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LIMING OF TEA FIELDS - A CRITICAL NEED

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INTRODUCTION

Tea grows well in soils in the pH range 4.5 to 5.5. Such soils release sufficient amounts of calcium for normal growth of tea requiring no additional inputs with routine fertilizer applications. In soils with a pH of around 5 or more, additional inputs of calcium could be harmful to tea. The only instance that some calcium is supplied is around pruning, when dolomite is applied at modest rates, mainly as a source of magnesium. The recommended quantity of dolomite has been 125 kg/ha/year of the pruning cycle, which amount supplies a very modest amount of calcium that is grossly inadequate to have any influence on soil acidity.

Since of late, the soil pH of a significant number of tea fields in Sri Lanka have declined markedly, to levels close to 4.0 and in some instances to levels even close to 3.5. This appears to have led to a serious situation in respect of the general health of the tea bush as well as the nutrient retentive capability of the soil in many areas. Besides the other restraining causes for stagnant and low productivity, increasing soil acidity and the concurrent reduction in soil organic matter seem to be very important contributory causes for low yields in Sri Lanka.

A meaningful economic response to added fertilizers can be expected only when the soil itself is receptive to such inputs. One of the important limiting factors to fertilizer response is a soil that has become too acidic. Large inputs of artificial fertilizer to soils with low pH is no doubt an uneconomic exercise. It is necessary to correct any such obvious deficiencies in the first instance, before one ventures into enriching and modifying fertilizer mixtures or enhancing rates of applications, to obtain the desired yields. Once the soil conditions are put right, economic yields can be obtained with existing fertilizer mixtures, at modest rates of application.

Causes of Soil Acidity

An increase in soil acidity is brought about by the removal of bases such as calcium and magnesium and the substitution with hydrogen; alkalinity is caused by the reverse process of an accumulation of bases. In the humid regions with high rainfall, the removal of bases is brought about largely by leaching, resulting in increasing soil acidity. The natural vegetation also has a marked influence on the rate of removal of bases by leaching. If the plant is a heavy feeder of calcium, there is a replenishment of the calcium supply in the surface soil as plant roots bring bases back to the surface from lower depths. On the other hand, if the plant is a light feeder on calcium, the rate of removal by leaching losses is more rapid.

Trees in general are light feeders on bases, whilst grasses are heavy feeders. Trees tend to survive in soils low in bases and they permit the soil to become more acid whilst grasses survive best in soils high in bases and prevent the soil from becoming too acid.

The accumulation of organic matter (humus) tends to decrease the per cent base saturation (per cent saturation of bases of the total cation-exchange capacity). Besides having a high cation-exchange capacity (over 200 meq/100 g) humus also contains more acid-forming material than base-forming material. Therefore, added organic matter produces acids directly on decomposition and produces humus that enhances the cation-exchange capacity significantly and consequently reduces the percent base saturation.

Hence in the humid forests with high rainfall, the soil tends to be acidic due to leaching losses of bases and further, with the concurrent accumulation of large amounts of organic matter (humus) that raises the total cation-exchange capacity, the base saturation is generally low in such soils.

Cation-exchange Capacity and Base Saturation

The available exchange sites for cations determines the cation-exchange capacity of a given material. The exchange sites may be occupied by the bases calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^{+}) and ammonium (NH_4^{+}), with the balance being occupied by hydrogen (H^{+}).

It is generally assumed that the five cations Ca^{++}, Mg^{++}, K^{+}, NH_4^{+} and H^{+} constitute about 99 per cent of the exchangeable cations in soils. Nevertheless, in acid soils a considerable part of the exchangeable cation content may be aluminium, the solubility and mobility of which is enhanced with increasing acidity. Copper (Cu^{++}), manganese (Mn^{++}) and zinc (Zn^{++}) also exist in trace amounts as exchangeable ions and their availability is also influenced by soil acidity.

Cation Retentive Material

The term soil broadly refers to a mixture of varying proportions of sand, silt, clay and humus. The clay fraction may consist of a varying combination of different clay minerals. The dominant clay mineral in Sri Lankan soils is the highly degenerate 1:1 mineral, kaolinite, which has a very low cation-exchange capacity, in the order of about 10 milliequivalents (meq).

