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# An Economic Analysis of Precision Application of Lime at Reduced Rates

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**Abstract**
Acidity is a growing concern for crop production in Zambia, affecting more than 300,000 smallholder farmers in all agro-ecological regions of the country. Unfortunately, evidence shows that lime applied at traditionally recommended rates of more than two metric tons per hectare are not only unattainable but also unprofitable in smallholder systems. This study uses data from on-station trials and demonstration plots to determine yield and financial gains from precisely applied lime at reduced rates. The results from marginal analysis show that lime applied at such reduced rates can be profitable in maize, soybean and groundnut production. When combined with compost, marginal returns can be as high as 150 percent.
**Keywords**: Lime, reduced rate, marginal returns, Zambia

## 1. Introduction

Acidity is believed to rank among the top hindrances to good yields (CIMMYT, 1998; Donovan *et al.* 2000). Approximately 30% of the world's total land area consists of acidic soils, and as much as 50% of the world's potentially arable lands are acidic (von Uexkull and Mutert, 1995)[1]. The production of staple food crops, and in particular grain crops, is negatively impacted by acid soils. For example, 20% of the maize and 13% of the rice production worldwide is on acid soils (von Uexkull and Mutert, 1995). Thus, acid soils limit crop yields in many developing countries where food production is critical. In most countries, high-input farming practices such as the extensive use of ammonia fertilizers are causing further acidification of agricultural soils.

Vast areas of arable land in the humid and dry tropics are strongly acidic Ultisols and Oxisols (i.e. pH $< 5.2$ measured in water), with a high degree of exchangeable Aluminum (Al) saturation (i.e. $> 40\%$ of effective cation exchange capacity - CEC) (Bennet and Breen, 1991). Because of the acidity, acid-tolerant roots like cassava and sweet potatoes are the most suitable for growing. However, the economic importance of these crops is not very significant. For cultivation of crops such as maize and beans, liming is needed not only to correct Al and/or Manganese (Mn) toxicity, but also to supply Calcium (Ca) and Magnesium (Mg) as plant nutrients. An important criterion for determining lime requirements is that acid tropical soils should reach a soil pH value of about 5.5, or to have the desired value of exchangeable Al saturation for a particular crop to be grown.

In Zambia soil acidity is a major soil fertility problem that is widespread and regarded as one of the major factors negatively affecting crop production (Ragnar, 1987). Soil acidity is not only limited to the regions that were initially known to be acidic, but it is present in almost all parts of Zambia. Although there has been no nation-wide survey that can give a map of acidity levels, recent physical and chemical characterization of the soil resources in agro-ecological regions I and II have shown that not only is there a general decline in soil organic matter and soil fertility but also that soil acidity is no longer confined to just agro-ecological region III (Chipeleme *et al.*, 1998; Banda *et al.,* 2001 in GART, 2002; Namayungu, 2008). This is a result of different land use practices that include conventional tillage systems, mono-cropping and application of nitrogen fertilizers. Siachinji-Musiwa (1998) contends that the problem is compounded by the high recommendation rates of about 4 metric tons of lime per hectare, which smallholder farmers cannot afford due to the high costs, especially transportation, associated with it.

By 2005, according to Mitchell *et al.* (2005), there were more than 700,000 smallholder farmers struggling with farming on acid soils. From the time of the green revolution, which in Zambia was after independence, the country went full scale into conventional agriculture which involves use of chemicals, including nitrogen fertilizers. In Zambia, the use of fertilizer is not even region-specific. Rather, the entire country has for years been encouraged to use one standard recommended rate of 200 kg of each of basal and top dressing fertilizers per hectare. This and other conventional practices, such as ploughing, combine to encourage leaching and soil acidification.

In recent years, Aluminum (Al) toxicity has come to be recognized as the principal constraint in highly acidic

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1.The extent of soil acidity, or pH, is measured by the amount of hydrogen and aluminum present in the soil. Hydrogen ($H^+$) is formed through the oxidation of organic matter and residues, root respiration and the oxidation of ammonal fertilizers (Thiubaud, 2000).

soils, but lime recommendations continue to be based on soil pH (Manjoka *et al.,*, 2007). Recently it has been recommended that soil texture and color be incorporated into recommendation criteria. These criteria may correlate reasonably well with the exchangeable Al contents of soils. Thus, it is necessary to re-examine the critical pH levels in relation to exchangeable Al content. Traditional pH-based methods appear to substantially over-estimate lime requirements.

