Local development of affordable lime in southern Africa

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Abstract

In many less developed countries, especially in southern Africa, there is a shortage of locally available, low-cost lime. This has serious implications, especially for farming where insufficient application of agricultural lime can lead to soil acidification, with associated aluminium / manganese toxicity and poor crop yields. As part of the UK Government's programme of technical aid to developing countries, the British Geological Survey (BGS) has recently carried out a project 'Local development of affordable lime in southern Africa', funded by the Department for International Development (DFID). The objective was to encourage lime production by matching suitable carbonate resources with appropriate production technology to provide a method for the establishment of local production sites. The project focused on Zambia, where there are widespread resources of limestone potentially suitable for use as aglime, but consumption of aglime is low due to poor local availability and high costs of transportation. Recommendations arising from the project for the small-scale production of lime involve the use of contract extraction, manual crushing and mechanical grinding. Trials showed that effective milling could be successfully accomplished using a Zambian-built hammer mill.

INTRODUCTION

Lime is an important industrial raw material used in the manufacture of chemicals, as a metallurgical flux, to control the pH of industrial processes, in waste and water treatment, in sugar refining, in construction and in agriculture. Strictly, lime is calcium oxide (CaO), produced by the calcination of limestone although it is also a commercial term used to denote a variety of products including ground limestone, calcined limestone and hydrated lime (calcium hydroxide, $Ca(OH)_2$).

Industrial nations have either developed their own indigenous lime production or have arranged ready access to lime. In less developed countries the availability of lime can be limited, either due to a lack of suitable limestone resources or to inefficient lime production or distribution. In southern Africa (excluding South Africa), lime production is typically centralised, resulting in high costs and a lack of availability to consumers remote from the plant. This shortage of locally available, low cost lime is a constraint on agricultural development. Limited access to lime has serious implications. Lime is used to condition agricultural land which, if unlimed, may become acidified and result in a reduction in food and cash crop yields.

In order to tackle this problem a project, “Local development of affordable lime in Southern Africa” (R6492), was carried out via the Knowledge and Research programme of the UK Government’s Department for International Development (DFID). The aim was to encourage production of low-cost lime by matching carbonate resources with appropriate lime production technology and to provide a methodology for the establishment of local production sites. The methodology was developed in Zambia, which was identified in a survey (AUSTROPLAN, 1990) of the SADC (Southern African Development Community) region as having a need to increase its production of agricultural lime (aglime). The main project activities included:

i) A lime evaluation programme, which aimed to identify carbonate resources suitable for use as lime close to the point of need. This included a ‘market survey’ of lime use, an investigation of limestone resources and laboratory evaluation trials.

ii) Small-scale lime production research, which aimed to identify a low-cost method for the small-scale production of lime. This involved a review of small-scale production methods and a small-scale lime production trial using a Zambian-produced hammer mill.

LIME EVALUATION PROGRAMME

Lime market survey

Ground limestone and dolomite is used to condition soils (aglime) where fertilisers are used. Continued use of nitrogen-based fertilisers has an acidifying effect on soil. Soil acidity is associated with aluminium and manganese toxicity and reduced crop yields. Liming can prevent acidification, reduce aluminium and manganese toxicity, and increase calcium and magnesium availability to plants. High soil acidity (<4.5 pH) occurs in those parts of Zambia, generally the northern provinces, with high annual rainfall. Also soil acidification has become exacerbated by the increased frequency between cycles of the traditional *Chitemene* (slash-and-burn) cultivation method due to increasing population pressure.

The consumption of aglime in Zambia has been estimated at 37,000 tonnes a year whereas the potential demand for aglime is estimated to be 140,000 tonnes per year. This is based on the amount of aglime required to neutralise estimated soil acidity, both natural and resulting from application of fertilisers (Shitumbanuma & Simukanga, 1995). The low consumption of aglime is due mainly to high transport costs, poor local availability and a lack of awareness of its benefits, especially amongst subsistence farmers. Larger scale commercial farmers, who have ready access to transport and finance, actively benefit from the use of aglime.

As well as reviewing data and information contained in existing literature a 'questionnaire mailshot' was carried out to determine the actual usage of aglime, its cost and availability. Respondents indicated that they apply aglime every 2 to 3 years, before ploughing, as a means of controlling soil pH. The majority follow the Government guideline by applying 1 to 2 tonnes of aglime per hectare. The cost of obtaining aglime varies from less than 64US$ to over 160US$ per tonne. Most respondents travel over 100 km (over 800 km in one extreme example) to collect their aglime, and identify the transport costs as the main problems associated with its use.

The recommendations of previous studies focus on establishing relatively high capacity lime production plants throughout Zambia to serve the provinces. These plants have not materialised mainly due to their high construction and operating costs. A more suitable approach is to establish small-scale lime plants using appropriate technology and local labour to keep production costs to a minimum.