Apart from the per cent composition of clay, the per cent composition of soil organic matter (humus) has a significant influence on the total cation-exchange capacity of a given soil. The cation-exchange capacity of soils, therefore, vary with (a) the kind of clay, (b) the per cent composition of clay and (c) the per cent composition of organic matter.

The cation exchange capacity of humus and some specific clay minerals are presented in Table 1.

TABLE 1

Material	Cation-exchange Capacity
Humus	200 meq
Vermiculite	150 meq
Montmorillonite	100 meq
Illite	30 meq
Kaolinite	10 meq

Soils may contain varying per cent composition of different clay minerals as well as varying amounts of humus. The capacities of the different exchange materials per one per cent of the relevant material are presented in Table 2.

TABLE 2

Cation-exchange Capacity

Per 1 % of Material	Meq
Humus	2.0
Vermiculite	1.5
Montmorillonite	1.0
Illite	0.3
Kaolinite	0.1

Thus, a soil with 55 % clay (of which 90 % is kaolinite and 10 % is illite) and containing 3 per cent organic matter will have a cation-exchange capacity of:

55 % clay X 90 % kaolinite	X 0.1	=	4.9 meq
55 % clay X 10 % illite	X 0.3	=	1.6 meq
3 % organic matter	X 2.0	=	6.0 meq
Total		=	12.5 meq

TABLE 3

pH	Exchangeable Cations*					C.E Cap.	Base Sat. %
	Ca	Mg	K	H	Al		
6.5	14.8	4.8	0.5	3.0	0	23.1	87.0 %
5.5	6.7	2.8	0.6	13.0	0	23.1	43.7 %
4.0	4.8	1.9	0.6	10.0	5.8	23.1	31.6 %
3.6	3.9	1.2	0.5	7.0	10.0	23.1	24.2 %

* Values in milliequivalents per 100 g oven dried soil.

It is thus evident from the above Table 3 that, with the reduction in bases and the concurrent reduction in base saturation, soil acidity keeps steadily increasing. Removal of bases, especially calcium and magnesium through leaching is the most important cause of soil acidity.

Relation of Crop Productivity to soil pH

The effect of soil pH to plant growth and its productivity is largely nutritional. Certain plants that need a high requirement of bases such as calcium can grow only under conditions where this base is available in abundance - usually in the pH range of 7 to 8. On the other hand, there are plants that grow best under very acid soils (like azaleas), mainly because of high requirement of certain essential nutrients such as iron, which become available in sufficient amounts only under very acid conditions. Some plants like tea, tolerate relatively high levels of aluminium which become available with increasing acidity, at least up to an acceptable or a critical level.

A tree crop like tea has a low requirement of calcium and grows well in acid soils, within the pH range 4.5 to 5.5. Nevertheless, when the soil acidity increases too much, leaching losses of other essential bases such as magnesium and potassium increases, leading to a state of nutrient imbalance. What is even worse is that, under conditions of high soil acidity, the level of exchangeable aluminium increases sharply. Though tolerant to some degree, high levels of exchangeable aluminium could be toxic to such an extent to limit productivity of tea. Further, the release of large amounts of the trivalent aluminium ion (Al^{+++}) that has a greater affinity for the retention sites could readily dislodge bases like calcium (Ca^{++}), magnesium (Mg^{++}) and potassium (K^{+}) which get leached even further. Thus a considerable part of the exchangeable-cation content may be aluminium rather than hydrogen in acid soils.

Under conditions of high soil acidity, with the concurrent losses of bases, the growth of the tea crop is bound to be poor and productivity could begin to decline. Further, with increasing soil acidity, besides the likely toxic effects of high levels of exchangeable aluminium, the solubility of manganese increases and this can be absorbed by the tea plant in quantities sufficient to be toxic. The initial symptoms of such manganese toxicity is a general yellowing of foliage that later develop the characteristic necrotic spots.

