conditioning involved covering seed with black polythene, burying or leaving seed on soil surface and using mulches.

Table 44. Effect of mulch on germination of directly sown tree species

	Seed germination (%) at 4 and 8 weeks after seeding								
	Flemingia congesta			*Cassia spectabilis*			*C. calothyrsus*		
Treatment	4wks	8wks	Total	4wks	8wks	Total	4wks	8wks	Total
No mulch	35	56	91	25	29	54	66	25	91
Grass mulch	44	51	95	32	43	75	28	29	57
Legume mulch	40	45	85	30	29	59	42	41	83

Sesbania macrantha, *Crotalaria* species and *Tephrosia vogelii* germinated easily without seed pretreatment. The *Acacia* species *Tephrosia vogelii* and *Albizia* germinated well when subjected to hot water treatment. Mechanical scarification enhanced germination of *Entada abyssinica* and *Acacia polyacantha*. Scarified seed germinated better when left on soil surface as the seed tended to rot when buried due to excess soil moisture and fungal infection. The other presowing seed treatments favoured burying for better germination.

Mulch type or generally mulching did not greatly affect germination percentage of seed (Table 44). It is however, preferable to apply mulch for moisture retention especially when raising seedlings during the dry periods of the year. The survival rate of directly sown and transplanted seedlings showed an advantage with transplanting well established seedlings (Table 45) but considering the resources and labour for raising seedlings direct sowing, where possible, seems attractive.

Table 45. Survival and growth of directly sown and transplanted leguminous woody species one year after each operation (Source: SPRP Annual Reports, 1987 & 1988)

	Planting method†			
	Direct sowing		Transplanting§	
Tree species	Survival	Biomass	Survival	Biomass
	(%)	(Kg ha^{-1})	(%)	(kg ha^{-1})
Gliricidia sepium	100	800	91	740
Enterolobium cyclocarpum	78	200	94	na¶
Cassia spectabilis	67	500	85	230
Calliandra calothyrsus	48	400	90	595

† Inconsistencies in tree species planted has been observed
§ Six months old seedlings from nursery transplanted late in March
¶ Data not available

3.11.1.2. Cultivar screening

3.11.1.2.1. Pigeon pea

Pigeon pea (*Cajanus cajan*) is a food crop in many tropical countries. It is not a new plant in northern Zambia as many households grow it although more as a live fence or ornamental than as a food crop. It is a good protein source with 22% seed protein. The plant is adapted to marginal soil conditions (low fertility, low pH, drought tolerant). Pigeon pea is a multi-purpose plant that can be used as food, mulch and fuel. It protects the soil against erosion by producing an early dense protective cover and contributes to soil fertility through nitrogen fixation and heavy litter fall. Pigeon pea may thus be an essential component in the growing of food crops under improved soil productivity conditions.

In order to promote systematic adoption of pigeon pea in farming systems it was necessary to screen and select cultivars which would suit the agroclimatic conditions of the area. Thirteen cultivars were procured and tested at Misamfu in 1984. In terms of obtainable grain yields Bahar G82K, Kaki-1948 and Linea7-1983 were candidate cultivars. These would yield more or less uniformly for a number of cropping seasons which in turn would be advantageous for the farmer.

Table 46. Pigeon pea cultivar screening

		Plant stand (%) and grain yield (kg ha^{-1})				
Cultivar	Source	1st Year	Yield	2nd Year	Yield	3rd Year
Kaki-1948	PuertoRico	100	1550	88	1140	28
Linea 7-1983	PuertoRico	100	1550	98	1060	66
Gwalior-3	ICRISAT	100	1060	85	320	21
Bahar G82K	ICRISAT	100	2940	78	1306	4
ICP-7035	ICRISAT	100	1710	78	160	4
ICP-9156	ICRISAT	100	820	82	160	5
6443	ICRISAT	100	2120	82	320	10
ICPL-310	ICRISAT	100	3100	55	160	10
1CPL-365	ICRISAT	100	1880	68	320	8
ICPL-265	ICRISAT	100	1550	20	0	0
ICPL-358	ICRISAT	100	820	85	650	12

Kaki-1948, Linea7-1983 and Gwalior-3 seemed good candidates in agroforestry research as their survival rate and coppicing ability showed (Table 46). Cultivars Bahar G82K and ICPL-310 may be good component in farming systems with annual crops. Generally, cultivars from ICRISAT are good contenders for mulch production in both Fundikila and Chitemene agriculture.

3.11.1.2.2. *Gliricidia sepium*

Gliricidia sepium is a multi-purpose tree species which during mass screening stage showed to have potential in agroforestry. Large genotypic variation for this species has been observed at IITA and ILCA where germplasm improvement studies on 30 different accessions is being carried out with the emphasis on forage production. The cultivar screening trial at Misamfu (1986) showed HYB 11, ILG 58 and ILG 50 cultivars to have some degree of soil acidity tolerance as evidenced from their survival rate (Table 47). In addition, more biomass was realized from these cultivars.

Characteristic of *Gliricidia sepium* is seasonal litter fall with prolonged dormancy of older shoots.

Table 47. *Gliricidia sepium* cultivar screening

Cultivar	Survival rate	Total dry biomass
HYB 11	64	680
ILG 58	87	670
ILG 50	68	650
IITA	41	280
ILG 63	37	280
Gualan	37	280

3.11.1.2.3. Castor bean

Castor bean on average contains 43% oil. The oil is used in the manufacture of soap, nylon, paints, varnishes, plastics, brake fluids and in the pharmaceutical industry. The oil cake is toxic to act as supplemental animal feed but can be used as an organic fertilizer or can be compacted with rock phosphates to produce organophosphates. Out of thirteen locally collected cultivars, the cultivars presented in Table 48 were the ones found to be high yielding as well as high in oil content and could easily be grown with minimum fertilizer inputs.