The investment required to apply lime for the prevention and amelioration of soil acidity can be difficult to justify when farm budgets are tight (Davies *et al.* 2008). One of the first things dropped from the budget is the soil neutralizing strategies as the benefits are considered minimal. The benefits to lime application can be analyzed in terms of how lime affects the returns to capital, labor and land. Many authors have proved that lime application results in better soils in terms of improved bacterial activity, improved soil moisture content and reduced acidity which happens to be the prime reason for its application (Dunn and Stevens, 2005; Mano *et al.*, 2008). However, improvement in soil characteristics cannot attract the farmer's attention if it does not result in observable benefits such as increased yields, reduced labor requirements, and increased profitability.

Existing evidence suggests the existence of agronomic benefits to liming at conventional application rates, which include better plant development, efficient use of fertilizers by the crops, soil structure improvement, and increased bacterial activity for better organic decomposition (Mead *et al.*, 2000). The yield benefits have also been shown to be evident especially when in combination with fertilizer (GART, 2001; Mitchell *et al.*, 2005). Financial benefits of liming at conventional rates have also been demonstrated with value-cost ratios greater than 2.0 for different application rates for different levels of acidity (Mitchell *et al.* 2005; Ragnar 1987). The agronomic and financial efficacy of precision application of lime at reduced rates of lower than 1 metric ton per hectare has not been investigated.

The Conservation Farming Unit (CFU) of the Zambia National Farmers' Union (ZNFU) has been carrying out on-farm demonstrations since 2001 to determine the efficacy of precision application of lime at substantially reduced rates of 350 kg per hectare (CFU, 2007). The reduced rates are applied on the crop or in the basin, or in the furrow (precision application) for ox farmers instead of broadcasting it over the field. If successful, the reduced rates are expected to improve the uptake of liming as an agronomic practice. However, to date there has been no comprehensive study to isolate the effects of lime at these reduced rates on yield and returns. Most prior studies have been based on traditional application rates of more than one metric tons per hectare and mainly focused on soil and agronomic effects (see for example Caires *et al.,* 2008; Farina *et al.,* 2000a, 200b; Manjoka *et al,* 2007).

This study aims to determine the yield and economic benefits of precision application of lime at reduced rates. The results indicate that liming even at reduced rates gives higher yields than non-limed plots and are profitable with high marginal rates of return. The results present enormous opportunities for increasing the uptake of lime and, thus, increasing smallholder farmer yields and incomes.

## 2. Methods and Materials

### *2.1 Data Source*

Two datasets are used to achieve the stated objectives. The first is from 2008/2009 demonstration plots on soybeans, maize and groundnuts conducted in Chisamba area by the Golden Valley Agricultural Research Trust (GART) and CFU. Chisamba is in agro-ecological region II with a baseline pH of 4.6. In these demonstration plots, treatments included i) a control (with no lime or fertilizer applied), ii) lime only at 100 kg per hectare, iii) compost only at 8 metric tons per hectare, iv) compost at 8 metric tons per hectare and lime at 100 kg per hectare, v) fertilizer only at 200 kg per hectare ( basal and top in equal proportions), and vi) fertilizer (both top and basal) at 200 kg per hectare and lime at 100 kg per hectare (lime). These were replicated twice.

The second dataset was from Batoka, an area in agro-ecological region I with baseline pH of 4.5. The main treatments in Batoka included five different fertilizer application rates (i.e. combinations of Compound D (CD) and Urea fertilizers) while liming and non-liming were the sub-treatments.[1] More specifically, the fertilizer treatment rates included: i) 100 kg $ha^{-1}$ CD only; ii) 200 $kgha^{-1}$ CD plus 100 $kgha^{-1}$ urea (56 kg N,40 kg P,20 kg K), iii) 300 kg $ha^{-1}$ CD plus 200 kg $ha^{-1}$ urea (122kg N,60kg P, 30kg K), iv) 400 kg $ha^{-1}$ CD plus 300 kg $ha^{-1}$ urea (178kg N,80 kg P, 40 kg K), and v) 500 kg $ha^{-1}$ CD plus 400 kg $ha^{-1}$ urea (234 kg N, 100 kg P, 50 kg K). Only one lime rate of 500 kg $ha^{-1}$ was used across all treatments for the plots that received lime. The experimental design was a split plot randomized in 4 blocks. Crop and input prices used in gross margin and marginal analyses were obtained from the Agricultural Market Information Centre (AMIC), a centre run and managed by the Ministry of Agriculture and Livestock. We use mean prices for the 2009/2010 agricultural marketing season, which were (in ZMK/kg): maize - 1,300, groundnuts - 4,330, soybeans - 4,000, compost - 40, lime - 140, fertilizer (urea and DC) - 4,000.