Influence of Soil pH on Soil Organisms

Survival of bacteria is known to be retarded in acid soils and their activity become reduced with increasing acidity. Nitrifying bacteria thus become reduced with increasing acidity. Nitrifying bacteria thus become inhibited as the pH decreases, especially to levels below 4.5. The rate of decomposition of organic matter and the release of nitrogen and other nutrients from such sources (rate of mineralization of organic matter) also gets retarded with increasing soil acidity. Survival of other important organisms like the earthworm, which plays an important role in the maintenance of good soil tilth, is also affected and their population disappear almost entirely at soil pH below 4.5.

Critical Levels of Soil Nutrients

Each crop has a critical level of base requirement and consequently a critical level of base saturation in the soil in which the crop grows. Productivity can be affected if this critical level is either exceeded or reduced. It is possible that, apart from the losses of essential bases and other resulting nutrient imbalances caused by increasing soil acidity, the limitation of high productivity is brought about by increasing levels of exchangeable aluminium, the level of which rises sharply with high acidity and low organic matter content. Even for a crop such as tea, which tolerates an appreciable level of aluminium, there is a critical limit beyond which productivity is likely to be affected and the crop begins to decline. Depending on the given soil type, this critical level of exchangeable aluminium could be reached at a specific soil pH, which condition may differ with different soil types.

What seems important is to determine what this critical tolerable limit of exchangeable aluminium is for tea. Having determined this critical limit, the relationship between soil pH, organic matter content and exchangeable aluminium can be determined and the lower limit of permissible soil acidity can be established for the respective soils.

With increasing solubility of aluminium, fixation of phosphates too can occur in certain soils, thus limiting the availability of the latter. The quantity of sulphur is usually lower in soils with low pH, due to leaching losses. Further, even nutrients that are usually required in trace amounts, like boron, copper and zinc also become limiting with increasing soil acidity, especially at pH levels below 4.5.

It is thus imperative that the soil pH is maintained within the optimal range for a given crop, for good growth and high productivity.

The Need for Liming

The annual loss of calcium depends on the rate of plant uptake, the amount and intensity of rainfall, on supplies of calcium in the soil, as well as the use of specific artificial nitrogenous fertilizers. The annual removal/loss of calcium could range from 100 to 500 kg Ca/ha. Artificial fertilizers that are added as ammonium salts displace exchangeable calcium from soil colloids and the displaced calcium is lost through leaching. Further, the ammonium that is subsequently nitrified to the negatively charged nitrate ion neutralizes more calcium and when the nitrate gets leached it takes away with it a proportionate amount of calcium. In addition to the leaching away of calcium with the nitrate formed from ammonium, the other anions that accompany such fertilizers, such as sulphate and bicarbonate, induce further leaching of calcium, with the greatest losses occurring with sulphate, which is the most mobile anion. In practice, using 100 kg of ammonium sulphate is considered to cause a loss of calcium equivalent of about 100 kg of calcium carbonate.

Urea is converted readily to ammonium bicarbonate or carbonate and when these are nitrified, cations are needed to neutralize the nitrate; some of the nitrate is inevitably leached with the concurrent loss of calcium; so the continuous use of urea also results in soil acidification, though not as quickly as with ammonium sulphate.

Calcium has a dual function in soil. It is an essential nutrient needed by all plants, yet the amounts required vary quite significantly. Calcium is also the dominant base that helps to keep soils neutral in reaction. If calcium ions are lost by leaching and are not regularly replaced, positively charged hydrogen ions (and aluminium) take their place and the resulting effect is that the soil becomes increasingly acid. If such a process of soil acidification is not arrested, the pH may fall to very low levels, to as much as 4.0 or even less. The important detrimental effects of such increasing acidity are summarised below:

1. The structure of the soil deteriorates;

2. Essential nutrients such as Ca, Mg and K get leached from the soil;

3. Iron, aluminium and manganese become increasingly soluble and their concentrations in soil solution may rise to toxic levels;

4. Phosphates become less soluble;

5. Many soil organisms do not thrive in acid soil, particularly the organisms that convert nitrogen to nitrate (bacteria) as well as those that decompose plant residue and causing them to be mixed into the soil (earthworms).

Since an acid condition in the soil is usually the result of leaching losses of bases, particularly calcium and magnesium, it is generally through an increase in calcium and magnesium that the soil pH is increased.