Table 48. Evaluation of castor bean

			Yield†			
Cultivar	Germination	Maturity	0	200	400	Oil
	(%)	(Months)	--------	kg ha^{-1}	-------	(%)
V-3	78	3	590	1070	990	45
V-5	93	4	690	1170	1280	44
V-6	52	4	410	760	960	42
V-12	87	na§	280	430	570	41

† Yield in response to fertilizer applied at 0, 200 and 400 kg compound D ha^{-1}

§ na = Data not available

3.11.1.2.4. *Leucaena leucocephala*

Leucaena leucocephala is one of the most widely used tree species in agroforestry. Although it performed poorly under acid conditions in northern Zambia a search for acid tolerant species suited to the agroecological conditions continues through acquisition of more cultivars. A cultivar trial with 16 entries was initiated from 1984 with a local entry *Leucaena diversifolia* included. Due to poor performance under acid conditions, testing was conducted under normal and limed conditions. To compare the potential of these cultivars, root collar diameter, height and biomass production were measured periodically.

Table 49. *Leucaena* species screening

Species	Ø Root collar		Height		Dry biomass	
	0 lime	2 lime†	0 lime	2 lime	0 lime	2 lime
	------------------ cm		------------------		---- kg ha^{-1} ---	
Leucaena collinsii	2.9	3.0	195	270	12000	12000
L. macrophylla nelsonii	2.3	2.0	220	160	2400	2800
L. diversifolia (indigenous)	2.0	2.0	145	140	1400	2200
L. esculanta paniculata	1.7	1.9	120	140	700	1300
L. diversifolia diversifolia line 1	2.0	2.2	145	165	700	1200
Leucaena salvadorensis	1.7	1.7	120	150	600	1100
Leucaena shannonii line 1	1.2	2.1	40	150	500	1100
L. diversifolia stenocarpa line 1	1.7	1.6	105	120	250	1000
L. leucocephala glabrata	2.0	2.0	105	90	500	570
Leucaena multicapitulata	2.2	2.0	125	110	500	500
L. lanceolata lanceolata	1.2	1.5	65	72	300	500
L. diversifolia diversifolia line 2	na	1.3	65	72	150	500
L. esculanta	1.9	1.2	90	49	100	300
L. diversifolia stenocarpa line 2	1.2	1.4	155	72	nil	300
Leucaena pulverulenta	1.0	0.9	40	35	nil	100
Leucaena trichoides	1.0	0.9	65	60	nil	nil

† Lime applied at 0 and 2 t ha^{-1} rate at beginning of experiment

Table (49) above shows measurements in the third growing season after establishment. Results to date show *Leucaena collinsii, L. macrophylla nelsonii* and *L. diversifolia* having greatest potential in terms of soil acidity tolerance, general growth and potential biomass production. The other cultivars that need further investigation are *Leucaena esculanta paniculata, L. diversifolia diversifolia* line 1, *L. salvadorensis* and *L. shannonii* line 1.

3.11.1.2.3. Tree species and cover crops in traditional farming systems

Introducing fast growing leguminous tree species in the traditional farming systems (Chitemene and Fundikila) may contribute in maintenance and/or build up of soil fertility through additions of organic matter by litterfall and root denudation, may prevent soil erosion and leaching of nutrients and contribute to soil nitrogen reserves through biological nitrogen fixation. Where fertilizers are being used as in some Fundikila circumstances, fast growing nitrogen fixing plants and cover crops may improve the productivity and sustainability of the system and reduce the need for fertilizer inputs.

Table 50. Improving Chitemene and Fundikila by use of leguminous trees and cover crops (all crops were grown only once in a rotation sequence)

Chitemene				Fundikila†			
Treatment	Millet	Gnut	Maize	Treatment	Millet	Gnut	Cowpea
	--------- kg ha^{-1} --------				--------- kg ha^{-1} -----------		
Chitemene	2470	1300	1480	Fundikila	380	850	380
+ *F. congesta*	2210	1300	1330	+ *F. congesta*	720	590	220
+ Pigeon pea	2100	1140	1260	+ Pigeon pea	1190	nd	430

† *Cassia spectabilis* and *Calliandra calothyrsus* investigated under Fundikila produced similar results as *Flemingia congesta* treatment

Flemingia congesta, Cassia spectabilis, Calliandra calothyrsus and pigeon pea were introduced in these traditional farming systems to test the above hypothesis. The test crops were fingermillet, groundnut, cowpea and maize grown in rotation as presented in Table (50). The results show only one cropping cycle, however. Except pigeon pea leguminous shrubs were pruned at regular intervals with the prunings incorporated in ridges. Findings indicated no benefits to inclusions of agroforestry shrubs in

Chitemene gardens. Terminating the experiment prematurely with one growing cycle only may have masked the intended benefits. The conclusion that "*Flemingia congesta* was found not to be a suitable agroforestry species for alley cropping" (SPRP Annual Report, 1989, p5) was hastily arrived at. Millet responded well to introduced legumes although the reasons for the decline in groundnut yield and cowpea are unclear. The tree species superimposed could not be directly implicated.

3.11.1.2.3. Agroforestry shrubs: Pruning heights and frequencies

Flemingia congesta, Cassia spectabilis and *Calliandra calothyrsus* were found to be promising agroforestry tree species. They are fast growing, well adapted to acid soils and they tolerate repeated prunings. Information on timing, frequency of pruning was needed to obtain the optimum quantity of biomass at the right time of the year for the food crop. The data on pruning management is difficult to interpret in that: (1) in 1988 data was pooled and expressed as percentage drymatter without knowing the actual amounts pruned for each frequency; (2) in 1989 only Cassia spectabilis data was presented and it was expressed in kg $plot^{-1}$ without giving plot size; (3) in 1990 the frequencies were confounded into data cumulative of all the prunings in one cropping season.