[1] Compound D comprised nitrogen (N), Phosphorous (P) and Potassium (K) in 10:20:10 kg combinations

*2.2 Analysis of Variance*

Analysis of variance (ANOVA) was used to identify the factors that contribute significantly to the yields of maize, groundnuts and soybeans using data from CFU's 2008/2009 demonstration plots in Chisamba. As stated above, the Chisamba experiment used a partial factorial design. The model was specified and estimated in Stata as follows.

$$Y_{pqr} = \mu + \tau_p + \beta_q + \delta_r + (\tau\beta)_{pq} + (\tau\delta)_{pr} + \varepsilon_{pqr} \quad (1)$$

where $Y_{pqr}$ is observed yield, $\mu$ is the grand mean for yield, $\tau_p$ is the lime effect, $\beta_q$ is the compost or manure effect, $\delta_r$ is the fertilizer effect, $(\tau\beta)_{pq}$ is the lime-manure interaction effect, $(\tau\delta)_{pr}$ is the lime-fertilizer interaction effect, and $\varepsilon_{pqr}$ is the random error term.

After the model estimation, contrasts were performed to test whether the lime effect was significant. The contrasts were given as;

$$\varphi_i = -1\,\mu_{N1i} - 1\,\mu_{N2i} + 1\,\mu_{L1i} + 1\,\mu_{L2i} \quad (2)$$

where, $\varphi_{Ti}$ is the contrast for treatment $i$ and $\mu_{N1i}$ and $\mu_{N2i}$ is the mean of the non-limed replication 1 and 2, and $\mu_{L1i}$ and $\mu_{L2i}$ is the mean of the limed replication one and two for the same treatment ($i$), for instance compost only (no lime applied) against compost with lime applied.

For the Batoka data, Equation (1) was modified by dropping other terms and leaving only the lime, fertilizer and the interaction effect because the experiment did not include use of compost manure. The resulting equation is;

$$Y_{pqr} = \mu + \tau_p + \delta_r + (\tau\delta)_{pr} + \varepsilon_{pqr} \quad (3)$$

In this model, since the number of replications was four, the contrasts were conducted as;

$$\varphi_i = -1\,\mu_{N1i} - 1\,\mu_{N2i} - 1\,\mu_{N3i} - 1\,\mu_{N4i} + 1\,\mu_{L1i} + 1\,\mu_{L2i} + 1\,\mu_{L3i} + 1\,\mu_{L4i} \quad (4)$$

with the meanings being same as in equation (2). The null hypothesis that $\varphi_i = 0$ is tested.

*2.3 Economic/profitability Analysis*

We use partial budgeting marginal analysis to calculate financial gains (CIMMYT, 1998. IThat is, partial budgeting was used to compare the financial benefits of different lime application rates in both AER I and II. A partial budget, by definition, includes only inputs that lead to variation in costs between treatments. In this case, the costs that varied were those associated with the purchase and application of inputs since everything else did not vary. Only Chisamba demonstration plots had cost data on input application, weeding and harvesting collected. Thus, marginal rates of return (MRRs) were only computed for that experiment. MRR was calculated as:

$$MRR_{a-b} = \frac{\Delta NB_{a-b}}{\Delta SF_{a-b}} * 100 \quad (5)$$

where $MRR_{a-b}$ is the marginal rate of return for moving from treatment $a$ to treatment $b$. $\Delta NB_{a-b}$ is the change in the net benefit for moving from treatment $a$ to $b$. $\Delta SF_{a-b}$ is the change in the scarce factor for moving from treatment $a$ to $b$.

