Optimization of lime applications to soils under permanent grassland and arable crops

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Abstract

Graphs of soil pH versus time were plotted for the Park Grass Experiment at Rothamsted Experimental Station, begun in 1856, and the Long-term Liming Experiments at Rothamsted and Woburn farms, begun in 1962. These showed that the magnitude and duration of the effect of lime applications varied with soil type, initial pH, fertilizer nitrogen application, and the crop grown. Simple equations for each situation were linked to form an empirical model which, with appropriate input data for soil type, crop, and initial and target pH, predicted the lime needed to reach that pH. Model predictions compared well with estimates from a Woodruff-type buffer method. The model forms a sound basis for an extended lime requirement model.

Key words: soil acidity, liming

Introduction

Liming soil with chalk or limestone ($CaCO_3$), quicklime (CaO), or slaked or hydrated lime ($Ca(OH)_2$) to raise its pH has been an integral part of crop husbandry for centuries. Current advice aims to tell a farmer how much lime to apply to achieve a certain pH. This requires both soil sampling and laboratory analysis. The latter are generally based on extraction with a neutral salt, titration, buffer solutions or the difference between exchangeable bases and the Cation Exchange Capacity (Thomas & Hargrove, 1984). However, a method or model, based on estimated annual losses of calcium by leaching and the response of soils to past lime applications, would permit a more precise determination of lime requirement and is more acceptable in principle; several have been suggested (Gasser, 1973, 1985; Bolton, 1977).

Both site and management factors determine lime losses. They include soil type, crops grown, rainfall or, more particularly, through drainage, atmospheric and fertilizer inputs of nutrients and pollutants and soil pH. The Park Grass Experiment at Rothamsted, begun in 1856 (see Warren & Johnston, 1964) and the Long-term Liming Experiments at Rothamsted and Woburn farms, begun in 1962 (see Bolton, 1977) enable soil pH changes to be related to these factors and permit a simple lime loss/requirement model to be constructed.

The Park Grass Experiment

This examines the effect of several manurial treatments on permanent grassland on the silty clay loam soil at Rothamsted. The grassland was at least 200 years old when the experiment began in 1856. Results were summarized by Thurston *et al.* (1976) and certain aspects of soil acidification by Johnston *et al.* (1986). The species composition of the pasture has been considerably altered by the different treatments, clearly seen in the well-defined boundaries between plots. The site is flat and never ploughed, so there has been little sideways movement of nutrients in drainage. A few tests of liming were made after 1883, and then between 1903 and 1965 lime was applied to one half of most plots at 4 t $CaCO_3$ ha^{-1}, once every four years (Warren & Johnston, 1964). Since 1965 the aim has been to maintain soil pH at 5, 6 and 7 on quarter plots, with one quarter left unlimed, lime dressings being applied periodically. Data for recent years were used to develop the model, whilst the earlier data were used to test it.

The Long-term Liming Experiments
These were begun in 1962 on the silty clay loam soil at Rothamsted and the sandy loam soil at Woburn (Bolton, 1977). Initially four rates of lime (0, 5, 10 and 20 t $CaCO_3$ ha^{-1} at Rothamsted; 0, 5, 12, 19 t $CaCO_3$ ha^{-1} at Woburn; hereafter called O, L, M, H) were tested; further smaller amounts were applied in 1978, 1982 and 1983. Effects on soil pH, the duration of the effects, and the interaction of liming and fertilizers on crop yields under an arable rotation have all been measured.

Experimental Methods

Soil pH, as a 1:2.5 soil:water suspension, has been monitored regularly. Initially, graphs of pH against time showed how quickly and by how much a certain application of lime increased pH, and for how long the effect lasted. Fig. 1 shows such data for the Long-term liming experiments. The data were then separated on the basis of soil type, crop, and where applicable initial pH and form of N applied, and a series of equations derived to describe the change in pH over a twelve-year period for a given lime application. (This period was dictated by the limited pH data from Park Grass.) These equations, similar to those in [3], [4] and [5], formed the basis of an empirical model which we are now testing for predicting the lime required to adjust present soil pH values to the required levels on the Rothamsted and Woburn experiments.

