Farmlime

Low-cost lime for small-scale farming

Economic Minerals Programme

Commissioned Report CR/03/066N

BRITISH GEOLOGICAL SURVEY

ECONOMIC MINERALS PROGRAMME

COMMISSIONED REPORT CR/03/066N

FarmLime
Low-cost lime for small-scale farming

C J Mitchell

Contributors

S Simukanga, V Shitumbanuma, D Banda, M Mwanza & M Mtonga (University of Zambia) B Muibeya & D Kapindula (Geological Survey Department of Zambia) E Steadman (BGS) B Walker (Consultant)

Keywords

Agricultural lime, Zambia, Southern Africa, Dolomite, Limestone, Socio-economic survey, Cost Benefit Analysis.

Front cover

Dolomite deposit in River Solwezi dambo, Solwezi, North Western Province, Zambia.

Bibliographical reference

C J MITCHELL, 2005. FarmLime Low-cost lime for small-scale farming. *British Geological Survey Commissioned Report*, CR/03/066N. 124pp.

Keyworth, Nottingham British Geological Survey 2005

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115–936 3241 Fax 0115–936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131–667 1000 Fax 0131–668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020–7589 4090 Fax 020–7584 8270
☎ 020–7942 5344/45 e-mail: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392–445271 Fax 01392–445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast, BT9 5BF

☎ 028–9038 8462 Fax 028–9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491–838800 Fax 01491–692345

Sophia House, 28 Cathedral Road, Cardiff, CF11 9LJ

☎ 029–2066 0147 Fax 029–2066 0159

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793–411500 Fax 01793–411501
www.nerc.ac.uk

Foreword

This report is the output of the project 'Low-cost lime for small-scale farming: FarmLime (referred to as FarmLime throughout this report), which was co-ordinated by the British Geological Survey (BGS). Funding for the project was provided through the Knowledge and Research (KaR) programme of the Infrastructure and Urban Development Division (IUDD) of the Department for International Development (DfID), in turn part of the Foreign and Commonwealth Office (FCO) of the UK Government.

The stated aim of DfID research is to "alleviate poverty" through improved access to knowledge and technology by poor people. The FarmLime project comes under the IUDD KaR programme geoscience sector theme G1 that aims to "enhance the productive capacity (of less-developed countries) in an environmentally sensitive manner". The FarmLime project aims to investigate the means of improving the agricultural performance of small-scale farms through the use of low-cost agricultural lime (aglime), produced by a facility within the farming district, using locally occurring dolomite.

The FarmLime project follows on from an earlier DfID project, 'Local development of affordable lime in southern Africa' (1996–1998), which investigated the feasibility of producing aglime using appropriate technology. This earlier project recommended a simple agricultural lime production method. The FarmLime project used the production method as the core of its research and is essentially the implementation phase of the earlier work.

This technical report results from research carried out in the first stage of the project (1999 to 2001). It is intended as a resource for dissemination workshops planned for the second stage of the project (2002 to 2005).

Clive Mitchell

BGS, UK

31st December 2005

British Geological Survey

Nicker Hill

Keyworth

Nottingham

UK

Tel.	+44 (0)115 936 3257
Fax.	+44 (0)115 936 3520
E-mail	cjmi@bgs.ac.uk
Web-site	www.bgs.ac.uk
	www.MineralsUK.com

Acknowledgements

FarmLime has been a multidisciplinary research project involving geologists and geoscientists, agricultural and mining engineers, agronomists and agricultural consultants, social scientists, chemists and economists. Most of the research has been carried out in Zambia by Zambian researchers and their institutes.

The authors would like to thank Diana Banda, Department of Agricultural Economics, School of Agricultural Science, UNZA and Mr Mlotha Damaseke, Programme Against Malnutrition (PAM) who were responsible for the socio-economic survey (Section 2).

The authors would like to thank Boniface Muibeya, Geological Survey Department (GSD), Ministry of Mines and Minerals Development (MMMD) and his colleagues David Kapindula, Isaac Sikala, Zulu Pharoah, Marvin Mumba, Marjorie Mumba, Davison Mulela and Kennedy Liyungu. Also to Mrs Ellie Steadman of the British Geological Survey, UK and her colleagues Barbara Vickers, Mark Allen, Mark Ingham and Charles Gowing. Also to former colleague Simon Inglethorpe who was involved from the outset and was responsible for a lot of the early project input. These two teams were responsible for carrying out the field assessment and laboratory evaluation of the carbonate resources (Section 3).

The authors would like to thank Professor Stepehen Simukanga at the School of Mines, University of Zambia (UNZA) and his colleagues Mathew Mtonga and Jonathan Kalusa. Also, Moffat Mwanza at the Technology Development and Advisory Unit (TDAU), UNZA and his colleagues Lawrence Chisesa, Imasiku Mulabwa and Mr Tambatamba. These two teams were responsible for leading and conducting research into the means of producing agricultural lime (Section 4).

The authors would like to thank Victor Shitumbanuma, Department of Soil Science, School of Agricultural Sciences, UNZA and his colleagues Dr Benson Chishala, Dr Olesegun Yerokun, Dr Obed Lungu and Christopher Phiri. Also to the small-scale farmers in Mkushi including Mr Mweemba and Chalata Camp Farmers Club and Mr Mulenga and his neighbours in Kasansama Camp. Thanks also go to the Mkushi extension officers, Mr Mweemba (Chalata Camp officer), Mr Chanda (Kasansama Camp officer) and Mr Mulenga (Senior Agricultural Officer) of Mkushi Farm Training Centre. These teams were responsible for carrying out the demonstration crop trials in Mkushi and will continue this work until 2005 (Section 5).

The authors would like to thank Briton Walker, Agricultural Consultant, Lincoln, UK for his advice and for carrying out the cost benefit analysis (Section 6).

The authors would like to thank the individuals in Zambia who have provided advice and support throughout the life of the project: Cris Muyunda, USAid; Mike Maillaux, CLUSA; Hugh Carruthers; Godfrey Munyoro, Economic Expansion in Outlying Areas (EEOA); Mr Munkanta, Mindeco Small Mines; Andy Anderson, Mkushi Farmers Co-operative Society and Walter Blechingberg, SHEMP.

Contents

FIGURES

PLATES

TABLES

Summary

FarmLime (Low-cost lime for small-scale farming) is a multidisciplinary research project that aims to increase the food security of small-scale farmers by improving their access to agricultural lime which neutralises soil acidity and adds nutrients. This project focused on farming districts in northern Zambia that have highly acidic soils with poor crop yields. The aim was to locate suitable carbonate rocks in these farming districts and produce agricultural lime using a low cost method, eliminating the high transportation costs that farmers currently incur if they use lime.

Perceptions

The commonly held view is that small-scale farmers do not use agricultural lime because they don't appreciate its benefits, it is expensive and difficult to obtain. A socio-economic survey carried out in Solwezi and Mkushi confirmed some of these views but indicated that farmers knew the benefits of using lime and that uptake of agricultural lime could be encouraged. The main constraints on the use of lime were the absence of soil testing and a lack of cash in the rural economy.

Lime Resources

Carbonate rocks occur throughout Zambia including those farming districts with highly acidic soils. A technical evaluation programme found that the dolomite from Solwezi and Mkushi is suitable for the production of agricultural lime. It has a Neutralising Value (NV) of 103–104% and a magnesium oxide (MgO) content of 19–21%. Dolomite suitable for agricultural lime (minimum 80% NV and 6% MgO) occurs in seven of the nine Zambian provinces.

Lime Production

A low cost production method would be an ideal way to provide agricultural lime for small-scale farmers. Current production methods and the best means of extracting and milling dolomite on a small scale were investigated. Large-scale operations use open cast quarrying, crushing and milling of dolomite to produce agricultural lime. This could be replicated on a small-scale using manual extraction and crushing, and hammer milling. The costs of producing agricultural lime from the Mkushi dolomite by large-scale operations are estimated to be US$31 per tonne. This cost could be reduced to about US$20 per tonne by quarrying a softer dolomite and incorporating a manual jaw crusher for the crushing stage. Following this research, entrepreneurs in Solwezi started small-scale production of agricultural lime.

Crop Trials

The most effective means of showing the benefits of using agricultural lime was thought to be through demonstration crop trials. Therefore, maize and groundnut trials were set up in Chalata and Kasansama camps in Mkushi. These sites had highly acidic soils (pH 4.6 to 5) and low crop yields (e.g. 1.5 tonnes of maize per hectare). The limed plots produced up to 6.7 tonnes of maize and up to 320 kg of groundnuts per hectare. These trials have convinced neighbouring farmers to use locally produced lime (from HiQwalime at US$1 per 50 kg bag).

Economics

The main economic justification for the use of agricultural lime is that money could be raised through the sale of surplus crops. Where the price of maize is high and the cost of agricultural lime is low the economic benefits are very high. However, where the opposite is true the economic benefits are marginal although still in favour of using lime. However, despite these positive economic benefits uptake of lime will still depend on the availability of cash in the rural economy.

1 Introduction

Clive Mitchell, BGS, UK

1.1 Farming is arguably the most important occupation for the people of southern Africa. A large proportion of the rural population depends on farming for their livelihood and food security (see Plates 1 and 2). However, despite the importance of agriculture the countries of southern Africa face the common problem of finding the best way to encourage and promote the development of small-scale farming. Small-scale farmers struggle from year to year with meagre resources to produce enough food for themselves and their families. Surplus food and other crops are usually only produced in years where sufficient rain allows them to grow a ‘bumper harvest’. But these are infrequent and are often the result of good fortune rather than good practice.

1.2 There are many factors that play a role in the fortunes of the small-scale farmer, including those that are outside their influence, such as the weather, access to resources (including financial, natural, human and infrastructure) and the market (where the price of crops varies from season to season).

1.3 Considering that many of these are outside the control of the small-scale farmer it is important that those factors within their control are used to their best advantage. These include the human resources, financial resources and natural resources.

1.4 Successful farming relies on careful management of the soil and maintenance of the crops grown. Simply growing crops on the same patch of ground every year would, after a few years, exhaust the natural fertility of the soil, because the plants would have taken up all of the nutrients. This would result in a gradual decline in the crop yield, until the soil becomes unusable and in the worst-cases (especially in an arid climate) lead to desertification.

1.5 Small-scale farmers have developed traditional farming methods over long periods of time (millennia in many cases) that help to maintain the condition of their soil. A shifting cultivation system, known as *chitemene* (otherwise known as ‘slash and burn’), is commonly practised in southern Africa (e.g. Zambia). A patch of ground is farmed for several years (4–5 years) and then left fallow for a generation (20–30 years). The farmer moves onto adjacent areas and farms them in the intervening period. Natural bush (e.g. Miombo bush) vegetation is allowed to develop in the unfarmed areas. Before these areas are re-entered for farming, branches are chopped from trees and laid out to dry (usually July to September). Before the start of the rains in November the wood is gathered into a heap and burnt. The ash from the burnt vegetation is ploughed back into the soil; in this way the soil is replenished with nutrients ready for the new crops.

1.6 This type of traditional farming method is adequate for sparsely populated rural areas. However, in recent times the population of developing countries has increased, especially around urban centres. The population in rural areas has also changed, with many people leaving to work in the towns, lured by the prospect of higher incomes and a better standard of living. This creates a demand for food in the cities that is partly met by the large-scale commercial farms that operate intensive farming systems. However, the small-scale farmers also provide a significant proportion of the food required and this market is an important source of income.

1.7 The pressure to increase food production has led to a partial breakdown of the traditional systems of farming in many areas. Demand for food from the cities has compelled the small-scale farmers to increase production and as a result farmland that should be left fallow has been farmed many years before it has had time to fully recover. Farmers faced with poor yields have increasingly shortened the fallow period of their farmland and have adopted modern farming methods. This means the use of fertilisers to provide the necessary soil nutrients and an increase in the farming of cash crops. Also, many urban dwellers keep a farm, usually maintained by their relatives, which they intend to return to when they retire, bringing more modern farming ideas with them. Currently, many small-scale farmers use a ineffective mixture of traditional and modern farming methods. The burning of fallow areas is still a common occurrence, typically in the months just before planting (September – October). When fertiliser can be afforded it is used to boost crop yield.

1.8 The soils in many parts of southern Africa are becoming more acid, which leads to reduced crop yields; this is often the case where there is high rainfall (greater than 1000 mm per year). Nutrients, such as calcium and magnesium, are leached out of the soil by downward percolating groundwater. If the soil acidity falls below a pH of 4.5 the crop yield is severely reduced. Acid soil is characterised by a low level of calcium and magnesium (in an exchangeable form), a low pH (<4.5) and toxic levels of available aluminium and manganese (which reduce crop growth by inhibiting the roots).

1.9 Traditional farming methods, when used as intended, help to maintain the correct soil pH. Commercial farmers realise that fertiliser has an acidifying effect and therefore make use of **agricultural lime** to maintain the pH of the soil. If small-scale subsistence farmers are to improve the condition of their soil then they also need to use agricultural lime.

Plate 1 Typical Zambian village, North Western Province, Zambia

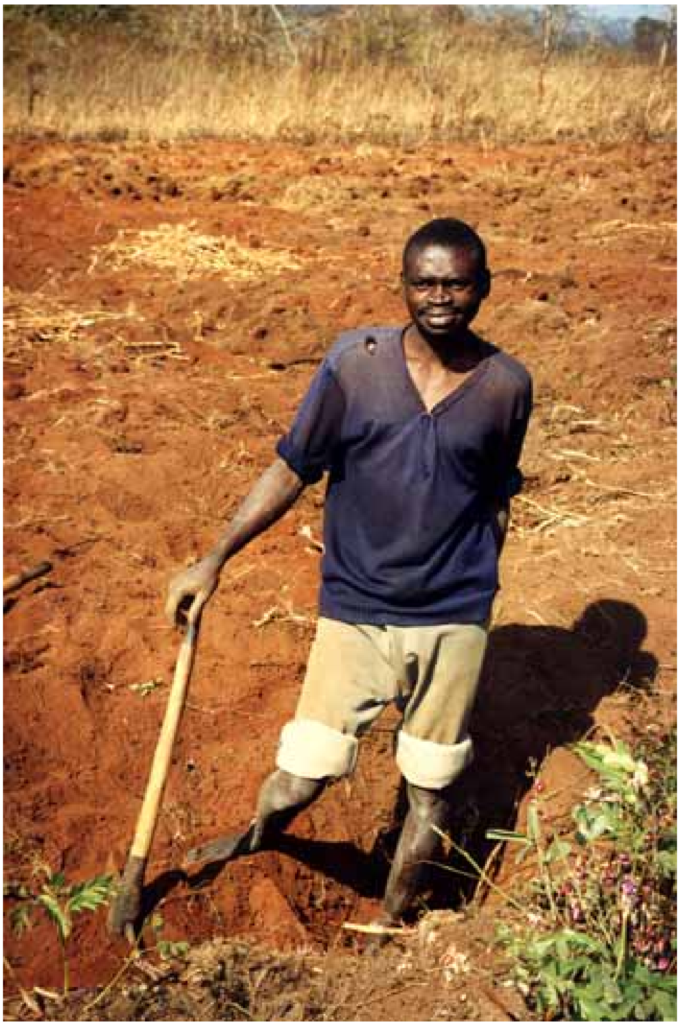

Plate 2 Typical small-scale farmer, North Western Province, Zambia

1.10 Agricultural lime is defined as material containing “the necessary qualities to neutralise acidic soils, provide essential nutrients to promote plant growth and correct magnesium deficiency” (ARC, 1996). The ideal agricultural lime is a ground dolomite or dolomitic limestone with a particle size of 100% <2 mm, 60%<400µm and up to 50% <150µm (Mitchell *et al*, 1998). The use of agricultural lime causes a chemical reaction within the soil, which can be summarised as follows:

$$(Ca, Mg)(CO_3)_2 + 4H^{+} \longrightarrow Ca^{2+} + Mg^{2+} + 2H_2O + 2CO_2$$

dolomite or dolomitic limestone	acid	calcium	magnesium	water	carbon dioxide

1.11 In the strictest sense the soil acidity decreases as the availability of hydrogen ions (H^+) is reduced. It is argued by many that bringing the soil pH up to or close to neutral is unnecessary. A pH of 5.2–5.5 would be adequate, as this would have the desired effect of raising crop yields. The amount of agricultural lime required to completely neutralise the soil pH would not only be more expensive but would also run the risk of having a negative effect on crop yield (known as ‘overliming’). The current approach is to determine the amount of agricultural lime to supply the necessary nutrients, and neutralise the aluminium and manganese toxicities, rather than achieve a neutral pH. The liming need is calculated through determination of the exchangeable aluminium content of the soil in preference to determination of pH. However, it is easier to measure soil pH and this can give a rough indication of the level of exchangeable aluminium and the liming need.

1.12 Currently, very few small-scale farmers use agricultural lime, as it is often locally unavailable and / or too expensive. In Zambia there are very few agricultural lime producers. If agricultural lime could be made locally available at an affordable price then it would give small-scale farmers an opportunity to improve their crop yields. This problem was addressed in a previous DfID research project ‘Local development of affordable lime in southern Africa’ (Mitchell et al, 1998) which concluded that a small-scale process could be used to produce agricultural lime from local dolomite within farming districts. This would overcome the main constraint on uptake i.e. the cost of transporting agricultural lime to the consumers.

1.13 The current DfID research project aimed to put the recommendations of the first project into action and to improve the sustainability of small-scale farming in southern Africa. The required outputs of the project include a socio-economic/technical report on the constraints of aglime production and use, a small-scale demonstration lime production facility (and distribution of lime to small-scale farmers), a manual detailing means of replicating the lime production facility, dissemination workshops and a project summary report, video & flyer.

1.14 The following sections of this technical report cover the research carried out in each of the main activity areas of the project:

- Section 2: Socio-economic survey. Small-scale farmers may or may not be aware of the benefits of using agricultural lime. Therefore, a survey was conducted to find out what farmers already know and whether uptake of agricultural lime would be likely.
- Section 3: Carbonate resource assessment. The production of agricultural lime requires rock of a particular quality present in adequate volumes and in the right places. A programme of field sampling and laboratory testing was carried out to determine the suitability of the available dolomite resources for production of agricultural lime. The results are presented including detailed dolomite analyses and resource estimates. Also, the agricultural lime potential of most of the significant carbonate deposits in Zambia is given in this section.
- Section 4: Lime production research. Agricultural lime is simply ground dolomite or limestone. However, production of a ground product from a deposit of carbonate rock requires mining, crushing and milling. A simple production process that involves manual extraction and crushing followed by mechanical milling was tested. The eventual process adopted was refined through laboratory and field production trials. The results and findings are presented, including detailed production findings, agricultural lime product quality and a recommended method for a production facility. The costs of producing agricultural lime using the mining and milling methods devised by the project are also given in this section.
- Section 5: Crop trials. Demonstration of the benefits of using agricultural lime is critically important. Crop trial demonstrations were carried out using agricultural lime produced during the project in the same farming districts in which it was produced. The results and findings are presented in this section, including characterisation of soil quality and crop yields.
- Section 6: Cost benefit analysis. The benefits of using locally produced agricultural lime depend largely on economic factors. If the locally produced agricultural lime is not cheaper than that from other sources then its uptake is unlikely. The most likely scenarios for uptake are those localities that are far removed from the current producers. The results of the cost benefit analysis are presented in this section, with consideration given to the production and use of agricultural lime.

2 Socio-economic survey

Diana Banda, UNZA, Lusaka, Zambia, Clive Mitchell, BGS, UK and Briton Walker, UK.

2.1 INTRODUCTION

2.1 The majority of Zambia's poorest people (i.e. those who live on less than 1US$ per day) live in rural areas and are involved in small-scale farming. Therefore, any measures to alleviate poverty in Zambia (and in other parts of southern Africa) would be best focused on improving the income generating-potential of the small-scale farmer.

2.2 Finding means of improving the income-generating potential of small-scale farmers is the fundamental reason for the research detailed in this report. The premise of the project is simple: by using agricultural lime to improve the condition of their soils, small-scale farmers will be able to increase their crop yields and ultimately their income. However, why is this not already happening? Most small-scale farmers do not use agricultural lime, in many cases they may not even be aware of it and its potential benefits. Therefore, the reasons why small-scale farmers do not use agricultural lime need to be identified.

2.3 This section of the report outlines a survey that was conducted in the Zambian farming districts of Mkushi and Solwezi (between 1999 and 2000). The aim of the survey was to 'investigate and identify the constraints faced by small-scale farmers when attempting to use agricultural lime in Zambia'. To help put the survey into context, this part of the report will include summary information about small-scale farming in Zambia, the economic and political environment in which it exists and the type of Government and institutional assistance on offer. The socio-economic survey was the first part of the wider research project, it provided guidance to the other project researchers and helped to identify the small-scale farmers to collaborate with, especially during the crop trials phase (section 5).

Overview of farming in Zambia

2.4 Currently, the Zambian economy relies heavily on the metal mining sector to sustain economic development. However, the changeable nature of the metals markets and the over reliance on direct foreign investment means that this industry cannot be relied upon for steady and sustainable development. When considering Zambian agriculture many commentators, especially in the Zambian media, proclaim the 'great untapped potential' that exists for boosting the economy through increased agricultural production. The newly elected president, Levy Mwanawasa, has signalled via the 'New Deal' budget of 2002 that agricultural development is a priority. Agriculture contributes 21% (2000) to Zambia's GDP, most of which comes from crops (mainly maize plus cassava, groundnuts and millet) and livestock and the remainder from forestry, fisheries and wildlife (Copestake, 1997).

2.5 Currently only 10 to 20% of the potential arable land in Zambia is cultivated (Oygard, 1987); 9 million hectares are classified as having medium to good agricultural potential and of this only 1.5 million hectares are cropped annually (of which more than half is maize). The Zambian rural population density is between 2 and 10 people per square kilometre (compared to over 100 people per square kilometre for many European countries). This means that, with important exceptions, agriculture is relatively unconstrained by the availability of land (and water) resources (Copestake, 1997). However, the development of agriculture in Zambia is hampered by the large distances between the rural districts and the urban centres of the country and the current poor state of its infrastructure.

2.6 In Zambia, according to a survey in 1998, 92% of the rural population is involved in farming, mainly on a small-scale (Table 1). Most of these farmers live below the poverty line; 85% of small-scale farmers and 75% of medium-scale farmers.

Table 1 Breakdown of the rural population in Zambia

Farming sector	**Proportion** (%)	**Proportion below the poverty line** (%)
All rural	100.0	84.0
Small-scale farmers	87.9	84.9
Medium-scale farmers	3.9	74.5
Large-scale farmers	0.2	17.7
Non-farmers	8.0	79.8

Source: Living Conditions Monitoring Survey 1998, 'Monitor' newspaper, March 15–18 2002; the poverty line in 1998 was defined as 49,000 Zambian Kwacha per individual per month, approx 1US$ per day (the exchange rate was approximately US$1 for 1500 Kwacha in 1998). (Kalungu, 2002).

2.7 There are a number of different systems for the classification of farmers, the most commonly used are based on the size (in hectares) of the farm (Table 2). The following draws on the classifications used by Oygard (1987) & Copestake (1997):

- Small-scale (traditional subsistence, or peasant) farmers. These farmers produce food mainly for their own need with any sales arising from surplus crops in years with a bumper harvest. They use traditional, manual cultivation methods. Though often called small-scale farmers, they are better referred to as 'rural householders' who mostly are just trying to grow sufficient crops to feed themselves and their families. The success of their crops is usually controlled by the weather, with drought or too much rain having an adverse affect and they often experience food shortages. The Zambian Government attempts to provide fertiliser to the farmers, but it often does not reach them due to poor management and a poor transport infrastructure. Some small-scale farmers plan to produce surplus crops for sale. They use traditional cultivation methods supplemented by the use of oxen or hired tractors. They may often grow cash crops (such as hybrid maize, cotton, sunflower and vegetables) and will purchase inputs such as seed and fertiliser.
- Medium-scale commercial farmers. These farmers mainly grow crops for the market. They use more modern cultivation methods with their own oxen and tractors. They purchase fertilisers, pesticides and seeds. This group is expanding with an increasing number of out-grower schemes such as Dunavant Cotton (80,000) and NGO training. They are normally located close to good transport routes and market the majority of their crop production. Farms vary in size (up to 30 or so hectares) and are partially mechanised. They could buy from co-operatives or retail distributors, but in recent years have been suffering from the general lack of cash in the economy. They are becoming aware of the need to use agricultural lime following Government initiatives, out-grower schemes such as Dunavant and NGO programmes such as those initiated by CLUSA (Co-operative League of the USA), EEOA (Economic Expansion in Outlying Areas) and World Vision.

- Large-scale commercial farmers. These farmers grow cash crops using modern cultivation methods, they are well mechanised and well managed and have a workforce of casual and permanent labour. They use agricultural lime when they can get it and recognise the need to protect and maintain their soils. (Corporate farms are similar but are owned and operated by commercial companies).

Table 2 Classification of farms & number of farmers in Zambia

	Small-scale subsistence farmers	**Medium-scale commercial farmers**	**Large-scale commercial and corporate farmers**
Farm size	Typically 1–2 ha. (rarely up to 10 hectares)	Range in size from 10–40 hectares	Typically 40 to 60 hectares (occasionally larger)
Number of farm households	600 to 700,000 (estimated 3 million dependents)	100,000	300

Based on MAFF classification & Oygard, 1987.

2.8 Small-scale farmers are significant producers of maize and other crops; 80% of them produce at least some maize (often less than one hectare) and they are responsible for 60 to 65% of all maize produced in Zambia. They account for 55% of maize sales (presumably the remainder is for personal consumption) and this confirms their vital importance to the rest of the country. They are also the predominant producers of cotton, groundnuts, sorghum and millet.

The current political situation & government policy

2.9 The presidential elections in December 2001 brought in a new president, Levy Mwanawasa (MMD, Movement for Multiparty Democracy).

2.10 The current government of Zambia has promised to make agriculture its priority. The Minister of Agriculture and Co-operatives Mundia Sikatana has stated that "the Government was aiming at improving the living standards of small-scale farmers and people at large through job creation, income generating activities and overall reduction in hunger and poverty” (Mengo, 2002).

2.11 The Ministry of Agriculture, Food and Fisheries (MAFF) operates a farming extension worker service that is spread across the agricultural districts and camps in Zambia. This service is hampered by a lack of resources. This means that extension workers rarely have access to many of the farmers they are meant to support.

2.12 Increasingly Non-Governmental Organisations (NGOs) have taken over some of the roles of the agricultural extension service through food security and agricultural research programmes. USAid has probably the largest involvement as part of their Country Strategic Plan for 1998–2002, which aims to “increase rural incomes of selected groups” (USAid, 2002).

2.13 Some of the groups and activities funded by USAid include CLUSA and ZATAC. CLUSA (Co-operative League of the USA) is involved in promoting small-scale farm groups, which take part in 'out-grower' schemes whereby cash crops (such as paprika, sunflower, soybeans, and maize) are grown under contract to agricultural commodity processors. ZATAC (Zambia Agribusiness Technical Assistance Centre) provides support to agribusinesses that sell to or buy from small-scale farmers.

2.14 Other groups and activities include CFU (Conservation Farming Unit) of ZNFU (Zambia National Farmers Union) and EEOA (Economic Expansion in Outlying Areas), which are independently, managed rural development programmes operating under the auspices of MAFF. Also, the Land Management and Conservation Farming (SCAFE) Programme (MAFF). This programme covers the Southern, Central and Eastern Provinces where more than 30,000 farmers are engaged, particularly in conservation farming. PAM (Programme Against Malnutrition) operates a 'Food Security Pack Programme'. PAM distributes food security packs (containing a cereal, legume root or tuber, fertiliser and lime). SHEMP (Smallholder Enterprises & Marketing Programme) is an agricultural initiative funded by IFAD (International Fund for Agricultural Development). SHEMP aims to improve the access of small-scale farmers to inputs and services from the private sector.

2.15 Other stakeholders with an interest in small-scale farmers in Zambia include: Dunavant Enterprises, Inc., which works with 80,000 small-scale 'out-growers' in Zambia on a contracted pre-planting price arrangement; FARMESA (Farm-level Applied Research Methods programme for East and Southern Africa) which is a regional collaborative initiative executed by the UN Food and Agriculture Organisation (FAO); World Vision, which is the world's largest Christian international relief and development agency.

2.2 SOCIO-ECONOMIC SURVEY/ATTITUDES TO INPUTS

2.16 In the previous project 'Local development of affordable lime in southern Africa' (Mitchell *et al*, 1998) a 'market survey' was carried out to determine the demand for agricultural lime, its quality, quantity and where it is most needed. The findings indicated that Zambia has a suppressed demand for agricultural lime, especially in the Northern provinces and those provinces that are more heavily cultivated. Agricultural lime consumption is held back by its poor availability and relatively high cost.

2.17 The main problem with the use of agricultural lime is perceived by the consumers to be the long distance (typically over 100 km and in some cases over 800 km) from lime production centres to the farms. The high transport cost is the chief cause of the high cost of agricultural lime at the point of use. This is compounded by the lack of available credit for buying agricultural lime, intermittent production and poor distribution. Also, many farmers were found to be simply unaware of the need for agricultural lime and were continuing to use the traditional *Chitemene* cultivation practice. It was also found that some MAFF extension workers were choosing not to educate the farmers on the use of agricultural lime. They realise that small-scale farmers will be frustrated when they either cannot afford or are unable to obtain agricultural lime. Other factors that contributed to this situation include the (mistaken) belief that fertiliser and agricultural lime are interchangeable, a lack of marketing by agricultural lime producers, a lack of information regarding its quality and use and its poor packaging/labelling.

Agricultural lime consumption, production & demand

2.18 The current consumption of agricultural lime in Zambia is relatively low, approximately 30,000 to 40,000 tonnes per year. This is equivalent to the current production from the main producers of agricultural lime, which are as follows:

- **Hi-Qwalime** is based at their quarry 18 km to the North of Mkushi Boma, their current production is approximately 10,000 to 15,000 tonnes per year and mostly serves the commercial farmers in Mkushi district.

  Contact details: Mr Tobie Visser, General Manager

  Hi_Qwalime Mining Ltd, Mkushi, Zambia

  Tel. +26 05 362488 / 181 Fax +26 05 362181 E-mail: tobie@gcs.co.zm

- **Lilyvale Farm** is based on a coffee plantation 24 km to the west of Kabwe. Current production is thought to be in the region of 5000 to 8,000 tonnes per year.

- **Mindeco Small Mines Ltd** is based at their custom milling plant in Lusaka, their current production is 3000 tonnes per year and mostly serves commercial farmers in Lusaka & Southern provinces.

  Contact details: Mr Nonde Munkanta, General Manager

  Mindeco Small Mines Ltd

  Stand No. 1605, Sheki Sheki Street, P.O. Box 32441, 10101 Lusaka Zambia

  Tel. 00 260 1 244685 Fax. 00 260 1 245683

- **Ndola Lime Co. Ltd** is based at their lime works in Ndola, their current production is unknown and mostly serves commercial farmers in Central and Copperbelt provinces.

  Contact details

  Ndola Lime Co. Ltd, P.O. Box 70057, Ndola, Zambia

  Tel. 00 260 2 610951/3, 611260/4, 611266 Fax. 00 260 2 615275, 612063

- **Uniturtle Industries (Z) Ltd** is based at their milling plant in Lusaka, their current production is 8000 tonnes per year and mostly serves commercial farmers in Lusaka and Southern provinces.

  Contact details

  Uniturtle Ind. (Z) Ltd, P.O. Box 35192, Lusaka Zambia

  Tel. 00 260 1 238121/3, 286258/904 Fax. 00 260 1 227519/287611

  E-mail: tbricks@coppernet.zm vipul@zamnet.zm

2.19 Other producers that have operated in the recent past include: Crushed Stone Sales Ltd, Lusaka and United Quarries Ltd, Lusaka.