Table 51. The effect of pruning height and frequency on biomass production of *Flemingia congesta, Cassia spectabilis* and *Calliandra calothyrsus*

Height	Frequency	Tree species		
		F. congesta	*C. spectabilis*	*C. calothyrsus*
(cm)		----- kg ha^{-1} -----		
25	2	955	2135	1095
25	3	725	1495	850
50	2	1295	2640	1505
50	3	1080	1410	1070
75	2	1730	2675	1180
75	3	1600	1790	1155

Only the two year data (1992 and 1993) address the trial objective and its the data means from these years that are presented in Table 51. In alley cropping where food crops are planted in alleys formed by tree hedges, pruning becomes an essential component in management to prevent shading of the food crops. The investigation's objective was to determine the optimum pruning height and pruning frequencies per cropping season in order to maximize the biomass production from these trees for incorporation into the soil and subsequent crop plant use. The experiment was conducted on Misamfu red soil series at Misamfu with each plant species pruned twice or thrice at 25, 50, and 75 cm height during the crop growing season.

The Table (51) above shows cumulative dry biomass yield expected in a single cropping season in relation to pruning sequence and plant height. The findings show that biomass production is optimized with two prunings per cropping season. This may be attributed to the increased number of nodes from which new shoots are able to coppice and the amount of time allowed for the tree species to vegetatively grow. Pruning at 50 or 75 cm height seemed to be the most convenient and at these heights more biomass was produced. Tree prunings are only effective when large quantities of biomass can be realized, whose decomposition in the soil will provide nutrients that will be utilized by the food crop. The dry biomass potential from all the trees tested is not large enough to be used effectively in agroforestry. Other literature estimate organic matter additions in excess of 10 - 20 tonnes dry matter per hactre as amounts that could be effective. The data in the next section clearly illustrates this reasoning.

3.11.1.2.4. Agroforestry shrubs: Crop response to prunings

In alley cropping prunings from the tree hedgerows are used to provide organic manure and mulch to improve soil fertility and sustain yields of food crops grown in alleys. It is difficult to determine the effect of the pruning applications on crop yield given the large variations encountered in soils and variations in biomass production from various tree species. Investigations in which known quantities of biomass from prunings when applied to a food crop would help to understand crop responses. A number of tree species were tried in alley cropping with known quantities of biomass (Table 52) but without inorganic fertilization (*Flemingia congesta, Cassia spectabilis*), and with inorganic fertilization (Table 53). Results show that the biomass realized from prunings was inadequate to be agronomically effective. Yields therefore, increased with increase in biomass application but without attaining the optimum yields such as those obtained with inorganic fertilization (Table 53). The situation was acerbated by no additions of inorganics which usually led to stunted growth and chlorosis in maize (SPRP 1990 p16).

Table 52. Maize response to pruning applications of *Flemingia congesta* and *Cassia spectabilis* (mean yield for five cropping seasons)

Treatment	No trees	*Flemingia congesta*	*Cassia spectabilis*
	------------------------------	kg ha^{-1}	------------------------------
Control	750		
Lima fertilizer rec	4290		
2 t ha^{-1} prunings		986	820
4 t ha^{-1} prunings		880	1430
6 t ha^{-1} prunings		1410	2870

Table 53. Alley cropping and maize yield

	Yield at three N levels					
	1985 - 1993 mean yield			1989 - 1993 mean yield		
Treatment	0	60	120	0	60	120
	----------	kg ha^{-1}	---------	----------	kg ha^{-1}	----------
No tree species	970	2580	3850	1000	3100	4560
Leucaena leucocephala	2030	3500	4000	2670	4550	5260
Gliricidia sepium	1260	2620	3590	1590	3360	4440
Flemingia congesta				1640	3700	5170
Due to fertilizer†		1610	2880		2100	3560
Due to *Leucaena*	1060	920	150	1670	1450	700
Due to *Gliricidia*	290	40	nil	590	260	nil
Due to *Flemingia*				640	600	610

† In addition to fertilizer nitrogen 2 t ha^{-1} dolomitic lime and 50 kg ha^{-1} multi-micronutrient compound were applied at trial inception plus yearly applications of 20 kg P ha^{-1} (SSP) and 100 kg K ha^{-1} (Muriate of potash)

In alley cropping where all nutrients were provided except nitrogen which was variable, the scenario did change (Table 53). Here we encounter yields comparable to those of inorganic fertilization but still crop yield due to fertilization remained superior to that of tree species. Alley cropping and agroforestry in general holds potential only when the trees employed are able to produce high amounts of biomass than the amounts produced currently. One avenue is to continue the screening and testing of tree species programme.

3.11.1.2.5. Comments, observations

Most field trials in agroforestry research concentrated on alley cropping only. (The exception is the fodder species trial). There is more to agroforestry than alley cropping only. A classical example is cited above under restoration of abandoned lands by use of perennial legumes. The same strategy could be carried out using agroforestry trees. This would win more acceptance by the client than the labour demanding alley cropping. Alley cropping however, still has a place but in niches such as on steep slopes.

Some agroforestry trials have been conducted with no consistency, starting with site selection, tree species employed, trial execution, up to data handling. More time should be spent on working out the trial objectives and subsequent trial designs to be employed. Agroforestry endeavours towards less use of inorganics but not using more organics as witnessed in the "High versus medium input alley cropping experiments" where apart from the difference in lime inputs the other inputs remained high (17 kg P and 16 kg K ha^{-1}); or no inputs as the investigations in this review show. The optimum inorganic fertilizer rates should be worked out whilst realizing the benefits from trees contributions.

On-farm experimentation is one of the major activities in agroforestry research yet the data from these are either not available or are inconsistently reported. These activities are recommended to be shelved until co-ordinated and comprehensive objectives are worked out.