To compare the model predictions with present lime requirement methods, stored soil samples from the two experiments and other experiments at Rothamsted, with pH values of 3.9 to 7.2, were analysed using the Agricultural Development and Advisory Service's (ADAS) method (see MAFF, 1981; 1985; 1986). This is essentially the buffer method of Woodruff (1948), in which the pH of the soil is measured after equilibration with a calcium acetate/*p*-nitrophenol/magnesium oxide buffer. The amount of lime required to adjust the soil to pH 6.5, the target pH for arable soils, is then calculated as follows:

(i) Soil pH 5.0 to 6.4 using 'single-strength' buffer

$$CaCO_3 \text{ required in t } ha^{-1} = (7\text{-measured pH}) \times 11.2 \qquad [1]$$

(ii) Soil pH <5.0 using 'double-strength' buffer

$$CaCO_3 \text{ required in t } ha^{-1} = (7\text{-measured pH}) \times 22.4 \qquad [2]$$

The calculated lime requirements from this buffer method were compared with those using our model calculations to bring the soils to pH 6.5.

Results and Discussion

The changes with time of soil pH under the various treatments of the Long-term Liming Experiment are shown in Fig. 1. An example of the lime-induced pH changes on the Park Grass Experiment is given in Fig. 2. This shows, for target pH 7 plots, the change in pH by 1984 arising from various additions of lime in 1975/6 to soils without N and those given different forms of applied N: ammonium sulphate, sodium nitrate, farmyard manure (FYM); the nitrate and FYM plots have been combined. There is some evidence of an effect from the form of N but there are too few data to test for significance. However, for target pH values of 5 and 6 on Park Grass and for both Long-term Liming experiments, there was no obvious effect of different forms of N. The data have therefore been combined for each experiment and site to give regression equations relating change in pH over a 12-year period, ΔpH, to lime added, L ($t\ ha^{-1}$) as follows:

Park Grass

$$\Delta pH = 0.060L - 0.315,\ r = 0.76,\ p < 0.001 \quad [3]$$

Long-term Liming:

Rothamsted $$\Delta pH = 0.109L - 0.690,\ r = 0.99,\ p < 0.001 \quad [4]$$

Woburn $$\Delta pH = 0.110L - 1.160,\ r = 0.98,\ p < 0.001 \quad [5]$$

The slope of the regression equations for both Long-term Liming Experiments is the same, and the difference between them is expressed in the constant. This may indicate that the slope of such an expression reflects the close similarity in management of the sites, especially cropping and nitrogen manuring, and the constant the site characteristics (soil type, through drainage, etc.).

Comparisons of the model and ADAS buffer predictions of lime requirement are presented graphically in Fig. 3. The buffer method calculates the amount of lime required to raise the pH of arable soils to 6.5 (MAFF, 1986) and maintain it at about that pH for 4-5 years (MAFF, 1981; 1985). Our model predicts the amount of lime required to reach and maintain a pH of 6.5 over a 12-year period. To make the model results comparable with the buffer method, amounts of lime required have been divided by 3, and these amounts are plotted in Fig. 3. We shall re-calculate the model on the basis of pH change 4 years after liming when sufficient data are available.

The relationships between the model and buffer calculations are linear. The fitted regression equations are:

Woburn Long-term liming	Model = 1.05 Buffer + 2.49; $r = 0.915$, $p < 0.001$.
Park Grass	Model = 0.70 Buffer + 3.81; $r = 0.988$, $p < 0.001$.
Various Rothamsted arable soils	Model = 0.78 Buffer + 1.12; $r = 0.958$, $p < 0.001$.
All data	Model = 0.82 Buffer + 2.36; $r = 0.950$, $p < 0.001$.

Agreement between the model and the buffer method is excellent. The relationship is not generally 1:1, and probably varies with site and management practice as do the 'ΔpH:Lime' relationships. Fig. 3 shows that data for the lighter textured soils (X) are all above the 1:1 line. This is probably because the model is based on measured pH changes over time, and on the sandy soil leaching losses may well have been larger than on the heavier textured soils. The buffer method does not inherently allow for subsequent leaching losses.