2.20 The current producers, especially those companies relatively new to agricultural lime production in Zambia, are keen to increase production. Prospective sites for future agricultural lime production by these companies include Chivuna (Southern Province) and Kabwe (Central Province). Other potential sites include Solwezi (North-Western Province), Matanda (near Mansa, Luapula Province), Isoka (Northern Province) and Nyimba (Eastern Province) However, there has been very slow progress on establishment of new sites of agricultural lime production in Zambia. This has largely been due to the prohibitive capital costs (in 1981 it was estimated that a milling plant with a capacity of 15,000 tonne per year would cost US$750,000). It is also constrained by high operating costs and a lack of infrastructure (including the training of manpower, provision of adequate power and water resources).

2.21 It can be argued that the demand for agricultural lime in Zambia is either relatively low or high, depending upon the rationale used. Some argue that current consumption is the true reflection of demand as in any free market economy a natural balance is achieved between the costs of the producer and the spending power of the consumer. However, others argue that there is a latent demand for agricultural lime that far exceeds current consumption and is ‘waiting’ for a trigger for it to be unleashed. There are several theoretical considerations, which assume that agricultural lime is freely available and affordable to all. Firstly, the amount of agricultural lime required to neutralise the acid present in currently cultivated land is estimated to be a one-off input of 131,000 tonnes. Secondly, the amount of agricultural lime required to neutralise acidity introduced by the use of fertiliser is estimated to be 145,000 tonnes per year. As only 15% of the potential arable land in Zambia is under cultivation this puts the maximum possible agricultural lime demand at close to 1 million tonnes per year. Therefore, it could be said that there is a great potential for the production of agricultural lime in Zambia. To create the demand every small-scale farmer would need to start using agricultural lime, which seems unrealistic. However, a gradual increase in demand would seem to be more achievable if agricultural lime could be made more accessible, especially to the small-scale farmers.

Summary of FarmLime survey methodology

2.22 In consultation with the project partners, Mkushi and Solwezi districts were selected as pilot investigation and demonstration areas (see district profiles and Figures 1 to 4). The survey, was carried out by a multi-disciplinary team consisting of a soil scientist and field workers from Ministry of Agriculture, Food and Fisheries (MAFF), agricultural researcher and social scientist from the School of Agricultural Sciences, University of Zambia (UNZA) and; agricultural engineer from the Technology Development and Advisory Unit (TDAU).

2.23 The methods used in collection of the primary data were based on discussions and questionnaire administration. Discussions were held with MAFF extension workers, agricultural input suppliers, Field Officers and Zambia National Farmers Union representatives. Structured questionnaire interviews were held with farmers. A total of 75 respondents located in Chalata and Musofu communities in Mkushi district and Mujimazovu, Mapunga and Solwezi Central communities in Solwezi district were interviewed (25 respondents in Mkushi district and 50 in Solwezi district). The respondents covered were closely gender balanced.

2.24 The issues investigated included; awareness of crop production constraints, knowledge of the benefits of agricultural lime, accessibility and distribution of agricultural lime, affordability, and issues that facilitate/constrain technology uptake. A summary of the findings is given in Table 3 and a copy of the questionnaire is shown in Appendix 1. Secondary information was gathered from a literature review of the various research reports carried out on lime activities in southern Africa.

Table 3 Summary of some of the findings in surveyed districts.

Character	Mkushi	Solwezi
Gender	68% males/32% females	64% males/36% females
Educational levels	50% literate (primary)	66% literate (primary & secondary)
Average family size	5 people per household	8 people per household
Knowledge of soil problem	84% aware 72% know benefits of lime 84% desire to use lime 60% positive about affordability	76% aware 62% know benefits of lime 98% desire to use lime 60% positive about affordability

Profile of Mkushi farming districts

2.25 Mkushi is located in the Central Province of Zambia about 300 km north of Lusaka (Figs 1 & 2). The district covers an area of 24,142 km^2, with an estimated population of 140,000 people (extension worker estimates), mostly of the Lala and Swaka ethnic groups. The Tonga, who were the most recent to settle in the area, are in the minority (Banda, 1997). Most of the families are male headed; although, because of the matrilineal system, women bear the larger proportion of the family responsibilities.

2.26 The district falls under agro-ecological Zone III (i.e. the zone that receives average annual rainfall greater than 1000 mm per year). The soils are heavily leached and as a result, have low pH. These soil types do not allow sustainable crop production and agricultural lime application is a vital necessity in the area.

2.27 The majority of people in Mkushi depend on farming for their livelihood. The area is divided into six agricultural blocks made up of 26 agricultural camps. One of the blocks is occupied by the commercial farmers and is called the Mkushi block. The bulk of the small-scale farmer households cultivate land areas ranging from 0.25 to 2 hectares. The nearby rich forest resources allow farmers to engage in bee keeping and saw milling while the youth, mainly males, engage in trading activities. The commercial farmers already use agricultural lime on their farms. Small-scale farmers are not in the habit of using agricultural lime and therefore, their current farming practices continue to be mainly subsistence, with a little surplus for sale.

Solwezi District

2.28 Solwezi is located in the North-Western Province of Zambia and is the provincial headquarters (Figs 3 & 4). The district covers an area of approximately, 140,000 km^2 with an estimated population of 204,000 people. The Kaonde speaking people form the majority of the population while small numbers of the Lunda, Luvale, Chokwe, Mbunda, Lozi, Tokaleya and Shona speaking people are scattered around the district.

2.29 Like Mkushi, the district falls under agro-ecological Zone III and receives average annual rainfall of between 1000 mm and 1200 mm. The soils are heavily leached and acidic with the larger proportion being light sandy or loamy sand. Due to leaching and excessive rainfall, the soils accordingly have low base saturation, which means they have low levels of exchangeable calcium and magnesium (Brammer, 1973).

2.30 People in the district derive their livelihood from subsistence cultivation of finger millet, sorghum, sweet potatoes, Bambara nuts, soybeans, groundnuts, cassava with beans and maize constituting the major cash crops. Shifting cultivation is a widespread farming practice and cultivation of sorghum and cassava predominates. The district is divided into 8 blocks, which consist of 52 agricultural camps of which only 30 have any significant concentration of farming families. The few alternative income-generating opportunities include brewing, charcoal burning, gardening, honey processing, crafts and fishing activities. Generally, the district consists of very few large- and medium-income people with most being very poor people. All these depend on axe and hoe cultivation and cropping systems.

Awareness of crop production constraints

2.31 Soils found in both Mkushi and Solwezi districts are sandy, acidic and heavily leached. As a result, the soils have a pH that is too low to allow reasonable crop yields. Most of the respondents in Solwezi and Mkushi indicated that they were aware of the soil problems. In recognition of this problem many farmers indicated that they were willing to participate in any demonstration crop trials involving the promotion of agricultural lime. This was in the belief that this would ameliorate soil acidity problems and enhance crop yields that have been dwindling over the past years.

2.32 The survey team concluded that the promotion of agricultural lime would best be carried out as part of a 'holistic' programme to improve agricultural practice. This could include using improved seed, fertiliser application, weeding and rotational practices. The team further observed that there was a need for soil testing to determine agricultural liming requirements.

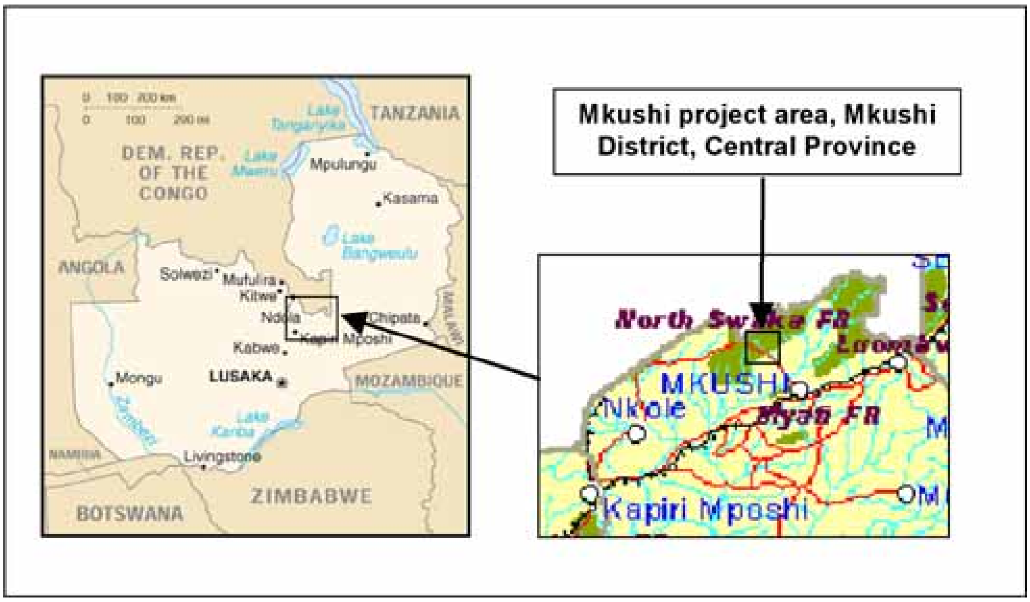

Figure 1 Location of Mkushi project area within Central Province, Zambia

Detail of province map from www.newafrica.com & Zambia map from www.cia.com

NB A further map of the Mkushi area is shown in Section 3: Carbonate Resources.

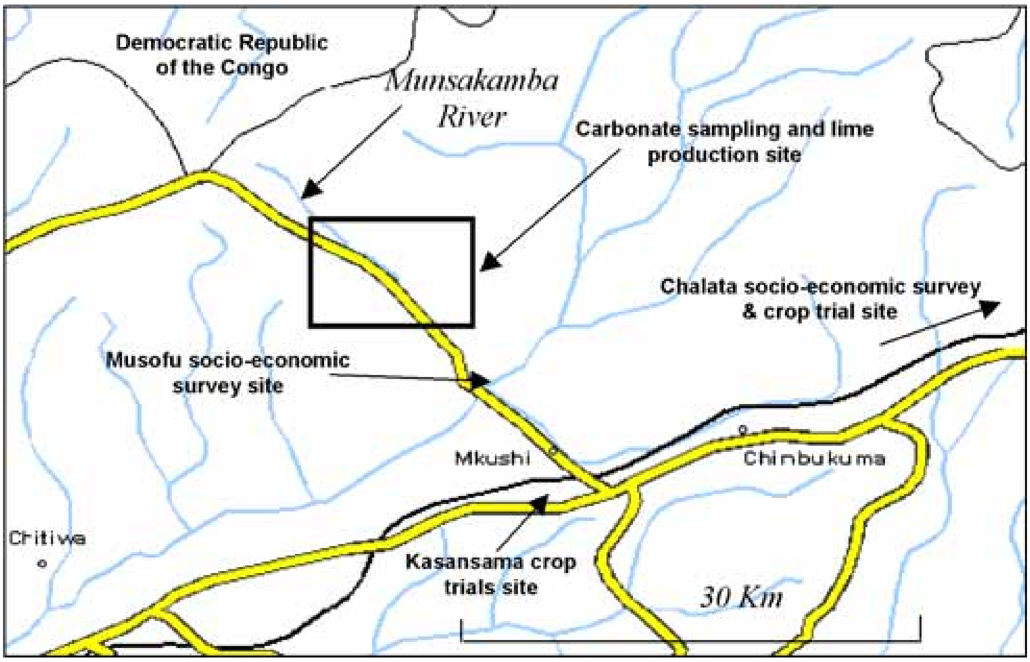

Figure 2 Map of Mkushi project area, Central Province, Zambia

(based on the 1:200,000 scale map available from www.multimap.com)

2.33 The extension services currently administered by MAFF have been instrumental in influencing the farming activities of the small-scale farmers. In particular these activities have included; application and management of agricultural inputs (e.g. fertilizer, seed and pesticides), agronomic practices (e.g. crop rotation, diversification, crop management and soil conservation), post harvest technologies (e.g. grain storage) and facilitation and formation of farm groups/co-operatives.

2.34 During discussions, it was clear that farmers thought the current agricultural extension services formed an effective communication channel and should be responsible for bringing agricultural lime closer to the farmers. It was proposed that agricultural lime could be stocked at district camps and area offices. Several co-operatives and input supply agencies already in place could be used to bring in agricultural lime alongside other agricultural inputs. Most farmers expressed a willingness to involve the extension workers in any agricultural lime demonstration activities. An important role for the agricultural extension workers would be to assist farmers in application of the agricultural lime on the farms. Also, it was suggested that the mechanisms already in place to provide agricultural inputs could also be used to access agricultural lime.

2.35 According to farmers in Mkushi district, the ‘farmer field schools’ concept could be adopted for communicating effects of lime use. This is a method whereby farmers learn farm management issues from each other (‘farmer to farmer’ concept of learning), which has already been introduced in four pilot areas. It was also suggested that the existing co-operatives set up for seed and fertilizer distribution could be used to procure agricultural lime in bulk and stored at certain strategic local sites.

Constraints on use of agricultural lime

2.36 The literacy levels of the farmers’ in the pilot areas are relatively high. Survey findings showed that half to two-thirds of farmers interviewed in Mkushi and Solwezi districts respectively are literate. Farmers generally felt that low levels of education would not constrain their uptake of agricultural lime and subsequent adoption of new farming technologies. School children could assist their parents who cannot read or write. Evidently, there is no ethnic inhibition to the take up of new ideas including the use of agricultural lime. In addition, farmers pointed out that the current knowledge used in the application of fertilizer with expert help from extension workers could be practically employed in agricultural lime application.

2.37 Some of the key factors constraining the uptake of agricultural lime by farmers in the survey areas were identified. These included accessibility and distribution, lack of emphasis on lime use, lack of soil sampling and testing facilities.

2.38 Accessibility and distribution of agricultural lime was identified as a major constraint on uptake of agricultural lime. Firstly, producers of agricultural lime are often located far from many of the small-scale farmers. As a result they are often forced to incur excessively high transport costs in their attempt to access agricultural lime. Secondly, most lime producers sell agricultural lime in bulk and do not cater for the requirements of small-scale farmers who only need smaller quantities ranging from one to five 50 kg bags.

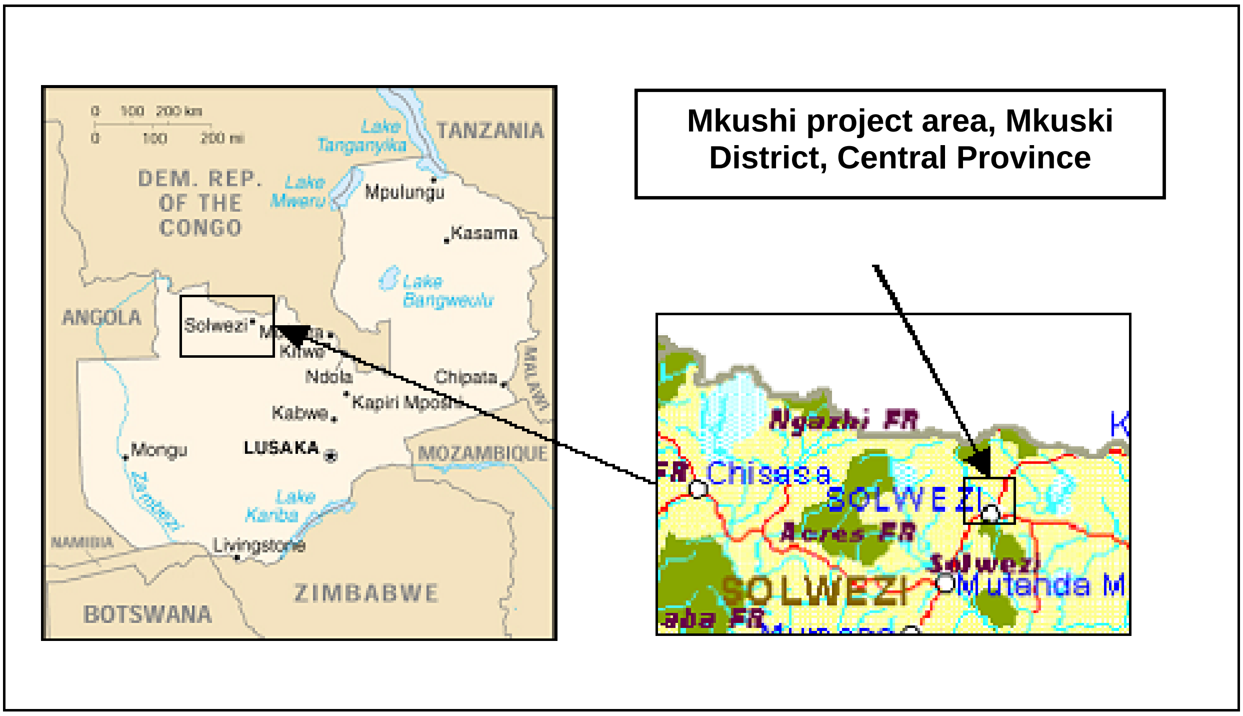

Figure 3 Location of Solwezi project area within NW Province, Zambia

(Detail of province map from www.newafrica.com & Zambia map from www.cia.com)

NB A further map of the Solwezi area is shown in Section 3: Carbonate Resources.

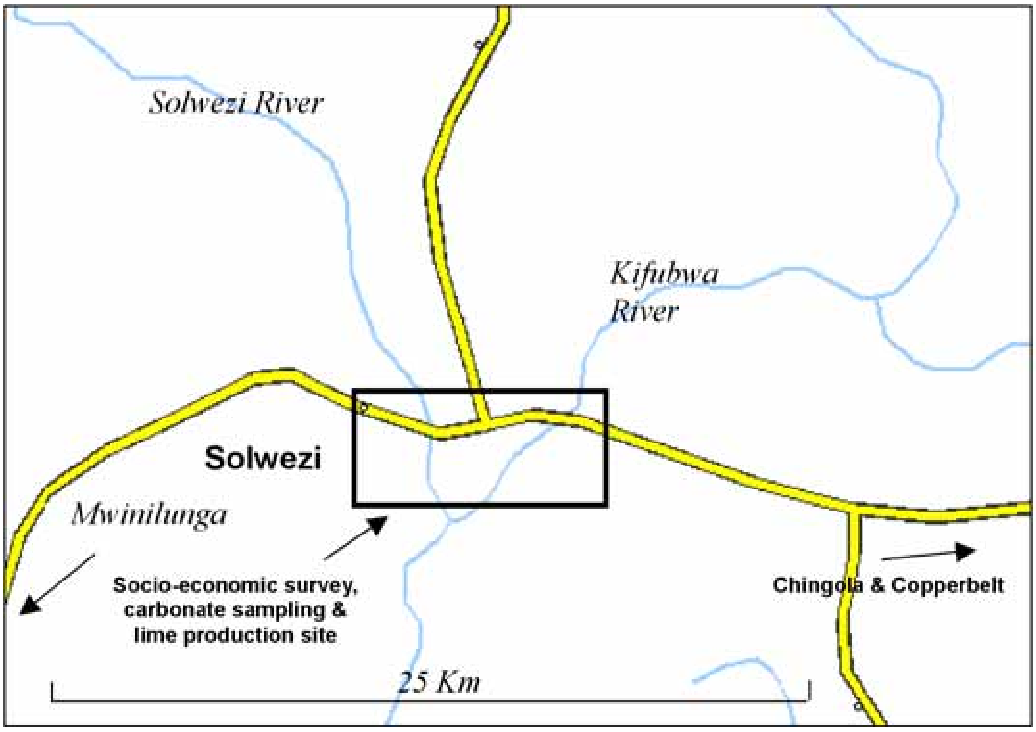

Figure 4 Map of Solwezi project area, North Western Province, Zambia

(based on the 1:200,000 scale map available from www.multimap.com)

2.39 Farmers reported receiving very little advice on agricultural lime application from agricultural extension workers. Hence, awareness of the use of agricultural lime is not as widespread as for other inputs, such as fertilizer, seeds and pesticides, as well as, other agronomic practices such as crop management and conservation techniques. In Solwezi district for instance, the inability of the extension workers to offer advice on agricultural lime use was reported to have led to some farmers being unwilling to use agricultural lime. Likewise, the successes of earlier crop trial demonstrations were not fully exploited to encourage small-scale farmers to use agricultural lime.

2.40 Soil sampling and testing should be carried out in order to achieve an efficient and effective use of agricultural lime. The survey results showed that no soil testing is being carried out for the farmers in Mkushi and Solwezi district areas. Thus, the levels of soil acidity and the corresponding amounts of lime to be applied especially by small-scale farmers are not known. The extension workers did however indicate that the processes of soil sampling and testing are costly, time consuming and could discourage farmers from participating in lime use despite knowledge of the benefits. Soil testing, as carried out at Mt. Makulu and at UNZA for example, costs K40, 000 (i.e. US $9) per sample excluding transport.

2.41 During discussions, a majority of farmers said that the testing of soil was too expensive given the low incomes of the small-scale farmers. Most of their income comes from livelihoods that are dependent on subsistence cultivation of crops coupled with, the restrictive income generating alternatives, of beer brewing, charcoal burning, gardening, honey processing, crafts and fishing activities. Distances to the testing stations, the high fees charged for tests and the late receipt of results are some of the complaints farmers cited regarding soil testing. There is therefore, a need to train and upgrade the knowledge of the extension workers to assist farmers to use appropriate soil sampling procedures and agricultural lime application.

Knowledge of benefits of agricultural lime

2.42 Discussions with some of the field officers in Mkushi revealed that there is a lack of awareness of the need for liming amongst farmers compared to the use of fertilizers. However, when interviewed, the farmers indicated that they were well aware of the benefits of using agricultural lime although, currently, its use is minimal. This included 72% of the respondents in Mkushi and over 60% in Solwezi.

2.43 The high proportion of small-scale farmers who are aware of the benefits of agricultural lime begs the question ‘why is agricultural lime not more widely used?’ It is possible that the respondents to the survey were embarrassed to admit that they did not know anything about the benefits of using agricultural lime and told the interviewers what they wanted to hear. If this were the case it would highlight an underlying reluctance to admit the need for help. This may partly explain the low uptake of agricultural lime, which may be considered tantamount to admitting that their farm is ‘failing’ in some way.

2.44 Small-scale farmers are aware of the benefits that agricultural lime brings; namely that it improves the soil conditions and enhances agricultural production by improving crop yields. Neighbouring commercial farmers use agricultural lime and produce up to 10 tonnes of maize per hectare compared to 1.7 tonnes per hectare produced by the small-scale farmers. While better farming methods and practices contribute to such high yields, the effect of agricultural lime cannot be under estimated.

2.45 The agricultural lime application demonstrations at Chalata and Musofu were reported to be instrumental in raising awareness among Mkushi farmers. Of the farmers interviewed in the survey areas, 84% expressed a desire to use agricultural lime. Some attempts to introduce the use of agricultural lime in selected areas of Solwezi (i.e. Mujimazovu, Kimasala, Mapunga, Mutanda and Chafukuma) mainly by MAFF, the Evangelical Mission (in Mutanda especially) and IFAD have been made.

2.46 There were reports of success in some Solwezi demonstration areas especially, during 1994/95, when free agricultural lime was provided to pilot demonstration areas. This culminated in field days being held in Mujimazovu. The attempt failed to attract farmer participation during 1995/96 when agricultural lime was made available at a subsidised price. This failure has been put down to the excessive transportation costs of the agricultural lime and the failure of the extension workers to sustain the pilot demonstrations.

2.47 A similar scenario was observed in Chalata, Mkushi. For instance, during the 1995/96 cropping season two farmers participated in the crop trials. In 1996/97, 12 farmers participated increasing to 14 farmers by the 1997/98 cropping season. When the project came to an end in 1998, the participating farmers were unable to source the inputs for themselves. Over 70% of the farmers interviewed in Solwezi reported not having handled agricultural lime in their production cycles.

Availability, accessibility and distribution of agricultural lime

2.48 Agricultural lime is available in a few centralised plants e.g. Ndola Lime Ltd; Hi-Qwalime (Mkushi and Kabwe) and all purchases are usually made direct from the lime production companies. It can also be accessed from Ndola, Kabwe and Mkushi. For farmers in Mkushi, the Great North road and TAZARA rail link currently provide good networks for transport of inputs into the rural areas. The poor road infrastructure generally found in most parts of Solwezi fails to offer the essential means of transport to farmers there. As a result, most farmers are use bicycle and 'head-loading' modes of transport.

2.49 Farmer knowledge of the major sources of agricultural lime in both districts is poor. Only 22% farmers in Solwezi mentioned that agricultural lime came from Ndola. Most farmers in Mkushi, generally were not aware of the sources of agricultural lime. However, farmers identified MAFF as the source of agricultural information and were aware of the existing input access points. In Mkushi, these include MAC, Mkushi River, Kafwa, Chalata Agricultural Cooperative societies, Omnia and in Solwezi, Dawako, FRA agents, Zamseed, Jokama, Omnia, Mutanda Evangelical Church and MAFF.

2.50 Clearly, agricultural lime suppliers do not have decentralised outlets to cater for the need of the small-scale farmers in remote areas. While it is possible that agricultural lime can be stocked in the co-operative depots, most farmers access to the product is restricted and remains a major problem. Most respondents are found several kilometres away from local suppliers. Some of the distances from suppliers for instance are up to 38 km in the case of Chalata, Mkushi district and over 60 km in the case of Mujimazovu, Solwezi district.

2.51 The farmers perceived the main problem associated with accessing lime to be the long distances to and from lime production centres. This introduces a transport cost factor, as farmers need to use hired transport, scotch carts and bicycles. Since, there are no credit facilities for major agricultural inputs, farmers are forced to meet the large and often prohibitive costs of transporting agricultural lime to farms unaided.

2.52 The costs of transportation and the size of packaging used constrain the farmers accessibility to agricultural lime. The producers/suppliers, for economic reasons, prefer to sell agricultural lime in tonnes rather than in small packages. Current practice is to supply large-scale farmers with relatively large volumes at US$20 per tonne (equivalent to Kwacha 90,000 at US$1 = Kwacha 4,500, 2002 exchange rate).

2.53 This appears to be the current (2002) universally acceptable ex-works price for agricultural lime within Zambia (i.e. the cost collected from the supplier). Hi-Qwalime charge an additional US$5.00 (i.e. equivalent to Kwacha 22,500) per tonne to cover transportation costs for delivery within the Mkushi farming district. Transportation costs within Zambia are accepted to be approximately US$0.10 per tonne per kilometre. At this cost the price per tonne increases by 9,000 Kwacha every 20 kilometres. This is too costly for the small-scale farmer and the quantities too large for their requirements.

2.54 Mkushi Agricultural Company (MAC) has gone some way to alleviate this problem by making agricultural lime available in 50 kg bags at US$1 (Kwacha 4500, March 2002). This price falls within the range that farmers indicated as affordable - 60% of farmers positively responded that they would be able to buy agricultural lime at a price between Kwacha 3, 000 to 5,000 per 50 kg bag. However, the demand for agricultural lime in 50 kg bags has been relatively low. Many of the small-scale farmers who have bought these 50 kg bags have often been the same farmers that have seen the results of the project crop trials.

Local agricultural lime production and application

2.55 Quite a large proportion of farmers in Solwezi expressed willingness to work in a co-operative organisation to produce lime at a local level to avoid traversing long distances to collection points. The setting up of a local agricultural lime production centre, in conjunction with a farm group or co-operative would require a significant amount of capital investment and business acumen. However, this would be small compared to the large sums required to establish agricultural lime production on the scale of the Hi-Qwalime operation in Mkushi. However, if a small-scale agricultural lime operation was established, its customers (i.e. the small-scale farmers) would have the right to expect the lime produced to match the quality and quantity expected of the larger producers.

2.56 Previous demonstration crop trials using agricultural lime have rarely been successful in sustaining its use beyond the life span of the supporting project. The reason for this is that farmers are unable to adequately source agricultural lime for themselves. This is apparently because it is beyond the financial capabilities of small-scale farmers. This would also seem to indicate that any co-operative venture set up to produce agricultural lime would also ultimately suffer the same fate. Farmers will have to be persuaded that using agricultural lime is of direct benefit to themselves, especially within the first year of application, before they will commit to any sort of scheme to produce agricultural lime locally.

2.57 To date, farmers knowledge of lime application can be classified into various categories. There are those elderly farmers who could have used it particularly during the project pilot demonstration period, farmers who had been taught about it by extension workers, those who have seen commercial farmers use it and those who have seen it but never used it. The Solwezi survey results reveal that 70% farmers were not aware of the need to use agricultural lime and that many in the surveyed districts have never used it.

2.58 The situation has been exacerbated by a host of factors. These include a lack of information on the use of agricultural lime, poor packaging and the long distances to the production centres. The first point is not helped by the fact that many MAFF extension workers have chosen not to educate farmers on the use of agricultural lime (Shitumbanuma and Simukanga, 1995). This is primarily to avoid frustrating those farmers who realise that one of the simplest means of improving their income generating potential is out of their grasp.

Affordability

2.59 Generally, farmers in both Solwezi and Mkushi indicated that they would be able to pay for agricultural lime in one way or another. Approximately 60% of the farmers felt that they could purchase agricultural lime on a cash basis while a smaller proportion (15–20%) preferred the idea of bartering. Those that preferred bartering had little idea of the cost of lime and thought that an appropriate barter rate would be difficult to establish. Despite this, exchange rates of between 30 kg to 90 kg of maize to 50 kg of lime were suggested. A small number of farmers still believe that agricultural lime should be made freely available and an even smaller number were not interested in using agricultural lime at all.

2.60 Further investigation into the option of bartering for agricultural lime revealed that most farmers had some form of prior experience. For example, blacksmith products are exchanged for chickens, maize for fertilizer, etc... In Mkushi, over half of the farmers were able to give a precise figure on the rate of exchange for fertiliser. This currently ranges from one to five 90 kg bags of maize (four bags on average) for a 90 kg bag of fertiliser. Their preference for bartering, particularly for seed and fertilizer, is probably due to their inability to raise the cash needed. Many of them are truly ‘subsistence’ farmers and as such survive outside the ‘cash economy’.

2.61 Although, the option for barter trade is generally acceptable it was observed that, some of the current barter practices tended to favour the suppliers more than the farmers. For instance, the terms of payment being made at post harvest period, compared to those at planting time, puts farmers in a weaker bargaining position with the suppliers determining the end price of their product. Hence, details of fair levels of exchange to determine fair price practices need to be thoroughly worked out. The agricultural extension workers in consultation with farmers could work out a fair product exchange with the suppliers.

2.62 The present abject poverty of the 600,000 or so small farmers/families in Zambia means that the inability of the rural farmer to pay for lime is a real constraint on its uptake. Barter systems cannot provide the full solution as commercial lime companies and distributors need cash to operate. NGO and Government food security programmes distribute free lime in starter packs that may well kick start the use of lime by small-scale farmers and eventually encourage cash purchases. The producers however should appreciate there is an opportunity to sell lime to Government or NGOs.

2.3 CONCLUSIONS

- The soils in Mkushi and Solwezi require the application of agricultural lime to reverse the effects of leaching due to high rainfall and acidification due to the use of fertilisers. Most of the farmers interviewed in the survey claimed to be aware of the benefits of using agricultural lime. However, it is unclear whether this holds true for the small-scale farming population as a whole. Demonstrations in Mkushi District, and the use of lime by large-scale farmers, clearly show that the use of lime substantially increases crop yields. However, its use by small-scale farmers is minimal, due to a lack of availability, access and promotion. It is recognised that MAFF extension workers do not have the appropriate resources to adequately support the sustainable uptake of agricultural lime by small-scale farmers. This is an issue that is widely accepted and will hopefully be tackled by the current Zambian Government in the near future.
- Soil sampling to determine the right quantities of lime to apply was identified as a costly and unsatisfactory exercise for small-scale farmers. The problems encountered included the long distance to the testing stations, high fees charged for tests and late receipt of results, which discourages the farmers.

- Paying cash for lime is difficult for small-scale farmers who operate on a subsistence basis and effectively live outside the ‘cash economy’. However, in order to gain access to agricultural lime small-scale farmers are willing to enter into a system of bartering as an alternative to cash payment. Barter deals are already in existence within the communities although suppliers of farm inputs seem to have a stronger bargaining position over the farmers. Also, it is recognised that agricultural lime producers need cash flow in order to sustain their operations. Therefore a maximum level of bartering, as a proportion of the total volume of agricultural lime sold, would need to be established. There is a need to invest in appropriate agricultural lime packaging to assist farmers who rely on bicycle and ‘head-loading’ mode of transport to improve their access to lime.
- Lime production is an expensive process requiring investments that are beyond the financial capabilities of small-scale farmers. Therefore, viable co-operative ventures to produce agricultural lime locally are only likely to start-up with the support of NGOs or the Government. Some farmers are willing to engage in co-operative farm-groups as long as they are equipped with the necessary resources to enable them to develop and sustain rural enterprises based on agriculture. As an alternative to lime production these groups could use their collective purchasing power to buy agricultural lime.