3.11.2. Intercropping

Intercropping, mixing or interplanting of a number of different crops on the same piece of land at the same time is a common practice among the subsistence farmers. The benefits of the system are manifold. Intercropping increases the use efficiency of scarce resources (for example fertilizer). It reduces risk of dependence upon a single crop that may be susceptible to environmental, biological and economic fluctuations and it offers variety of return from land and labour. A critical study under agroecological conditions of the high rainfall area was required to study not only the interaction between the component crops but also their agronomy so as to develop more efficient systems thereby increasing agricultural productivity. A number of field experiments were conducted at Misamfu with cereal-legume intercropping common in the region. The findings are discussed in this review.

Groundnut, bean and soybean were intercropped with maize and compared with monocropping of each crop. Table 54 shows yields that can be achieved from pure stands with standard fertilizer recommendations and at designated plant spacings and populations. Once intercropping was introduced the plant population densities for each intercropped crop immediately reduced in size and consequently a reduction in yield was apparent (Table 55). Soybean and bean, nevertheless, indicate the positive use efficiency of applied fertilizers mainly designated for maize uptake. Groundnut, in contrast, suffered heavily when intercropped since it was top dressed with about 50 kg N ha^{-1} during maize top dressing. as will later be illustrated in this review, groundnut is susceptible to heavy nitrogen applications resulting in grand vegetative growth with little or no seed development.

Table 54. Crop responses to NPK (pure stand)

	Crops			
	Maize	Soybean	Bean	Groundnut
Treatment	40000	160000	160000	80000†
		kg ha^{-1}		
Control (no fertilizer)	2200	1500	500	N/A
200 D + 150 A/N	4500	1900	1000	1000
400 D + 300 A/N	6950	2000	1200	N/A

† Groundnut received 200 kg D ha^{-1} only and was planted at 1.0 x 0.12 m spacing. The other legumes were subjected to treatments as indicated at spacing of 0.5 x 0.12 m

Table 55. Crop responses to NPK (intercropped with maize)

	Plant stand and yield†			
	Maize	Soybean	Bean	Groundnut
Treatment	28000	72000	72000	40000†
	kg ha^{-1}			
Control (no fertilizer)	1050	800	200	N/A
200 D + 150 A/N	3500	1000	400	370
400 D + 300 A/N	4250	1200	700	N/A

† Soybean and bean occupied 33% of pure stand maize. Groundnut was planted between maize plants in same row achieving same population density as that of maize.

It seems intercropping beans and soybean with maize seems beneficial to both crops. The legumes usually provide ground cover and thus maintain soil moisture while at the same time reducing the rainfall impact on the soil surface. Weed infestation usually is least affected.

When fingermillet was intercropped with soybean at 0.5-m rows spacings soybean successfully reduced weed infestation, which otherwise is the main reason farmers do not grow fingermillet without burning (Chitemene). In addition intercropping soybean with fingermillet at 1:2 ratio (Table 56) did not drastically reduce yields of either crop suggesting this was the most profitable combination with fertilization at 18 kg P, 40 kg K and 45 kg N ha^{-1}.

Table 56. Fingermillet soybean intercropping

		Yield	
Cropping	Crop proportion	Soybean	Fingermillet
		kg ha^{-1}	
Sole crop	1:0	850	600
Intercropping	1:1	465	253
Intercropping	1:2	545	668
Intercropping	2:1	653	383

3.12. Crop management

Fertilizers alone are incapable of realizing the yield potential of crops. Equally important is the role of management in agricultural production. Management increases crop production in various ways (weed, disease and pest control, soil fertility maintenance, fertilizer use efficiency, etc.).

3.12.1. Weed control under maize production

Weeding is a factor which largely suppresses crop yields. Without proper management farmers stand to lose more than 30% of their crop due to weed infestation. Weeding is a farm operation which competes with other pressing farm operations and hence labour becomes a constraint. The problem is further compounded by unaffordable herbicides. Leguminous cover crops may offer some protection against soil erosion, help maintain soil fertility and suppress weeds. Commonly encountered weeds associated with maize production are ox grass (*Eleusine indica*), nut sedge (*Cyprus esculentus*), pigweed (*Ameranthus hybridus*) and wondering Jew (*Lucas martinicensus*).

Table 57. Weed control methods and crop yield

Management	Maize yield (Kg ha^{-1})
No weeding	1000
One weeding	2300
Clean weeding (2 - 4 weedings)	3700
Pre-emergence herbicide (Atrazine)	4000
Post-emergence herbicide (Glyphosphate/Roundup)	2062
Cover crops†	710

† Cover crops *Stylosanthes guianensis, Pueraria phaseoloides, Centrosema pubescens*, cowpea and *Crotalaria zanzibaricum*

Multi-location and multi-year experiments were conducted to evaluate manual weeding and frequencies, herbicides and the performance of cover crops and their compatibility with maize in a minimum tillage system. The effectiveness and economics of these weed control methods were also studied. The experiments were conducted at Misamfu and Mansa on Mufulira sandy loam, and at Katito on Katito sandy clay loam between 1984 and 1989 seasons. Cover crops were *Stylosanthes guianensis, Pueraria* *phaseoloides, Centrosema pubescens, Crotalaria zanzibaricum* and cowpea. Herbicides were pre-emergence (Atrazine) and post-emergence (Roundup). Hand weeding and weeding frequencies were, none, one and two to four (clean) weedings. Fertilizer rates applied to the maize crop were 24 kg P ha^{-1} through single superphosphate, 40 kg K ha^{-1} as muriate of potash and three nitrogen levels (40, 80 and 120 kg N ha^{-1}).