The incremental benefits were calculated for each treatment. The incremental benefits are computed as: Net incremental benefits = (yield * estimated field price) – (field costs of all inputs). The field costs are given by

$$FC = \sum p_k * q_k$$

, where FC are field costs, and $p$ and $q$ are price and quantity of input $k$ respectively.

The MRRs were then compared to the minimum accepted rate of return, where the latter was computed using the monthly interest rate that banks paid on deposits. At the time of the analysis this was about 8.5% per six months on fixed deposits, where interest was calculated on the remaining balance. Since the farming season is approximately 6 months, we take 8.5% as the minimum acceptable rate of return, or opportunity cost of the funds used to purchase lime and other inputs. This is the base rate of return upon which recommendations were made for moving from one treatment to the other.

## 4. Results and Discussion

*4.1 Crop Yields under Lime (Chisamba data)*

The ANOVA results for maize (Table 1) showed no significant differences in yield across the different treatments. This could be due to the overall good clay loamy soils in Chisamba, where maize tends to do well even with minimal fertilizer application

Unlike maize, the overall factorial ANOVA results for groundnuts were statistically significant. Also, all the three factors (compost manure, lime and fertilizer) were individually significant at 95% confidence level although none of the factor interaction terms were significant. Similarly, the partial factorial ANOVA results were significant for soybeans as well, significance emanating mainly from the lime only and lime-fertilizer interaction.

**Table 1: Partial factorial ANOVA results for compost, lime and fertilizer in maize, groundnut and soybean production, 2008-2009 agricultural season.**

| | **Maize** | | **Groundnuts** | | **Soybeans** | |
|---|---|---|---|---|---|---|
| **Treatment** | **F-test** | **P-value** | **F-test** | **P-value** | **F-test** | **P-value** |
| Compost only | 1.62 | 0.2506 | 7.73 | 0.0320** | 0.20 | 0.6742 |
| Lime only | 0.02 | 0.9058 | 13.65 | 0.0102** | 8.09 | 0.0294** |
| Fertilizer only | 2.75 | 0.1481 | 12.43 | 0.0124** | 0.06 | 0.8092 |
| Lime x compost | 0.06 | 0.8122 | 1.17 | 0..3209 | 0.01 | 0.9325 |
| Lime x fertilizer | 0.38 | 0.5584 | 0.35 | 0.5748 | 7.20 | 0.0363** |

**statistically significant at 95% confidence level.
Dependent variable = Yield in kg per hectare
Source: Data from CFU demonstration plots, 2009.

Contrast analysis results show that applying lime to a groundnut or soybean field could result in statistically significant increases in yield, and that the increase would be substantially larger if combined with compost manure (Table 3). This compost-lime synergy is not surprising as lime is expected to facilitate the release of nitrogen held by the compost manure. However, the lime effect is not immediately apparent if the field has also had inorganic fertilizers applied to it. In fact, the contrast estimate implies a yield decreasing effect although not statistically significant.

**Table 2: Differential effects of treatments in soybeans and groundnuts, 2008/09.**

| | Soybeans | | Groundnuts | |
|---|---|---|---|---|
| **Contrasts** | Estimate | P-value | Estimate | P-value |
| [Control] - [Lime only] | -361 (168) | 0.075* | -36 (44) | 0.4642 |
| [Compost only] - [Compost & Lime] | -382 (168) | 0.063* | -102 (44) | 0.0601* |
| [Fertilizer only] - [Fertilizer & Lime] | 277 (168) | 0.150 | 71.5 (44) | 0.1563 |

Source: Data from CFU demonstration plots (2009)
* statistically significant at 90% confidence level.
() the numbers in parenthesis are standard errors.

*4.2 Crop Yields under Lime(Batoka data)*

Figure 1 shows maize grain yield from various treatments at Batoka. Generally the limed plots had higher yields than the non-limed plots. The difference increased as fertilizer levels were increased until it reached the level in Treatment 3. After that, the difference remained positive but decreasing with increases in fertilizer rates. With the baseline pH of 4.5, the non-limed crop which produced 1.5 metric tons ha$^{-1}$ gave 36% lower maize yield than the limed crop, though the difference was not statistically significant as indicated by the ANOVA results (Table 3). For the limed crops, yield increased almost linearly with increase in the rate of fertilizer applied from 100 kg ha$^{-1}$ to a total of 500kg ha$^{-1}$ (DC and urea) while for the limed the yield reduced. With 300kg ha$^{-1}$ CD plus 200kg ha$^{-1}$ urea, a farmer would gain 108% (1.3tons ha$^{-1}$) extra yield from liming.