3 Carbonate resource assessment

Clive Mitchell[1], Boniface Muibeya[2], Ellie Steadman[1], & David Kapindula[2].
[1] BGS, UK; [2] GSD, Lusaka, Zambia

3.1 INTRODUCTION

3.1 Many of the farming districts in northern Zambia have acidic soils and overlie carbonate rocks that could be used to help neutralise the soil acidity. Unfortunately, there is often little relationship between the pH of the soil and its underlying rock formations. This is because of the downward movement of nutrients caused by excessive rainfall. For the carbonate rock to have any beneficial effect it has be extracted, crushed and applied on top of the soil.

3.2 Dolomite and limestone are sedimentary rocks that are composed, respectively, of the minerals dolomite, $CaMg(CO_3)_2$ (calcium magnesium carbonate) and calcite, $CaCO_3$ (calcium carbonate). Carbonate rocks with varying proportions of these minerals also occur: calcitic dolomite contains 10 to 50% calcite and dolomitic limestone contains 10 to 50% dolomite (Table 4). The metamorphic and igneous varieties of carbonate rock are known respectively as marble and carbonatite.

Table 4 A mineralogical and chemical classification of limestone and dolomite

Carbonate rock type	**Calcite** ($CaCO_3$) Weight %	**Dolomite** ($CaMg(CO_3)_2$) Weight %	**Calcium Oxide (CaO)** Weight %	**Magnesium Oxide (MgO)** Weight %
Pure limestone	**100**	**0**	**56.1**	**0.0**
Limestone	90–100	10–0	53.5–56.1	2.2–0.0
Dolomitic limestone	50–90	50–10	43.2–53.5	10.9–2.2
Calcitic dolomite	10–50	90–50	33.0–43.2	19.7–10.9
Dolomite	0–10	100–10	30.4–33.0	21.9–19.7
Pure dolomite	**0**	**100**	**30.4**	**21.9**

3.3 Carbonate rocks occur throughout Zambia, especially along the line of rail from Livingstone to North-Western Province, as well as in Luapula, Northern and Eastern provinces. Most of the carbonate rocks in Zambia have been metamorphosed to form dolomitic marble and calcitic marble. In some areas there are very little or no carbonate resources, for example in Northern Province carbonatite is the only significant deposit of carbonate rock and in Western Province there are no significant carbonate deposits.

3.4 If carbonate rocks are crushed and milled to a powder they can be used as agricultural lime. Dolomite is preferred as it contains both of the important plant nutrients (calcium and magnesium) and has a high neutralising capacity (i.e. a fixed weight of dolomite will neutralise more soil acidity than the same amount of limestone). However, limestone is still important as it can be used for liming soil that does not require additional magnesium and in the absence of dolomite its use is still preferable to leaving the soils in an acid state.

3.5 The aim of this part of the project was to determine the quality of the dolomite resources at sites identified in Mkushi, Central Province and Solwezi, North-Western Province.

3.2 THE GEOLOGY OF COMMERCIALLY WORKED CARBONATES

3.6 The carbonate rocks currently worked commercially in Zambia include the calcitic marbles of the Mampompo Limestone and the Lower Kundelungu Formation. Chilanga Cement Ltd works the calcitic marble of the Mampompo Limestone in the production of cement in Chilanga, Lusaka Province. The same limestone is also worked by Crushed Stone Sales Ltd, United Quarries Ltd, Mindeco Small Mines Ltd and Uniturtle Industries (Z) Ltd for the production of aggregate, agricultural lime and ground limestone mineral fillers. The calcitic marble of the Lower Kundelungu Formation is worked by Ndola Lime Ltd for the production of burnt lime and by Chilanga Cement (Ndola) Ltd for the production of cement in Ndola, Copperbelt province. The dolomitic marble of the Lower Kundelungu Formation is worked by Hi-Qwalime Ltd to produce agricultural lime in Mkushi, Central Province.

3.3 FIELD SURVEY WORK

3.7 Field sampling of dolomite in both Mkushi and Solwezi was carried out in 2000. A total of 77 samples were collected mainly from surface exposures and from small pits (down to approximately 1 metre). A description of each deposit is given below. Laboratory test work to determine their suitability for use as agricultural lime was carried out at the GSD in Lusaka. The laboratory methodology, sample list and results are given in Appendices 2 to 9. Full major element chemical analysis on selected samples was also carried out at the BGS.

3.3.1 Mkushi case study area

3.8 The dolomite (referred to as the ‘Munsakamba dolomite’) is located to the north-west of Mkushi Town, which is the District Administration headquarters (Boma) for this part of Central Province, Zambia (Figures 1, 2 & 5; plates 3 & 4). The road access to Mkushi Town (the full width tarmac Great North Road linking Zambia with Tanzania in the north) is very good. This degenerates into a rather poor track, which links Mkushi Town with the north-central part where the Munsakamba dolomite is located. The dolomite was identified by the Zambian Geological Survey Department (Stillman, 1965) and evaluated for use as agricultural lime by the former Mineral Exploration department (Caruthers, 1986). The Mkushi Small Farmers Association was actively involved in the promotion of the dolomite for production of agricultural lime; which ultimately led to the establishment of the Hi-Qwalime agricultural lime production operation in 2000.

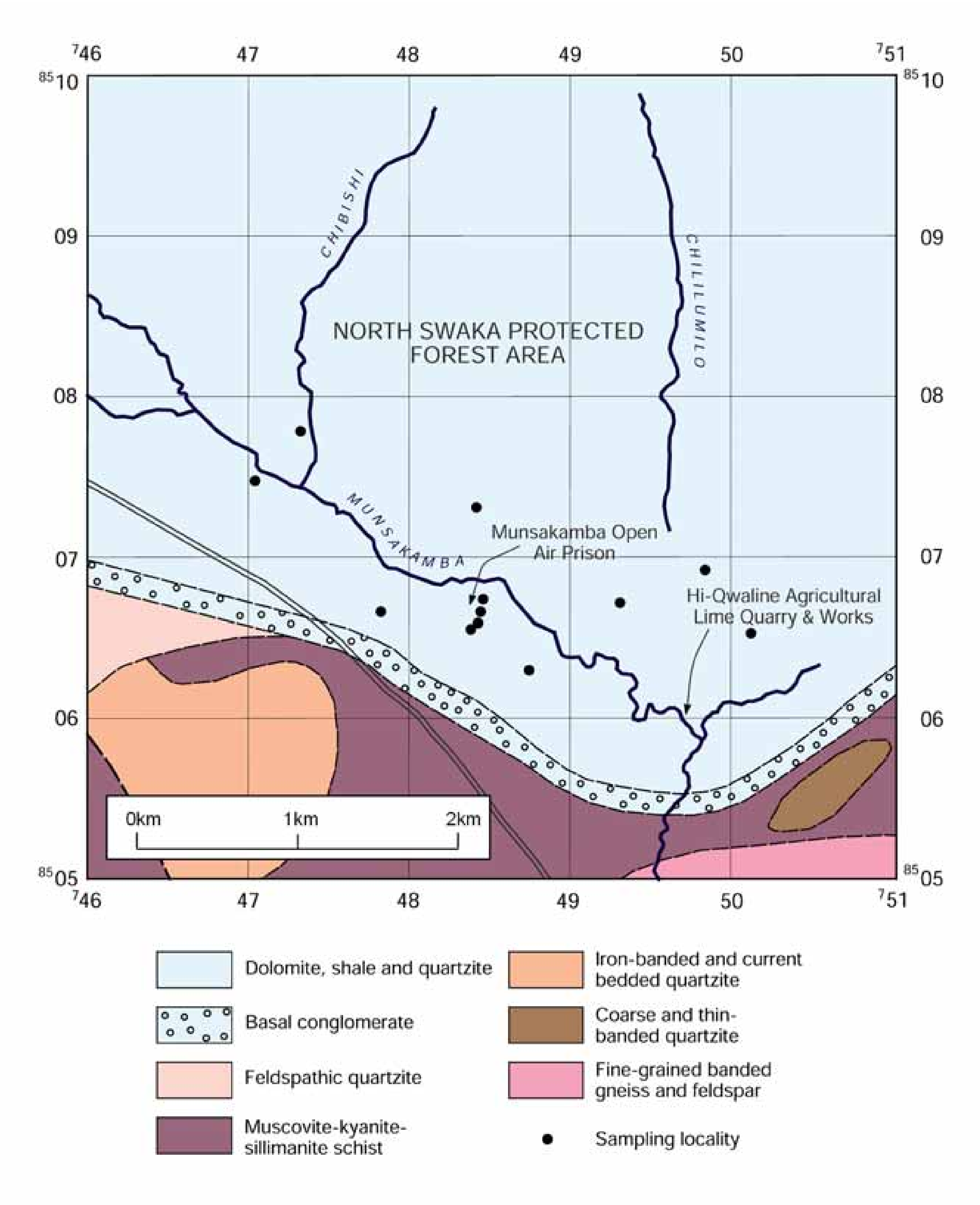

Figure 5 Geological map of the Mkushi study site

(NB The numbered lines indicate the 1,000 metre Universal Transverse Mercator Grid Zone based on Republic of Zambia 1:50,000 topographic map sheets 1329 A4 and C2 with geological linework superimposed from the Geological Survey 1:100,000 Geological Map of the Mkushi Area; the vertical gridlines are oriented north-south; each grid square is 1 kilometre across)

3.9 Access to the dolomite deposit is via an 18-kilometre track leading from Mkushi Town to Munsakamba Basic School. The track traverses one major perennial river, the Lunsemfwa, which is crossed by means of a fairly robust bridge (intermittently flooded during the rainy season) and suitable for light to medium heavy trucks of up to 35 tonnes. Access to other outcrops of the dolomite is via Hi-Qwalime quarry, and through the turn-off to the Munsakamba Open Prison some 13 or so kilometres further up on the road to Musofu Mission.

3.10 The soil is fairly thin in some places but generally it is well developed and obscures the dolomite. The area can be characterised as being sparsely populated with little to no agricultural or pastoral activities. The Zambia National Services camp owns a large part and the remainder is within the North Swaka Forest Reserve. There is virtually no supply of power and infrastructure. A series of streams, namely the Munsakamba, Chamulilo and Chiswa Stream traverse the area. These streams seem to be fed by aquifers originating from the North Swaka Forest Reserve and all discharge into the Lunsemfwa River.

3.11 The study area is shown in the accompanying geological map (Figure 5). The Munsakamba dolomite forms part of the Lower Kundelungu Formation, which also contains shale and quartzite. The dolomite ranges in colour from pinkish white, white to grey and yellowish grey (Photos 3 & 4) and it can be massive, coarsely crystalline or laminated, sometimes with a sugary texture. It often exhibits contortions and calcite veins up to 5 cm thick. The dolomite overlies older rocks, which include the Mine Series (feldspathic quartzite), the Musofu Formation (iron-banded and current bedded quartzite), the Irumi Formation (schist and banded quartzite) and the Mkushi Gneiss Formation (banded gneiss).

3.12 The overburden in the area is locally quite thick and the water table very high with most pits dug during the survey intersecting the water table at only 1m depth. Some pits were dug to a depth of 4m without intersecting bedrock, especially those on higher ground. Most samples were collected from the lower ground adjacent to the river. Twenty-three samples were collected. No marble exposures were encountered further north and east of the surveyed area where the land encountered is generally hilly and forested with numerous quartzite ridges. The sample numbers and their respective co-ordinates (UTM) are presented in Appendix 7.

3.13 The areal extent of these dolomites is 420,000 square metres (600 metres x 800 metres). Assuming the dolomites extend to a depth of 5 metres their total volume would be 2,100,000 cubic metres. Assuming the density of the dolomite is 2.84 g/cm^3 (which is equivalent to 2.84 tonnes per cubic metre) the estimated dolomite resources present within the study area are 5.96 million tonnes. This is a relatively conservative estimate as a borehole in an adjacent area showed the dolomite to be 20 metres thick. If this was consistent across the area then resources would be over 20 million tonnes. Outside the study area there are more dolomite outcrops and it is possible that the resource figure could be significantly increased with further exploration work.

Plate 3 Outcrop of dolomite, Munsakamba, Mkushi, Central Province, Zambia

Plate 4 Sampling of dolomite, Munsakamba, Mkushi, Central Province, Zambia

3.3.2 Solwezi case study area

3.14 The dolomite is located immediately south of Solwezi town, which is the provincial headquaters of North-Western Province (Figures 3, 4 & 6; plates 5 & 6). Further occurrences of the same dolomite occur throughout this part of North-Western Province. The road to Solwezi from the Copperbelt is relatively poor, especially the 50 km immediately encountered west of Chingola. This dolomite was identified in the 1960s by the Geological Survey Department (Arthurs, 1974). A report on the suitability of the dolomite for use as agricultural lime was prepared by MINEX (Rao, 1984). Since then there has been little or no interest shown in the dolomite; apart from small-scale working for construction material.

3.15 Access to the dolomite is via a 1 km stretch of tarmac road that leads south from Solwezi town towards the nearby teacher training college. The dolomite crops out in a relatively large dambo area (a broad topographical depression) that is transected by the Solwezi and Kifubwa rivers. It forms characteristically rounded pale grey outcrops and in some parts of the dambo the dolomite is more thinly bedded. Generally the dolomite is well exposed, especially along the Solwezi river (Photos 5 & 6).

3.16 The area surrounding the dolomite deposit is heavily populated with small-scale farms occurring immediately to the west and east. Availability of power and infrastructure is not a problem as the main tarmac roads, as well as electrical, water and labour supplies are close at hand.

3.17 The study area is shown in the accompanying geological map (Figure 6). The dolomite forms part of the Chafugoma Marble Formation, which consists of calcitic and dolomitic marble with minor intercalations of slate and schist. The dolomitic marble varies in colour from yellowish white, white, pinkish white to grey and dark grey. It is either massive or finely laminated and quite friable. It generally strikes NE-SW and dips gently to the NW. The dolomite overlies the older Chafugoma Schist Formation (dark coloured, medium-grained schists), the Lower Ironstone Formation (dark coloured, iron-banded quartzites) and the Upper Roan Formation (light-coloured calcareous quartz-mica schists and quartzites). It is overlain by the younger Solwezi Biotite-Quartzite Formation (quartzites, schists and phyllites) and partly intruded by basic igneous rocks (scapolite-hornblende rocks and amphibolite).

3.18 Sixteen samples were collected during the initial reconnaissance visit to the area and a further 34 samples were collected during the second visit, making 50 samples in total. The sample numbers and their respective UTM co-ordinates are presented in Appendix 7. The main outcrop of dolomite has an areal extent of 2.1 million square metres. Assuming the dolomite extends to a depth of 5 metres the total volume would be 10.5 million cubic metres. Assuming the density of the dolomite is 2.84 g/cm^3 (which is equivalent to 2.84 tonnes per cubic metre) the estimated dolomite resources present within the study area is 29.82 million tonnes.

3.19 This is a conservative estimate based on pits dug within the study area; it is likely that the dolomite extends to a greater depth, however to what extent is unknown. The resource figures could be much higher, possibly upto100 million tonnes. Outside the study area there are more dolomite outcrops and it is possible that the resource figure could be significantly increased with further exploration work.

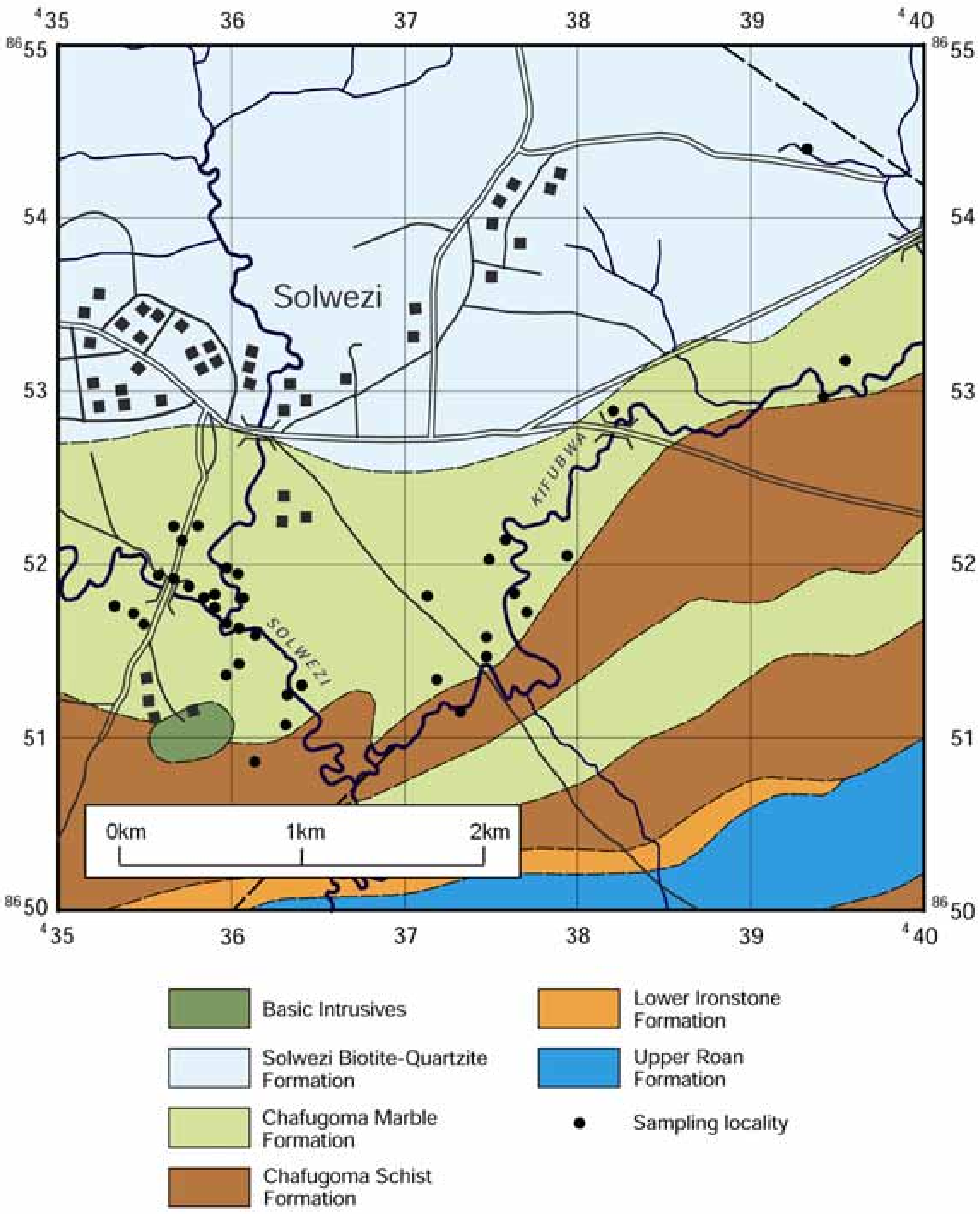

Figure 6 Geological map of the Solwezi study site

(NB The numbered lines indicate the 1,000 metre Universal Transverse Mercator Grid Zone based on Republic of Zambia 1:50,000 topographic map sheet 1226 A2 with geological linework superimposed from the Geological Survey 1:100,000 Geological Map of the Solwezi Area; the vertical gridlines are oriented north-south; each grid square is 1 kilometre across)

Lusaka East & Changushi case study areas

3.20 Five samples of dolomite were collected in the Leopards Hill area of Lusaka. The dolomite is mainly grey coloured and medium grained; although white to whitish grey and yellowish grey varieties also occur. Locally the dolomite exhibits slaty cleavage and is easily broken into flat slabs. Finely disseminated sulphide minerals also occur. The dolomite in this area is very extensive and boreholes have encountered up to 45 metres of dolomite. Based on the areal extent and the thickness it is likely that the resources are several hundred million tonnes. The samples are listed in Appendix 7.

3.21 Two samples were collected from the Changushi area, which is 25 km SW of Solwezi town. The dolomites from Changushi were from the Chafugoma Marble Formation but are darker coloured, much coarser grained and harder than the dolomite occurring close to Solwezi town. The dolomite occurs extensively within the area and it is likely that the resources are significant. The samples are listed in Appendix 7.

3.4 LABORATORY ANALYSIS OF LIMESTONE AND DOLOMITE FOR USE AS AGRICULTURAL LIME

3.4.1 Introduction

3.22 The limestone and dolomite samples collected in the study areas (Plates 7 & 8) were evaluated to determine their suitability for use in the production of agricultural lime (Plates 9 & 10). From a previous review of limestone and dolomite testing (Mitchell *et al*, 1998), four properties were identified as being the most useful to determine. These were as follows (detailed test methods are given in Appendices 2 to 6):

1. **Neutralisation ability**

   This is expressed as the weight percentage Calcium Carbonate Equivalent (CCE) and is often referred to as the Neutralisation Value (NV). This is the amount of calcite ($CaCO_3$) and/or the equivalent amount of dolomite ($CaMg(CO_3)_2$). This is determined by the test method ASTM C25–95. (Appendix 2).

2. **Plant nutrient content**

   This is expressed as the weight percentage calcium oxide and magnesium oxide, respectively CaO and MgO. This is determined by the test method ASTM C25–95. (Appendix 3).

3. **Ease of pulverization**

   This is otherwise known as the Grindability Index and is expressed as the weight percentage of fine particles generated in a milling trial. This is determined by the test method ASTM C110–95. (Appendix 4).

4. **Agronomic effectiveness**

   This is otherwise known as the reactivity and is a measure of the rate at which agricultural lime neutralises soil acidity. This is determined by the test method of Bornman *et al*, 1988. (Appendix 6).

3.23 A fifth property, the **fineness** was also identified as a critical property requiring determination. This is a limited measurement of the particle-size distribution and is only intended for the evaluation of ground material and not for rock samples. The fineness is expressed as the weight percentage of material finer than 8 mesh (2.36 mm) and 60 mesh (250µm). The fineness is determined by dry sieve analysis determined by the test method ASTM C602–95 (Appendix 5).

Plate 5 Outcrop of dolomite, Solwezi, North Western Province, Zambia

Plate 6 Sampling of dolomite, Munsakamba, Mkushi, Central Province, Zambia

3.24 The fineness can be used to determine one of the most meaningful measures of the overall effectiveness of agricultural lime. This is the 'Effective Calcium Carbonate Equivalent' (ECCE), which is calculated using a two-step method as follows:

i) Calculation of the 'Fineness Factor':

Fineness factor (%) = 0.5(% between 2.36 mm & 250 mm) + % finer than 250µm

ii) Calculation of the ECCE:

Effective Calcium Carbonate Equivalent = Fineness Factor multiplied by CCE

3.25 The ECCE value can only be calculated for ground material, therefore the neutralisation ability is the best criterion for evaluating the suitability of limestone and dolomite rock samples for the production of agricultural lime.

3.26 In a reconnaissance programme the neutralisation ability would be the best property to determine in the initial test work. If a sample contained greater than 80% CCE it would progress onto the next stage of the test work programme. However, if the sample contained less than 80% CCE it would be eliminated from the test work programme. In this way determination of the neutralisation ability would act as a 'screen' to remove unsuitable samples. This would help to conserve the available test work resources and focus the evaluation programme on the material most suitable for the production of agricultural lime.

3.27 In this research project all of the agricultural lime properties were determined for each of the samples, as virtually all of them had a CCE greater than 80%. This meant that the GSD staff were able to acquire a thorough understanding of the test methods and helped to establish a specialist agricultural lime evaluation laboratory at the GSD. This capability at the GSD could be applied to the evaluation of carbonate rock for use in the production of agricultural lime and also quality control test work on agricultural lime for existing producers.

3.28 The following sections provide summary information on the properties tested and summary results of the seventy plus samples collected and tested by the Zambian GSD. Where available, the data from previous test work carried out on samples from the same areas was incorporated into the evaluation to provide a greater volume of information. The full data can be found in Appendix 8. Summary information from test work carried out on all of the samples collected from sites across Zambia on the previous project has also been included at the end of this section.

3.4.2 Results and discussion

Neutralisation Ability

3.29 Reducing soil acidity is the prime function of agricultural lime. Generally, the amount of available plant nutrients and the plant growth rates reach optimum levels at or near neutral pH. The addition of agricultural lime to acid soil improves the uptake of the nutrients in fertilisers, such as nitrogen, phosphorus, potassium and sulphur. It also decreases the availability of toxic elements such as aluminium and manganese.

3.30 The neutralisation ability of agricultural lime is usually expressed in terms of the CCE. The CCE value for pure limestone is 100% and for pure dolomite 108%. Dolomite has a higher CCE value because magnesium carbonate (a component of dolomite) has a lower molecular weight but the same neutralising power per molecular unit as calcium carbonate. A CCE value of 80% is considered to be a minimum for agricultural lime. A summary of the CCE values for the different sample areas is given in Table 5 (and given in full in Appendix 8).

Plate 7 Sampling dolomite, Solwezi, North-Western Province, Zambia

Plate 8 Recording sample data, Solwezi, North Western Province, Zambia

Table 5 Average neutralising ability data for Zambian carbonate samples

	Solwezi		**Mkushi**	**Lusaka East**	**Changushi**
	Dolomite CCE %	Limestone CCE %	Dolomite CCE %	Dolomite CCE %	Dolomitic limestone CCE %
Average	104	95	103	88	98
Count	44	5	25	5	2
Minimum	100.3	89.1	96.3	64.8	97.5
Maximum	107.2	98.7	104.8	98.3	97.9

NB Count represents the number of samples analysed.

3.31 Samples from each of the areas studied have average CCE values higher than 80%, with samples from Solwezi and Mkushi averaging over 100%. Within these two areas, the CCE values are relatively consistent; this bodes well for any future production from these sites.

3.32 On the basis of the CCE values most of the samples have the potential to neutralise acid soils. Therefore, all of the samples were progressed to the next stage of laboratory testing.

Plant nutrient content

3.33 An important function of agricultural lime is to provide essential plant nutrients in the form of calcium and magnesium. Therefore, it is important to quantify the amount of Ca and Mg in limestone and dolomite used as agricultural lime. The method used to determine the CaO and MgO content of the samples conformed to ASTM C25–95.

3.34 A MgO content of 6% is considered to be a minimum for agricultural lime (Tether & Money, 1989). Limestone does not contain sufficient MgO. Dolomitic limestone (with more than 27.5% dolomite), calcitic dolomite and dolomite would qualify for use in the production of agricultural lime on this basis. It is commonly accepted that a dolomitic agricultural lime is preferable to a calcitic agricultural lime. A dolomite with a CCE of 80% would have an MgO content of 17.5%.

3.35 There is no minimum CaO content quoted in the literature. However, if the minimum CCE of 80% is applied this would give a mimimum CaO content of 44.8% CaO for limestone and 24.3% CaO for dolomite.

3.36 The CaO and MgO contents of the samples are summarised in Table 6 (and given in full in Appendices 8 and 9). In summary, the dolomite samples from Solwezi and Mkushi met the minimum plant nutrient requirement for magnesium (6% MgO). Most of the Solwezi and Mkushi dolomite samples contain between 29% and 35% CaO and 18% and 21% MgO. The other samples did not meet the MgO requirement despite having CCE values greater than 80%. Under normal circumstances those samples not meeting the minimum MgO content would be eliminated from the test programme. However, all of the samples were retained in the test programme to enable GSD staff to become more familiar with the test methods.

Table 6 Average plant nutrient content data (CaO & MgO) & summary statistics

	Solwezi		Mkushi	Lusaka East	Changushi
	Dolomite Wt %	Limestone Wt %	Dolomite Wt %	Dolomite Wt %	Dolomitic limestone Wt %
Calcium Oxide (CaO)					
Average	32.2	52.4	30.5	43.6	49.6
Count	44	5	25	5	2
Minimum	20.7	50.4	25.1	22.4	49.2
Maximum	36.6	53.9	34.4	52.2	50.0
Magnesium Oxide (MgO)					
Average	19.3	2.6	19.1	4.0	2.8
Count	44	5	25	5	2
Minimum	16.6	1.4	14.9	1.4	2.6
Maximum	22.4	4.5	21.3	9.8	2.9

Ease of pulverisation

3.37 It is necessary to grind (or pulverise) limestone and dolomite to produce the fineness required for their use as agricultural lime. The relative ease with which limestone and dolomite is ground to meet the required fineness is referred to as its “grindability”. This can be determined using the grindability index test method (ASTM C110–95 1995). There is no upper or lower requirement for this property.

3.38 The real value of the grindability index is in the determination of the relative amount of energy required to grind different samples of limestone and dolomite. The test method involves tumbling a fixed amount of rock of a specified particle size in a container that contains a grinding media charge. After tumbling for a set period the amount of fines generated are measured by screening the sample using a 200 mesh (75µm) sieve. The weight proportion of fines generated is the grindability index value. Samples with a higher value are easier to pulverise compared to samples with lower values. Samples with lower values would require more grinding energy to reduce them down to the required particle size than samples with higher values.

3.39 Table 7 shows summary data for the grindability index of the samples from the different study areas (with full data given in Appendix 8). Overall there is a great deal of variation between the samples within each study area as indicated by the wide range of results. The Solwezi study area, for example, has a considerable range from 38% to 88%.

Table 7 Average grindability data & summary statistics

	Solwezi		Mkushi	Lusaka East	Changushi
	Dolomite Wt % <75µm	Limestone Wt % <75µm	Dolomite Wt % <75µm	Dolomite Wt % <75µm	Dolomitic limestone Wt % <75µm
Average	72.5	82.9	71.5	74.8	80.7
Count	44	5	25	5	2
Minimum	38.0	78.7	60.0	62.3	79.8
Maximum	87.8	90.4	98.6	78.9	81.7

3.40 It is observed that the grindability index increases with increasing calcite content (Figure 11) i.e. the limestone samples are easier to grind than the dolomite samples. This correlates well with the hardness of the respective minerals; calcite has a Mohs hardness of 3 whereas dolomite has a Mohs hardness of 3.5 to 4.

Plate 9 Laboratory evaluation of dolomite for use as agricultural lime

Plate 10 Laboratory evaluation of dolomite for use as agricultural lime

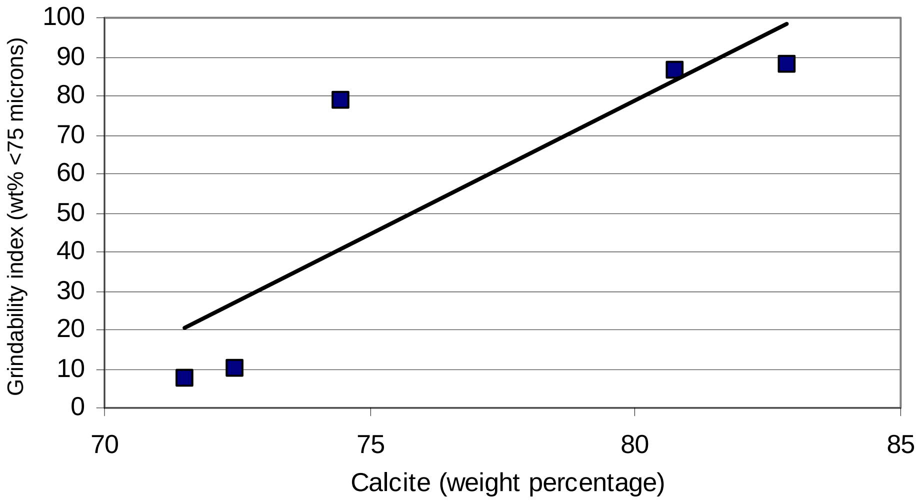

Figure 7 Correlation between calcite content and grindability

Agronomic effectiveness

3.41 Agronomic effectiveness or reactivity is a measure of the rate at which agricultural lime neutralises soil acidity. The test method developed by Bornman *et al.* (1988) was used to determine agronomic effectiveness. This method simulates the interaction between agricultural lime and soil. It is only useful for comparisons between different samples. High reactivity values indicate a sample that reacts at a fast rate whereas low values indicate a sample that reacts at a slower rate.