Review of the carbonate resources of Zambia

Carbonate rocks are known to occur throughout Zambia, especially along the line of rail from Livingstone to North-Western Province. Most of the carbonates occur in the Katanga Supergroup (Upper Precambrian), with a smaller proportion in the older Basement Complex (Lower Precambrian). The carbonates occur as calcitic and dolomitic marbles (Table 1), often banded and associated with calc-silicate rocks.

Table 1. Chemistry of selected dolomitic carbonates, Zambia

Stratigraphy	**CaO** wt %	**MgO** wt %
Basement Complex (Sasare Group)	38.1*	12.6*
Lower Katanga Supergroup		
Mujimbeji Marble, Monze Group,	29.4	18.2
Mampompo Limestone, Broken Hill Group	33.0*	20.0*
Upper Roan Formation, Mine Series Group	28.62 – 55.86*	0.4 – 27.72*
Upper Katanga Supergroup		
Kakontwe Limestone, Kundelungu Group	30.7	20.8
Muchinda Limestone, Kundelungu Group	30.1*	16.0*
Luapula Beds, Kundelungu Group	28.6	17.8
“Mkushi Dolomite”, Kundelungu Group	28.2	20.6
Undifferentiated Katanga Supergroup		
Mapanza Carbonate Formation	28.8*	17.0*
Mvuvye Marble, Mvuvye Group	28.1	27.5
Nkombwa Hill (Dolomitic Carbonatite)	24.0	19.0

NB Values are averages unless marked with *

Carbonates younger than the Katanga Supergroup are restricted to argillaceous limestones in Southern Province and impure calcretes in Western Province. Carbonatites (igneous carbonates) also occur, the most significant of these at Nkombwa Hill, near Isoka in Northern Province which consists of white dolomitic carbonatite.

Evaluation of limestone and dolomite for use as agricultural lime

Aglime can be defined as material having the necessary qualities to neutralise acidic soils and provide essential nutrients to promote plant growth. The key properties of limestone and dolomite relevant to their use as aglime are:

i) **Plant nutrient content**, expressed as calcium oxide (CaO) and magnesium oxide (MgO) content. In the UK, >15% MgO is recommended for dolomitic limestone used as aglime, whereas in Zambia >6% MgO is recommended (Tether & Money, 1986).

ii) **Particle-size** is a principal factor in controlling the effectiveness of aglime. Coarse particles have relatively little agronomic value, whereas finer particles react quickly upon contact with soil.

iii) **Neutralisation ability** is a measure of the amount of carbonate available for the neutralisation. It is expressed as calcium carbonate equivalent (CCE), i.e. the weight percent of calcium carbonate (limestone CCE is 100%; dolomite CCE is 108%).

iv) **Agronomic effectiveness**, or the reactivity, is defined as the rate at which aglime will neutralise soil. This is typically expressed as the proportion of neutralisation achieved.

v) **Ease of pulverisation**, or grindability, is an indication of the relative ease of grinding of limestone and dolomite. This is expressed as the proportion of material finer than 75 microns after milling under standard conditions.

In the UK, aglime products are typically defined by their neutralising value and the proportion of material finer than 0.15 mm. Dolomite is preferable as it has a higher neutralising value than limestone and contributes both calcium and magnesium to the soil. The ideal aglime is a dolomitic carbonate that has been ground to a particle-size 100% finer than 2 mm, of which 40% is finer than 150 microns.

Occurrences of limestone and dolomite potentially suitable for use as aglime were identified from the carbonate resources review. Samples were collected from across Zambia and evaluated in a laboratory established at the Zambian Geological Survey Department. The dominant rock types were dolomitic marbles, marbles and dolomites. The samples were “screened” to identify those suitable for use as aglime, based on their neutralising ability and plant nutrient content (especially magnesium). Those samples with a Neutralising Value higher than 80% CCE and a MgO content higher than 6% were considered to have potential for use as aglime (Table 2).

SMALL-SCALE LIME PRODUCTION RESEARCH

Review of lime production

A review of small-scale lime production methods was carried out by Intermediate Technology Zimbabwe (ITZ) based in Harare. The most commonly used production stages were identified as the following (and their costs are given in Table 3) :

i) Removal of overburden (“stripping”). Soft or unconsolidated material is typically removed manually using hammers, picks, shovels and wheel barrows. Harder material may require the use of graders, bulldozers or rippers.

ii) Extraction / quarrying. Opencast quarrying is preferred. Soft forms of carbonate (such as calc-tufa) can be removed manually using picks, hammers and crowbars. Harder carbonates may require drilling and blasting.