As a further test, the pH change on the limed Park Grass half-plots during the 36 years 1923-1959 when lime (4 t $CaCO_3$ ha^{-1}) was added every 4 years was compared with the model predictions for the effect of these lime dressings. The model predicted a mean pH increase of 0.41 pH units while the increase measured was 0.38 pH units. Thus, whilst the model could be used over a period of 20-30 years with checks on soil pH at this interval but with lime applied more frequently, it is more likely that it would be used over a 4-8 year period so that soil pH does not fluctuate over a wide range.

The Woodruff buffer method has been found to be one of the most reliable methods of predicting lime-requirement in practice (Mohebbi &

Mahler, 1988). Thus the good agreement between it and the model supports the veracity of the model. However, the buffer method is not applicable to all soils (e.g. Logan & Floate, 1985) and requires ever more costly sampling and analytical services. A widely-applicable model using a periodic determination of soil pH is therefore of considerable value. The present test, while limited to two soils does suggest that the model is worth extending, for which data is needed from other soil types and sites.

Conclusions

A model, based on a broad data set which reflects different soil types, initial pH values, through drainage and agronomies offers the best way forward in predicting lime requirement. The simple model presented here provides estimates of lime requirement for two experiments under grass and arable crops and on two soil types that compare well with those from a Woodruff-type buffer method. It thus forms a sound basis for an extended lime-requirement model.

References

BOLTON, J. 1977. Changes in soil pH and exchangeable calcium in two liming experiments on contrasting soils over 12 years. *J. agric. Sci., Camb.* 89, 81-86.

GASSER, J.K.R. 1973. An assessment of the importance of some factors causing losses of lime from agricultural soils. *Exp. Husb.* 25, 86-95.

GASSER, J.K.R. 1985. Processes causing loss of calcium from agricultural soils. *Soil Use Manag.* 1, 14-17.

JOHNSTON, A.E., GOULDING, K.W.T. & POULTON, P.R. 1986. Soil acidification during more than 100 years under permanent grassland and woodland at Rothamsted. *Soil Use Manag.* 2, 3-10.

LOGAN, K.A.B. & FLOATE, M.J.S. 1985. Acidity in upland and hill soils: cation exchange capacity, pH and lime requirement. *J. Sci. Food Agric.* 36, 1084-1092.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD. 1981. *Lime and liming.* Ref. Book 35, London: HMSO.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD. 1985. *Fertiliser recommendations.* Ref. Book 209, London: HMSO.

MINISTRY OF AGRICULTURE, FISHERIES AND FOOD. 1986. *The analysis of agricultural materials.* Ref Book 427, London: HMSO.

MOHEBBI, S. & MAHLER, R.L. 1988. Evaluation of lime requirement tests for northern Idaho soils. *Comm. Soil Sci. Plant Anal.* 19, 153-166.

THOMAS, G.W. & HARGROVE, W.L. 1984. The chemistry of soil acidity. Ch. 1 in *Soil Acidity and Liming,* 2nd edition, ed. F. Adams. Agronomy No. 12, Madison: ASA/SSSA, pp 3-56.

THURSTON, J.M., WILLIAMS, E.D. & JOHNSTON, A.E. 1976. Modern developments in an experiment on permanent grassland started in 1856: Effects of fertilizers and lime on botanical composition and crop and soil analyses. *Ann. Agron.* 27, 1043-1083.

WARREN, R.G. & JOHNSTON, A.E. 1964. The Park Grass Experiment. *Roth. Exp. Stn, Rept 1963*, 240-262.

WOODRUFF, C.M. 1948. Testing soils for lime requirement by means of a buffered solution and a glass electrode. *Soil Sci.* 66, 53-63.