3.42 The reactivity data are summarised in Table 8 (and given in full in Appendix 8). Overall, there is considerable variability between the samples tested from within the same study area. This is likely to be due to the variables that influence reactivity such as the relative proportion of calcite and dolomite and the fineness of the sample. The Solwezi study area, for example, has a range of reactivity from 70% to 91%.

Table 8 Average agronomic effectiveness data & summary statistics

	Solwezi		**Mkushi**	**Lusaka East**	**Changushi**
	Dolomite Wt % Reactivity	Limestone Wt % Reactivity	Dolomite Wt % Reactivity	Dolomite Wt % Reactivity	Dolomitic limestone Wt % Reactivity
Average	80.4	88.5	77.1	84.93	89.4
Count	44	5	25	5	2
Minimum	70.4	86.5	63.2	68.6	87.8
Maximum	90.8	89.8	83.8	89.8	91.0

3.43 It can be discerned, however, that the reactivity increases with increasing calcite content (Figure 14) i.e. the limestone samples react faster than the dolomite samples. This correlates with the relative reactivity of the minerals that make up these two rocks. Calcite reacts strongly with acid (e.g. Hydrochloric acid, HCL) whereas dolomite will only react when powdered or when the acid is heated. Calcite reacts with acid approximately 3 to 4 times faster than dolomite.

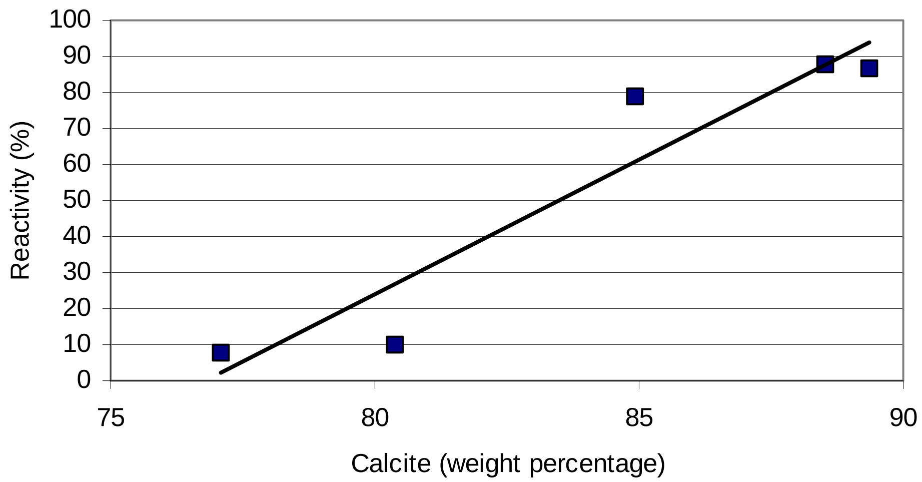

Figure 8 Correlation between calcite content and reactivity

3.4.3 Comparison with commercial agricultural lime

3.44 The laboratory evaluation of the dolomite and limestone would not be complete without comparing the test data with that known for commercial agricultural lime. Table 9 gives a summary of the test data for the samples studied in this evaluation in comparison with data from agricultural lime products available in Zambia.

3.45 The properties of the Mkushi dolomite samples tested are similar to those of the agricultural lime produced by Hi-Qwalime as they are working the same material.

3.46 The samples that show the best potential for production of agricultural lime are the dolomite samples from Solwezi and Mkushi. They have CCE, MgO, CaO and reactivity values comparable with the Lilyvale Farm agricultural lime (which is produced from a dolomite). The test values for the Solwezi limestone are comparable with those of the Ndola Lime Ltd agricultural lime (which is produced from a limestone).

3.5 OVERALL ASSESSMENT OF CARBONATE RESOURCES IN ZAMBIA

3.47 Carbonate resources across Zambia were sampled as part of an evaluation programme carried out under the previous agricultural lime research project. Whereas this was not a comprehensive evaluation of all known carbonate deposits in Zambia, it did attempt to evaluate all of those that were thought to have some potential for the production of agricultural lime. Table 10 gives a summary of the agricultural lime properties of all of the samples tested on both this and the previous research project.

Table 9 Comparsion with commercially available agricultural lime

Sample site	**Neutralisation ability** CCE wt %	**Plant nutrient content** CaO Wt %	MgO Wt %	**Ease of pulverisation** Grindability Wt% <75µm	**Agronomic effectiveness** Reactivity %
FarmLime sites					
Solwezi					
- dolomite	104.3	32.2	19.3	72.5	80.4
- dolomitic limestone	95.1	52.4	2.6	82.9	88.5
Mkushi					
- dolomite	103	30.5	19.1	71.5	77.1
Lusaka East					
- dolomitic limestone	87.9	43.6	4.0	74.8	84.9
Changushi					
- dolomitic limestone	97.9	49.6	2.8	89.4	80.7
Commercial agricultural lime					
Lilyvale Farm					
- dolomite	106	30.7	21.1	97.2	84.2
- limestone	98.8	54.5	0.6	nd	nd
Ndola Lime Ltd					
- limestone	98.7	53.7	1.9	81.4	90.42

Table 10 Summary of data on carbonate resources in Zambia

Sample site	**Neutralisation Value (NV)** CCE wt %	*CaO* Wt %	*MgO* Wt %	*Grindability* Wt% <75µm	*Reactivity* %
Central Province					
Chombela dolomite	106.5	33.1	20.1	51.3	71.7
Lilyvale Farm dolomite	106.0	30.7	21.2	97.2	84.2
Lilyvale Farm limestone	98.8	54.5	0.6	nd	nd
Lukunyi dolomite	108.3	30.9	21.3	98.0	73.7
Mandanji dol. st	81.9	44.2	1.2	99.0	73.7
Mandanji dolomite	62.8	17.2	11.5	99.0	89.5
Mkushi dolomite	103	30.5	19.1	71.5	77.1
Nampundwe calc. dol.	63.7	19.6	11.5	nd	nd
Copperbelt Province					
Chingola dolomite	100.4	27.8	20.4	97.8	68.4
Mpongwe calc. dol.	105.0	34.4	18.6	97.1	89.3
Mpongwe limestone	100.0	55.3	0.5	nd	nd
Ndola Lime Ltd limestone	98.7	53.7	1.9	81.4	90.4
Eastern Province					
Mvuvye limestone	91.2	49.4	1.2	95.9	84.2
Mvuvye dol. lst	85.1	43.6	2.9	92.6	86.8
Mvuyve dolomite	101.0	28.9	19.9	91.9	68.4
Chipata dolomite	87.8	25.8	16.8	96.3	63.2
Luapula Province					
Matanda dolomite	99.4	30.3	18.2	94.2	68.4
Lusaka Province					
Chilenje South calc. dol.	101.74	33.65	17.50	nd	nd
Chilenje South. dol. lst	98.97	52.77	2.07	nd	nd
Lusaka East dol. lst	87.9	43.6	4.0	74.8	84.9
Lusaka West dol. lst	98.87	48.86	4.64	nd	nd
Kabwe Road dol. lst	96.84	52.10	2.35	nd	nd
Southern Province					
Chivuna dolomite	108.3	30.2	21.8	64.0	65.9
Masangu limestone	99.0	55.1	0.2	67.2	86.8
Northern Province					
Nkombwa Hill dolomite	92.4	27.3	17.6	98.0	68.4
Mpangala calc. dolomite	88.2	42.4	5.0	98.9	73.7
North-Western Province					
Changushi dol. lst	97.9	49.6	2.8	80.7	89.4
Solwezi dolomite	104.3	32.2	19.3	72.5	80.4
Solwezi dol. lst	95.1	52.4	2.6	82.9	88.5

NB dol. lst = dolomitic limestone; calc. dol. = calcitic dolomite; nd = not determined

3.48 Assessment of the suitability of carbonates for the production of agricultural lime was carried out by strict application of the thresholds for neutralisation ability (80% CCE) and plant nutrient content (6% MgO). A sub-division was devised to rank the carbonate deposits in terms of their suitability for the production of magnesium-rich agricultural lime All of the carbonate deposits tested over the two research projects were assessed and ranked accordingly (Table 11).

Table 11 Suitability of carbonate rocks in Zambia for agricultural lime production

Highest potential for production of high-magnesium agricultural lime			
Carbonates with a CCE value of 100% or higher, plus a MgO content greater than 6%.			
Dolomite	**Location**	**Dolomite**	**Location**
Lilyvale Farm	CP (1423 A3)	Chombela	CP (1226 B3)
Mkushi	CP (1329 A3)	Lukunyi	CP (1323 A)*
Solwezi	NWP (1226 A2)	Chingola	CBP (1227 D2)
Mvuvye	EP (1430 D2/D4)	Chivuna	SP (1627 B2)
Calcitic dolomite		**Calcitic dolomite**	
Chilenje South	LUP	Mpongwe	CBP (1327 B4/1328 C1)
Moderate potential for production of high-magnesium agricultural lime			
Carbonates with a CCE value between 80 and 100%, plus a MgO content greater than 6%.			
Dolomite	**Location**	**Dolomite**	**Location**
Nkombwa Hill	NP (1032 B2)	Chipata	EP (1332 A1)
Matanda	LP (1128 A4)		
Lowest potential for production of high-magnesium agricultural lime			
Carbonates with a CCE value lower than 80% and/or a MgO content less than 6%.			
Dolomite	**Location**		
Mandanji	CP (1324 A4)		
Dol. limestone		**Dol. limestone**	**Location**
Mvuvye	EP (1430 D2/D4)	Mandanji	CP (1324 A4)
Lusaka East	LUP	Nampundwe	CP (1527 B4)
Kabwe Road	LUP	Lusaka West	LUP
Changushi	NWP (	Chilenje South	LUP
Mpangala	NP (1032 B3)		
Limestone		**Limestone**	
Solwezi	NWP (1226 A2)	Ndola Lime	CBP (1:250K CB)
Lilyvale Farm	CP (1423 A3)	Mpongwe	CP (1327 B4/1328 C1)
Masangu	SP (1628 A1)	Mvuvye	EP (1430 D2/D4)

NB CP = Central Province, NWP = North-Western Province, CBP = Copperbelt Province, EP = Eastern Province, SP = Southern Province, LUP = Lusaka Province, NP = Northern Province, LP = Luapula Province; Brackets = 1:50K topographic sheet (* indicates 1:100K topographic sheet)

3.6 CONCLUSIONS

- There are ample resources of dolomite available within the farming districts in Mkushi and Solwezi. There are estimated to be approximately 6 million tonnes of dolomite within the Mkushi study area and approximately 29 million tonnes of dolomite within the Solwezi study area. It is estimated that the available carbonate resources within the Lusaka East & Changushi areas are very large (upwards of several hundred million tonnes, although this has yet to be investigated).
- The Geological Survey Department (GSD) is capable of carrying out laboratory property testing for agricultural lime.
- The Neutralising ability is the single most important property to determine in an evaluation of dolomite and limestone for use as agricultural lime. This is expressed as the Calcium Carbonate Equivalent (CCE) value. All samples tested had average CCE values greater than 80% (the minimum threshold for agricultural lime) and on this basis have the potential to be used as agricultural lime.
- The plant nutrient content is the proportion of calcium oxide (CaO) and magnesium oxide (MgO) present in the sample. All of the dolomite samples from the Solwezi and Mkushi areas exceeded the minimum threshold (6% MgO) required for magnesium-rich agricultural lime (which is the preferred form). The dolomitic limestone from Solwezi, Lusaka East and Changushi contain on average less than 4% MgO; however these could be used if no alternatives are available.
- The ease with which dolomite and limestone can be ground to a powder is known as the ‘ease of pulverisation’ and is expressed as the Grindability Index. This was found to vary with the relative proportions of the main carbonate minerals (dolomite and calcite); the dolomite samples were harder to grind than the limestone samples. This is because dolomite, the main mineral in the rock dolomite, is harder than calcite, the main mineral in limestone.
- The amount of time it takes for agricultural lime to neutralise soil acidity is known as its ‘agronomic effectiveness’ and is expressed as its reactivity. A short time equates to a rapid reaction rate (and a high reactivity value) and vice versa. This was found to vary with the relative proportions of the main carbonate minerals (dolomite and calcite); the limestone samples were found to neutralise soil acidity faster than the dolomite samples. This is because calcite is much more reactive with acid than dolomite.
- Carbonates with the highest potential for the production of magnesium-rich agricultural lime are found in North-Western (Solwezi), Copperbelt (Chingola and Mpongwe), Central (Mkushi), Southern (Chivuna) and Eastern (Mvuvye) provinces. Carbonates with moderate potential are found in Central (Mandanji), Eastern (Chipata), Northern (Mpangala) and Luapula (Matanda) provinces.

4 Lime production research

Stephen Simukanga, Moffat Mwanza & Mathew Mtonga, University of Zambia

4.1 INTRODUCTION

4.1 The production of agricultural lime is relatively straightforward. It involves the extraction (quarrying and/or mining) of rock from the ground and the processes of crushing and milling to a powder (Table 12). Agricultural lime is often produced as a co-product in an operation that is primarily geared to producing such things as road stone aggregate, quick and hydrated lime, cement and/or mineral fillers.

Table 12 Typical agricultural lime production processes

Process	Operation
Extraction	• Site clearance, including removal of vegetation, soil and overburden. • Drilling and blasting of rock ‘benches’ in a quarry. • Breaking of large rocks using pneumatic drills. • Removal of rock to a processing plant.
Crushing	• Primary crushing (using a jaw or gyratory crusher). • Screening of crushed material to remove the fines, which usually contain soil and fine-grained material (potential agricultural lime). • Secondary and tertiary crushing using cone or jaw crushers. • Screening of crushed rock to produce sized material for aggregate or feed to lime or cement plants.
Milling	• Milling of crushed material using a mill (hammer, ball and/or impact mill) to produce mineral filler and/or agricultural lime. • Bagging into bulk bags (<1 tonne) or small bags (50 to 100 kg).

4.2 Dedicated agricultural lime production plants do exist, especially in countries where agriculture is one of the main stays of the national economy such as in sub-Saharan Africa. Such plants often operate a much simpler production process, which nevertheless consist of the three main components of extraction, crushing and milling.

4.3 This section of the report outlines the research carried out to determine the best means of producing agricultural lime on a small-scale, preferably using appropriate technology and manual labour. This involved establishing the best means of production and commissioning the methodology through field trials on ‘production’. The research followed the recommendations made in the previous research project for the small-scale production of agricultural lime (Mitchell *et al*, 1998).

4.4 The research was sub-divided into two parts; the first considered the most appropriate limestone extraction method and the second involved agricultural lime production trials in Mkushi and Solwezi.

4.2 APPROPRIATE METHODS OF SMALL-SCALE EXTRACTION

4.5 An assessment of the potential for small-scale mining was carried out with site visits based mainly on the dolomite deposit in the Munsakamba area to the north of Mkushi, but with some reference to the dolomite deposit in Solwezi. A preliminary appraisal was carried out which involved visits to the dolomite outcrops identified at Munsakamba Open Air Prison and surrounding areas (Plates 11 & 12).

Availability of resources/infrastructure

4.6 The dolomite deposit in Munsakamba lies in an area with little or no infrastructure. Hence any permanent quarrying operation would be required to erect structures such as offices, storage sheds, social and working amenities for the site workers. This would require a substantial capital outlay which would impact on the production costs and hence the price of the final product. The other, and possibly more attractive alternative would be to erect skeleton infrastructure for equipment maintenance, materials storage and housing for a limited number of security personnel. The rest of the quarry operatives would, as is the case at Hi-Qwalime, be shuttled to and from work to their homes on a shift or daily basis.

Availability of mining machinery

4.7 The only source of mining equipment within Mkushi would be Hi-Qwalime, a private agricultural lime company, which owns and operates the following equipment:

- Two rehabilitated Euclid 50 tonne capacity rear end dump trucks,
- Two small capacity backhoe hydraulic shovels for pit loading operations,
- One small front-end loader for loading onto trucks,
- One electricity power generator (500 Volts to 380 Volts),
- Two hand-held blast-hole drills
- Assorted pit dewatering pumps & an electrically driven compressor

4.8 Considering the intensity of operations at Hi-Qwalime, it would seem unlikely that this equipment could be available for use by a competing mining operation.

Availability of electric power

4.9 The national grid does not reach the Munsakamba area and hence any operations requiring electric power would have to be supplied through on-site generation using diesel powered generation sets, as is the case at Hi-Qwalime.

Availability of Manpower

4.10 Unskilled to semi-skilled manpower is available. The bulk of which originally worked at a nearby abandoned quarrying operation, which had provided road stone aggregate to the Great North Road rehabilitation project (funded by the Danish aid agency, DANIDA). The quarrying operation was relatively large and lasted for sometime during which many local people became acquainted with mining operations. Currently, the supervisors and the bulk of the workers at Hi-Qwalime are former employees of the DANIDA quarry.

Geotechnical Characteristics of Munsakamba Limestone

4.11 A layer of unconsolidated soil of varying thickness covers the dolomite deposit. This would require simple excavation and storage for subsequent use as backfill and for landscaping (where feasible) upon completion of dolomite extraction. Simple mining precautions (safety berms, benches etc) could be incorporated in the bench design to eliminate any possible danger from sloughing of the soils.

4.12 Representative samples of dolomite from Munsakamba and surrounding areas were collected for geotechnical testing at the School of Mines, UNZA. The results of the tests show that the Munsakamba dolomite is a fairly competent rock. It has a uniaxial compressive strength ranging from 1.17 to 1.92kN/cm^2 (average 1.42kN/cm^2) and a tensile strength (Brazilian Method) ranging from 0.41 to 0.49kN/cm^2 (average 0.44kN/cm^2). This indicates that the dolomite is medium hard to hard; therefore successful extraction of the Munsakamba dolomite will require the use of drilling and blasting operations**.**

Mining Method Selection

4.13 The original terms of reference for the project required that production should involve low-cost and labour intensive methods. Therefore, it was decided that simple manual methods would be used in preference to more sophisticated extraction methodologies.

Mining the Mkushi dolomite: Unit operations

4.14 The following consideration is based on open-pit quarrying of the dolomite; bearing in mind it is intended that the quarrying and processing of the dolomite will be carried out on a small-scale employing manual labour. Except for drilling, blasting, and milling, the bulk of the operations will be based on manual labour with hand implements such as shovels and wheelbarrows.

4.15 Manual operations in mining are limited and are strongly dependent on factors such as the production target (volume in tonnes per unit time), the amount of working space in the pit and capacity of the production equipment per unit-time. The operation would start with bush clearing and soil removal. Rock extraction would start with excavation of an access ramp (4m wide and at a 8% gradient), followed by drilling and blasting, loading and haulage of the rock from the quarry and delivery to the crushing site. The topsoil and other loose waste material would be stockpiled for future back-fill operations to replicate the original landform configuration, preferably before mine abandonment.

Bush Clearing and Loose Soil Removal

4.16 Bush clearing and removal of the top-most loose soil would be carried out using manual labour over an area in excess of 100m wide. The bush and loose soil cover on the dolomite is limited, with no more than 500 mm of soil. In the process of bush clearing and loose soil removal, some large blocks of limestone will be excavated. Depending on their size, it is recommended that these be broken up manually, using sledgehammers, and loaded onto wheelbarrows for direct feeding to the crusher. Blocks that are too large to be broken manually should be broken using either placed charges or through drilling of shot holes**.** The estimated amount of loose limestone boulders recoverable during removal of the soil is less then 5% of the total cleared.

4.17 In order to clear the site a labour force would be equipped with sledgehammers, crowbars, picks, wheelbarrows and protective wear. It is estimated that two thousand tonnes of soil would need to be cleared from the site. Assuming one man can load and move 5 tonnes per day, 2000 tonnes would take 400 man-days. At a labour rate of US$1 per day, plus equipment, it would cost US$1.13 to move each tonne of loose soil (see Appendix 12 for details).

Drilling and Blasting

4.18 The first bench of 29m length, 20m width and 2m depth will be opened up for extraction of limestone in strips measuring 4m wide and 2m depth. The bench floors should be slightly inclined from the horizontal towards the Chililumilo Stream for ease of rainwater flow and to avoid slope instability through accumulation/percolation of rainwater and weathering of the upper bench ledges. This sequence of events will be repeated in the extraction of neighbouring outcrops and, upon exhaustion, in outcrops across the Chililumilo Stream.

Drilling

4.19 This could be accomplished by either subcontracting the work to a quarrying company or by procuring the necessary equipment and personnel to carry out the work. Due to the isolation of the area, subcontracting the work to a quarrying company would entail substantial costs particularly for mobilisation and demobilisation of the drilling equipment to and from the mine site.

4.20 Two options were considered for drilling blast holes into the dolomite, firstly a compressor/jack-hammer combination and secondly a petrol-powered portable breaking hammer. The most appropriate compressor-jackhammer combination was thought to be an Atlas Copco STS 48 Dd (or equivalent) compressor powered by a Magirus Deutz F4L912 air-cooled diesel engine with Atlas Copco RH 658–4LS (or equivalent) rock drills for hand held bench drilling. The total rock drilling ownership and operating costs were calculated to be US$14.76 per hour of drilling. The details are given in Appendix 12.

Plate 11 Munsakamba dolomite, Mkushi, Central Province, Zambia

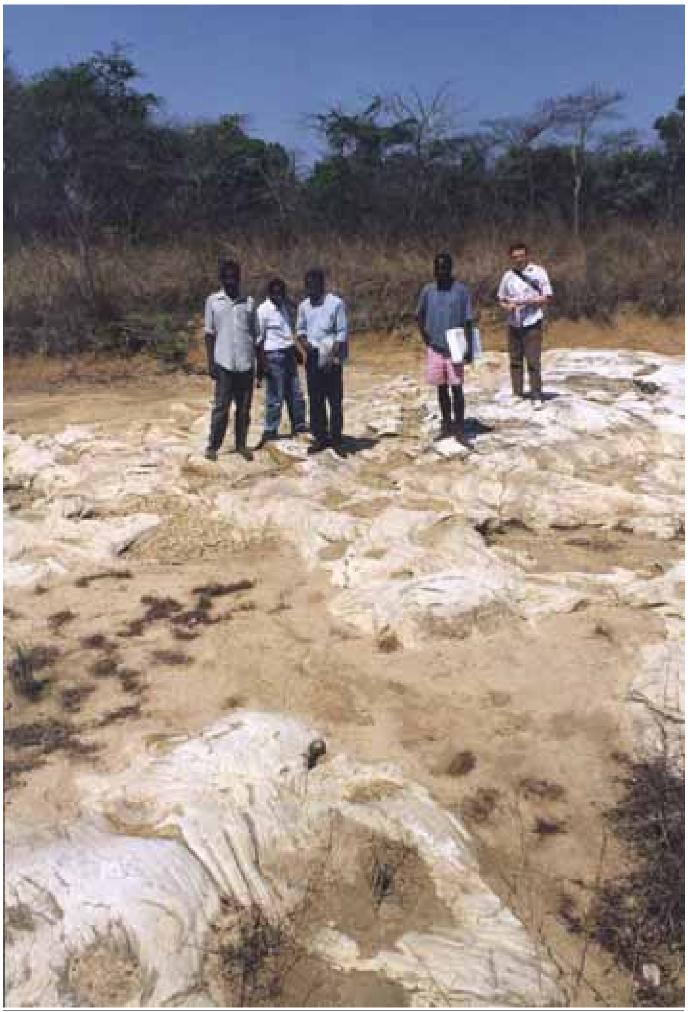

Plate 12 Mkushi farming district, Central Province, Zambia

4.21 The second option was a petrol-powered combination drill with an integral single cylinder (cast iron) air-cooled two-stroke engine. Use of a portable hammer would translate into very low overall production costs of agricultural lime at Munsakamba. The total rock drilling ownership and operating costs were calculated to be US$4.87 per hour of drilling. The details are given in Appendices 13.

4.22 The portable hammer drill would result in significantly lower drilling costs than the jack-hammer/compressor combination. It is therefore, recommended that portable hammer drilling should be the chosen method of blast hole drilling.

4.23 In order to achieve the maximum possible fragmentation, a close drill pattern and high powder factor would have to be used to achieve maximum size reduction during blasting. Achieving a high degree of fragmentation would reduce the manual effort required for primary size reduction prior to milling (Appendix 14).

Blasting

4.24 It is recommended that blasting of the dolomite be done with "Waterproof Dynamite" (60% Nitroglycerine) high explosive with Nitroglycerine-based "Cordtex Detonating Fuse" used for initiation. The use of Waterproof Dynamite would result in maximum fragmentation of the dolomite (which would reduce upstream manual labour requirements for primary crushing), efficient and effective detonation in "wet holes" (which are anticipated at lower benches) and the use of small diameter high explosive in jackhammer drilled blast holes. As the Munsakamba dolomite is a medium-hard to hard rock, it is estimated that the average explosive consumption would be 0.68 kg per cubic metre or 2.85 kg per blast-hole.

4.25 The broken rock yields would range from 10.8 tonnes of rock per drill hole at a cost of US$0.70 per tonne to 12.2 tonnes at a cost of US$1.01 per tonne (Table 13).

Table 13 Rock yield and high explosive consumption

Drilling and blasting factors	
Broken rock per drill hole - Cubic metres (tonnes)	4.0 (10.8) to 4.5 (12.2)
High explosive consumption (kilograms per tonne of rock)	0.24 to 0.26
Rock yield per metre of blast hole - Cubic metres (tonnes)	2.0 (5.3) to 1.7 (3.6)
Cost (US$) of rock yield per - Cubic metre (tonne)	1.88 (0.70) to 2.72 (1.01)

Plate 13 Original TD Hammer Mill

Plate 14 Original TD Hammer Mill on trial in Mkushi, Central Province, Zambia

Loading and Hauling

4.26 Manual loading and hauling of dolomite with a wheelbarrow is recommended. Typical wheelbarrows in use are all-steel construction mounted on wide rubber tyres with roller bearings. They have a 70 to 80 litres heaped capacity, which is equivalent to 100 to 120 kg.

4.27 For each man-shift, two men working as a team (one on shovel and one on wheelbarrow) will be able to load and move 10 tonnes of limestone over an average tramming distance of 500 metres in an eight-hour working shift. Adopting a shift remuneration of $2.5 for unskilled manpower will give a unit cost of $0.25 per tonne for loading and US$0.25 per tonne for hauling. This gives a total loading and hauling cost of $0.50 per tonne or US$1.35 per cubic metre. A contingency of 10% of costs should to be built for secondary manual size reduction. This will therefore give a total loading and hauling cost of US $0.55 per tonne or US $1.49 per cubic metre of rock hauled to the processing plant located not more than 500 metres from the mine.

4.3 CRUSHING AND MILLING

4.28 The Technology Development and Advisory Unit (TDAU) and the School of Mines of the University of Zambia, were contracted to develop an appropriate milling unit for production of agricultural lime based on the TD hammer mill.

4.29 The TD hammer mill was developed at the TDAU for the Zambian market based on the design concept of the African Regional Centre for Engineering Design and Manufacturing (ACEDEM) in Nigeria. The TD hammer mill was originally conceived for producing maize meal flour.

4.30 The TD hammer mill was designed to be portable (it only weighs 90 kg) and flexible in its use (Plates 13 & 14). The mill can be used for milling maize meal and stock-feed. It requires minimal maintenance and is highly efficient as the hammers are driven directly by the engine shaft without the use of expensive bearings. Also, there is no cyclone or belt attachment, which would increase maintenance costs. It is driven by a simple single-piston petrol engine (8 hp), which can easily be maintained.

4.31 A portable hammer mill, produced by the TDAU underwent rigorous laboratory and field milling trials in Mkushi using the local dolomite as feed material. Results from these trials formed the basis for redesigning the mill to make it more suitable for milling dolomite. A modified mill was tested and commissioned using the Mkushi and Solwezi dolomite.

4.32 The development work involved the determination of the optimal feed size of the dolomite, quality of the ground output, technical evaluation of the mill performance and modification of the mill to increase its performance. Determination of the cost of producing agricultural lime formed part of the work. This report outlines the trials conducted on the hammer mill and the results obtained.

Plate 15 Crushed dolomite used as feed to TD Hammer Mill during laboratory trials

Plate 16 Product from TD Hammer Mill during laboratory trials

Original TD hammer laboratory trials

4.33 The aim was to use the TD hammer mill to produce agricultural lime that contains particles 100% finer than 2 mm, 60% finer than 400 microns and up to 50% finer than 150 microns (Mitchell *et al*, 1998). This section of the report outlines the performance of the mill. The parameters monitored during the trials include the mill feed particle-size, the milling rate, fuel consumption, the wear parts and the fineness of the mill product. The mill product data obtained only applies to the Mkushi dolomite, dolomites from other locations would need to be tested as they will have different physical properties that would affect the fineness of the agricultural lime produced. Recommendations are also made for the most appropriate mill operating parameters to use and modifications to the mill to improve its performance.

Effect of mill feed size on performance of mill sieve

4.34 Mill feed of different sizes was produced using a laboratory jaw crusher at gape settings of 7, 9, 11 and 19 mm (referred to in the report by their crusher setting). Plate 15 shows typical mill feed material and plate 16 shows typical mill product. The 7 mm mill feed contained 95% of material finer than 10 mm, the 9 mm, 81%, the 11 mm, 41% and the 19 mm, 31%. Two mill sieves were used for this trial with apertures of 2 mm and 3 mm respectively. The 2 mm sieve was used as it represents the size of the coarsest particle required in the agricultural lime. The 3 mm sieve was used to determine whether the product particle-size specification could be met using a coarser product sieve.

4.35 Three 10 kg sub-samples for each mill feed size were used for the milling trials. The milling rate was determined by noting the time taken to mill each 10 kg sample. The 2 mm product sieve was able to handle the 7 mm and 9 mm mill feed without any damage, but was perforated by the material from the 11 mm mill feed. The 3 mm sieve was able to handle the 11 mm mill feed without damage, but was perforated by the 19 mm mill feed. It was observed that there was significant material loss during milling due to dust escaping through the mill body joints, the hood and at the product outlet (sack).

Effect of mill feed size on the fineness of the mill product

4.36 Three 10 kg sub-samples for each mill feed size were used in the trials to monitor the effect of mill feed size on product fineness. The mill feeds (Figure 19) used in these trials were the 7, 9, 11 and 19 mm and were fed at a constant feed rate. The 3 mm product sieve was used. Assessment of the fineness of the mill products (Figure 20) was by particle-size analysis, using 2 mm, 425 micron and 150 micron sieves (a 425 micron sieve was used instead of the 400 micron sieve). A lot of dust was produced during milling, which mostly escaped through openings in the sides of the mill, resulting in an average loss of 13.6 % of the feed. The noise level in the mill increased with an increase in feed size. The results are shown in Table 14.

Table 14 Mill Product using different crusher feed sizes and 3 mm sieve

Particle-size	7 mm feed (wt% passing)	9 mm feed (wt% passing)	11 mm feed (wt% passing)
2 mm	93.0	92.1	93.1
425 microns	58.4	57.5	59.7
150 microns	42.8	42.6	43.1

4.37 The proportion of material passing 150 microns was used as a measure of the fineness of the mill product. It is clear that the mill feed size has no little or no effect on the fineness of the product. The results also show that using the 3 mm sieve does not give the required quality of agricultural lime. The average fineness of the product at 3 mm mill sieve size was 93% finer than 2 mm, 58% finer than 425 microns and about 43% finer than 150 microns. This fell short of the quality required for agricultural lime. Therefore, it was decided to try a finer mill sieve size of 2 mm to see whether it would give a mill product closer to the required quality. The results from these trials are shown in Table 15.