Table 2. Zambian carbonate rocks with potential for use as agricultural lime

Sample	**Neutralisation Value** % CCE	**MgO** Wt %	**CaO** Wt %	**Reactivity** **%**	**Grindablity** % < 75 µm
Dolomitic marble Chivuna Limestone, Chivuna	106	21.83	30.24	65.9	64.0
Dolomitic marble Mujimbeji Marble, Solwezi	107	21.86	30.96	70.4	41.1
Dolomitic marble Mujimbeji Marble, Chombela	107	20.08	33.06	71.7	51.3
Dolomite Upper Roan Fm, Mpongwe	105	18.59	43.4	89.3	97.1
Dolomite Muchinda Limestone, Kabwe	106	21.55	31.22	84.2	97.2
Dolomite Mujimbeji Marble, Lukunyi	106	21.31	30.93	73.7	98.0
Dolomitic marble Lower Roan Fm, Mkushi	103	20.94	29.6	63.2	98.4
Dolomitic marble Lower Roan Fm, Mkushi	104	21.25	30.04	68.4	98.6

iii) Dressing. Manual dressing involves the use of sledge hammers to reduce the quarried rock (>500 mm) to a manageable size (<200 mm) for the crushing stage.

iv) Crushing. Manual crushing is carried out to reduce the rock to a size suitable for milling (<20 mm). This can be carried out using sledge hammers, but is labour intensive. Jaw crushers are a commonly used means of mechanical crushing.

v) Grinding / milling. Milling is carried out to produce ground material suitable for use as aglime. Manual milling is possible but is more labour intensive than crushing. Ball mills and hammer mills are commonly used methods of mechanical milling.

vi) Screening. This is carried out to return unmilled rock for further milling. Manual screening is possible. Standing screens, rotating barrel ("trommel") screens and vibrating screens are common means of mechanical screening.

vii) Bagging / packaging. Milled carbonate can be manually bagged, with the use of platform scales. Mechanical bagging is rarely used in small-scale lime production.

Table 3. Costs of small-scale aglime production (per tonne of aglime produced)

Production stage	**Manual production** US$	**Mechanical production** US$
Overburden stripping	0.13	0.85
Extraction	5.22	4.36
Dressing	4.11	As manual
Crushing	10.24	0.94
Milling	As mechanical	3.32
Bagging	3.34	As manual
Total (inc. 10 % overheads)	28.99	18.61

NB Assuming unconsolidated overburden (1 m thick), 10 m thickness of workable carbonate, 200 working days per annum, built-in capital costs, and a labour cost of US$2.50 per day.

Lime production trials

A small-scale lime production trial was carried out by the Technology Development Advisory Unit, University of Zambia, using the TD Hammer (manufactured in Lusaka). This mill is relatively lightweight and portable, with a milling compartment containing 12 hardened steel hammers directly driven by a small petrol engine. Mill feed is introduced by gravity, is ground by the hammers and the milled product drops through the screen at the base.

The aim of the milling trial was to produce ground carbonate suitable for use as aglime. An 80 kg sample of dolomitic marble from Mkushi in Central Province was collected and jaw crushed to pass 20 mm. The jaw-crushed carbonate was used as the feed material for two separate milling trials; one using the mill fitted with a 1.5 mm aperture screen and the second with a 1 mm aperture screen.

The results of the milling trials are summarised in Table 4. The material milled through 1.5 mm contained 75% finer than 0.4 mm and that milled through 1 mm contained 80% finer than 0.4 mm. The 1.5 mm trial has the highest throughput capacity, and consequently, a lower production cost per tonne than for the 1 mm trial. The results demonstrate the effectiveness of this method for producing aglime.

Table 4. Results of the milling trials using the TD Hammer mill

Property	**Feed**	**1.5 mm trial**	**1.0 mm trial**	**Target**
Particle-size wt %				
<10 mm	82.2	nd	nd	na
<2 mm	29.5	96.1	97.5	100
<1 mm	20.6	90.8	92.8	na
<0.4 mm	nd	74.4	79.5	40
<0.1 mm	nd	63.9	79.3	na
Capacity kg / hour	na	174	142	na
Cost US$ / tonne	na	4.76	5.66	na

NB Labour cost, US$0.12/hr; fuel cost, US$0.63/litre petrol. na = not applicable; nd = not determined

RECOMMENDATIONS FOR THE SMALL-SCALE PRODUCTION OF LIME

The following are recommended prior to the small-scale production of aglime. A study of the aglime market including the qualities and quantities required and the constraints on production and consumption. In addition a limestone / dolomite resource investigation needs to be carried out to identify suitable deposits and to evaluate the technical properties of the carbonate rocks. It is recommended that small-scale production of lime should involve manual procedures as this reduces the costs, simplifies the production process and maximises the employment potential. The recommended procedure for the production of lime is summarised in Figure 1. The production process should involve the manual removal of overburden, contract drilling and blasting, manual stone dressing and crushing, mechanical grinding and manual bagging. As well as producing ground limestone and dolomite for use as aglime, this production procedure could also meet local demands for aggregate, and also feed material for the production of burnt lime and mineral filler.