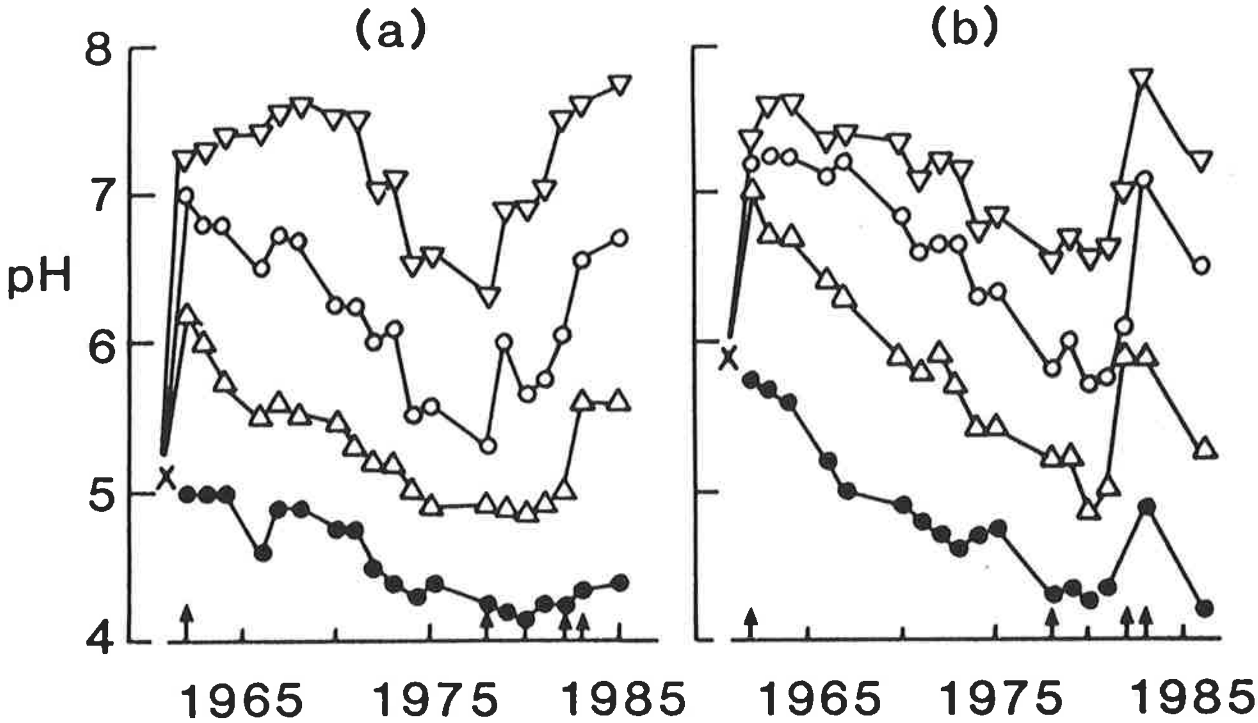

Fig. 1. The change with time of the mean pH of surface (0-23 cm) soils at (a) Rothamsted and (b) Woburn receiving 0 (●-●), and Small (Δ-Δ), Medium (O-O) and Large (∇-∇) amounts of lime at times indicated (↑).