Table 15 Mill Product using different crusher feed sizes and 2 mm sieve

Particle-size	7 mm feed (wt% passing)	9 mm feed (wt% passing)
2 mm	96.9	94.7
425 microns	75.9	72.4
150 microns	62.1	57.9

4.38 These results clearly show that the 2 mm sieve gave a much finer mill product than the 3 mm sieve. Also, it was finer than the target agricultural lime quality. At this point, it seemed that the 2 mm product sieve would be the most appropriate for the production of agricultural lime from the TD hammer mill. The performance of the 2 mm sieve was further tested to determine its life in terms of the amount milled before failure. The trials that followed used a 2 mm sieve and the results are shown in the following paragraphs.

Effect of milling rate on the fineness of the mill product

4.39 These trials were conducted using the 9 mm mill feed and a 2 mm product sieve. The feed rate was varied between 107 kg/hr and 376 kg/hr. This was done using a sliding gate in the mill chute that increased or reduced the feed opening. Three 10 kg sub-samples were milled for each feed rate and the mill products were sieved to determine their particle-size distribution (Table 16).

Table 16 Mill Product for different feed rates to TD hammer mill

Particle-size	Feed rate to mill			
	107 kg/hr (wt % passing)	**153 kg/hr** (wt % passing)	**272 kg/hr** (wt % passing)	**376 kg/hr** (wt % passing)
2 mm	95.2	95.9	94.7	91.4
425 microns	71.6	70.5	69.8	60.0
150 microns	55.6	53.7	54.9	43.4

4.40 The proportion of material passing 150 microns was used as an indication of mill product fineness. It is apparent that the fineness of the mill products decreases as the feed rate increases; the lowest feed rate gave a mill product with 56 % passing 150 microns and the highest feed rate gave a mill product with 43 % passing 150 microns. The results also show that feed rates of 272 kg/hr and lower produce ground dolomite that is within the required agricultural lime quality.

Dust loss during operation

4.41 The main sources of 'dust loss' were the joints of the main body and the cover, the hood and the outlet, which had a sack for collection of agricultural lime. The 'dust loss' averaged about 16 % of the feed material.

Fuel consumption of the TD Mill

4.42 This was determined as the weight of material milled per litre of petrol used. The fuel tank of the mill was filled to capacity (3 litres). The mill was run until only half a litre of the petrol remained and the weight of material milled was recorded. A total of 310 kg were milled using 2.5 litres of petrol giving a fuel consumption of 124 kg/litre. This figure was to be verified with more trials.

Original TD hammer mill field trials

4.43 A field trip was undertaken to Mkushi to test the original TD hammer mill in the production of agricultural lime using the Munsakamba dolomite (Figures 21 & 22). The objectives of the field trials were to test the performance of the mill, to determine the life span of a 2 mm product sieve, to make recommendations for the field operating parameters and recommendations for design changes to improve the efficiency of the mill.

Plate 17 Extraction of loose dolomite blocks during field milling trials

Plate 18 Manual crushing of dolomite blocks during field milling trials

Mining and Crushing

4.44 Mining consisted of taking the boulders around outcrops along the Chamulilo stream using crowbars and 10lb sledgehammers (Plate 17). The boulders were crushed manually in two stages, first to 5–10 cm and then to 10 mm. Hand crushing to 10 mm, which constituted the feed to the mill, was carried out using 4lb hammers (Plate 18). A team of eight people was employed for the manual crushing stage. On average each person produced 100 kg of crushed material (finer than 10 mm) per day. The screen analysis of the feed to the mill is given in Table 17. This shows that only 71% is finer than 9.5 mm; a simple means of controlling the feed size would be to screen it using a 10 mm sieve and crush the oversize.

Table 17 Screen Analysis of feed to Mill

Particle-size (mm)	**Mill feed** (wt % passing)
37.5	100.0
26.5	100.0
9.5	71.8
6.3	29.1
Pan	

Milling

4.45 An attempt was made to determine the milling rate for a known weight of feed through the mill (Figures 23 & 24). The material loss due to dust was also determined. The results are shown in Table 18. Some of the activities during milling of dolomite are shown in Plates 19 and 20. The feed rate ranged between 200 to 375 kg/hr. The feed rate is difficult to control as there is no feeding mechanism and it has to be done manually. This depends on the mill attendant, as shown in Figure

Table 18 Milling rate and dust losses

Mill feed kg	**Milling Time,** minutes	**Milling rate,** kg/hr	**Mill Product,** kg	**Weight loss** %
50*	8–15	200–375	42–46	8–16
60	10	360	54	10
65	18	216	60	8
84	17	296	74	12

* = summary of 6 milling trials

4.46 Two 2 mm product sieves were perforated after milling 310 kg and 309 kg each. In terms of sieve consumption, this means that if the mill produces 900 kg of agricultural lime per day, three 2 mm mill sieves would be required. Trials were carried out using a 3 mm mill sieve to determine its life span. The mill product from the 3 mm mill sieve as determined in the laboratory tests was within required range and so, could replace the 2 mm mill sieve. The total fuel used to produce 1000 kg of material was 5 litres giving a fuel consumption of 200 kg/l. In the laboratory tests a fuel consumption of 124 kg/l was obtained.

Plate 19 Feeding TD Hammer Mill with crushed dolomite during field trials

Plate 20 Dust produced during TD Hammer Mill field trials

Mill product

4.47 The screen analyses of the mill products from the field trials using the 2 mm and 3 mm product sieves are shown in Table 19.

Table 19 Mill product using a different product sieve sizes

Particle-size	**2 mm product sieve** (wt % passing)	**3 mm product sieve** (wt % passing)
2 mm	91.80	87.6
425 microns	67.00	55.5
150 microns	51.40	34.1

4.48 The mill product using the 2 mm product sieve size was comparable to that obtained from the laboratory tests. However, that from the 3 mm product sieve size was slightly coarser than the one obtained from the laboratory tests. Due to the fragile nature of the 2 mm sieve, it was recommended to use the 3 mm product sieve since its product size range was within acceptable limits, although this needed to be tested further.

Dust Generation

4.49 Dust coming from the mill was reduced as the hood had been extended and more of the dust was being collected in the hood. However, dust losses through the collection sacks continued (see Figure 24).

Bagging and Delivery

4.50 The agricultural lime was bagged in 50 kg bags. Nine bags (450 kg) of agricultural lime were delivered to the Farmers Training Centre in Mkushi, who carried out field trials with some small-scale farmers. Another 450 kg was delivered to Chalata Agricultural Office, 32 km north of Mkushi for similar trials.

Overall performance of original TD hammer mill during trials

<u>Mill Engine</u>: During laboratory trials, no major problem was experienced mainly because the engine was running for shorter periods of time per batch (average 3 minutes). The only major problem noticed arose from the dust clogging the air filter as a result of poor sealing of the housing covers and hood.

4.51 During the field trials, the aim was to determine how the engine would perform under conditions of continuous use and non-uniform dolomite sizes. It was noticed that the engine tended to slow down upon loading. On the third day of the initial five-day field trials, the engine developed an ignition failure and carburettor flooding. This was as a result of extensive usage and dusty condition at the production site, resulting into clogging of valves and filter. A general service had to be done.

4.52 After servicing and resumption of production, the speed of the engine could not be set to the optimum required, hence a much higher speed was set which might not have been suitable for the feed rate.

<u>Product Sieves</u>: Due to continuous production of agricultural lime under field conditions, there was a significant increase in the number of 2 mm product sieves that failed during operation. On average, 300 kg of lime was produced per sieve. The 3 mm sieve performed very well at more than 360 kg of lime per sieve. It is expected that many more sieves would be required if a larger volume of lime was produced. The other major problem experienced was in fixing the sieve onto the sieve cage, especially when the sieves were not cut to exact size.

<u>Rotor Sub-assembly</u>: Noticeable wear on the hammers was found. This was particularly so on the outside set of hammers because they were under impact for most part of the grinding process. The amount of wear was expected to increase with longer milling periods.

<u>Housing</u>: The front cover of the housing case was difficult to open and close. On average, it took almost 3 minutes to have the cover properly closed using clamps. The wing nuts were found to be too weak to properly secure the housing unit. It was hence found necessary to use sealing tape to minimise the dust.

<u>Main stand</u>: The stand showed no sign of instability or movement during grinding.

<u>Main driving shaft</u>: The main drive shaft had to be tightly fitted to prevent oil leaking onto the final product. There was no noticeable bending on the shaft or main bolt.

<u>The dust collection sack (hood)</u>: There was a lot of dust escaping from the machine through the joint between the hood and the housing. The hood was found to be too short for dust collection, it was therefore decided to extend its length. The sealing tape was also used to lessen the dust escaping through the joint.

Conclusions and recommendations from the trials using the original TD Hammer Mill

The following conclusions and recommendations were drawn from the milling trials:

- One person is capable of crushing about 100 kg of limestone to 10 mm size in an 8 hour shift. More people should be used to increase the manual crushing rate. A manual jaw crusher could be introduced at this stage to speed up the process.
- The feed rate for the mill ranged from 200 to 375 kg/hr. A feed rate mechanism should be fitted to the mill hopper to allow better control of the feed rate to the mill. The mill should be operated at a feed rate close to 272 kg/hr, as this is the maximum rate for production of acceptable quality agricultural lime.
- The 2 mm sieve is the most appropriate for production of the required quality of agricultural lime. The maximum feed size is 9 mm, larger sizes perforate the sieve. It is recommended that a 9 mm mill feed and a 2 mm product sieve are used for the production of agricultural lime using the original TD hammer mill. A coarser mill sieve size (3 mm or 4 mm) should be tested to determine its suitability in order to prolong the life of the sieves.
- The fineness of the mill product reduced when the feed rate increased using a 2 mm mill sieve. It reduced from 56% at 107 kg/hr to 43% at 376 kg/hr. The fineness of the mill product met the required quality for agricultural lime at feed rates below 272 kg/hr.
- The dust loss averaged 15%; mostly through the space between the hood and the mill body, body joints and at the product outlet.
- The fuel consumption was found to be 124 kg/l (laboratory) and 200 kg/l (field). Further trials to determine the rate of fuel consumption should be carried out.

Performance of the modified TD Hammer Mill

Redesign objectives

4.53 As a result of the observations made during the laboratory and field milling trials, changes to the mill were proposed and a modified TD hammer mill was built (Plates 21, 22 & 23). The modified mill was commissioned in Mkushi and Solwezi.

4.54 The modifications were made with the objectives that it remains portable, is robust enough for milling of dolomite, has better dust control, requires low maintenance and uses a simple engine with a high efficiency drive mechanism for the hammers. A 'key-way' connection between the driving shaft and the rotor assembly was adopted, reinforced by central bolting. Although no major problems were anticipated from the prime mover, it was proposed that a higher horsepower engine (11 hp) of comparative dimensions and weight be used. This could improve the machine performance and output.

4.55 To minimise dust loss it was recognised that the mill inlet and outlet should be restricted and that rubber lining should be included in the fabrication to reduce dust loss through the joints. The design of the mill body was changed to remove the outer casing and a circular or oval shaped outlet channel was adopted. This greatly reduced the dust emissions and allowed easy fixing of the sack to the outlet channel.

4.56 To improve the grinding efficiency of the mill the mill hammers were hardened and the mill liners were made easy to remove and increased in number. The thickness of the hammers was increased from 4 mm to 6 mm. The working surfaces of the hammers were reclaimed using eutectic 680 electrodes; this increased the surface resistance to wear and tear. The number of mill liners was increased to enable a greater milling rate. They were also made removable to allow for replacements of worn liners (each hammer being 295 mm long by 115 mm wide).

4.57 To improve the life of the product sieve it was made stronger. The sieve cage was redesigned to accommodate thicker sieves, which were made from 5 mm thick mild steel plate. Where available 3 mm thick stainless steel sheet should be used. An allowance for small sieve movements was incorporated to take care of dynamic impact shocks.

Plate 21 Interior of modified TD Hammer Mill

Plate 22 Close up of modified TD Hammer Mill beaters

Plate 23 Close up of modified TD Hammer Mill beaters

Laboratory Trials

4.58 The laboratory trials on the modified TD hammer mill were similar to those carried out on the original mill. Dolomite samples from the Mkushi deposit were crushed to produce mill feed of four different sizes (9 mm, 11 mm, 16 mm and 19 mm). Four 10 kg sub-samples of each feed size were used in the milling trials. The time taken to mill each sub-sample was noted to determine the milling rate and the product weighed to determine the dust losses. The product was then subjected to screen analysis to compare it with the required agricultural lime quality (100% finer than 2 mm, 60% finer than 400 microns and up to 50 % finer than 150 microns). Also, the rate of fuel consumption was determined by noting the total amount of rock milled and the quantity of petrol used. Results are shown in Tables 20 and 21. A total of 180 kg was milled using 600ml of petrol (a fuel consumption of 300 kg/l).

Table 20 Milling rate, dust loss and fines content of mill product

Feed size (mm)	**Milling rate** (kg/Hr)	**Loss as dust** (wt %)	**Passing 150 microns** (Wt %)
9	358	7.7	90.7
11	285	15.8	80.0
16	250	12.6	70.1
19	169	19.0	63.9
Hand crushed (9–10 mm)	333	9.4	74.0

Table 21 Screen analysis of mill product from jaw crusher feed of different sizes

Particle size	**9 mm** (Wt% passing)	**11 mm** (Wt% passing)	**16 mm** (Wt% passing)	**19 mm** (Wt% passing)
2 mm	100.0	100.0	100.0	100.0
425 microns	96.7	93.1	88.4	85.8
150 microns	90.7	80.0	70.1	63.9

4.59 The milling rate decreased with increasing feed size from 358 kg/Hr using the finest mill feed to 169 kg/Hr using the coarsest mill feed. This was expected as the larger feed sizes contained less fines and required longer milling time. The mill product fineness, as indicated by the weight percentage passing 150 microns, decreased with increase in mill feed size. The finest mill product resulted from milling of the finest mill feed (91% finer than 150 microns) and vice versa, the coarsest mill feed gave the coarsest mill product (64% finer than 150 microns). The products from all the milling trials exceeded the fineness quality requirements. This could be due to the increased number of mill liners, which provided a large surface area for grinding compared to the original TD hammer mill.

4.60 The dust loss increases with increasing feed size. The dust losses for the finest feed sizes were similar to those for the original, unmodified mill. Although the sealing between the mill parts was satisfactory, a significant amount of material was still lost as dust. As the inlet and outlets have been restricted this could be due to pressure building up in the mill and forcing the fines out as dust.

4.61 During the commissioning of the Modified TD hammer mill in Mkushi, the engine performed very well, though there was an increase in the consumption of oil and clogging of the air filter The initial proposed changes to the prime mover involved extension of the air filtration system. The extended air filtration system did not perform well due to a reduction in the amount of air getting into the combustion chamber and was therefore removed. Generally, the rotor sub-assembly performed well. The 3 mm sieve performed very well with no sign of weakness.

Field commissioning of the Modified TD Hammer mill

4.62 Following the laboratory trials, the modified mill was taken to Mkushi for field commissioning (Figures 28 & 29). The objectives of commissioning the mill were similar to those for the field trials of the unmodified hammer mill. The feed to the mill was hand-crushed to a size corresponding to about 10 mm. Ten men were employed to do this work and they produced a total of 930 kg of crushed dolomite per day. The modified TD hammer mill commissioning trials were carried out to investigate the effect of milling rate on the fineness of the product and the rate fuel consumption of the mill.

4.63 To investigate the effect of the milling rate, two feed rates were employed, one corresponding to the maximum opening of the feed door and the other corresponding to half open. The time required to mill 100 kg of hand crushed dolomite was noted and used to determine the feed rate. The maximum opening of the feed door gave a feed rate of 532 kg/hr and the half-open feed door gave a rate of 436 kg/hr. However, for bulk production, an average milling rate of 503 kg/hr was employed. The fuel consumption was 375 kg/litre. The products obtained at these feed rates were sampled and subjected to screen analyses as shown in Table 22.

Table 22 Screen Analysis of the Mill Product at different feed rates

Particle-size	**436 kg/Hr** (wt % passing)	**503 kg/Hr** (wt % passing)	**532 kg/Hr** (wt % passing)
2 mm	100.0	100.0	100.0
425 microns	86.4	86.6	84.5
150 microns	68.4	69.8	64.9

Production of agricultural lime in Solwezi

4.64 Field trials on the modified TD hammer mill were also carried out in Solwezi, with the aim of producing agricultural lime for local crop trials (Plates 24 & 25). Also this was an opportunity to test the performance of the mill on the Solwezi dolomite, which is more crystalline and softer than the Mkushi dolomite.

4.65 The dolomite in Solwezi was extracted manually from the outcrops using seven men equipped with sledgehammers and chisels. As the Solwezi dolomite is relatively soft it was decided to use a coarser mill feed size (25 mm). A total of 1700 kg of rock was hand crushed at a rate of nearly 144 kg/man/day compared to about 100 kg/man/day for the Mkushi dolomite. An analysis of the feed to the mill is shown in Table 23.

Table 23 Screen analysis of mill feed from Solwezi dolomite

Particle-size	**Mill feed** (Wt % passing)
37.5 mm	100.0
26.5 mm	91.8
9.5 mm	6.4
6.3 mm	1.8

4.66 Trials were carried out to determine the milling rate using 100 kg sub-samples of dolomite. Since the main aim was to produce agricultural lime in bulk, the feed opening of the mill was put at maximum throughout the exercise. Nevertheless, an average feed rate (559 kg/Hr) and the fuel consumption (250 kg/litre of petrol) were determined. The mill product was sampled and subjected to screen analysis. The results are shown in Table 24.

Table 24 Screen analysis of milled product from Solwezi dolomite

Particle-size	**Mill product** (Wt % passing)
2 mm	100.0
425 microns	99.2
150 microns	76.5

4.67 Approximately 1500 kg of agricultural lime were produced in two working days. One tonne was left with the Senior Agricultural Officer (SAO) for crop trials (Plates 26 & 27).

Plate 24 Manual crushing of dolomite during modified TD hammer mill trials

Plate 25 Manual feeding of crushed dolomite during modified TD hammer mill trials

Overall conclusions from the trials using the modified TD Hammer Mill

The following conclusions could be drawn from the laboratory and field trials:

- The ten men employed to hand-crush the Mkushi dolomite were able to crush at a rate of 12 kg/man/hr from big boulders (about 50 cm) to 10 mm material. The manual crushing rate in Solwezi was higher (144 kg/Man/day) compared to Mkushi (100 kg/Man/day); this was due to the soft nature of the Solwezi dolomite and the coarser mill feed used.
- Increasing the mill feed rate reduced the fineness of the mill product, however the mill products still met the fineness requirements for agricultural lime.
- The average feed rate of 559 kg/Hr used was higher than that at Mkushi.
- The fuel consumption for the Mkushi dolomite was 300 kg/litre (laboratory) and 375–408 kg/litre (field). For the Solwezi dolomite it was same in the laboratory but in the field it was only 250 kg/litre. The higher fuel consumption was probably due to the greater amount of energy required to grind the coarser mill feed.
- The Solwezi mill product (77% passing 150 microns) was much finer than the quality requirement (up to 50 % passing 150 microns) and the Mkushi mill product (70% passing 150 microns).
- There was minimal wear on the mill hammers, liners and product sieves. The product sieve should outlast the sieve used in the unmodified mill.
- There was a high dust loss from the mill, which is probably due to a pressure build up within the milling chamber forcing dust through the outlet.
- The production rate of the modified mill was estimated to be 800 to 1,000 kg of agricultural lime per day.

The foregoing has shown that the mill could be used to mill dolomite from Solwezi.

Plate 26 Loading of milling trial product (agricultural lime) for distribution

Plate 27 Distribution of agricultural lime to small-scale farmers

4.4 COST OF PRODUCING AGRICULTURAL LIME

4.68 The costs for the production of agricultural lime from the Munsakamba dolomite in Mkushi are given in Table 25. The extraction costs are based on drilling and blasting using a staggered square drill pattern (alternative 1). The processing costs are based on manual crushing and use of the TD hammer mill. The overall production scenario is for 5000 tonnes per year.

Table 25 Summary of costs per unit operation for agricultural lime production

Unit operation	**Cost per tonne** (US$)
Bush clearing & soil removal	1.13
Drilling & blasting	1.41
Loading & haulage	0.55
Manual crushing	10
Milling (and bagging)	20.10
Total production cost	**33.19**

4.69 Many assumptions were made to produce the production cost estimate. The costs for bush clearance and loose soil removal were restricted to the development and opening up of a single outcrop. A portable hammer drill was chosen as it would considerably reduce the cost of drilling the blast holes. The use of "Waterproof Dynamite" high explosive for blasting was chosen as it would ensure maximum fragmentation and reduce upstream processing costs, as the dolomite would need less crushing prior to milling. Loading and hauling would be manual with the aid of shovels and wheelbarrows. Crushing of the dolomite would be carried out manually using hammers to the required mill feed size (10 mm). Crushing of the Solwezi dolomite was estimated to be only US$6.95 per tonne (as it is a softer rock). This element of the production process proved to be slow and expensive. In future, a manually operated jaw crusher would be used to speed up the crushing process; this could reduce the cost of the crushing to less than US$1 per tonne. A relatively large number of hammer mills (11), each producing 1.2 tonnes of agricultural lime per day, would be needed in order to meet the yearly production target of 5000 tonnes. Bagging of the agricultural lime would also be done manually.

4.5 CONCLUSIONS

- The production of agricultural lime in the Western cape of South Africa is a sophisticated process involving extraction, primary crushing, impact milling and screening. The large-scale lime producers in Zambia follow the process used in South Africa with varying degrees of success and generally production is lower. The main producers in Zambia are Hi-Qwalime, Uniturtle, Lilyvale Farm, Mindeco Small Mines and Ndola lime.
- The method of extraction considered for quarrying of the Munsakamba dolomite in Mkushi was drilling and blasting. Manual bush clearing and soil removal was estimated to cost US$1.13 per tonne. Drilling and blasting using a portable hammer drill and “Waterproof Dynamite” was estimated to cost US$1.41 per tonne. Manual loading and hauling using a shovel and wheelbarrow was estimated to cost US$0.55 per tonne.
- A manual method of crushing the dolomite was considered. It was estimated that one man could, with a hammer, crush 100 kg of dolomite to the required mill feed size (less than 10 mm) in a day (giving a crushing cost of US$10 per tonne). The rate of crushing softer dolomite (such as that at Solwezi) was 144 kg per day; this would reduce the crushing cost to US$6.95 per tonne. This stage is the production process bottleneck. A quicker and cheaper method would be to use a manually operated jaw crusher, which would reduce the crushing costs to less than US$1 per tonne.
- The method of producing agricultural lime from the crushed dolomite was by mechanical milling. The original TD hammer mill was tested (in the laboratory and the field) and modified to produce a mill that was capable of producing agricultural lime of the required fineness (100% finer than 2 mm, 60% finer than 400μm and up to 50% finer than 150μm). The mill was capable of producing up to 1.2 tonnes of agricultural lime per day at a cost of US$20.10 per tonne (including bagging).
- The overall estimated cost of producing agricultural lime from the Munsakamba dolomite in Mkushi was US$33.19 per tonne (which is US$1.66 per 50 kg). Production of agricultural lime from the dolomite in Solwezi is estimated to cost US$30.10 per tonne (US$1.5 per 50 kg) as this is a softer rock. Use of a manual jaw crusher would probably reduce the production costs to US$20 to 25 per tonne (US$1 to 1.25 per 50 kg).

5 Crop trials

Victor Shitumbanuma, School of Agriculture, University of Zambia

5.1 INTRODUCTION

5.1 Crop trial demonstrations were carried out, as part of the project, in Mkushi using agricultural lime produced from locally occurring dolomite. The results of the crop trials are presented, including characterisation of the soil quality and the crop yields.

5.2 CURRENT FARMING

5.2 Soil acidity is a particular problem in high rainfall regions (mean annual rainfall of more than 1000 mm) and in some areas of more moderate rainfall with intensively cultivated soils (Plates 28 & 29). (Lungu and Chinene, 1993). In areas with strong to very strongly acid soils (pH <5.0 to pH <4.5), crops such as maize, groundnuts, soybeans, and tobacco, cannot be grown over successive years without applying agricultural lime to neutralize soil acidity (Shitumbanuma and Simukanga, 1995).

5.3 STATUS OF AGRICULTURAL LIMING IN ZAMBIA

5.3 The International Fund for Agricultural Development (IFAD) commissioned the Small Holder Enterprise and Marketing Programme (SHEMP) to carry out a national study on the use of agricultural lime in Zambia. One of the objectives of this study was to draft terms of reference for a comprehensive long-term research program for the application of lime, to be carried out over a period of 5 to 6 years. If implemented, it will complement the work currently being conducted by the FarmLime project.

5.4 Despite the increased interest in the use of agricultural lime there is a problem regarding the method of determining the amount of lime to apply to acid soils. There are many different methods of determining the lime requirements of the soil. The Soils and Crops Research Branch (SCRB) of the Ministry of Agriculture Food and Fisheries recommends an application of 1.0 and 1.5 metric tonnes of lime per hectare for sandy and clayey soils respectively, every four years (Mwale *et al*, 2000). According to the SCRB, these rates are aimed at reducing the risk of overliming, which can occur if too much lime is applied to the soil. The Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU), recommends application of two cups ("No.8 fertiliser cup") of lime into small holes (15 cm deep, 35 cm square) spaced 70 cm x 90 cm apart. According to their estimates, this supplies an equivalent of 250 to 300 kg of lime per hectare. This amount of lime is recommended yearly for land that is under crop rotation (Conservation Farming Unit, 2001). However, the technical basis for this lime recommendation is not clear.

5.5 A full soil test for major nutrients, minor nutrients and pH is time consuming, expensive and impractical for the majority of small farmers in Zambia, most of whom cultivate less than half a hectare. The most practical method for most small-scale farmers to calculate lime requirement would be to determine soil pH. For many small-scale farmers the initial problem is not to achieve a soil pH that would realise maximum crop yield, (about pH 6.5), nor even for optimum return on investment (a little lower). The most practical starting point for small-scale farmers is to reduce their soil pH from its highly acidic state (pH 4, which produces minimum crops yield) to a pH greater than 5, where moderate crop yields can be achieved.

The main methods for measuring pH are:

5.6 Electric pH meter: This is the standard method used in laboratories. However, they are difficult to use in the field, time consuming and their accuracy is unreliable (even in laboratory conditions).

5.7 Indicator solutions: This method uses a ‘universal indicator’ (a chemical reagent used to indicate acidity or alkalinity) that is added to a test tube of soil mixed with water and compared against a colour chart. This is a simple, rapid field test, although the accuracy depends on the use of clean water, uncontaminated containers and fresh indicator chemicals. This method is cheap but requires experienced operators and is not appropriate for small-scale farmers. A variation on this method is the use of indicator papers. This makes use of strips of paper coated with a pH indicator chemical. The colour change of the strips can be compared with a chart (printed in a test strip booklet). This is a low-cost option.

5.8 Soil coloration: The simple classification of soil types using their physical appearance, including their colour, has been recently publicised by SHEMP. This rough and ready pH test appears to be the simplest and most appropriate of the pH test methods currently available for small-scale farming areas. Its relative accuracy would have to be routinely verified by cross checking with more accurate pH test methods. Using this method would eliminate the need for soil samples to be sent to a central testing facility and cut the costs of soil testing considerably. However, before any of these test methods are adopted, further research would be needed to compare the different methods to determine their comparative advantages/disadvantages including their relative accuracy, ease of use, costs, etc…

Plate 28 Mkushi farming district, Central Province, Zambia

Plate 29 Typical small-scale farm, Central Province, Zambia

5.4 TECHNIQUES OF MANAGING SOIL ACIDITY

5.9 Soil acidity is usually a problem in soils where the pH, measured in 0.01M $CaCl_2$, is less than 5; under such conditions, crop growth may be hindered by toxic concentrations of aluminium and manganese. The solubility of aluminium in soil increases with decreasing acidity, and at pH values of less than 5 it can be the dominant exchangeable cation in the soil. Besides being toxic to plants, aluminium also reacts with phosphates in the soils, forming soluble compounds, which reduce the availability of phosphorus to crops grown on acid soils.

5.10 The aim of liming acid soils in the tropics is to reduce the risk of aluminium and manganese toxicity. In practice there are several approaches to managing soil acidity. The first approach is to apply enough lime to correct the soil acidity by raising the pH to between 6.5 and 7. However, this approach has the potential to induce deficiencies of micronutrients such as boron, zinc, and manganese (Kamprath, 1980). The second approach is to apply enough lime to neutralise the exchangeable aluminium present in the soil. A third approach is to apply sufficient lime to neutralize the exchangeable acidity, (Al^{3+} + H^+ ions) in the soil. According to Kamprath (1980), a general rule is that the milli-equivalents of exchangeable acidity per 100 grams of soil multiplied by two, gives the milli-equivalents of $CaCO_3$ per 100 grams of soils required to neutralize the acidity. The fourth approach to managing soil acidity is to use crop varieties that are tolerant to aluminium and manganese toxicity.

5.5 ESTABLISHMENT OF CROP TRIALS USING AGRICULTURAL LIME IN MKUSHI DISTRICT

5.11 Following the successful production of agricultural lime by the FarmLime project team, it was decided to set up small-scale crop trials in Mkushi district (Figures 32 & 33) to demonstrate the benefits of using lime to small-scale farmers.

5.12 Mkushi is in the Central Province of Zambia and is one of the most important farming districts of Zambia. It is home to both large-scale commercial farmers as well as small-scale farmers; the latter engage in subsistence farming and cash crop production. Mkushi district has a continental tropical climate and is suitable for the cultivation of a wide range of horticultural and field crops. Some of the crops grown in Mkushi include maize, wheat, soya beans, tobacco, tomato, groundnuts and sunflower. Mkushi was chosen as a trial site as it has occurrences of both carbonate rock and farmland with acid soils.

5.5.1 Selection of crop trial sites

5.13 The criteria used to select the trial sites were:

(i) that the location had to be accessible to small-scale farmers,

(ii) that the soils had to be acidic, with a pH of less than 5.0,

(iii) that the farmers or owners of the land would be willing to allocate some of their land and be interested to work with the team on the lime trials.

5.14 A number of prospective sites were visited and three locations were identified. Small-scale farmers work two of the sites (Chalata and Kasanama) and the third was at the Mkushi Farm Training Centre. The next step was to determine whether the soils would be suitable for the crop trials.

Chalata camp

5.15 An area of approximately 0.5 hectares was allocated to the project. Field measurements of the soil pH were made on samples representing the four quadrants of the plot. The results of these measurements showed that all four sections of the plot were in the desired pH range for application of lime. Composite samples of the soils from the top 20 cm in depth were collected from the four quadrants of the plot for laboratory analysis.

5.16 Before leaving, the team also made arrangements with the farmer and his friends (who had collectively formed a “farmers club”) to assist in preparation of the land for planting so that they would be involved in the project from the onset of the field activities. While at the farm, the Camp Officer further informed the team that soils in the area were generally suitable for cultivating a number of crops. The only fertility problems he cited in the area were that tomatoes sometimes exhibited symptoms of a condition known as ‘blossom end rot’ which is associated with calcium deficiency and that groundnuts sometimes produced ‘pops’ (aborted embryos), a condition also associated with calcium deficiency. This information made the team more confident about the likelihood of getting some crop response to the lime applied to the soils at this site particularly with groundnuts.

Kasansama camp

5.17 A plot of about 0.3 to 0.4 hectares was allocated to the project. Soils samples from the plot were tested for acidity, and results of the field pH measurements indicated that all samples tested had pH values between 4 and 5. On the basis of the soil pH test results and on the enthusiasm shown by the farmer and his neighbours in the project, the team decided to select this location as the second on-farm site. Four composite soil samples representative of the four quadrants of the plot allocated to the project were collected for laboratory analysis. Before leaving the farm, the team requested the farmers to assist the project in preparing the land for planting, so that upon return to the site, the team together with the farmers would apply the lime and plant the test crops.

Mkushi Farm Training Center

5.18 After selecting the two “on farm” crop trial sites, the team returned to Mkushi Farm Training Centre. An uncultivated plot of land could be used for the lime trials if it was found to acidic enough to be suitable for lime trials. When soil samples from the four quadrants of the plot were tested for their pH, the results indicated that the pH was between 4 and 5, except for an area near an anthill, which had pH values between 6 and 7. Composite soil samples were collected from the plot, excluding the portion around the anthill, for further laboratory analysis.