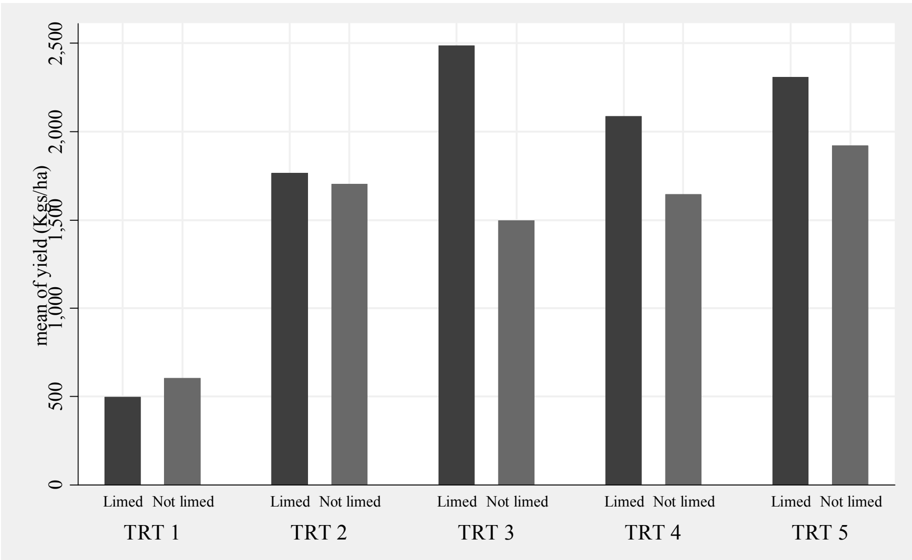


**Figure 1: Maize grain yield in Batoka**

Notes: TRT 1= 100kg ha$^{-1}$; TRT 2= 200 kg ha$^{-1}$ DC + 100 kgha$^{-1}$ urea TRT 3= 300 kg ha$^{-1}$ DC+200 kg ha$^{-1}$ urea;

TRT 4= 400kg ha$^{-1}$ DC +300kg ha$^{-1}$ urea; TRT 5 = 500 kg ha$^{-1}$ DC + 400 kg ha$^{-1}$ urea. Lime was applied at 500 kg ha$^{-1}$.

ANOVA on Batoka data (Table 3) showed that limed and non-limed plots in Batoka had yields that were not statistically different[1]. The insignificant effect could be due to the huge amounts of fertilizer applied, suppressing the marginal effect of lime. The significance of the overall ANOVA model was driven solely by one factor, fertilizer. The lime effect was not significant whether individually or in interaction with fertilizer.

**Table 3: ANOVA results for Batoka maize yield**

| | **Maize** | |
|---|---|---|
| **Treatment** | **F-test** | **P-value** |
| Lime | 2.00 | 1.1681 |
| Fertilizer | 5.05 | 0.0031*** |
| Lime x fertilizer | 0.56 | 0.6930 |

Dependent variable = Yield in kg ha$^{-1}$

Source: Data from the GART demonstration plots at Batoka (2011).

*4.3 Financial Benefits of Lime Use at Reduced Rates*

Table 4 presents the results of financial analysis of the lime effect based on data from on data from CFU demonstration plots for 2009. GART demonstration plots (2011) data was not used because costs were not recorded as the experiment was more concerned with agronomic effects. Treatments were arranged in an ascending order of costs that vary. For maize, the lime only treatment was dominated because it had lower net benefits compared to the higher variable costs than the control. The compost and lime, fertilizer only, and fertilizer and lime treatments were dominated since they had higher costs that vary compared to their lower net benefits than the compost only treatment. Given the farmer is not applying anything in his/her field of maize in Chisamba, if these results are anything to go by, then he/she would be getting ZMK134 for every ZMK100 spent in applying manure. While compost only had relatively lower costs in terms of the purchase price, the yields were relatively very good. Compost is not valued by most farmers as a potential fertilizer, but the results even in other research have indicated positive returns (e.g. Langmead 2000). Well prepared compost is very reach in nitrogen.