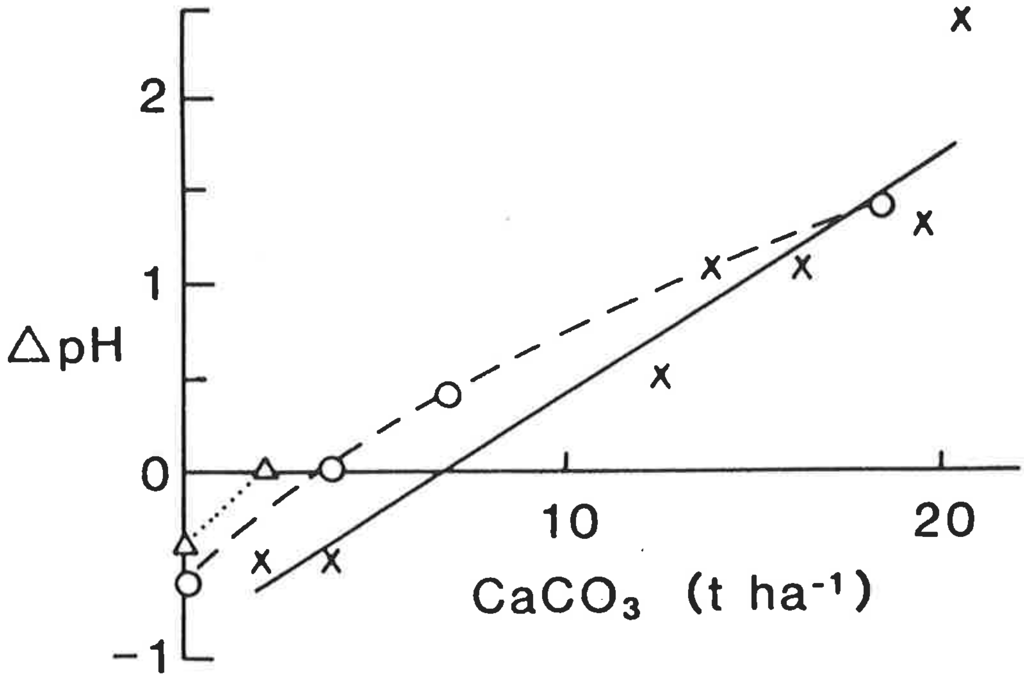

Fig. 2. The changes in pH caused by various applications of lime on the 'a' plots (target pH 7) of the Park Grass Experiment: unmanured (0), ammonium-N (X), nitrate-N and FYM (Δ).

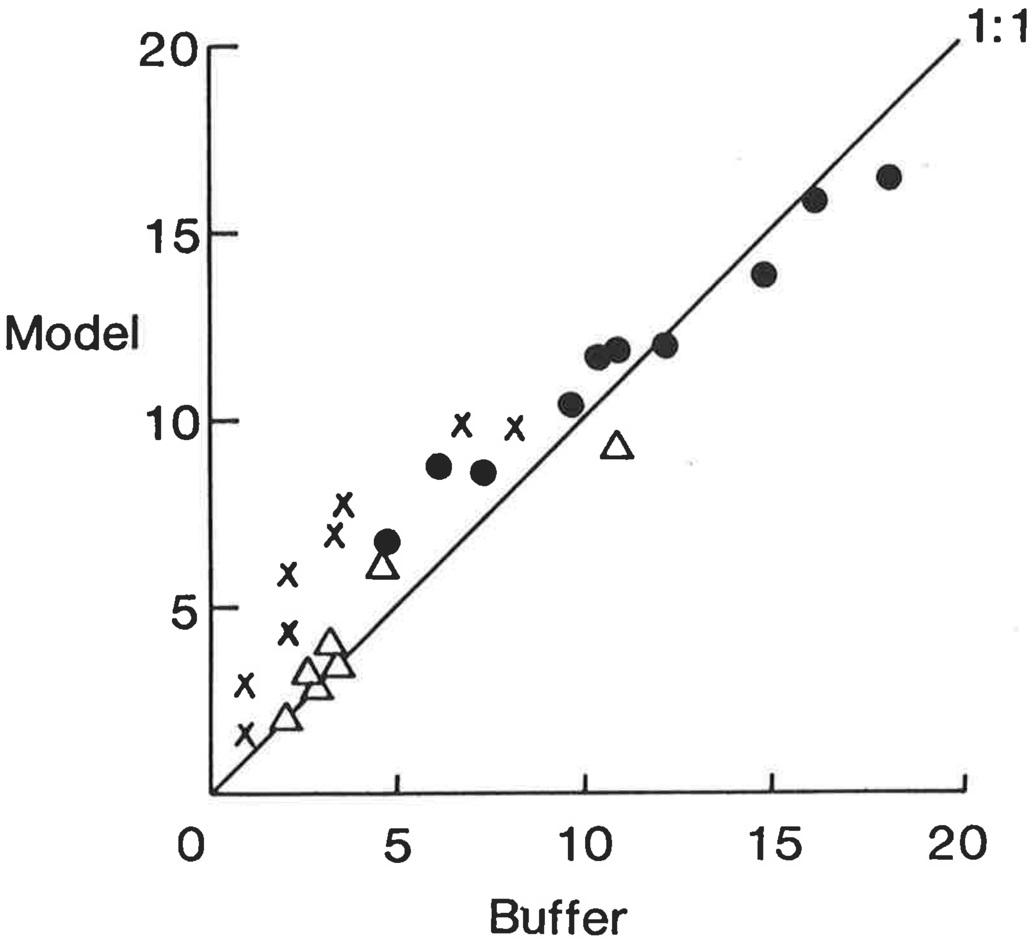

Fig. 3. Lime requirement for Woburn Long-term liming (X), Park Grass (●) and various Rothamsted arable soils (Δ) predicted by the buffer method and the model.