Characterization of soils

5.19 The soils at the three sites were similar in their physical properties. They were all pale coloured sandy soils that are derived from sandstone and belong to the Mushemi Soil Series. Veldkamp (1987) describes the soils from the three sites as moderately leached strongly to medium acid, reddish brown clayey to loam soils with sandy to coarse loamy topsoil, derived from acid rocks. Soil samples collected from each of the sites were tested for their pH and exchangeable aluminium contents. A summary of the data is given in Table 26 (full data in Appendix 16). The data confirms that the soil at each of the test sites is highly acidic.

Table 26 Mean pH and acidity of the soils from the crop trial sites, Mkushi, Zambia

Location	**Soil pH** 0.01M$CaCl_2$	**Exchangeable cations** (Al^{3+}+H^+) (meq/100g soil)
Chalata	4.56 ± 0.07	0.24 ± 0.04
Kasansama	4.89 ± 0.06	0.11 ± 0.001
Mkushi Farmers Training Center	4.98 ± 0.02	00.11 ± 0.02

5.5.2 Land preparation

5.20 The demonstration crop trial sites (see Fig 47) were prepared in late December 2000 for the first year trials and in November 2001 for the second year trials. At each location a plot of land with dimensions of approximately 25 m x 50 m was cultivated. The local community at each of the sites prepared the land and both men and women participated in the clearing and cultivation of the land. Nearly all the sites selected had already been cleared of trees, except for a few shrubs and old tree stumps (which were removed). The land was prepared for planting using the traditional manual methods employed by small-scale farmers using hand hoes and axes. After the initial site preparation, ten plots (each 10 m x 10 m) were marked out at each site and separated by one metre wide spaces to allow for movement around the plots.

5.5.3 Lime application and planting

5.21 After establishing the plots at each site, holes were dug in rows following the recommendation of the Ministry of Agriculture Food and Fisheries for small scale farmers, for planting maize (*Zea mays*) and groundnuts (*Arachis hypogea*). The maize variety planted was SC 501 from SEEDCO, an early maturing hybrid.

5.22 For groundnuts, the seed initially purchased was a late maturing variety (Chalimbana). This variety requires 5 to 6 months to mature, and was not the best seed for planting in mid January, about a month and half after its recommended planting date of early November. The Chalimbana variety was, however, planted at Mkushi Farm Training Centre (MFTC), the first site at which the plots were established. The Chalimbana variety, according to McPhillips (1987), is susceptible to the development of aborted embryos called “pops” on acid soils.

5.23 After planting at MFTC, seeds of the early maturing variety, Natal Common were purchased in Mkushi. Natal Common is an early maturing variety requiring 100 to 120 days (i.e 3 to 4 months) to mature. It is more suitable than the Chalimbana variety for late planting and was then sown at Chalata and Kansansama.

5.24 Before planting the crops, lime was applied to the trial sites (Plates 30 & 31). Of the ten plots, five were assigned to maize and five to groundnuts. For each crop one plot was left unlimed as a ‘control’ plot. Two lime application rates were used. The first was equivalent to the lime requirement determined after testing the soils in the laboratory and the second was twice the lime requirement. The liming rates for the different sites are presented in Table 27.

Plate 30 Agricultural lime (from milling trials) used in crop trials

Plate 31 Typical crop trials plot

Table 27 Estimated agricultural lime rates for the crop trial sites.

Location	Lime Requirement (kg/ha)	Lime rates applied (kg/ha)		
Chalata	360	0	450	900
Kasansama	165	0	200	400
MFTC	165	0	200	400

5.25 Two methods of applying lime were used. The first method was to spread the lime by hand over the plot ("broadcast application") and the second method was to apply the lime directly into the seed hole ("spot application"). For spot application, the lime was first evenly applied to each hole and the remaining lime was then evenly spread around the seed hole, with an average radius of about 5 cm around the hole.

5.26 An equivalent of 200 kg of Compound D (10:20:10) fertilizer per hectare was applied to the maize plots (including the control plot). No fertilizer was applied to the groundnuts plots. These treatments were in line with traditional practices of the farmers and with the MAFF recommendations for small-scale farmers (1979). Two maize seeds were planted per hole at a spacing of 90 cm x 25 cm giving a total plant population equivalent to 44,000 per hectare. The groundnuts were planted following recommendations of the MAFF.

5.5.4 Crop monitoring

5.27 In April 2001, researchers from the crop trial team travelled to Mkushi to monitor the crops at the three sites. At the Mkushi Farm Training Center the researchers found that the plots were heavily infested with weeds. In addition, there were a lot of gaps in both the maize and groundnuts plots. The crops were generally in a poor state, and there appeared to be no evidence of fertilizer applications. One possible reason was the high rainfall received during the growing season. Results of the observations indicated that groundnuts but not maize would be harvested. Crop trials were not continued at this site in subsequent years.

5.28 At Chalata and Kasansama, the management of the plots was much better, and the plots had been weeded. The maize crops at these sites were also small and indications from the observations were that there was unlikely to be any maize yield from both sites. The groundnut crops looked healthier and at Kasansama, groundnut plants that had received applications of lime looked larger and healthier. Crop trials were continued at these sites into following years.

5.5.5 Data Collected

5.29 Data on crop performance such as plant height, nodulation, colouration and other parameters were not collected. However, data on total pod weight, grain weight and 100 seed weight were collected at harvest. Using data on pod weight, and grain weight, the shelling percentage for groundnuts was calculated. In the first year trials, the maize crop failed to produce cobs at all the three sites due to late planting and late application of the top dressing fertilizer.

5.6 RESULTS

5.30 This section gives the results of the year one (2000/01) and year two (2001/02) crop trials at the sites in Mkushi. It is important to note the trends in the response of the crops to the local lime and to the method by which the lime was applied. Although maize and groundnuts were used as test crops, yield data were only collected for groundnuts in year one. No data were collected on the response of maize to liming until year two. A graphical representation of the yield data is given in Appendix 22.

5.6.1 Groundnut Yield

5.31 Table 28 shows the grain yield of groundnuts in response to the different lime treatments (see Plates 32 & 33). The groundnuts exhibited a significant yield response to liming, with the yields from most lime plots exceeding that of the unlimed control plots. The most significant yields are shown in the year two harvest (primarily due to a more optimal planting time) with yields up to 320 kg/ha in some plots.

5.32 At Chalata the trial plots limed at the application rate (450 kg/ha) exhibited a greater response than those with double the lime application rate (900 kg/ha). Spot application of lime appeared to give slightly higher yields in the groundnut trial. At Kasansama the opposite effect appeared to be the case. The plots limed at twice the application rate (400 kg/ha) have a greater yield than those limed at the application rate (200 kg/ha). Also, the plots that had broadcast application of lime gave higher yields than those that had spot application.

5.6.2 Maize Yield

5.33 Table 29 shows the grain yield of maize to the different lime treatments (see Plates 34 & 35). The maize does show an increase in yield as a response to liming, however the increase is not as dramatic as with groundnuts. The trials at Chalata were split into two, with demonstration plots and experimental plots (the latter consisted of duplicate trials to improve the statistical accuracy of the yield data). As with the groundnuts at this site, spot application appeared to give the higher yields. However, liming at double the application rate gave higher yields than liming at the application rate, which contradicts the findings of the groundnut trials. The trials at Kasansama also contradict the findings of the groundnut trials. Maize gave higher yields in those plots limed at the application rate. However, those plots limed by broadcast application gave higher yields than those limed by spot application, which confirms the groundnut findings.

5.6.3 Shelling Percentage

5.34 The shelling percentage is the ratio of unshelled (pods + groundnuts) to shelled groundnuts; the higher percentage the better. Calcium deficiency in soil results in a low shelling ratio, which is due to the development of empty groundnut pods (known as ‘pops’). The formation of pops is very common in acidic soils. Liming improved the shelling percentage in groundnuts (Appendix 17). At Chalata, a shelling percentage of 69% was obtained at the rate of 900 kg/ha of lime applied by broadcasting. At Kasansama, a shelling percentage of 73% was obtained at the rate of 400 kg/ha of lime applied by broadcasting. At MFTC, there was no improvement in the shelling percentage as a result of applying lime to the soils.

Table 28 Groundnut yield from agricultural lime trials in Mkushi, Zambia

Treatment/ Location	**Year One 2000–01** (Grain yield kg/ha)	**Year Two 2001–02** (Grain yield kg/ha)	
Chalata		Demonstration plot	Experimental plot
Control	92	183	179
450 kg/ha (spot)	84	259	320
450 kg/ha (broadcast)	79	244	242
900 kg/ha (spot)	108	154	208
900 kg/ha (broadcast)	86	88	149
Kasansama			
Control	48	183	
200 kg/ha (spot)	106	201	
200 kg/ha (broadcast)	168	210	
400 kg/ha (spot)	183	182	
400 kg/ha (broadcast)	212	320	
Mkushi Farmer Training Centre			
Control	84	-	
200 kg/ha (spot)	51	-	
200 kg/ha (broadcast)	45	-	
400 kg/ha (spot	42	-	
400 kg/ha (broadcast)	69	-	

Plate 32 Crop trials with groundnuts at Kasansama, Central Province, Zambia

Plate 33 Groundnuts from Kasansama crop trial

Table 29 Maize yield from agricultural lime trials in Mkushi, Zambia

Treatment/ Location	**Year Two 2001–02** (Grain yield kg/ha)	
Chalata	Demonstration plot	Experimental plot
Control	2489	4414
450 kg/ha (spot)	3053	4747
450 kg/ha (broadcast)	3567	4107
900 kg/ha (spot)	3426	4883
900 kg/ha (broadcast)	3110	4490
Kasansama		
Control	5203	
200 kg/ha (spot)	5490	
200 kg/ha (broadcast)	6764	
400 kg/ha (spot)	4787	
400 kg/ha (broadcast)	5613	

5.6.4 Grain Weight

5.35 Grain weight is a measure of the extent to which individual grains accumulate dry matter. This is calculated by weighing 100 groundnuts. There was an improvement in the seed weight with liming (Appendix 17). At Chalata, the best grain weight was 56g per 100 seeds; this was recorded at a rate of 900 kg/ha of lime applied by broadcasting. At Kasansama, the best grain weight was 61g per 100 seeds; this was achieved at the rate of 400 kg/ha of lime applied by broadcasting. At MFTC, the best seed weight was 73g per 100 seeds; this was recorded at the rate of 400 kg/ha of lime applied by broadcasting.

Plate 34 Maize grown during crop trials at Kasansama, Central Province, Zambia

Plate 35 Maize grown during crop trials at Kasansama, Central Province, Zambia

5.7 CONCLUSIONS

- Crop trials demonstrations are an important means of highlighting the benefits of using agricultural lime and improving its uptake amongst small-scale farmers.
- Demonstration trials were set up in Mkushi to show local farmers that agricultural lime could help to increase crop yields. The sites chosen were Chalata camp, Kasansama camp and Mkushi FarmTraining Centre.
- The soils at each trial site were characterised as pale coloured sandy soils that are heavily leached and acidic. The soil pH was found to be within the range 4.6 to 5. The agricultural lime requirements were found to be 165 to 360 kg per hectare. The lime produced by the project trials had an effective neutralising value of 81%, which meant that the lime addition required was 200 to 450 kg per hectare.
- The crops chosen for the demonstrations were maize and groundnuts. The sites were prepared and divided up into 10 plots (5 for each crop). These included a control plot, two ‘broadcast’ lime application plots (one at the lime requirement rate and the second at twice the requirement) and two spot lime application plots (one at the lime requirement and the second at twice the requirement). Fertiliser (Compound D) was added to each maize plot and none to the groundnut plots.
- The crops were monitored several months before harvest and the crops were harvested in May. The groundnut yield in year 2 (2002 harvest) ranged from 90 to 320 kg per hectare, with the highest yields coming from the plots limed at the required rate. The shelling percentages and grain weight of the groundnuts had significantly improved in those harvested from the limed plots. The maize yield in year 2 ranged from 2.5 to 6.7 tonnes per hectare, with the highest yields coming from the limed plots.
- Broadcast application of lime seemed to be more beneficial for the groundnuts whereas such a distinction was not possible to discern from the maize plot results.

6 Cost benefit analysis

Briton Walker, Consultant, Lincoln, UK

6.1 INTRODUCTION

6.1 The success of small-scale agricultural lime production will depend largely on the demand from small-scale farmers. Uptake of agricultural lime is likely only if it is cheaper than that available from other sources. Small-scale farmers far removed from the current sources of agricultural lime are the most likely to benefit from agricultural lime produced locally. The following stakeholders will benefit from the production and use of agricultural lime:

- farmers growing additional crops for themselves and surplus for sale or barter
- lime producers who make profits and provide employment
- the nation which will import less or export more crops (benefiting the balance of payments)
- local communities will benefit from greater employment opportunities
- the environment will benefit from the improvement in soil condition

6.2 The results of a cost benefit analysis are presented, with consideration given to the production and use of agricultural lime.

6.2 THE BENEFIT TO FARMERS

6.3 For those farmers that can afford to pay (US$25 to US$30 per tonne) the application of lime will show a good return. This is especially true for maize where the small-scale farmer has been using fertiliser. With very acid soils most other crops would similarly benefit.

6.4 In theory, farmers will use lime if the resulting increase in their income is larger than the cost of using lime. However, farmers have alternative uses for their limited cash, are generally not credit worthy and may consider the effectiveness of lime not yet proven. They will require hard evidence to persuade them to use a new input such as agricultural lime.

6.5 For short-term analyses, the Value Cost Ratio (VCR) is a simple economic method of evaluating the benefits of using lime.

$$\text{VCR} = \frac{\text{(Weight of extra crop produced) x (Unit value of the crop)}}{\text{(Costs of lime plus any other associated costs)}}$$

6.6 The United Nations Food & Agriculture Organisation (FAO) believe that for small emergent farmers a VCR above 2 is required for uptake of new inputs. In Zambia the VCR required for uptake is likely to be considerably higher. This is due to the uncertainties of the weather, Government involvement in input and output marketing, the erratic nature of input availability and its price, the variation in harvested crop prices and the shortage of cash. Added to this is the fact that farmers will often take receipt of fertiliser as a loan which they will probably fail to pay back. Many farmers will expect to receive lime on the same basis.

6.7 The VCRs expected in Zambia are often in double figures. This is because of the acid soils in Zambia and the dramatic responses to the use of good quality agricultural lime.

6.3 VALUE OF THE CROP

6.8 The price received by the farmer for his crop varies greatly. Food grown in remote areas will be used to feed the family and the sale of surplus will be a secondary consideration.

6.9 A large commercial farmer with good knowledge and negotiating skills, the ability to store the crop until the optimum delivery or selling time and close proximity to mills was able to get well over US$200 per tonne for maize (2002). Small farmers without these benefits in remote areas have achieved less than US$50 per tonne or have had to barter their surpluses for second-hand clothes or other items. The same variability will apply, though of less magnitude, to other crops. It should also be noted that for farmers in the remotest rural areas, the food produced could at times of shortage be the difference between life and death.

6.10 In our VCR scenarios we have taken the price of maize as US$50 and US$110 per tonne. In 2002, the prices that commercial farmers realised for their maize was high, however the smaller farmer cannot predict or rely on high prices.

6.4 PRICING OF LIME

6.11 Lime in Zambia is expensive compared to other countries that produce lime on a larger scale. The price a small-scale producer will be able to charge for his lime will depend on that charged by other (commercial) producers and on what the farmer is willing to pay. For example, the price of Hi-Qwalime lime at Mwinilunga (which is 550 km from Mkushi, where it is produced) may be approaching US$100 per tonne, but crop responses and prices and cash availability may mean farmers will only be prepared to pay US$20 per tonne. It should be recognised that improvements in rural roads may reduce the transport costs of the large producers and affect the VCR of using lime in remote areas.

6.12 Uniturtle, Mindeco Small Mines, Lilyvale farm and Hi-Qwalime lead the market and tend to set the prices. Ndola Lime sells a by-product, which is the dust from the crushing of limestone for burnt lime production; this is a poor quality material with a low MgO content and is not considered to be a credible competitor to producers of good quality lime.

6.13 Tables 30 and 31 give the price of agricultural lime and the costs of transporting it across Zambia (2002). The price of agricultural lime primarily depends on the ex-works cost plus the cost of transporting the lime from the producer to the consumer. The large commercial lime producers will not be willing to deal directly with farmers purchasing only a small amount. Small-scale farmers are more likely to access lime through distributors, co-operatives, retail outlets or NGOs whose profit margin is unlikely to be less than 10%. At present few farmers in Zambia understand the difference between good and poor quality agricultural lime; the value of finer-grained more reactive lime with a high magnesium content will eventually become apparent.

Table 30 Prices of agricultural lime

Producer	**Packaging**	**Ex-works Price** US$ per tonne
Uniturtle, Hi-Qwalime, Mindeco Small Mines	25 & 50 kg bags	18 to 22
Uniturtle, Hi-Qwalime, Mindeco Small Mines	Bulk	14 to 18
Ndola Lime	Bulk only	2 to 3

Table 31 Costs of transport

Transport route	**Tranport cost** US Cents/ tonne/km
Main tarred roads (+ option of back load)	5 to 10
Other tarred roads	10 to 12
Non tarred feeder roads	15 to 18
Tazara Railway	4 to 6

6.5. Value Cost Ratios

6.14 The benefits of using agricultural lime will vary greatly. Small-scale farmers living close to the source of their inputs, farming highly acid soils and can realise a high price for their maize, will see the greatest increase in their incomes. Farmers living a long distance from the source of their inputs, farming moderately acid soils and can only realise a low price for their maize will have greater costs and a smaller increase in their income. The VCRs of the first farmer will be higher than those achieved by the second farmer (Table 32)

6.15 The application of lime is highly profitable except where there is little response to liming of the soil and the farmer is remote from markets. In a good season, where the maize prices may reach US$200 per tonne, the use of lime is worthwhile even on the less acidic soils Table 32)

Table 32 Value Cost Ratio (VCR) scenarios for maize

	Value Cost Ratio (VCR)			
Lime cost per tonne	**High** US$60		**Low** US$30	
Maize price per tonne	**High** US$110	**Low** US$50	**High** US$110	**Low** US$50
Extremely acid soil pH <4.5; Response 5 tonnes of maize to 1 tonne of lime	9.1	4.2	18	8.3
Very acid soils pH<5; Response 3 tonnes of maize to 1 tonne of lime	5.5	2.5	11	5
Acid soil pH 5–6; Response 1.5 tonnes of maize to 1 tonne of lime	2.7	1.3	5.5	2.5

NB The ‘Response’ referred to in the table indicates the additional amount of maize grown over and above that normally expected and that can be reasonably attributed to the use of agricultural lime.

6.5 POTENTIAL LIME USAGE

6.16 Assuming the farmer is convinced that the use of lime will give him a good return, he still needs to find the cash to pay for it. Most small-scale farmers have higher priorities for their cash. Loan schemes have suffered, as farmers have not kept up the repayments, for example for fertilisers. In spite of this, the very high VCRs for lime use on very acid soils and the increasing awareness of lime benefits through the recent NGO lime promotions, will encourage more farmers to use lime.

6.17 It is reasonable to predict that by 2005 the national consumption of lime by small-scale farmers will increase to approximately 10,000 tonnes per year. It is in the best interest of Zambia for the lime consumption of small-scale farmers to be much higher than this. However, unless the Government, with the support of the aid donors and the large lime producers, initiates a major nationwide program, it is unlikely that the consumption of lime by small-scale farmers will exceed the predicted 10,000 tonnes per year. Based on this prediction, and a distribution similar to that for fertilisers, the likely use of agricultural lime in each province is given in Table 33.

6.18 Fertiliser use by small-scale farmers, as reported by the Zambian Central Statistical Office, is around 85% on maize, 10% on tobacco, 3% on soyas and negligible amounts on other crops. It could be expected that a similar pattern would apply to lime applications, (except where outgrower organisations and NGOs have had an impact).

Table 33 Predicted annual use of agricultural lime by small-scale farmers in Zambia by 2005

Province	**Central**	**Copperbelt**	**Eastern**	**Luapula**	**Lusaka**
Lime use (tonnes)	2500	1000	2500	250	500
Province	**Northern**	**North Western**	**Southern**	**Western**	**Total**
Lime use (tonnes)	1000	100	2500	100	10,450

6.6 BENEFITS TO SMALL-SCALE PRODUCERS OF LIME

6.19 There is little money in the economy for cash purchases of lime. In addition the existing producers will all fight for the market in their area. Small-scale lime production is only likely to succeed at distances far from the bigger competitors and where VCRs are high.

6.20 Small-scale lime production operations will only be successful when their costs are minimal, the production methods simple, they sell to local farmers, who collect from the lime works and pay cash. It is important that the overheads for such an operation (e.g. administration, safety, blasting, marketing and cash control) are kept low. The operation may only succeed where supervised by a local agricultural co-operative or farm group, who could market the products or via a local commercial farmer who would himself benefit from the availability of high quality lime.

6.7 COSTS OF SMALL SCALE LIME PRODUCTION.

6.21 In Zambia, the likely volume of agricultural lime that would be required in any given small-scale farming district would be limited to a few hundred tonnes per year. Therefore, two small-scale lime production scenarios have been considered.

Scenario A (400 tonnes per year)

6.22 The following assumptions have been made (see Table 34). The dolomite rock worked is relatively soft, of reasonable quality and can be extracted by hand without drilling and blasting. Processing would consist of one hand operated jaw crusher feeding one TDAU hammer mill to produce fine-grained lime. The lime would be bagged into second-hand bags. The small-scale farmers within the local farming district would collect the lime themselves. The operation would have very simple management with either a self-motivating group or assistance from a local agricultural co-operative or entrepreneur. The capital costs would be low, with the main costs being the mill (US$1800 3 year life), crusher (US$1000 3 year life) and working capital for wages (US$1 per man day) and consumables. The production would be 2 tonnes of lime per day in the dry season, 200 working days per year and sales mainly from September to November for cash.

Table 34 Unit operation costs for small-scale agricultural lime production

Unit operations	**Annual costs US$**	**Per tonne costs US$**
Bush clearance (5 men 20 days)	100	0.25
Extraction by hand (5 men 200 days)	1000	2.50
Crushing (Jaw crusher 2 tons/man day)	200	0.50
Milling and bagging (4 men 200 days)	400	1.00
Petrol at (3.3 litres per ton lime)	1,056	2.64
Oil (.25 litres/day)	100	0.25
Bags (US$4.5/ton)	1,800	4.50
Mill screens (life of 100 tons at US$10 each)	40	0.10
Mill hammers (life of 12 tons US$2.5/set)	333	0.83
General hand tools, barrows, hammers etc	200	0.50
Clothing	100	0.25
Administration	100	0.25
Management/supervision	1000	2.50
Depreciation over 3 years	933	2.33
Total	**7762**	**19.41**

6.23 Around US$5000 cash would be needed to start the operation, for the purchase of the crusher and mill and for wages since income would not start until September to November when lime is usually applied. For very small entrepreneurs in rural areas this is a prohibitive sum unless it could be funded as part of a donor or NGO funded programme.

Scenario B (1200 tonnes per year)

6.24 The following assumptions have been made (see Table 35). This is a slightly larger operation that extracts harder rock and requires drilling and blasting (carried out by contractors). One hand operated jaw crusher would be used to produce the 10 mm feed material for three TDAU hammer mills. The sales to third parties would be larger. Well-organised management would be necessary. Higher wages at US$1.5 per man-day would be required and more protective clothing as the Labour Regulations and Donor/NGO fair-trading stipulations may come into force.

6.25 The ease with which the carbonate rock can be extracted is one of the most critical factors in small-scale lime production. The minimum cost of drilling and blasting is likely to be at least US$10,000. Where the volumes are unlikely to exceed 1000 tonnes per annum per quarry, this adds approximately US$10 per tonne to the production cost. Management costs rapidly expand as the operation moves from a small co-operative venture with workers who are willing perhaps, to accept delayed wage payment and where all operations are on a shoestring.

Table 35 Unit operation costs for medium-scale agricultural lime production

Unit operations	**Annual costs** US$	**Per tonne costs** US$
Bush clearance (7 men 25 days)	263	0.22
Drilling and blasting	10,000	8.33
Extraction by hand (2 men 200 days)	600	1.50
Crushing (Jaw crusher 2 tons/man day)	600	0.50
Milling and bagging (12 men 200 days)	3600	3.00
Petrol at (3.3 litres per ton lime)	3168	2.64
Oil (.75 litres/day)	300	0.25
Bags (US$4.5/ton)	5400	4.50
Mill screens (US$10 per 100 tonnes lime)	120	0.10
Mill hammers (life of 12 tons US$2.5/set)	1000	0.83
General hand tools, barrows, hammers etc	400	0.33
Clothing	700	0.58
Administration	1000	0.83
Management/supervision	10000	8.33
Depreciation over 3 years	2167	1.81
Total	**39016**	**32.76**

6.8 BENEFITS TO THE NATION

6.26 Each tonne of lime applied increases the amount of maize grown by an extra 3 to 5 tonnes per hectare. If half of the farms growing maize on acid soils were to use lime an extra 750,000 tonnes of maize could be produced. At a typical import/ export parity of US$100 per tonne this would generate or save US$75 million. In 2002 with the need to import between 200,000 and 400,000 tonnes at over US$200 per tonne the saving would be US$150 million.

6.27 The costs of lime production are mostly domestic (except for petrol, which is less than 10% of the production cost) and make little demands on foreign currency. Small-scale lime production requires 5 man-days per tonne of lime and would pay each worker about US$1 per day. If 50,000 tonnes of lime were used by small farmers (which could be achieved with Government support) this would put US$250,000 into the rural economy and employ 125,000 workers for 200 days per year.

6.28 Although there is a demonstrable economic benefit, the use of lime will ultimately depend on the availability of cash in the rural economy. Therefore, an important criterion in the decision to start up small-scale lime production would be the willingness and ability of the local small-scale farmers to pay for the lime. Programmes that demonstrate the effectiveness of agricultural lime would be fundamental in raising awareness.

6.29 With most soils classified as acidic, farmers need to move on to new land under the Chitemene system after only a few years. The use of lime would allow continuous rotational cropping and increase yields. A nationwide acceptance of lime would reduce the devastation and erosion seen in some areas of Zambia. Fertilisers can be used with lime to produce extra crops and maintain the organic content of the soil. Without the use of lime, fertilisers will increasingly acidify the soil until eventually crops will fail completely.

6.9 CONCLUSIONS

- The Value Cost Ratio (VCR) is a simple method of evaluating the economic benefits of using agricultural lime. Any income generated through the sale of surplus crops should be at least double that spent on using agricultural lime.
- The increase in crop yields with the use of agricultural lime is well documented. Maize yields of up to 8 tonnes per hectare can be achieved using agricultural lime in conjunction with Conservation Farming (CF) methods. The quality of the agricultural lime and the use of good farming practice are important in achieving high crop yields.
- The sale price of maize varies from as much as US$200 per tonne to as little as US$50 per tonne. Also, the price of agricultural lime varies from US$14 to US$22 per tonne depending on supplier and volume purchased (whether in bags or bulk). Transport of the lime to the farm can add between US$5 to US$18 per tonne per 100 km.
- Where a farmer realises a relatively high price for the additional maize grown, and can buy cheap lime, he may earn up to 18 times the cost of the agricultural lime used. Conversely, where low maize and high agricultural lime prices prevail his earnings may be as low as 2.5 times the cost of lime used. Either way the use of agricultural lime is economically beneficial to the small-scale farmer.
- It is estimated that the demand for agricultural lime by small-scale farmers by 2005 will be approximately 10,000 tonnes. Most of this will come from the farming districts in Central, Eastern and Southern provinces.
- The estimated cost of small-scale agricultural lime production (400 tonnes per year) using manual extraction and mechanical milling are just under US$20 per tonne. The estimated cost of medium-scale production (1200 tonnes per year), using drilling and blasting and a larger number of mills, is approximately US$33 per tonne.
- Although there is a demonstrable economic benefit in the use of agricultural lime its use will ultimately depend on the small-scale farmer having enough cash to buy it. If only half of the small-scale farmers used lime it would increase maize production by 750,000 tonnes and save Zambia several hundred million US$ in imports yearly. Establishment of small-scale lime production sites across Zambia would be a boost to rural economies creating employment and injecting cash into the poorest section of the Zambian population.

7 Conclusions

Socio-economic survey

7.1 Small-scale farmers claim to be aware of the benefits of using agricultural lime but their use of lime is minimal. Demonstrating increased crop yields through the use of lime was thought to be an important means of persuading farmers to use lime. Once the farmers are persuaded to use lime, a simple and cheap soil test is needed to determine the lime demand of their soils. Bartering may be the solution for farmers that cannot pay cash for lime, and many were willing to exchange goods or labour for lime. Also, farmers are willing to participate in co-operatives or farm groups set up to produce agricultural lime on a small-scale.

Carbonate resource assessment

7.2 There are ample resources of dolomite rock available for agricultural lime production, not only within the farming districts in Mkushi and Solwezi but throughout Zambia. It is important to determine the Neutralising Value (NV) and this should be greater than 80% Calcium Carbonate Equivalent (CCE). In addition, the magnesium oxide (MgO) content should be greater than 6%. The resource assessment showed that dolomitic rock meeting these requirements occurs in seven of the nine Zambian provinces. Dolomite from Mkushi and Solwezi was used for the lime production trials.

Lime production research

7.3 Extraction of the Munsakamba dolomite in Mkushi will require the use of drilling and blasting. Manual crushing of the rock to less than 10 mm proved to be a slow process and one man could only crush 100 kg per day. A manual jaw crusher would be a faster and cheaper means of crushing rock. The modified TD hammer mill was shown to be capable of producing up to 1200 kg of agricultural lime per day of the required particle size (100% <2 mm, 60%<400µm and up to 50% <150µm). The overall production cost was found to be relatively high at US$33 per tonne for the Mkushi dolomite and US$30/tonne be for the softer dolomite in Solwezi. Use of a manual jaw crusher could reduce the cost to US$20 – 25 per tonne.

Crop trials

7.4 Demonstration plots (maize and groundnuts) were established in Mkushi in an attempt to convince local small-scale farmers of the benefits of using agricultural lime. The soil in these plots was highly acidic (pH<5) and had a lime demand of 200 to 450 kg per hectare. By the time of reporting harvesting of 2 seasons of demonstration crops had been completed. The highest yields were 6.7 tonnes of maize and 320 kg of groundnuts per hectare, this compared to the lowest control plot (unlimed) yields of 2.5 tonnes maize and 48 kg groundnuts. There was anecdotal evidence of agricultural lime uptake by farmers neighbouring the crop trials, who were purchasing lime at US$1 per 50 kg bags (equivalent to US$20 per tonne)

Cost Benefit Analysis

7.5 The use of agricultural lime could lead to maize yields in the range of 5 to 8 tonnes per hectare. The economic benefits to the small-scale farmer can be summarised as the Value Cost Ratio (VCR). The VCR is determined by subtracting the cost of using agricultural lime from the value of the additional crops grown. The cost of locally-produced agricultural lime is likely to be between US$20 and US$33 per tonne. The value realised by small-scale farmers for their maize varies from US$50 to US$200 per tonne. The estimated demand for agricultural lime by small-scale farmers by 2005 is approximately 10,000 tonnes per annum. Although there is a demonstrable economic benefit, the use of agricultural lime will ultimately depend on the availability of sufficient cash in the rural economy.

8 Recommendations

FarmLime agricultural lime production methodology

It is recommended that small-scale lime production be encouraged and supported in those small-scale farming districts that have acid soils and poor access to agricultural lime. The FarmLime production methodology would be a suitable means of producing agricultural lime in these areas. This method uses manual extraction, a manual jaw crusher and a hammer mill and has low capital and operating costs. The following is a summary of the FarmLime agricultural lime production methodology:

<u>Extraction</u>: Manual quarrying of carbonate rock:

- Removal of soil and overlying material
- Extraction of rock using sledgehammers and crow bars. Setting fires on top of the rocks and throwing water onto the heated rocks causing cracking helps to break up the rock
- Removal of the blocks of rock from the quarry to the crushing area

<u>Crushing</u>: Crushing the carbonate rock to a size suitable for milling:

- Sledgehammers are used to break large blocks of rock to fist-sized lumps
- Smaller hammers are used to break the rock down to lumps which are 10 mm in diameter and finer
- This stage could be enhanced by the use of a manual jaw crusher; this would increase the crushing rate and reduce production costs.
- The crushed rock is stockpiled ready for milling.