Findings: Cover crops were intended to suppress weeds but this was not met as testified in SPRP Reports (1986 & 1987). Manual weeding in cover crops had to be conducted two to three times so that the cover crops could establish themselves. Even during cases where establishment seemed not to be a serious problem (as portrayed in sunhemp and cowpea), manual weeding still had to be performed. The objectives of this trial were therefore, not met or unless the justification was not clear from the beginning.

Clean weeding and pre-emergence herbicide out yielded all other weed control methods (Table 57). Post-emergence herbicide application performed below expectations probably due to poor handling in the field which could have caused damage to the crop. When no weeding was performed a yield of about 3000 kg ha^{-1} was lost due to weed competition. All cover crops competed for nutrients even more than ordinary weeds as they drew most of the nutrients intended for the maize crop as evidenced by the dismal yield (710 kg ha^{-1}) was obtained (Table 57).

Recommendations: As no effective cover crops for weed suppression are available, clean manual weeding for the resource-poor farmer seems the only option. Competition for added fertilizers can be minimized by side dressing or spot application. Intra plant spaces will be devoid of added nutrients, thus maximizing fertilizer availability and uptake by the intended crop. For the cash-advantaged farmer, weed control using herbicides seems to be labour saving but crop damage should be avoided by spraying on non-windy days and below the crop at near soil level. The residual effect of herbicides may be persistent and this could affect the following crop in rotation. The safety label should be studied carefully.

3.12.2. Crop rotations

Crop rotations are practised for maintenance of soil fertility, for fertilizer use efficiency and for weed, pest and decease control. Rotating a cereal after a legume has beneficial effects to the cereal crop which would utilize the residual nitrogen fixed by the legume crop the previous season. The ability for a legume to supply a cereal with this residual nitrogen varies. Good contenders in this regard are aerial legumes (beans, soybean, cowpea) the roots of which are left undisturbed after harvest and would decompose to release the nitrogen. Uprooting groundnuts and bambaranut during harvest upsets the supply. Legumes also help improve water infiltration rates.

Residual inorganic fertilizers from a well fertilized cereal (for example maize) benefits greatly the succeeding legume. It is a recommended practice to rotate cowpea, soybean and common bean after a well fertilized maize crop. Expected yields following this practice are good. Caution should be sounded with regards to hypogyls (groundnut and bambaranut) however. The residual nitrogen from a cereal may sometimes be in such large amounts that vegetative growth would be promoted at the expense of pod formation (SPRP, 1986; Singh, 1989; Mapiki, 1993). Where high nitrogen amounts are suspect, a soil test should be carried out before planting. A typical case in point are results obtained in Table 58 below. Groundnut yield was very poor due to residual nitrogen after maize which had received 88 kg N ha^{-1} through 200 kg ha^{-1} compound D and 200 kg ha^{-1} ammonium nitrate. Fingermillet on the other hand received 30 - 60 kg N ha^{-1} which was just adequate to act as starter nitrogen for the soybean crop.

Table 58. Crop rotations and yields

	Yield†			
Cropping system	Maize	Groundnut	Fingermillet	Soybean
	kg ha^{-1}			
Rotation	3400	730	500	600

† Yields as mean of five year rotation of Maize/groundnut and Fingermillet/soybean

Rotations help control weeds, pests and diseases. There are known associations in nature which persist with monocropping and disappear once rotations are introduced. There is no known effective method in the control of witchweed, but rotations seem to eliminate the weed. Bean stem maggot can easily be eliminated by growing a cereal. *Heliominthosporum* in cereals is eradicated by introduction of legumes.

3.12.3. Planting methods for maize

It is a common practice in the high rainfall area to plant maize on ridges. Ridging holds advantage over planting on flat on soils known to develop water logging due to sealing of micropores by silt illuviation. The raised ridges therefore provide a soil environment for rooting with free air and water exchange. The other reason is aluminum toxicity. Although there seems to be no abrupt change in soil pH with soil depth the percent aluminum saturation (hence toxicity) sharply increases below 20 cm soil depth (Table 59), thereby confining most roots above this depth. To exploit a larger and deeper volume of soil that is less toxic, the farmer raises the adjacent 15 - 20 cm soil into a ridge so that the effective soil depth free from aluminum toxicity is actually 30 - 40 cm. Ridging also covers crop residue from previous season thereby accelerating its decomposition and nutrient release from thereof.

Table 59. Soil acidity in soils and toxicities due to aluminum

Soil series	Soil depth (cm)	pH-$CaCl_2$	% Al saturation
Misamfu yellow	0 - 20	4.4	47
	20 - 40	4.4	71
Misamfu red	0 - 20	4.5	23
	20 - 40	4.2	80
Konkola	0 - 20	4.4	38
	40 - 40	4.3	55

Table 60. Planting methods and crop yield (kg ha^{-1})

Fingermillet		Maize	
Treatment	Yield	Treatment	Yield
Direct broadcast	570	Planted on ridges	3970
Transplant mid-December	840	Planted on flat	3500
Transplant early January	760		
Transplant mid-January	660		

Making ridges is a farm operation performed during the dry season (on light soils) or on the onset of the rainy season. It is not uncommon that the crop residue from previous season is burned either deliberately (to keep the farm clean, and to kill known weed seed during the process), or unintentionally (through accidental fires or in search of rats as a protein supplement). Under such circumstances, planting on flat seems attractive.

Results obtained from Misamfu seem to suggest that there may be no differences to planting maize by either method provided that the fertilizer recommended rates and weeding were followed (Table 60). However, for the reasons cited above, planting on ridges should be encouraged. Most soils are light textured and can successfully be worked during the dry season. Incorporation of crop residue before it is lost may be taken advantage of considering the already low organic matter contents of most of the cropped lands.