CONCLUSIONS

i) A lime market survey confirmed that aglime is under-used in Zambia, mainly due to poor availability, cost of transportation and ignorance of its benefits.

ii) A carbonate resources study revealed that ample material suitable for use as aglime occurs in Zambia. A suite of carbonate samples were evaluated to determine the key aglime properties: plant nutrient content, neutralisation value, reactivity and grindability.

iii) A review of small-scale lime production indicated that aglime could be produced using contract extraction, manual crushing and mechanical milling. Successful milling trials were carried out using a Zambian built hammer mill.

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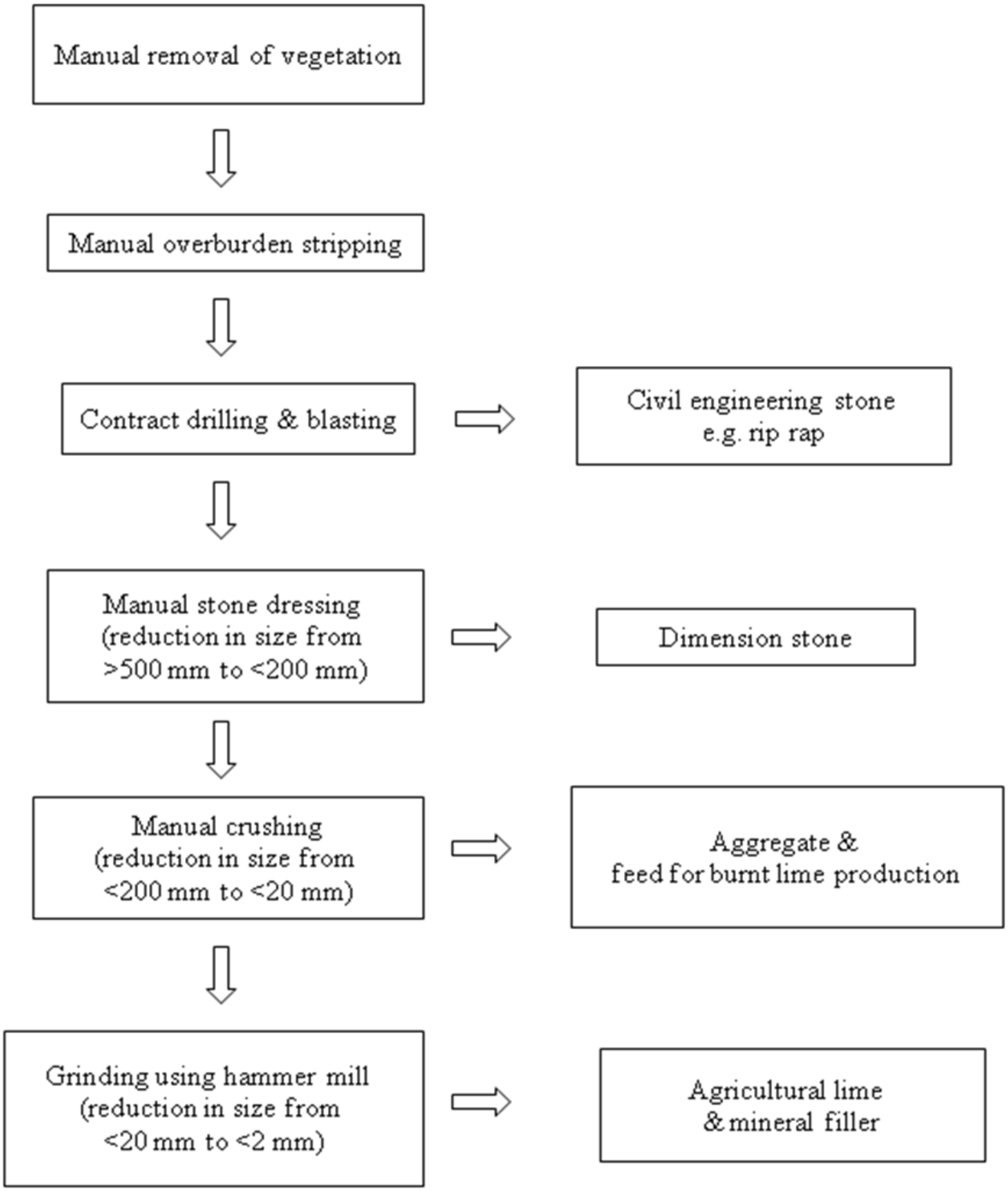

Figure 1. Recommended process route for small-scale production of lime (and other products)