<u>Milling</u>: Production of agricultural lime from crushed rock:

- Hammer mill(s) would be used to grind the carbonate rock to a powder which has 100% of particles finer than 2 mm, 60% finer than 0.6 mm and up to 50% finer than 0.15 mm.
- The agricultural lime would be stored and sold in 50 kg bags.

Diversification of small-scale enterprise

It is recommended that small-scale private enterprises be encouraged and supported to produce agricultural lime using the FarmLime methodology. There are many small-scale operations in existence that currently produce building and road stone aggregate from carbonate rocks that are also suitable for the production of agricultural lime. These operations are the best placed to make a success of the FarmLime approach. This approach is supported by the uptake of an existing aggregate producer in Solwezi. This small-scale producer took the initiative in contacting the project, learnt about the FarmLime methodology and built a hammer mill suitable for producing agricultural lime.

The benefits of taking this approach are several:

- Mineral production is already well established at the proposed site for agricultural lime production. This ensures that it would have minimal environmental and social impacts.
- Diversification of an existing small-scale business would improve its financial sustainability and increase the job security of its workers. There is also the prospect of additional employment being created by agricultural lime production.
- The small-scale business would have a strong incentive to promote and distribute agricultural lime amongst small-scale farmers

Demonstration of the benefits

It is recommended that further education and demonstration of the benefits of using agricultural lime should be carried out in all small-scale farming districts. UNZA should be commissioned to establish further crop trial demonstrations (using maize and groundnuts) such as those carried out by the FarmLime project across all of the main farming districts.

Soil testing

A simple and cheap test should be researched and made available to test soil for small-scale farmers. It is recommended that UNZA is commissioned to devise a reliable test that enables the demand for agricultural lime to be determined.

Affordability

It is recommended that an alternative means of paying for agricultural lime, such as bartering, should be available to those farmers that cannot afford it. Access to affordable agricultural inputs should be regarded as a natural right of every farmer. Schemes, such as the 'Mealie Mill' proposal, can only be successful if the small-scale farmer has the ability to purchase the agricultural lime produced. However, it should be recognised that any small-scale operation would need a certain amount of its income to be in cash rather than in kind.

Resources suitable for production of agricultural lime

Information on the quality of the carbonate resources that are suitable for agricultural lime should be made widely available. It is recommended that the GSD is commissioned to produce a resource map of Zambia and ensure that it is disseminated to all stakeholders.

Appendix 1 Farmlime socio-economic survey questionnaire

A. GENERAL BACKGROUND

1. Gender
2. Marital staus
3. Educational level
4. Members of household
5. Ethnic group

B. ECONOMIC ACTIVITIES

1. Type of crops grown
2. Income generating activity

C. LEVEL OF AWARENESS OF CROP PRODUCTION CONSTRAINTS

1. Do you know the problems of soil acidity?
2. Do you know the soil types in your area?
3. Do you know the benefit of lime to redress the situation?
4. Do you know the suppliers of lime or information sources?
5. Who are these sources and what assistance have they given or would give?

D. MARKETING

1. What do you know about farmlime?
2. Would you want to use it and what would you expect to get?

E. PRODUCTION

1. How would you envisage getting lime?
2. Would you work in a co-operative to produce lime?
3. At what level of payment?
4. If payment were in kind how many bags of lime would you give?

F. PURCHASING

1. Are you able to pay for lime? (state price from producers)
2. Would you consider taking part in an exchange scheme?
3. Do you have experience in other bartering-type schemes?

G. DISTRIBUTION

1. How are you currently accessing other agricultural inputs e.g. fertiliser and seeds?
2. What/which agencies are assisting you?
3. How are the inputs transported/distributed?
4. What are the current methods of payment?
5. Would it be possible to make available lime in the same way?
6. Would you consider trading off one bag of fertiliser for agricultural lime?

H. APPLICATION

1. In what areas do you receive advice from agricultural extension workers?
2. Would you work with them on the agricultural lime activities as well?
3. What time of year would you apply agricultural lime, would you need expert advice?
4. Would you be willing to participate in project crop trials? If not, why?

Appendix 2 Laboratory test methods

Method 1. Calcium carbonate equivalent (CCE) (after ASTM C25-95)

Reagents

1 litre 1.0N hydrochloric acid, prepared from concentrated ampoules

20 g sodium hydroxide, analytical grade

10 g phenolphatalein

100 ml ethanol, analytical grade

Apparatus

1 litre volumetric flask	100 ml pipette	Pipette filler
Plastic dropper	500 ml Erlenmeyer flask (x10)	50 ml burette
Weighing bottles (x10)	Burette clamp and stand	Drying oven, 110°C
Desiccator	Magnetic stirring plate	Magnetic followers (x4)

1 litre polyethylene bottle (+ siphon tube & soda lime guard tube)

Preparation of 1.0N HCl solution

1. In accordance with the manufacturer's instructions, transfer HCl from concentrated ampoules to a 1 litre volumetric flask and dilute 1 litre.

Preparation of 0.5N NaOH solution

1. Dissolve 20.000 g (+ 0.001 g) of analytical-grade sodium hydroxide (NaOH) in 150 ml of carbon dioxide-free water.
2. Cool to room temperature, transfer to a 1 litre volumetric flask and dilute to 1 litre.
3. If possible, store solution in a polyethylene bottle with a siphon tube and soda lime guard tube to prevent absorption of carbon dioxide from air.

Preparation of phenolphthalein indicator

1. Dissolve 1 g of Phenolphthalein in 100 ml of analytical-grade ethanol.

Procedure

1. Transfer approximately 5 g of the dry sample from an air tight container to a 500 ml Erlenmeyer flask and record weight in g to 3 decimal places (W).
2. Add 110 ml (V1) of HCl 1.0N (N1) from a pipette. (Note: please see calculation below for further advice on volume of HCl addition.)
3. Boil gently for 5 minutes or until only an insoluble residue remains.
4. Add 2–3 drops of phenolphthalein indicator to the flask and add a magnetic follower.
5. Place the flask on a magnetic stirring plate and adjust so that contents are stirred gently.
6. Titrate the sample against 0.5N NaOH (N2) added from a burette. As the end-point is being approached, a change from a clear solution to a pink colouration is observed in the area at centre of the flask where the titer is added. The end-point is reached when sufficient titer is added to achieve a pervasive and persistent bright pink colouration.
7. At the end-point, record the amount of NaOH titer added from the burette to the nearest 0.05 ml (V2).

Calculation

The CCE (%CaCO3) is calculated as follows: CCE (%CaCO3) = [5.0045 (V1 N1–V2 N2)]/W

Where V1 = Volume of HCl solution used*, N1 = Normality of HCl solution = 1N, V2 = Volume of NaOH titer at the end-point in ml, N2 = Normality of NaOH solution = 0.5N, W = Sample weight in (g) recorded to three decimal places **Note *V1 = 110 ml for dolomites or unknown samples = 100 ml for limestone samples**

Method 2. CaO and MgO by EDTA titration (after ASTM C25–95)

Reagents

100 g EDTA disodium dihydrogen, analytical grade

500 g potassium hydroxide, analytical grade

100 g ammonium chloride, analytical grade

1 litre 33% Ammonia solution (SG = 1.18)

100 g calcium carbonate, analytical grade

100 g magnesium carbonate (analytical grade or metal turnings)

10 g Calmagite

500 ml triethanolamine

2 litres conc. hydrochloric acid

500 g hydroxy naphthol blue indicator

Apparatus

Magnetic stirring plate

pH meter and pH calibration buffer solutions

2 litre volumetric flask

1 litre plastic bottles for chemicals (x3)

20 ml pipette

Burette stand and clamp

10 ml measuring cylinder

Funnels (x3)

250 ml volumetric flasks (x2)

300 ml screw top bottles (x10)

Magnetic follower

Hotplate

1 litre volumetric flask (x5)

10 ml pipette

50 ml burette

100 ml measuring cylinder

25 ml measuring cylinder

500 ml Erlenmeyer flask (x2)

250 ml beakers (x10)

Preparation of 0.4% EDTA solution

1. Dissolve 8.00 g of disodium dihydrogen EDTA in distilled water, transfer to volumetric flask and dilute to 2 litre.

Preparation of standard KOH solution

1. Dissolve 56.00 g of potassium hydroxide in distilled water, transfer to a volumetric flask and dilute to 1 litre.

Preparation of ammonia buffer solution (pH 10.5)

1. Dissolve 67.50 g of ammonium chloride in 300 ml of distilled water, add 570 ml of 33% ammonia solution and dilute to 1L in a volumetric flask

Preparation of 10% HCl

1. Add 100 ml of conc. HCl to 900 ml of distilled water.

Preparation of 50% HCl

1. Add 500 ml of conc. HCl to 500 ml of distilled water.

Preparation of 33% triethanolamine

1. Add 250 ml of conc. triethanolamine to 500 ml of distilled water

Preparation of CaO standard solution (1 mg/ml)

1. Dry 2–3 g of analytical grade CaCO3 overnight at 105°C
2. Weigh 1.785 g of the dried CaCO3 into a 250 ml beaker and add 100 ml of 10% HCl.
3. Place on hot plate and heat gently until all CaCO3 has dissolved. Allow solution to cool to room temperature.
4. Transfer to a volumetric flask and dilute to 1 litre.

Preparation of MgO standard solution using MgCO3 (1 mg/ml)

1. Weigh 0.603 g of Mg metal turnings (or 2.0919g of analytical grade MgCO3) into a 250 ml beaker and add 100 ml of 10% HCl.
2. Place on hot plate and heat gently until all metal has dissolved
3. Transfer to a volumetric flask and dilute to 1 litre.

Preparation of MgO standard solution using Mg metal turnings (1 mg/ml)

1. Weigh approximately 2 g of Mg turnings
2. Carefully add the turnings to 100 ml of 5% HCl for 2–5 seconds
3. Pour off the acid
4. Add water and rinse the turnings several times
5. Rinse into an evaporating dish and decant off any excess water and wait for them to completely dry (1–5 are carried out inorder to remove any oxidised coatings on the Mg turnings).
6. Weigh out 0.603 g of the dry turnings and transfer to a beaker and add 00 ml of 10% HCl.
7. Once all the turnings have dissolved transfer to a 1 litre volumetric flask and dilute to the mark.

Preparation of the calmagite indicator solution

1. Weigh 0.25 g of calmagite and transfer to a 250 ml volumetric flask using distilled water.
2. Shake vigourously then make up to the 250 ml mark (note this is not precise due to the indicator bubbling).

CaO standardization

Note: CaO standardization is carried out on each new batch of EDTA solution prepared.

1. Pipette 10 ml of the CaO standard solution into a 500 ml Erlenmeyer flask and add 100 ml of distilled water
2. Place the flask on the magnetic stirrer and add approximately 10 ml of 0.4% EDTA solution to prevent precipitation of calcium.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to between 12–12.5 by addition of the standard KOH solution an addition of circa 15 ml KOH is necessary. Add KOH stepwise drop-by-drop.
5. Add 0.4 of hydroxy naphthol blue as an indicator. (Note: the 0.2–0.3 g of indicator recommended by the ASTM procedure imparted insufficient colour.)
6. Titrate against 0.4% EDTA solution until a clear blue end-point is obtained.
7. At end-point, record amount of 0.4% EDTA titre soln added (incl the 10 ml added initially) to the nearest 0.05 ml.
8. Carry out two replicate analyses. Average EDTA end-point value obtained from the three separate determinations.
9. Calculate the concentration of CaO in standard solution as follows:

CaO in standard solution (mg/ml) = 10 mg CaO/average EDTA end-point

MgO standardization

Note: MgO standardization is carried out on each new batch of EDTA solution prepared.

1. Pipette 10 ml of the MgO standard solution into a 500 ml Erlenmeyer flask and add 100 ml of distilled water
2. Calibrate pH meter for the alkaline pH range.
3. Immerse pH electrode and adjust the pH of the solution to pH 10.0 with the ammonia buffer solution. (Note: addition of around 2 ml of ammonia buffer was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml ammonia buffer is necessary. Add ammonia buffer stepwise drop-by-drop.)
4. Add approximately 10 drops of the calmagite solution.
5. Titrate against 0.4% EDTA solution. At the end-point a purple-to-deep blue colour change is observed.
6. At the end-point, record the amount of 0.4% EDTA titer solution added to the nearest 0.05 ml.
7. Carry out two replicate analyses. Average EDTA end-point value obtained from the three separate determinations.
8. Calculate the concentration of MgO in standard solution as follows:

MgO in standard solution (mg/ml) = 10 mg MgO/average EDTA end-point

Sample digestion

1. Weigh approximately 0.5 g of sample and record weight in g to three decimal places
2. Transfer to a 250 ml beaker and add 10 ml of 50% HCl and slowly evaporate to dryness on the hotplate
3. Dissolve residue obtained in 25 ml of 10% HCl.
4. Dilute to 100 ml with distilled water and gently warm on a hotplate for 15 minutes until digestion is complete, then allow to cool to room temperature.
5. Transfer to a 250 ml volumetric flask and dilute to the 250 ml mark, mixing thoroughly.
6. Transfer the solution to a 300 ml screw top bottle and label with sample code.

Determination of CaO

1. Pipette 20 ml aliquot of the sample solution into a 500 ml Erlenmeyer flask. Add 130 ml of distilled water.
2. Add a magnetic follower and place flask on magnetic stirring plate.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to between 12–12.5 by addition of the standard KOH solution. (Note: addition of around 2 ml of KOH was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml KOH is necessary. Add KOH stepwise drop-by-drop.)
5. If sample is suspected to contain significant Fe, Mn or heavy metals, add 10 ml of 33% triethanolamine solution.
6. Add 0.4 of hydroxy naphthol blue indicator. (Note: the 0.2–0.3 g of indicator recommended by the ASTM procedure imparted insufficient colour.)
7. Titrate against 0.4% EDTA solution until a clear blue end-point is obtained.
8. At the end-point, record the amount of 0.4% EDTA titer solution added to the nearest 0.05 ml.

Calculation of CaO content (%)

Calculate CaO content of sample (%) as follows:

CaO content of sample (%) = CaO in standard solution (mg/ml) x EDTA end-point (ml) x 1.25/sample wt. (g)

Determination of MgO

Note: in this titration, combined calcium and magnesium in solution is determined.

1. Pipette 20 ml aliquot of the sample solution into a 500 ml Erlenmeyer flask. Add 100 ml of distilled water.
2. Add a magnetic follower and place flask on magnetic stirring plate.
3. Calibrate pH meter for the alkaline pH range.
4. Immerse pH electrode and adjust the pH of the solution to pH 10.0 with the ammonia buffer solution. (Note: addition of around 2 ml of ammonia buffer was found to be sufficient, whereas the ASTM procedure indicates an addition of circa 15 ml ammonia buffer is necessary. Add ammonia buffer stepwise drop-by-drop.)
5. Add 10 drops of the calmagite solution.
6. If the sample is suspected to contain significant Fe, Mn or heavy metals, add 10 ml of the 33% triethanolamine solution.
7. Initially, titrate a volume of EDTA solution equivalent to the end-point obtained in the CaO determination for that sample.
8. Continue to titrate against 0.4% EDTA solution. At the end-point a purple-to-deep blue colour change is observed.
9. At the end-point, record the total amount of 0.4% EDTA titer solution added to the nearest 0.05 ml (including the volume added initially in step 7).

Calculation of MgO content (%)

Calculate MgO content of sample (%) as follows:

Firstly, True EDTA MgO end-point (ml) = EDTA end-point in MgO determination - EDTA end-point in CaO determination

Then, MgO content of sample (%) = MgO in standard solution (mg/ml) x True EDTA end-point (ml) x 1.25/sample wt. (g)

Method 3. Grindability index (after ASTM C110–95)

Apparatus

Ball mill: Rotating mill (US Stoneware No 753-RM rotating mill, or equivalent)

Ceramic mill jar (US Stoneware mill jar No 774-B-00, or equivalent)

14 cm (5.5 inch) diameter by 17.2 cm (6.75 inch) height

Cylindrical ceramic grinding elements (x7)

23 g individual weight approx.

21 mm (3/16 inch) by 21 mm dimensions

160 ± 1 g total weight of grinding elements

Jaw-crusher: Bico-Braun “chipmunk” type crusher, or equivalent

Capable of breaking large rocks to <6.35 mm (0.25 inch)

US Standard 8 inch diameter sieves: 6 (3.35 mm), 20 (850 µm), 40 (425 µm) and 200 mesh (75 µm) aperture

Drying oven (110°C)

Riffle splitter, 12.7 mm (1/2 inch) diameter chute

Stopwatch

Reagents

Milling solution: 0.1% solution of an acrylate-based dispersant

e.g. Alcosperse 149*, Alco Chemical Corp, or equivalent

*Supplier: Narlex LD31 (an equivalent acrylate dispersant)

National Starch and Chemicals Limited, Speciality Polymers Division, Bruanston, Daventry

Northamptonshire, NN11 7JL United Kingdom Tel +44 1788 890248 Fax +44 1788 891489

Procedure

1. Pass approx. 500 g of material through a jaw-crusher able to crush rocks to <6.35 mm (0.25 inch).
2. Dry-sieve the jaw-crushed material on a 850 µm (20 mesh) and a 425 µm (40 mesh) sieve. Please refer to method 5 below for guidance on the correct sieving technique.
3. Weigh out 20 +0.01 g of dried 20 by 40 mesh rock (W1).
4. Add 180 ml of milling solution to a clean empty mill jar. Add the seven grinding elements and transfer the weighed sample to the mill jar.
5. Place the mill jar on the rotating mill and operate the mill for exactly 5000 revolutions.
6. Rinse the entire contents of the mill jar (slurry and grinding elements) onto an upper 3.35 mm (6 mesh) sieve and underlying 75 µm (200 mesh) sieve with distilled water. The grinding elements are retained on the upper 3.35 mm sieve and should be washed thoroughly to remove all rock particles.
7. After washing, remove the 3.35 mm sieve and grinding elements. Wet sieve the sample on the 75 µm sieve. Retain and dry the <75 µm fraction passed through the sieve.
8. Dry and weigh (to the nearest 0.01 g) the >75 µm residue remaining on the sieve (W2).
9. After weighing, re-combine the >75 µm and <75 µm sieve fractions.

Calculation

Calculate grindability index as follows:

Grindability index (GI) (%) = [(W1 - W2)/W1] x 100

Method 4. Sieve analysis of agricultural liming materials (after ASTM C602–95)

Note: this procedure should be carried out on the product obtained from the grinding index test (method 3 above).

Apparatus

Drying oven

Balance

Air-tight container

Hard rubber roller

8 inch (203 mm) No.8 (2.36 mm) sieve

8 inch (203 mm) No.60 (250 µm) sieve

Procedure

1. Dry the sample to constant weight at 110+5°C and store in an air-tight container. Use a riffle box, sample splitter or quartering method (see ASTM D3176) to obtain a 100–150 g sub-sample.

2 Agglomeration of fine particles can occur in limestones containing clay. These agglomerates should be broken by gently rolling the dry sample (e.g. with a hard rubber roller) without crushing limestone particles.

3. Weigh the dried sample to an accuracy of 0.1 g. Sieve the sample through an 8 inch (203 mm) diameter No.8 (2.36 mm) sieve and an 8 inch (203 mm) diameter No.60 (250 µm) sieve conforming to specification ASTM E11.

4. Samples should be shaken through both lateral and vertical movement of the sieve. This should be accompanied by periodic jarring to ensure continuous movement of the sample over surface of the sieve.

5. Continue sieving until <0.5% of the total weight passes either sieve during 1 minute of operation.

6. Calculate the amount of material passing 2.36 mm and 250 µm to the nearest weight percent of dry sample

7. If required, calculate moisture content as follows:

8. Moisture (%) = 100 x (wt. as received - dry wt.)/wt. as received

Method 5. Reactivity by the resin suspension method (after Bornman et al., 1988)

Note: this procedure should be carried out on the product obtained from the grinding index test (method 3 above).

Reagents

500 g Amberlite ® CG-50 ion exchange resin*

(200 to 400 mesh grade, CEC = 10 cmol p+ kg-1)

1 litre acetic acid, concentrated

100g calcium carbonate, analytical grade, micronized or reprecipitated

*Supplier: Product number 20211–5000

Fisher Scientific UK, Bishop Meadow Road, Loughborough, Leicestershire, LE11 0RG United Kingdom

Tel + 44 1509 231166

Apparatus

600 ml glass beakers (x10)	Glass stirring rod (x10)
Watch glasses (x10)	pH meter and pH calibration buffer solutions
50 ml measuring cylinder	500 ml measuring cylinder
500 ml plastic bottle	5 litre plastic container

Preparation of dilute acetic acid (pH 4.0)

1. Pipette 3 ml of concentrated acetic acid into a 500 ml plastic container. Add 500 ml of distilled water and mix thoroughly. Label and retain solution.
2. Decant a 20 ml aliquot of this solution into a measuring cylinder. Transfer to a 5 litre plastic bottle and dilute with distilled water to 5 litres. Check that the pH of this dilute acetic acid is around pH 4 (+ 0.05 pH units). This dilute acetic acid solution is used for the reactivity experiment.

Procedure

1. Weigh out 1.000 g of resin (+ 0.001 g). Transfer to a 600 ml beaker
2. Weigh out 0.200 g of sample (+ 0.001 g). Transfer to the 600 ml beaker.
3. For each sample, repeat steps 1 and 2 to obtain a duplicate.
4. Add 500 ml of dilute acetic acid solution from a measuring cylinder
5. Stir the suspension vigorously for 1 minute with the glass stirring rod and then cover with watch glass
6. Allow beaker and contents to stand at room temperature (25¡C) for a period of 24 hours.
7. Calibrate pH meter for an acid pH range.
8. After a 24 hour period has elapsed, stir the suspension vigorously for 1 minute with the glass stirring rod. Allow to settle, immerse pH electrode and record the pH after 15 minutes.
9. For each batch of samples tested, a control sample and a blank sample need to be included. 0.200 g (+ 0.001 g) of analytical grade $CaCO_3$ (reprecipitated or micronized) is used as the control sample. For the blank sample, 1.000 g (+ 0.001 g) of ion-exchange resin is used with no sample addition. Duplicate analyses for both blank and control are also necessary.
10. Average the two pH reading obtained from the duplicate analyses. (Note: Bornman et al. suggest that results are discarded and the whole test repeated if the pH of the duplicates differ by more than 0.1 pH unit.)

Calculation

Reactivity (%) = [(pHL - pH0)/(pHC - pH0)] x 100

Where pHL = pH of sample after 24 hours; pHC = pH of control after 24 hours; pH0 = pH of blank after 24 hours

Appendix 3 Carbonate samples, Zambia

Mkushi, Central Province

Sample No.	Eastings	Northings	Colour	Description
01	747822	8506717	Pinkish grey	Massive, coarse grained
02	748757	8506297	Light grey	Finely laminated
03	748379	8506556	Pinkish white	Massive, coarse grained
04	748442	8506659	Light grey	Massive, medium grained
05	748419	8506659	Grey	Massive, coarse grained
06	748421	8506599	Grey	Massive, coarse grained
07	748396	8506565	Light grey	Massive, coarsely crystalline
08	748468	8506709	Grey	Shaly, contorted
09	748457	8506689	Grey	Massive, coarse grained
10	748478	8506722	Grey	Massive, coarse grained
11	748478	8506730	Whitish grey	Massive, coarse grained
12	748492	8506692	Light grey	Massive with calcitic veinlets
13	748483	8506686	Grey	Massive, coarse grained
14	748469	8506640	Grey	Massive, coarse grained
15	748450	8506593	Grey	Massive, coarse grained
16	749371	8506709	Light grey	Finely laminated
17	749307	8506712	Grey	Laminated, medium grained
18	748422	8507312	Grey	Massive, medium grained
19	749830	8506896	Light grey	Medium grained, contorted
20	750123	8506513	Grey	Massive, coarse grained
21	747322	8507780	Pinkish grey	Massive, coarse grained
22	747011	8507456	Grey	Laminated, medium grained

Solwezi, North-Western Province

Sample No.	Eastings	Northings	Colour	Description
23	435743	8652140	Grey	Laminated,
24	435823	8652001	Grey-Dark grey	Laminated,
25	435707	8652033	Grey-Dark grey	Laminated,
26	435679	8651880	Dark grey	Weakly laminated,
27	435785	8651845	Dark grey	Weakly laminated,
28	435601	8651895	Dark grey	Weakly laminated,
29	437184	8651753	Brownish grey	Laminated
30	437490	8651554	Grey	Laminated,
31	437521	8652001	Whitish grey	No lamination
32	437610	8652153	White – dark	Laminated
33	436423	8651285	Light grey	Sugary texture, very friable, weakly
34	436090	8651759	Grey	Sugary texture, friable, weakly laminated
35	435942	8652076	Light grey	Weakly laminated, very friable
36	436002	8651954	White – greyish	No lamination
37	438237	8652873	Dark – light	Sugary texture, weakly laminated, relatively
38	439562	8653182	Brownish grey	Friable
39	434951	8651455	Grey	Laminated, medium grained
40	435377	8651713	Dark grey	Fine laminated, medium grained
41	435904	8651796	Grey	Laminated, friable, medium grained
42	435868	8651744	Grey	Laminated, friable, medium grained

Solwezi, North-Western Province cont/d

Sample No.	Eastings	Northings	Colour	Description
43	435888	8651746	Light grey	Laminated, friable, medium grained
44	435915	8651724	Light grey	Weakly laminated, friable
45	435894	8651701	Grey	Fine laminated, friable, medium grained
46	435440	8651721	Grey	Laminated, friable, medium grained
47	435933	8651698	Dark grey	Massive, homogeneous, coarse grained
48	435952	8651693	Dark grey	Massive, coarse grained
49	435966	8651681	Grey	Weakly laminated, coarse grained
50	435988	8651655	Grey	Laminated, coarse grained, friable
51	435982	8651624	Grey	Laminated, medium grained, friable
52	435994	8651608	Whitish grey	Medium grained, friable
53	436011	8651598	Dark grey	Massive, medium grained (230/30NW)
54	436062	8651547	Dark grey	Massive, coarse grained
55	436034	8651391	Grey	Massive, coarse grained
56	435996	8651343	Grey	Laminated, medium grained, 40 x 50 m
57	436346	8651219	Grey	Massive, coarse grained
58	436321	8651062	Grey	Massive, coarse grained
59	437356	8651168	Grey	Massive, coarse grained, calcite veinlets
60	437214	8651302	Greyish pink	Massive, coarse grained
61	437500	8651425	Pinkish White	Coarse grained, sugary, friable
62	436184	8651562	Grey	Massive, coarse grained
63	436016	8651935	Light grey	Fine grained, friable, 50x50 m exposure
64	435534	8651619	Light grey	Weakly laminated, medium grained
65	436171	8650809	Light grey	Laminated, med grained
66	437705	8651669	Light grey	Massive, medium grained, calcite veinlets
67	437652	8651760	Whitish grey	Medium grained, friable
68	437919	8652037	Yellow-white	Sugary, coarse grained, friable
69	439459	8652920	Yellow-white	Sugary, coarse grained, friable
70	439328	8652933	Yellow-white	Sugary, coarse grained, friable
71	418428	8654355	White	Massive, coarsely crystalline
72	418357	8654430	Light grey	Coarse grained, light/dark bands, calcitic

Lusaka East, Lusaka Province

Sample No.	Eastings	Northings	Colour	Description
73	648264	8290125	Whitish grey	Massive, medium grey
74	648204	8290141	Yellow grey	Fine sulphide dissemination
75	648191	8290172	Dark grey	Laminated, slaty cleav, sulphides
76	648268	8290144	Dark grey	Massive, med grained
77	648323	8290170	Whitish grey	Intermediate white/dark grey lst

Appendix 4 Agricultural lime evaluation testwork data

Mkushi, Central Province

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization Value % CCE
01	32.72	19.44	78.37	69.79	100.75
02	31.81	18.81	79.95	62.73	101.98
03	32.03	17.97	77.62	61.83	100.58
04	31.24	19.71	81.23	65.69	101.80
05	30.42	18.61	78.38	59.99	102.80
06	30.05	20.83	82.52	63.22	103.13
07	31.22	19.02	79.98	80.17	101.60
08	33.74	17.12	83.21	63.75	103.33
09	30.78	19.00	80.10	62.03	102.90
10	32.07	18.69	79.88	65.34	103.00
11	30.06	19.76	81.22	64.41	103.50
12	31.29	18.27	80.72	69.11	102.25
13	31.78	18.88	80.22	68.63	103.10
14	32.20	14.92	82.31	78.24	102.33
15	29.74	17.52	68.33	79.28	104.15
16	30.35	19.81	79.11	65.78	104.65
17	30.34	19.82	83.77	69.29	103.75
18	31.85	18.74	80.56	70.91	102.55
19	34.41	17.26	75.38	69.72	102.10
20	32.30	17.26	71.12	66.18	103.85
21	32.87	17.09	72.36	67.93	104.75
22	30.52	19.45	70.73	68.33	103.40

Solwezi, North-Western Province

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization Value % CCE
23	30.38	21.61	72.73	64.25	106.41
24	29.98	22.44	74.31	53.12	105.32
25	32.04	19.02	83.47	62.70	106.48
26	32.10	20.79	80.12	71.33	106.56
27	34.80	18.63	79.11	61.21	107.19
28	33.84	19.46	81.66	70.13	106.97
29	32.21	20.41	71.03	61.78	106.36
30	32.50	19.09	80.56	67.19	106.10
31	32.07	20.38	74.75	60.92	106.99
32	30.63	19.67	81.18	37.99	106.65
33	30.26	20.80	79.99	81.38	106.73
34	32.78	19.16	90.71	87.82	100.31
35	32..72	19.73	82.62	79.17	106.61
36	30.91	20.44	81.33	73.89	102.68
37	30.61	20.63	80.78	69.82	105.38
38	32.58	19.57	86.42	79.92	103.53
39	30.13	19.48	76.31	65.66	104.75
40	31.81	19.02	80.56	70.99	105.25

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization **Value** % CCE
41	31.23	18.56	90.82	83.98	102.20
42	30.49	18.11	83.12	72.23	102.12
43	31.80	19.95	79.28	70.91	101.45
44	33.33	18.03	80.48	68.78	103.65
45	32.45	18.27	80.71	78.89	104.50
46	31.43	19.21	78.32	77.41	102.25
47	20.70	19.66	76.48	75.33	103.95
48	33.83	18.34	79.77	82.18	103.85
49	33.90	19.59	80.22	79.13	103.75
50	31.57	19.27	81.91	80.82	102.75
51	32.44	18.97	79.88	72.10	102.65
52	33.76	18.91	78.33	70.11	102.79
53	35.68	17.45	82.34	80.10	101.79
54	33.82	19.99	80.80	78.90	103.10
55	33.86	18.70	79.98	75.02	103.73
56	32.62	18.06	80.88	78.35	103.78
57	32.23	17.72	88.61	80.53	104.37
58	32.76	17.82	80.55	81.87	103.63
59	31.27	19.95	81.80	73.61	104.48
60	32.55	19.92	80.67	71.32	104.68
61	31.94	19.12	88.24	86.23	105.96
62	32.86	19.85	78.92	70.81	105.58
63	36.61	17.69	81.78	82.37	102.30
64	35.65	17.45	78.87	80.51	103.26
65	53.87	01.42	88.32	81.89	89.11
66	50.37	04.47	89.77	83.22	93.39

Solwezi, North-Western Province

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization **Value** % CCE
67	52.60	02.55	89.12	78.71	96.88
68	53.48	01.90	86.51	90.38	97.31
69	34.29	16.56	76.21	75.92	100.32
70	51.80	02.66	88.92	80.09	98.71