For soybeans, the economic analysis showed that the lime only treatment was the only profitable one. The rest of the treatments were dominated. Soybean had a good response to lime, and this could be biologically due to the longer roots that enable it to tap minerals made available through liming. Also the application of lime at the rate of 100kg/ha had relatively low costs compared to other treatments that included compost or fertilizer which were applied at higher rates.

Net benefits came from compost and lime only treatment, which also had higher yields. The fertilizer only and fertilizer with lime treatments were dominated for groundnuts. The compost-only treatment also was dominated because it had lower net benefits than the lime-only treatment. The lower net benefits were due to low yields of groundnuts under compost only. Starting to apply lime in groundnuts assuming the farmer used no fertilizer at all, would earn ZMK2.15 for every ZMK1 that is used both in purchase and other costs involved in application of lime. If to this lime, the farmer introduced compost at the rate of two handfuls per pace or basin, they would yield a return of 163% to their capital outlay. The response of groundnuts to lime is in line with what has been found by Langmead (2004) who found that lime increased yields of groundnuts in agro-ecological region III by 22 percent. Even under lime and fertilizer treatment the yields were relatively high but the cost of fertilizer meant that the profits were reduced.

## 5. CONCLUSION

Lime use among smallholder farmers though still low, has shown agronomic gains in terms of improving the soil. There has also been an increase in the number of companies producing lime. The question the study was answering was whether there are any benefits that accrue in terms of yield and financial returns if a farmer committed their capital to lime alone and in synergistic combinations with compost and fertilizer. The results suggest a non-linear relationship between the quantity of lime applied and the resulting yield effect. Some lower rates gave higher yields while in other plots higher application rates gave higher yields. Lime also gave higher yields compared to not applying anything in the fields. Most of the results showed superior yields with lime than the control. The application of lime at reduced rates with compost was found to be good synergy as it consistently gave higher yields than when compost was applied without lime.

Lime even at reduced rates showed to be economically profitable as its use had high marginal rates of return, greater than 50% in most cases. The compost-lime synergy showed especially positive returns in soybeans.

[1] No differential effects contrasts were computed for Batoka data as the ANOVA results for the liming sub-treatment were not statistically significant.

Fertilizer at rates as high as 400kg/ha, whether applied alone or in combination with lime, are not very profitable due to the high prices of fertilizer especially in areas where soils are relatively better. This was the case in Chisamba. Use of lime at reduced rates could be encouraged especially for farmers who don't apply anything else in agro-ecological regions I and II.

**Table 4: Profitability of lime use in maize, soybeans and groundnuts 2008-2009**

| | **Maize** | | | | **Soyabeans** | | | | **Groundnuts** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | Costs that Vary* (ZMK/ha) | Net benefits* (ZMK/ha) | D | MRR | Costs that Vary* (ZMK/ha) | Net benefits* (ZMK/ha) | D | MRR | Costs that Vary* (ZMK/ha) | Net benefits* (ZMK/ha) | D | MRR |
| Control | 0 | 4752000 | | | 0 | 8852000 | | | 0 | 2173500 | | |
| Lime only | 48550 | 4236000 | D | | 48550 | 9647450 | | 1631% | 48550 | 2277950 | | 215% |
| Compost only | 273750 | 5118000 | | 134% | 273750 | 9186250 | D | | 273750 | 2215700 | D | |
| Compost and Lime | 322300 | 4915000 | D | | 322300 | 8661700 | D | | 322300 | 2723250 | | 163% |
| Fertilizer only | 1885000 | 3517000 | D | | 1885000 | 8123000 | D | | 1885000 | 1022000 | D | |
| Fertilizer and Lime | 1933000 | 3780000 | D | | 1933000 | 696450 | D | | 1933000 | 649450 | D | |

D = Dominated

Source: Data from the CFU demonstration plots at Chisamba (2009).

Good labour data are important for economic analysis of on-station and on-farm trials. This was, however, the weakest point for this study as labour data were not consistently collected. The effects of lime tend to be residual and may not show quickly. We recommend that repeated measures trials are undertaken in order to facilitate a more complete assessment of the lime effect.

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