3.12.4. Fingermillet planting methods

As one of the few adapted crops in the region fingermillet is widely grown in the high rainfall area. Screening and selection tests show stability across the acid gradient. It is therefore possible to grow this crop on normal upland soil without the current Chitemene practice. Being a small grain crop belonging to the same family as ox grass (*Eleusine indica*), farmers find it easier to manage the crop under weed-free conditions hence the Chitemene practice. To manage this crop under normal cultivation practices planting in lines would facilitate weeding and top dressing. Furthermore, raising seedlings in a separate seedbed followed by transplanting onto a larger field (as is practised in paddy rice production) seems feasible. It is argued that the farmer could use the time for other farm/crop activities while the seedlings in the nursery establish.

Results from direct broadcast and transplanting techniques above (Table 60) show that the farmer would devote the first month of the rainy season (mid November to mid December) to other crops and transplanting thereafter and still get superior yields to that of direct broadcast. The yields under the normal Chitemene however, are higher than the averages cited herein. In another development, with some degree of tolerance to soil acidity, it has been shown that fingermillet can successfully be grown in upland soils using simple hand driven line seeders (SMIP, 1994). Under such a practice 80 kg ha^{-1} of proven variety seed is required with basal dressing of 200 kg compound D and top dressing with 100 kg ammonium nitrate. With weeding and bird scaring, yield potentials of between 4000 and 6000 kg ha^{-1} are possible

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Appendix 1. Experiments conducted

A. *Soil fertility*

A.1. Assessment of cause of blind ears in rice in the Chambeshi flood plains. One site, conducted from 1991 - 1994 (HC Goma & S. Phiri)

A.2. Crop response to phosphorus fertilizer on soils with different phosphate adsorption capacities. Conducted 1986 - 1989 (Mai Guldberg)

A.3. Cropping systems to potassium fertilization. One location, two sites. Conducted from 1986 - 1990 (BR Singh, HC Goma, A. Mapiki & S. Phiri)

A.4. Effect of boron, potassium and nitrogen on pod filling failure in groundnut. Pot study, 1989. Field experiment, 1990 - 1994 (Samuel Phiri)

A.5. Effect of organic matter additions through compost and mulch with and without lime and fertilizers on maize yields. Single site, one year experiment, 1984 (P. Eriksen & A. Mapiki)

A.6. Establishment of critical levels of boron for sunflower on some soils of the high rainfall area. Pot study, one year, 1986 (Sibongo Lubinda)

A.7. Establishment of critical levels of zinc for maize on some soils of the high rainfall area. Pot study, one year, 1986 (Daniel Banda)

A.8. Evaluation of indigenous liming materials as ameliorants of acid soils. One site experiment. Conducted fro 1982 - 1989 (Tveitnes & HC Svads, P. Eriksen, A. Mapiki, BR Singh, HC Goma & S. Phiri)

A.9. Evaluation of indigenous rock phosphates and product alternatives. Multi-locational trial. Conducted from 1984 - 1994 (A. Mapiki, BR Singh, S. Phiri & HC Goma)

A.10. Lime needs of some benchmark soils for crop production. Multi-locational experiment. Conducted from 1986 - 1991 (BR Singh, HC Goma, A. Mapiki, M. Guldberg & S. Phiri)

A.11.Long term fertilizer trial with continuous maize. Multi-locational national trial conducted from 1965 - 1989 (JK McPhilips, S. Tveitnes, HC Svads, P. Eriksen, A. Mapiki, BR Singh, S. Phiri & HC Goma)

A.12.Long term study of direct and residual effects of liming on maize and groundnut (Multi-locational National trial) conducted from 1971 - 1989 (JK McPhilips, S. Tveitnes, HC Svads, P. Eriksen, A. Mapiki, BR Singh & HC Goma)

A.13.Management of subsoil acidity. One site, conducted from 1986 - 1991 (BR Singh, HC Goma, A. Mapiki, M. Guldberg & S. Phiri)

A.14.Nitrogen-15 balance studies in a maize-groundnut crop rotation system in Zambia. One site, conducted from 1988 - 1993 (Alfred Mapiki)

A.15 Rejuvenation of abandoned land: Soil resilience trial, conducted 1991 - 1994 (S. Phiri & IBSRAM)

A.16.Relationship of calcium, magnesium and potassium in soils and plants. One year pot study, 1987 (Alfred Mapiki)

A.17.Response of maize and groundnut to potassium fertilization with and without lime. One location, two sites experiment. Conducted in 1985 - 1987 (P. Eriksen & A. Mapiki)

A.18.Response of maize to macro- and micronutrients on a soil from a long term fertilizer trial. One year pot study, 1986 (S. Phiri & BR Singh)

A.19.Response of maize to zinc. One site, one year, 1988 (M. Guldberg & A. Mapiki)

A.20.Study of phosphorus application methods for maize. One site experiment. Conducted from 1982 - 1986 (HC Svads, S. Tveitnes, P. Eriksen, A. Mapiki & HC Goma)

B. *Agronomy*

B.1 Comparison of clean weeding with partial or no weeding for maize and bean production. One site. Conducted in 1984 (Kåre Strande)

B.2 Comparison of maize and beans intercropping with the sole crop for grain yields. One site. Conducted from 1983 - 1989 (HC Svads, K. Strande, T. Mwambazi, J. Mwanamwenge & K. Mikkelsen)

B.3 Comparison of maize and soybean intercropping with the sole crops for grain yields. One site. Conducted from 1983 - 1989 (HC Svads, K. Strande, T. Mwambazi, J. Mwanamwenge & K. Mikkelsen)

B.4 Comparison of maize, groundnut and beans monoculture, rotation and intercropping systems for grain production. One site. Conducted from 1982 - 1989 (HC Svads, S. Tveitnes, K Strande, J. Mwanamwenge & K. Helgarker. K. Mikkelsen)

B.5 Comparison of soybean-fingermillet intercropping and rotation to their sole cropping under two nitrogen levels. One location, one site, conducted 1986 - 1990 (T. Mwambazi, K. Helgaker & J. Mwanamwenge)

B.6 Effect of delayed fertilizer application in maize production. Multi-locational investigation, conducted 1987 - 1989 (T. Mwambazi & K. Mikkelsen)

B.7 Effect of fertilizers and organic manures on the yield of fingermillet and groundnut grown sequentially on a newly cleared land. One site experiment conducted 1983 - 85.(S. Tveitnes, K. Strande, K. Helgaker)

B.8 Effect of grass and *Stylosanthes* on crop yield and soil properties. One site, one year, 1987 (K. Helgaker & T. Mwambazi).