Lusaka East, Lusaka Province

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization **Value** % CCE
73	53.87	01.91	89.78	78.39	98.33
74	26.22	08.62	68.61	62.31	64.77
75	52.29	01.45	88.33	77.94	95.76
76	53.46	01.74	88.34	76.21	96.94
77	40.08	04.20	89.61	78.92	83.72

Changushi, North-Western Province

Sample No.	CaO Wt %	MgO Wt %	Reactivity %	Grindability %	Neutralization **Value** % CCE
78	52.22	02.54	87.76	79.78	97.54
79	53.27	01.94	90.98	81.67	98.19

Appendix 5 Chemistry of selected carbonate samples from Zambia

Mkushi		1	5	9	13	17	21
SiO_2	wt %	2.9	2.35	2.72	2.24	2.33	6.28
TiO_2	wt %	0.04	0.03	0.03	0.03	0.02	0.03
Al_2O_3	wt %	0.54	0.38	0.46	0.43	0.32	0.53
Fe_2O_3t	wt %	0.61	0.39	0.36	0.36	0.36	0.52
Mn_3O_4	wt %	0.06	0.05	0.06	0.06	0.05	0.06
MgO	wt %	20.34	20.37	20.33	20.33	20.33	19.42
CaO	wt %	28.9	29.1	28.98	29.09	29.06	27.92
Na_2O	wt %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
K_2O	wt %	0.26	0.23	0.23	0.26	0.15	0.3
P_2O_5	wt %	0.02	0.02	0.02	0.02	0.02	0.03
SO_3	wt %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr_2O_3	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SrO	wt %	0.02	0.02	0.02	0.02	0.02	0.02
BaO	wt %	0.02	0.02	<0.02	<0.02	<0.02	<0.02
LOI	wt %	45.14	45.48	45.3	45.62	45.6	43.64
Total	wt %	98.85	98.44	98.51	98.46	98.26	98.75

Solwezi		23	27	29	30	31	35
SiO_2	wt %	<0.01	0.02	0.02	<0.01	<0.01	0.05
TiO_2	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Al_2O_3	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fe_2O_3t	wt %	0.14	0.11	0.61	0.09	0.19	0.12
Mn_3O_4	wt %	0.02	0.02	0.04	0.02	0.02	0.01
MgO	wt %	20.06	20.09	20.47	20.26	20.37	20.28
CaO	wt %	29.16	29.16	29.71	29.26	29.35	29.4
Na_2O	wt %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
K_2O	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
P_2O_5	wt %	0.06	0.12	0.03	0.03	0.02	0.13
SO_3	wt %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cr_2O_3	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SrO	wt %	<0.01	0.01	0.02	0.01	0.01	0.01
BaO	wt %	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
LOI	wt %	46.33	46.33	46.83	46.93	46.63	46.57
Total	wt %	95.77	95.86	97.73	96.6	96.59	96.58

Solwezi		39	43	47	50	51	55	59	63	67	69
SiO_2	wt %	0.2	0.14	0.23	0.09	0.11	0.18	0.05	0.02	0.03	0.41
TiO_2	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Al_2O_3	wt %	0.08	0.05	0.08	0.01	0.02	0.06	0.02	<0.01	<0.01	0.03
Fe_2O_3t	wt %	0.11	0.07	0.09	0.8	0.09	0.07	0.13	0.2	0.16	0.64
Mn_3O_4	wt %	0.02	0.02	0.01	0.04	0.01	0.01	0.03	0.03	0.02	0.02
MgO	wt %	20.65	20.63	20.52	20.88	20.47	20.55	20.55	20.59	20.57	20.83
CaO	wt %	29.9	30.03	29.94	30.46	29.88	29.94	29.8	29.89	29.77	30.46
Na_2O	wt %	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
K_2O	wt %	0.03	0.02	0.04	<0.01	0.01	0.03	<0.01	<0.01	<0.01	0.02
P_2O_5	wt %	0.21	0.17	0.19	0.11	0.13	0.2	0.04	0.11	0.08	0.02

SO_3	wt %	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1
Cr_2O_3	wt %	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SrO	wt %	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01
BaO	wt %	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
LOI	wt %	46.39	46.4	46.27	46.97	46.41	46.21	46.5	46.5	46.51	47.06
Total	wt %	97.6	97.54	97.38	99.38	97.14	97.26	97.14	97.35	97.15	99.6

		Mill product	**Lusaka East**		**Changushi**				
			73	**74**	**78**	**79**	**80**	**81**	**82**
SiO_2	wt %	4.3	1.81	0.08	29.77	2.5	0.51	13.65	2.66
TiO_2	wt %	0.06	0.02	<0.01	0.35	0.03	<0.01	0.14	0.04
Al_2O_3	wt %	0.8	0.37	<0.01	6.29	0.49	0.09	2.6	0.74
Fe_2O_3t	wt %	0.56	0.25	0.05	1.15	0.38	0.12	0.85	1.2
Mn_3O_4	wt %	0.05	0.04	<0.01	0.06	0.1	<0.01	0.07	0.04
MgO	wt %	20.16	1.71	2.59	9.78	1.37	2.87	4.28	2.94
CaO	wt %	28.67	52.18	50.03	22.35	51.69	51.13	40.73	49.17
Na_2O	wt %	<0.05	<0.05	<0.05	0.05	0.08	<0.05	<0.05	0.41
K_2O	wt %	0.38	0.13	<0.01	2.46	0.15	0.04	0.96	<0.01
P_2O_5	wt %	0.04	0.03	0.06	0.13	0.06	0.04	0.1	0.23
SO_3	wt %	<0.1	0.2	<0.1	<0.1	0.2	<0.1	<0.1	0.8
Cr_2O_3	wt %	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SrO	wt %	0.02	0.02	0.03	<0.01	0.21	0.07	0.02	0.04
BaO	wt %	0.05	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
LOI	wt %	44.35	42.88	43.7	27.7	42.25	43.89	36.65	41.3
Total	wt %	99.45	99.64	96.54	100.09	99.51	98.76	100.05	99.57

Appendix 6 Estimation of dolomite resources at Mkushi

Tonnage estimate for BENCH 1

1.1 Surface Area $A_1B_1B'_1A'_1$ = ***522.3 m²***

1.2 Volume of Bench 1 = ***1 044.60 m³***

1.3 Tonnage in Bench 1 limestone SG of 2.7 tonnes/m³ = **2 820.42 Tonnes**

Tonnage estimates for BENCH 2

At two meters depth, the outline dimensions of Bench 1 will be reduced by a 0.5 m wide safety berm bounding all sides of the exposed surface. This will be for the purpose of trapping subsequent rocks from upper benches as mining progresses at depth. Dimensions of Bench 2 will therefore be:

2.1 Surface Area $A_2B_2B'_2A'_2$ = ***601.65 m²***

2.2 Volume of Bench 2 = ***1 203.3 m³***

2.3 Tonnage in Bench 2 limestone SG of 2.7 tonnes/m³ **= 3 248.91 Tonnes**

Tonnage calculations for BENCH 3

Proceeding as for Bench 2, the dimensions of Bench 3 were calculated to be:

3.1 Surface Area $A_3B_3B'_3A'_3$ = ***700.30 m²***

3.2 Volume of Bench 3 = ***1 400.6 m³***

3.3 Tonnage in Bench 3 at a limestone SG of 2.7 tonnes/m³ **= 3 781.2 Tonnes**

Tonnage calculations for BENCH 4

Proceeding as for Bench 3, the dimensions of Bench 4 were calculated to be:

4.1 Surface Area $A_4B_4B'_4A'_4$ = ***831.98 m²***

4.2 Volume of Bench 4 = ***1 663.96 m³***

4.3 Tonnage in Bench 4 at a limestone SG of 2.7 tonnes/m³ **= 4 492.69 Tonnes**

The total tonnage of dolomite limestone in Outcrop1, if mined in two-meter thick benches down to a depth of eight meters is summarised in Table 1.

Table 1 Summary of total calculated in-situ limestone in Outcrop 1 at Munsakamba Open Prison

Bench No.	**Bench dimensions**				**Surface area** (m²)	**Volume** @ 2m depth	**Tonnage** @ 2.7t/m³
	A - B	B - C	C – D	D – A			
1	17.00	29.00	22.00	25.00	522.30	1 044.60	2 820.42
2	18.00	31.50	23.63	27.00	601.65	1 203.30	3 248.91
3	19.13	33.75	25.46	29.25	700.30	1 400.60	3 781.62
4	20.40	36.84	28.64	31.79	831.98	1 663.96	4 492.69
TOTAL							14,343.64

Appendix 7 Cost estimation for bush clearing and loose soil removal

Labour costs to clear an area of approximately $800m^2$ at 500 mm thickness (adopting an in-situ SG of $2.5t/m^3$ for loose soil): Total volume = **2000.00 tonnes**

At 10 tonnes per man-shift, this will give 2,000 tonnes. At 10tonnes per man-shift this equates to 200 man-shifts. Each loading crew is made of two persons, i.e. the total number of man-shifts required to load and haul is 2 * 200 = 400 man-shifts. With persons forming 5 x 2-man crews, the total number of shifts to accomplish the assignment will be 400/5, i.e. 80 shifts or days.

Total labour consumption, adopting a shift remuneration of US$2.5 per man-shift and assuming 400 man-shifts **= US$1000.00**

Safety Attire (composed of overalls, hard-hat, gloves, goggles, gum boots or safety shoes) estimated at US$75.00 each for 10 workers = US$750.00

Five heavy-duty wheelbarrows, estimated at US$45.00 each = US$225.00

Ten heavy-duty picks/mattocks, estimated at US$20.00 each = US$200.00

Ten heavy-duty shovels, estimated at US$18.00 each = US$180.00

Ten heavy-duty (10–15lb) hammers, estimated at US$40 each = US$400.00

Ten heavy-duty crow-bars, estimated at US$10 each = US$100.00

Total Cost on Tools = US$1855.00

Overall cost US$2255/2000 = US$1.13/tonne

Therefore, the overall cost bush clearing and loose soil removal is US$1.13 per tonne of soil removed.

Appendix 8 Specifications, ownership and operating costs estimates for the drilling compressor & rockdrill

Compressor: Atlas Copco STS 48 Dd (or equivalent) powered by a Magirus Deutz F4L912 air-cooled diesel engine.

Normal operating pressure………………..…75 l/sec

Normal operating effective pressure……..….7 bar

Maximum operating effective pressure…….8.8 bar

Volume of compressor lubrication system…5 litres

Maximum loaded speed……………………1750 rpm

Rockdrill: Atlas Copco RH 658–4LS (or equivalent) for hand held bench drilling.

Atlas Copco RH 658–4LS (or equivalent) for hand held bench drilling

Mass…………………….25.5 kg

Length………………….640 mm

Piston diameter…………65 mm

Rotation…………………Rifle bar type

Air consumption………56 l/sec

Ownership and Operating Cost Estimates

Estimated Purchase Price US$30,000.00 for compressor & US$3000.00 for rockdrill (cif-inclusive of accessories). Annual usage 1600 hours per year and expected lifespans of 3 and 10 years respectively.

Compressor (fixed) costs: Depreciation of US$1.88 + Annual Interest (I) @ 15% = US$1.55 gives a total ownership cost of **US$3.43** per hour of use.

Rockdrill (fixed) costs: Depreciation of US$0.63 + Annual Interest (I) @ 15% of US$0.19 gives a total ownership cost of **US$0.82** per hour of use.

Compressor operating (variable) costs: Fuel consumption approximately 10 litres per hour fuel at US$0.85 per litre of diesel gives a fuel cost of US$8.5 per hour of use. Lubricants, oils, filters and other consumables, estimatedat US$0.5 per hour of use. Repairs reserve, estimated to be 20% of hourly fuel costs, US$1.75per hour of use. Operator hourly rate adopt US$0.65. Total Operating Costs = US$11.4 per hour of use

Rockdrill operating (variable) costs: Compressed air consumption of 201.6 m^3 per hour and cost of US$0.055 per cubic metre gives a compressed air cost of US$11.08 per hour. Consumables (lubricants, hoses, bits, shanks and rods) cost of US$0.55 per hour. Repairs reserve, estimated to be 15% of hourly fuel costs, US$1.66. Operator hourly rate adopt US$0.65 per hour. Total operating costs = US$13.94 per hour of use.

Total Compressor ownership & operating costs = US$14.83 per hour of use.

Total Rockdrill ownership & operating Costs = US$14.76 per hour of use.

Appendix 9 Ownership and operating cost estimates for portable petrol-powered rock-breaking hammer

Type: Petrol-Powered combination drill/breaker with function switch for changing from Drilling to Breaking. Integral single cylinder (cast iron) air cooled two-stroke engine with reverse flow scavenging and recoil starter.

Ownership and Operating Cost Estimates

Estimated Purchase Price US$2500.00 (cif-inclusive of accessories). Annual usage 1600 hours per year and expected lidespan of 3 years.

Ownership (Fixed) Costs

Depreciation of US$0.52 per hour + Annual Interest (I) @ 15% of US$0.16 per hour gives a total ownership cost of US$0.68 per hour

Operating (Variable) Costs

Petrol consumption is 1.5 litres per hour at approximately US$1.00 per litre gives a cost of US$1.5 per hour. Lubricant consumption (oil added to petrol at a ratio of 1:2) is 0.75 litres per hour at approx. US$2.25 per litre gives a cost of US$1.69 per hour. Total fuel and lubricants cost is US$3.19 per hour.

Consumables and replacement costs (bits, shanks and rods) of US$0.55 per hour. Repairs reserve, estimated to be 15% of hourly fuel and lubricants costs = US$0.48 per hour. Operator hourly rate adopt US $ 0.65 per hour. Total Operating Costs = = US$1.68 per hour.

Total rock drilling ownership & operating costs (Alt. 2) = US$4.87 per hour

Recommendation

Through the use of a portable hammer drill, there is a radical reduction of more than two-thirds (67%; US$4.87 per hour as opposed to US$14.76 per hour) in drilling costs as compared to the use of a jack-hammer/compressor combination. It is therefore, strongly recommended that portable hammer drilling at Munsakamba, and especially Solwezi limestone, be the chosen method of blast hole drilling.

Appendix 10 Drilling and blasting

In order to achieve the maximum possible fragmentation, the drill pattern and explosive types must be selected for maximum size reduction during blasting. This will entail employment of a close drill pattern and higher powder factor. This will facilitate the achievement of the highest degree of fragmentation and reduce the manual effort required for production of the feed to the TDAU hammer mill.

Adopting a blast hole drill bit of 38 mm (used in jackhammer and small drill wagons) on a 25 mm drill steel, using High Explosive for maximum fragmentation and allowing for the limestone strength, the calculated burden can is 1500 mm. Having established the Burden, the spacing of blast drill holes in a row was calculated. This will further close the drill pattern for maximum fragmentation, to 1.5 metres. The sub grade or overdrill length will be 0.3 metres**,** total blast hole drill length 2.3 metres, stemming length 0.75 metres and charge length 1.55 metres.

Blasting of the limestone will be done with Nitroglycerine based High Explosives.

The three types of High Explosives worth considering are “Waterproof Dynamite” of 60% Nitroglycerine, Ammon Gelignite of 32% Nitroglycerine and Dynagel of 8% Nitroglycerine. All these explosive types are available in 25 mm x 200 mm (130g) and 32 mm x 200 mm (200g) cartridges delivered in 25 kg cartons each with 4 packets. Average of 48 cartridges and 31 cartridges per packet respectively.

Waterproof Dynamite (60% Nitroglycerine) of 32 mm diameter and 200 mm length is recommended for charging into the 38 mm blast holes. Despite being more expensive, use of Waterproof Dynamite will ensure effective and maximum fragmentation of limestone. This will ensure reduced upstream manual labour requirements on primary size reduction (hammering) and elimination of anticipated major bottleneck in the feed to the mill(s). Also, efficient and effective detonation in “wet holes” anticipated at lower benches and use of small diameter high explosive in jackhammer drilled blast holes. Recommended initiation methods for various types of explosives are given in Table 1.

The initiation of Waterproof Dynamite can be done with either the 6d Detonator or the Cordtex Detonating Fuse. It is recommended that the Cordtex Detonating Fuse be employed in the blasting of limestone.

As the Munsakamba dolomite limestone is characterised as medium hard to hard formation, a range of specific explosive consumption from 0.55 to 0.8 kg/m^3 is deemed applicable, thus giving an average of 0.68 kg/m^3.

Explosives consumption would be on average 2.85 kg per blast-hole. The amount of rock broken (Yield) per hole would range from 4.0 m^3 (10.80 tonnes) to 4.5 m^3 (12.15 tonnes) per hole. Specific Explosive Consumption or Powder Factor would range from 0.633 kg/m^3 (0.235 kg/tonne) to 0.712 kg/m^3 (0.264 kg/tonne). The Specific Yield would range from 1.74 m^3 (3.60 tonnes) to 1.96 m^3 (5.28 tonnes) per metre of blast-hole length.

The unit cost of drilling and blasting is estimated to range from US$1.88/m^3 (US$0.70/tonne) to US$2.72/m^3 (US$1.01/tonne).

Appendix 11 Crushing and milling cost estimates

The crushing and milling cost estimate is for a years operation, using the TD Hammer Mill and using 2000 exchange rate K3500 to US$1. The following were assumed:

- Ten men can crush 1 tonne to 10 mm (mill feed size) per day
- Ten men (crew) per mill (11 mills were used assuming a 3 year lifespan)
- 5000 tonnes to be produced per year at a production rate of 1.2 tonnes per day.
- Fuel consumption of 300 litres of petrol per tonne of lime produced
- Mill screens one screen per 100 tonnes and mill hammers 12 tonnes per set
- Leather gloves at a pair per man per 3 months
- One pair of overalls and a pair of leather boots per man per 6 months.
- Clear goggles at a pair per man per 6 months.
- Four shovels and two wheelbarrows per crew per 6 months.
- Four 1.5lb hammers and two 10lb hammers per crew per 3 months.
- 2.5 litres of engine oil and 2 spark plugs per mill per month.
- 760 x 50 kg empty bags and 4 rolls of mutton cloth per month per mill.

Item	**Unit cost** (US$)	**12 months** (US$)
Crushing labour cost	1.0 man	50,000
11/2 lb Hammers	2.15 each	378.40
10 lb Hammers	7.31 each	643.28
Petrol	0.92 litre	15,333.33
Depreciation of hammer mills	833.33 each	9,166.63
Mill screens	10 each	500
Mill hammers	2.5 set	1041.67
Engine oil	2.05 litre	676.50
Leather Gloves	2.03 pair	893.20
Spark plugs	5.13 each	1,354.32
Overalls	9.23 each	2,030.60
Clear Goggles	1.97 each	433.40
Safety boots	12.82 pair	2,820.40
Wheel barrows	30.51 each	1,342.44
Remuneration	1.0 man	41,668
Shovels	6.67 each	586.96
50 kg empty bags	0.21each	21,067.20
Mutton cloth	1.10 roll	580.80
Total cost		150,517.13
Cost per tonne of lime processed		30.10
Cost per 50 kg Bag of Lime		1.51

Appendix 12 Crop trial soil characterisation data

Table 1 Soil pH, exchangeable aluminium ($Al^{3+)}$) and exchangeable acidity (Al^{3+} + H^{+}) of soil from crop trial sites, Mkushi, Zambia

Lab No	Location	Quadrant	PH CaC1$_2$	(Al^{3+} + H^{+}) me/100g	Al^{3+} me/100g
665	Chalata	NW #1	4.68	0.18	0.12
666	Chalata	SW #2	4.67	0.18	0.08
667	Chalata	SE #3	4.38	0.34	0.16
668	Chalata	NE #4	4.52	0.26	0.14
669	M.F.T.C.	SN #1	4.91	0.12	0.06
670	M.F.T.C.	#2	4.97	0.08	0.02
671	M.F.T.C.	#3	4.9	0.12	0.02
672	M.F.T.C.	#4	4.99	0.12	0.04
673	Kasansama	SN #1	4.98	0.10	0.02
674	Kasansama	NE #2	4.95	0.06	0.04
675	Kasansama	NW #3	4.70	0.12	0.06
676	Kasansama	SW #4	4.66	0.16	0.12

Table 2 Chemical properties of soils from the crop trial sites, Mkushi, Zambia

Location	Quadrant	pH $CaCI_2$	K me/100g	Na me/100g	Ca me/100g	Mg me/100g	P mg/kg	Cu mg/kg
Chalata	SW #2	4.67	0.07	0.04	1.93	0.54	14.77	0.60
Chalata	SE #3	4.38	0.05	0.05	1.98	0.50	10.50	0.60
Chalata	NE #4	4.52	0.06	0.03	2.08	0.58	12.08	0.40
MFTC	#2	4.97	0.10	0.07	1.95	0.54	28.74	0.60
MFTC	#3	4.9	0.10	0.06	2.25	0.42	10.36	0.60
MFTC	#4	4.99	0.12	0.05	2.28	0.46	36.99	0.60
Kasansama	NE #2	4.95	0.18	0.04	2.38	0.63	30.98	0.40
Kasansama	NW #3	4.70	0.13	0.05	1.33	0.25	40.04	0.40
Kasansama	SW #4	4.66	0.13	0.07	1.35	0.17	37.98	0.40
Chalata	SW #2	11.60	35.40	0.98	Trace	0.02	1.10	0.04
Chalata	SE #3	10.20	18.20	1.06	Trace	0.01	1.47	0.08
Chalata	NE #4	9.80	18.60	0.98	Trace	0.02	1.54	0.08
MFTC	#2	14.00	6.00	0.18	Trace	0.02	1.54	Trace
MFTC	#3	15.00	17.80	0.32	Trace	0.03	1.83	0.11
MFTC	#4	14.60	12.40	0.14	Trace	0.03	1.69	0.06
Kasansama	NE #2	15.40	10.20	0.36	0.24	0.04	1.47	0.06
Kasansama	NW #3	22.20	11.80	0.18	Trace	0.03	1.32	0.07
Kasansama	SW #4	18.00	9.60	0.28	0.41	0.02	1.61	0.07
Chalata	SW #2	0.18	0.08	0.13	74.80	4.40	20.80	SL
Chalata	SE #3	0.34	0.16	0.26	74.80	8.40	16.80	SL
Chalata	NE #4	0.26	0.14	0.23	76.80	6.40	16.80	SL
FTC	#2	0.08	0.02	0.03	68.80	4.40	26.80	SL
FTC	#3	0.12	0.02	0.03	68.80	6.40	24.80	SL
FTC	#4	0.12	0.04	0.07	66.80	6.40	26.80	SL
Kasansama	NE #2	0.06	0.04	0.07	70.80	4.40	24.80	SL
Kasansama	NW #3	0.12	0.06	0.10	72.80	6.40	20.80	SL
Kasansama	NW #4	0.16	0.12	0.20	70.80	4.40	24.80	SL
MFTC = Mkushi Farm Training Centre								

Table 3 Chemical properties of soil after harvesting year one crop trials, Mkushi, Zambia

Sample Identity	**Lime application per hectare**	**pH** CaCI$_2$	**Ca** me/100g	**Mg** me/100g	**(Al^{3+} + H^+)** me/100g	**Al^{3+}** me/100g	**L.R. tonnes /acre** $CaCO_3$
Chalata - gn	450 kg - spot	4.53	0.30	0.17	0.16	0.14	0.50
Chalata - gn	900 kg - spot	4.52	0.43	0.13	0.12	0.08	0.66
Chalata - gn	450 kg - b/cast	4.58	0.50	0.25	0.06	0.04	0.79
Chalata - gn	900 kg - b/cast	4.45	0.15	0.17	0.22	0.16	0.68
Chalata - gn	no lime	4.60	0.35	0.17	0.08	0.04	0.62
Chalata – m	450 kg - spot	4.76	0.63	0.08	0.14	0.1	0.66
Chalata - m	900 kg - spot	4.80	0.38	0.13	0.12	0.08	0.62
Chalata - m	450 kg - b/cast	4.34	0.33	0.04	0.32	0.26	0.79
Chalata - m	900 kg - b/cast	4.69	0.35	0.13	0.16	0.12	0.55
Chalata - m	no lime	4.58	0.35	0.08	0.20	0.14	0.68
M.F.T.C. - gn	200 kg - spot	4.75	0.48	0.13	0.12	0.06	0.93
M.F.T.C. - gn	400 kg - spot	4.72	0.40	0.08	0.10	0.06	0.62
M.F.T.C. - gn	200 kg - b/cast	4.84	0.38	0.17	0.12	0.10	0.59
M.F.T.C. - gn	400 kg - b/cast	4.92	0.53	0.21	0.12	0.10	0.65
M.F.T.C. - gn	no lime	4.84	0.55	0.08	0.10	0.08	0.90
M.F.T.C. - m	200 kg - spot	4.77	0.48	0.13	0.14	0.10	0.48
M.F.T.C. - m	400 kg - spot	5.07	0.78	0.29	0.08	0.06	0.38
M.F.T.C. - m	200 kg - b/cast	4.77	0.70	0.21	0.10	0.08	0.75
M.F.T.C. - m	400 kg –/cast	4.66	0.78	0.21	0.12	0.08	0.29
M.F.T.C. - m	no lime	4.46	0.45	0.17	0.20	0.14	0.29
Kasansama - gn	200 kg - spot	5.03	1.05	0.08	0.06	0.02	0.26
Kasansama - gn	400 kg - spot	4.76	0.63	0.13	0.10	0.04	0.22
Kasansama - gn	200 kg - b/cast	4.68	0.73	0.17	0.10	0.04	0.50
Kasansama - gn	400 kg - b/cast	4.84	0.78	0.21	0.10	0.04	0.78
Kasansama - gn	no lime	4.75	0.68	0.21	0.04	0.02	0.39
Kasansama - m	200 kg - spot	4.80	1.23	0.38	0.08	0.04	0.75
Kasansama - m	400 kg - spot	5.15	1.38	0.38	0.12	0.08	0.60
Kasansama - m	200 kg - b/cast	4.59	0.65	0.04	0.12	0.04	0.73
Kasansama - m	400 kg - b/cast	4.83	1.08	0.17	0.08	0.04	0.53
Kasansama – m	no lime	4.53	0.68	0.04	0.18	0.12	0.74

KEY: gn = groundnuts; m = maize b/cast = broad cast; L.R. = Lime requirement

Appendix 13 Shelling percentage and 100 seed weight of groundnuts in response to liming of crop trials in Mkushi, Zambia

Treatment/Location	Shelling Percentage (%)		100 Seed Weight (g)	
	Year One	Year Two	Year One	Year Two
Chalata				
Control	62		42	
450 kg/ha (spot application)	66		53	
450 kg/ha (Broadcast)	65		37	
900 kg/ha (spot application)	59		37	
900 kg/ha (Broadcast)	69		56	
Kasansama				
Control	37		46	
200 kg/ha (spot application)	44		51	
200 kg/ha (Broadcast)	60		57	
400 kg/ha (spot application)	63		50	
400 kg/ha (Broadcast)	73		61	
Mkushi Farmer Training Centre				
Control	44	-	66	-
200 kg/ha (spot application)	39	-	46	-
200 kg/ha (Broadcast)	38	-	55	-
400 kg/ha (spot application	39	-	38	-
400 kg/ha (Broadcast)	42	-	73	-

References

SOUTHERN, A R C. 1996. *Arclime – Agricultural Magnesian Limestone*. Special products factsheet SP6.
ARTHURS, J W. 1974. *The geology of the Solwezi area: Explanation of degree sheets 1226, NW quarter and 1126, part of SW quarter*. Ministry of Mines and Co-operatives. Report of the Geological Survey, No. 36, 48pp.
BANDA, D J. 1997. *Baseline study on Constraints Analysis of post production sector in Zambia*.
BOSSE, H R. 1996. *Zambia in Limestone and dolomite resources of Africa*. Geologisches Jahrbuch, Reihe D, p.495–512.
BRAMMER, H. 1973. *Soils of Zambia*. Soil Survey Report 11. Chilanga.
CARRUTHERS, H E. 1986. *The dolomites north of Mkushi as a source of agricultural lime*. Minex Dept., ZIMCO Ltd, Lusaka.
Conseration Farming Unit. 2001. Technical Release No.8. *Low cost Environmentally Sustainable CF Maize Production Systems for Agro-Ecological Regions I, II, and III, based on the use of lime. Zambia National Farmers Union*. Conservation Farming Unit.
COPESTAKE, J C. 1997. *Supporting sustainable smallholder agriculture in Zambia*. Centre for Development Studies, University of Bath website article.
Website www.bath.ac.uk/~hssjgc/asrsaz.htm
Department of Agriculture. 1979. Lima crop Memo. *North western province. "Small scale farmer recommendations by Research Branch"*. Department of Agriculture. Republic of Zambia.
MC PHILIPS J K (edit). 1987. *Commercial Crop production Recommendations*. Department of Agriculture. Republic of Zambia.
GOMA H C, and SINGH B R. 1993. *Liming in relation crop production in Ultisols and Oxisols in Northern Zambia. Ecology and Soil Management Paper No.4*. The Ecology and Development Programme. The Agricultural University of Norway.
KALUNGU, F. 2002. *How to eradicate poverty in Zambia*. The Monitor (newspaper), March 15–18 2002, p 10–11.
KAMPRATH, E. 1980. *Soil acidity in well drained soils of the tropics as a constraint to food production. In: Soil related Constraints to Food production in the Tropics*. International Rice Research Institute and New York State College of Agriculture and Lift Sciences, Cornell University.
LUNGU, O I, and CHINENE V R N. 1993. *Cropping and Management Systems and their Effect on Soil Productivity in Zambia*. A Review. Ecology and Development Paper No.5. The Ecology and Development Programme. The Agricultural University of Norway.
MENGO, V. 2002. *Kapiri woman sees hope in Heifer Project International*. Zambia Daily Mail (newspaper), Monday, March 11, 2002, p 7.
Ministry of Agriculture, Food and Fisheries. 2002. Website www.maff.gov.zm
MITCHELL, C J, INGLETHORPE, S D J, TAWODZERA, P, BRADWELL, S & EVANS, E J. 1997. *Local development of affordable lime in southern Africa*. Brittish Geological Survey Technical Report. WC/97/20, pp 120.
MONEY, N J. 1986. *An outline of the geography and geology of Zambia*. Gelolgocal Survey Department of Zambia, Occassional paper, No 122.
MWALE M, MAPIKI A, DAMASEKE, M I, and MUKANDA, N. 2000. *Soil fertility Technologies. Available from Soils and Crop Research Branch*. A paper presented at the Soil Fertility Initiative Workshop, in Kafue, Zamia. 17–18 July, 2000.
MWALE, M, PHIRI, L, and DAMASESKE, M I. 1997. *Evaluation of Nampudwe tailings as a source of agricultural lime under field conditions*. A paper prepared to be presented to Zambia, consolidated Copper Mines (ZCCM).
ØYARD, R. 1987. *Economic Aspects of Agricultural Liming in Zambia*. Occassional Paper No 7. Norwegian Centre for International Agricultural Development. NORAGRIC. Agricultural University of Norway.
RAO, L P. 1984. *Agricultural limes potential in North-Western Province*. Minex Dept., ZIMCO Ltd, Lusaka.
STILLMAN, C J. 1965. *The geology of the Musofu river and Mkushi areas: Explanation of degree sheet 1329, part of NW quarter and SW quarter*. Ministry of Mines and Co-opeatives, Report of the Geological Survey, No 12, 52pp.
USAid. 2002. Website www.usaid.gov/zm
VELDKAMP, W J. 1987. *Soils of Zambia 2nd Edition*. Soil Bulletin No 13. Soil Survey Unit. Department of Agriculture. Mt Makulu. Ministry of Agriculture and Water Development Republic of Zambia.
SHITUMBANUMA, V , and SIMUKANGA, S. 1995. *Potential use of Carbonate Rocks for Agriculture in Zambia, PP 161–173. In:* MAMBWE, S H, SIMUKANGA S, SIKAZWE, O N, and KAMONA, F. *Proceedings of 1995*. International Conference on Industrial Minerals: Investment Opportunities in Southern Africa. 7–9 June, 1995. Pamodzi Hotel, Lusaka, Zambia. Council of Geosciences. South Africa.