Liming materials, which include calcium and magnesium compounds, correct these conditions since they help to neutralize soil acidity caused by hydrogen ions. Liming is also essential to remove the toxic influence of excess aluminium that could limit crop productivity. The amount of lime needed would thus be that amount which would help to alleviate restrictions caused by excess aluminium in a given soil.

Estimating Lime Requirements

The pH value measures only the intensity of the acidity and does not indicate the quantity of lime needed to bring soils back to the desired condition. To effect the same change in pH value, a heavy soil may need twice as much lime as would a lighter soil. Measurements of acidity are usually converted into figures for "lime requirements" (the amount of lime needed to make the soil suitable for optimal crop productivity), by taking into account the total cation exchange capacity, the prevailing base saturation as well as the exchangeable aluminium.

The desired pH depends in part on the type of soil, as well as on the particular plant species. As mentioned earlier, the optimal pH range for tea is between 4.5 and 5.5. There are two ways of determining to what extent one should lime a particular soil to achieve what is thought to be the desired condition for optimal growth and good productivity. In some instances liming is undertaken to an extent just sufficient to remove any limiting factors, such as toxicity caused by excess aluminium, which becomes readily available with increasing soil acidity. The more commoner practice, however, is to add sufficient lime to maintain the soil pH within the established optimal range.

When one is to undertake liming to maintain the soil pH within the established optimal range, the calculation of the amount of lime required is based on the total cation-exchange capacity of the soil and on the per cent base saturation at different pH values. It is obviously not practical to determine the exchange capacity and the per cent base saturation for all soils routinely sent for testing. The usual procedure is to prepare a pH-base saturation calibration curve for a given region or locality and it is from such a calibration curve that one determines the base saturation needed to attain a required pH (Fig. 1).

Lime Requirement Based on Soil Aluminium

As already mentioned, tea is a crop that tolerates appreciable levels of exchangeable soil aluminium. Yet, there is no doubt that a critical limit exists and this limit needs to be established by correlating exchangeable aluminium and the yield of tea. Once this critical limit of exchangeable aluminium is known, the permissible lower limit of soil pH can be established from data correlating exchangeable aluminium and soil pH (Fig. 2). The decision to lime may be taken when the exchangeable aluminium exceeds the established upper limit. The amount of lime needed to elevate the pH to the desired level can be determined from the pH-base saturation calibration graph (Fig. 1) or from an equation relating observed exchangeable aluminium and the desired exchangeable level of aluminium for the crop concerned.

Calculation of Lime Requirement (as $CaCo_3$)

One milliequivalent of hydrogen in 100 g of soil is the same as 22 kg of hydrogen in a hectare furrow slice of soil. Calcium carbonate has an equivalent weight of 50 and consequently, 50 kg of calcium carbonate is equivalent to 1 kg of hydrogen. Therefore, in terms of calcium carbonate, one milliequivalent of hydrogen is equal to:

22 X 50 = 1,100 kg of calcium carbonate per hectare.
i.e. meq X 22 X equivalent weight.

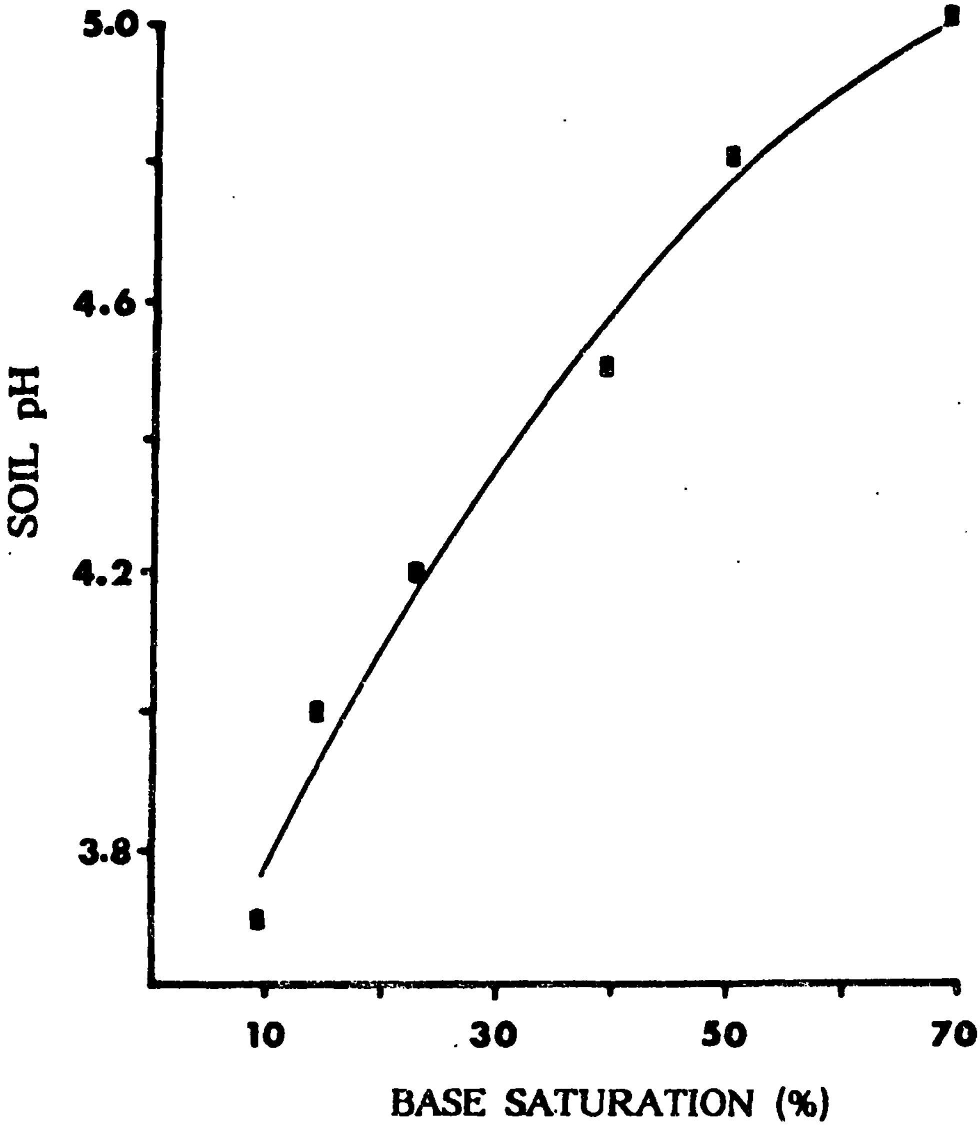

Fig. 1 - The influence of variations in base saturation on soil pH

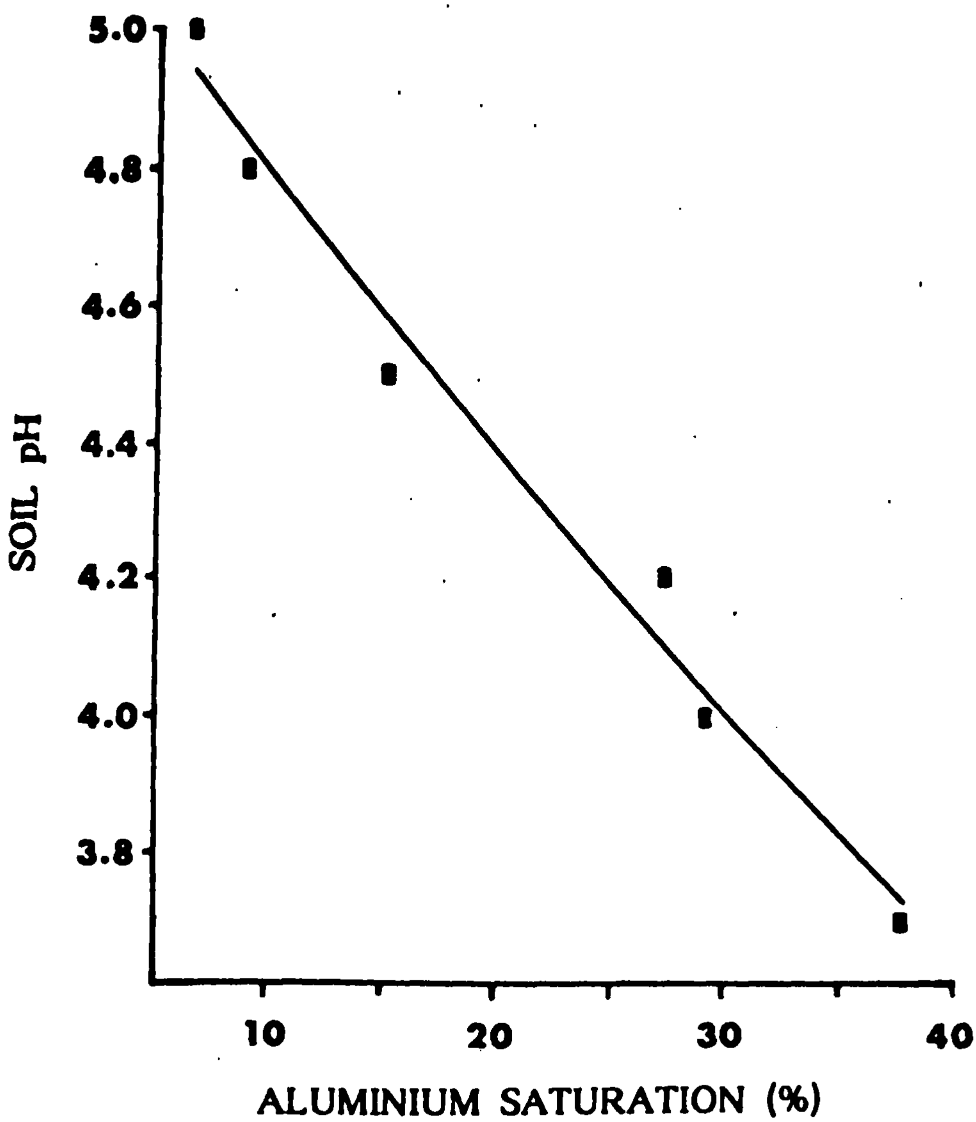

Fig. 2 - The influence of the variation in soil acidity on Aluminium saturation in tea soils

Thus, for each milliequivalent (meq) of base needed per 100 g soil, the calculated lime requirement is equal to 1,100 kg of pure calcium carbonate per hectare.

As could be seen from the figure, the base saturation at pH 4.0 is 20 % and if we expect to elevate the pH to 4.8, we need to elevate the base saturation to 50 %. Having estimated the total CEC of the soil (which in this case is 12 meq), we could estimate the lime requirement as follows:

pH 4.8 (50 % X 12) = 6.0 meq
pH 4.0 (20 % X 12) = 2.4 meq

Difference = 3.6 meq

Since the base saturation will need to be elevated by 3.6 meq the lime requirement in terms of calcium carbonate will be:

3.6 X (22 X 50) = 3,960 kg $CaCO_3$/hectare, i.e. almost four metric tonnes/ha.