B.9 Effect of lime, sulphur, molybdenum and *Rhizobium* on soybean yield on an acid soil. One site, conducted from 1986-1990 (K. Helgaker & T. Mwambazi)

B.10 Effect of some cover crops on maize grown at different nitrogen levels. Two locations, two site, conducted from 1986 - 1990 (T. Mwambazi, K. Helgaker & K. Mikkelsen)

B.11 Effect of time, rate and methods of fertilizer application on maize yield from two benchmark soils. Two locations, two sites. Conducted from 1986 - 1990 (J. Mwanamwenge, K. Mikkelsen & T. Mwambazi)

B.12 Establishment of pasture legumes for soil improvement. One location, one site, conducted 1987 - 1989 (T. Mwambazi, K. Mikkelsen, J. Mwanamwenge)

B. 13 Evaluation of some soil-crop management systems for sustained crop production and environmental enhancement in Zambia, conducted 1992 - 1994 (T. Mwambazi, A. Mkonda & CSD)

B.14 Evaluation of weed control methods for yield and economy of a maize crop. One site, conducted from 1986 - 1989 (K. Helgaker & T. Mwambazi)

B.15 Growing fingermillet by the technique of transplanting. Conducted 1988 - 1990 (T. Mwambazi & J. Mwanamwenge)

B.16 Improvement of abandoned land by use of perennial legumes. On-farm, one site, conducted 1986 - 1991 (T. Mwambazi)

B.17 Improvement of Fundikila, conducted 1988 - 1994 (T. Mwambazi)

B.18 Improvement of late planted beans by Fundikila through green manuring, conducted 1992 - 1994 (T. Mwambazi, A. Mkonda & CSD)

B.19 Preliminary studies on methods of planting maize. One site, one year experiment conducted in 1984 (Kåre Strande)

B.20 Preliminary studies on testing and screening of new crop cultivars. One site, one year experiment conducted in 1985 (Knut Helgarker)

B.21 Response of a cropping system to nitrogen, phosphorus, and potassium fertilization on two benchmark soils. Two sites, two locations. Conducted from 1986 - 1990 (K. Helgaker, J. Mwanamwenge, T. Mwambazi & K. Mikkelsen)

B.22 Response of upland rice to phosphorus fertilization. Two locations, conducted 1989 - 1990 (Joseph Mwanamwenge)

B.23 Soybean planting dates. Multi-locational, four sites, conducted in 1991(J. Mwanamwenge & T. Mwambazi)

B.24 Study of short and long term effects of wood burning and additions of ash versus fertilizer and lime applications on crop production. One shifting site conducted

1984 - 1990 (K. Strande, K. Helgaker, K. Mikkelsen, T. Mwambazi & J. Mwanamwenge)

B.25 Study of weeds and their incidence in test crops in agronomic studies at Misamfu. One site, one year study, 1983 (Steinar Tveitnes)

B.26 Testing of upland rice varieties at different levels of nitrogen. One location, one site, 1987 - 1990 (Joseph. Mwanamwenge)

B.27 Time of establishment and incorporation of green manure in a maize-soybean rotation. Two locations, two sites, 1992 - 1994 (T. Mwambazi, A. Mkonda)

B.28 Upland rice screening trial. One site, conducted from 1986 - 1989 (J. Mwanamwenge & K. Helgaker)

C. *Agroforestry*

C.1 A study on methods of direct establishment of some fast growing woody leguminous species for agroforestry systems. 1985 (K. Solberg, S. Holden & S. Lungu)

C.2 Agroforestry monitoring and evaluation survey started in 1986 - 1994 (ICRAF, ST Holden, D. Otika)

C.3 An ecological evaluation of some trees and shrubs in relation to their potential use for agroforestry in Zambia. One site, conducted from 1986 - 1987 (S. Lungu)

C.4 Ash fertilization as a substitute to lime and fertilizer application for raising plants in the nursery. Conducted 1985 - 86 (KH Solberg & ST Holden)

C.5 Crop response to applications of *Flemingia congesta* and *Cassia spectabilis* prunings conducted 1990 - 1994 (J. Volk, S. Lungu & S. Bwembya)

C.6 Fodder species survival, growth, biomass production and palatability, conducted 1988 - 1993 (S. Lungu & J. Volk)

C.7 Direct sowing of leguminous tree species with and without mulch, conducted 1987 - 1989 (S. Lungu, RB Matthews & J. Volk)

C.7 Effect of mulch and sowing time on biomass production of *Cassia spectabilis*. one site. Conducted from 1985 (ST Holden & J Volk)

C.9 Evaluation of woody leguminous species as n source in an alley cropping system. One location, three site, conducted from 1984 - 1994 (KH Solberg, S. Lungu, ST Holden, J. Volk & RB Matthews)

C.10 Germination performance of various species in the agroforestry nursery. One location, one year, 1988 (Smart Lungu)

C.11 *Gliricidia sepium* cultivar trial, conducted at one site, 1988 - 1990 (S. Lungu, J. Volk & RB Matthews)

C.12 Growth rate and coppicing ability of *Sesbania macrantha* after repeated prunings at various heights. One site. Conducted 1986 (J. Volk & ST Holden)

C.13 Improvement of the Chitemene system through the introduction of agroforestry species. One site, conducted from 1986 - 1990 (ST Holden & S. Lungu)

C.14 Improvement of the grass mound farming system. One site, conducted from 1986 - 1990 (ST Holden & S. Lungu)

C.15 Late planting of tree species, conducted 1986 - 1988 (S. Lungu & ST Holden)

C.16 *Leucaena leucocephala* trial conducted at one location from 1985 - 1994 (KH Solberg, S. Lungu, J. Volk & S. Bwembya)

C.17 Observation trial on survival and growth performance of some tree species in the nursery, 1984 (Karl H. Solberg)

C.18 On-farm alley cropping trial, conducted 1988 - 1994 (S. Lungu, ST Holden, RB Matthews & S. Bwembya)

C.19 On-farm pigeon pea cultivar trials, conducted 1988 - 1990 (S. Lungu & ST Holden)

C.20 Performance of late planted tree species in new grass mound field. One site, conducted from 1986 - (Stein T. Holden)

C.21 Pigeon pea cultivar trial. One location. conducted 1984 (Karl H. Solberg)

C.22 Pruning management of *Flemingia congesta* and *Cassia spectabilis*, conducted 1988 - 1994 (S. Lungu, J. Volk & RB Matthews)

C.23 Survival and growth rate of some directly sown woody leguminous species. One site, conducted 1986 - 1990 (J. Volk & ST Holden)

C.24 Testing of castor bean cultivars for germination, survival, seed yield and oil content, conducted on one site, 1988 - 1990 (Smart Lungu)

C.25 Transformation of Chitemene on semi-permanent system by use of leguminous trees and cover crops, conducted 1986 - 1991 (S. Lungu & ST Holden)

C.26 Tree species screening trial. One site. Conducted 1985 (KH Solberg)

D. *Soil microbiology*

D.1 Competition for nodule site in soybean between strains of *Bradyrhizobium japonicum* (Kirchner) applied as inoculum and strains of cowpea *Rhizobia* in the soil. Conducted on two locations, multi-site, 1989 - 1991 (MK Sakala & B. Mwakalombe)

D.2 Dynamics of litter decomposition from some Zambian trees and crops. One site, conducted 1986 only (Bengt Wessen)

D.3 Effect of organic matter quality and fertilizer on soil microbial activity and maize growth in a frame trial. One site, one year evaluation, 1988 (Bengt Wessen)

D.4 Effect of *Stylosanthes* species on soil microbial activity. One site, conducted 1986 only (Bengt Wessen)

D.5 Effect of residual *Rhizobium leguminosarium* biovar *phaseoli* on bean production. Conducted on two locations, multi-site, 1989 - 1993 (B. Mwakalombe & Sakala MK)

D.6 Effect of applied nitrogen on nodulation in soybean in the high rainfall area in Zambia. Two locations, two sites conducted in 1989 (Masauso K Sakala)

D.7 Examining the potential for nitrogen fixation in groundnut by strain and host selection with and without lime application. Two locations, conducted 1989 - 1991 (MK Sakala & B. Mwakalombe)

D.8 Evaluation of local *Rhizobium* germplasm to identify host-strain interaction and nitrogen fixation efficiency in soybean. Two locations, multi-site, conducted 1988 - 1990 (MK Sakala & B. Mwakalombe)

D.9 Litter decomposition and nutrient release from some Zambian litter types. One year evaluation, 1988 (Bengt Wessen)

D.10 Microbial activity in some soils of the high rainfall area of Zambia. Conducted 1986 only (Bengt Wessen)

D.11 Organic farming-Effects on soil microbial activity. Conducted 1992 - 1994. On-station and on-farm experimentation (B. Mwakalombe & Bwembya S)

D.12 Persistence of introduced *Bradyrhizobium japonicum* in Misamfu red soil series. One location, Conducted 1989 - 93. (Sakala MK & B Mwakalombe)

D.13 Response of bean to inoculum and fertilizer application. Multi-locational trial, conducted 1989 - 1992 (B. Mwakalombe & Sakala MK)

D.14 Soil microbial activity in a maize-*Leucaena leucocephala* alley cropping trial. One site, conducted 1986 only (Bengt Wessen)

D.15 Soil microbial activity in Zambian farming systems and forests. Two seasons, 1987 - 1988 (B. Wessen & MK Sakala)

D.16 The effect of pasture and cultivation on soil microbial activity. On-farm, one site, one year evaluation, 1989 (Masauso K. Sakala)

Appendix 2. Fertilizer conversion schedule

EXPRESSION OF PLANT NUTRIENTS

In this review, plant nutrients are expressed either in their elemental or oxide form. For ease of reference the following conversion factors are provided:

P_2O_5 x 0.4364 = P and P x 2.2919 = P_2O_5

K_2O x 0.8302 = K and K x 1.2046 = K_2O

CaO x 0.7147 = Ca and Ca x 1.3993 = CaO

MgO x 0.6030 = Mg and Mg x 1.6582 = MgO

Appendix 3. Fertilizers and composition

Fertilizer	N	P_2O_5	K_2O	S	B
Compound D	10	20	10	10	0
Compound X	20	10	5	10	0
Compound C	6	18	12	10	0.1
Compound A	2	18	15	10	0.1
Compound R	20	20	0	10	0
Compound V	4	18	15	10	0.1
Single superphosphate (SSP)	0	19	0	12	0
Triple superphosphate (TSP)	0	44	0	1	0
PAPR	0	22	0	12	0
Muriate of potash (KCl)	0	0	60	0	0
Sulphate of potash (K_2SO_4)	0	0	50	16	0
Ammonium nitrate (NH_4NO_3)	34	0	0	0	0
Urea	46	0	0	0	0
Sulphate of ammonia	21	0	0	24	0
Calcium ammonium nitrate	26	0	0	0	0

Shaded are commonly available in the region