Soils with lower CEC (as is commonly encountered in low-grown tea areas) are poorly buffered and would need a lesser quantity of lime to attain the desired base saturation. Further, the base saturation needed to attain the required pH (4.8) in this instance will also be lower, in view of the lower total CEC. Thus, in such a case, had the total CEC been 7 meq, the required elevation of the base saturation to attain the pH of 4.8 could be 45 %. Thus the elevation in base saturation needed will be:

pH 4.8 (45 % X 7) = 3.1 meq
pH 4.0 (20 % X 7) = 1.4 meq

Difference = 1.7 meq

In this instance, when the base saturation has to be elevated by only 1.7 meq, the lime requirement will be:

1.7 X (22 X 50) = 1,870 kg $CaCO_3$/hectare, i.e. less than two metric tonnes per hectare.

Thus, as a consequence of a lower total CEC in low-grown tea areas, the lime requirement needed to bring about a specific change in soil pH will be far less than what is needed for high-grown tea areas that have a higher total CEC.

Kinds of Liming Materials

The materials that are in common use for liming include:

1. Calcium oxide (CaO), sold as burnt lime or quicklime;

2. Calcium hydroxide ($Ca(OH)_2$), sold as hydrated lime or slaked lime;

3. Calcium carbonate ($CaCO_3$), sold as ground limestone;

4. Calcium carbonate and Magnesium carbonate ($CaCO_3$, $MgCO_3$), sold as dolomitic limestone or dolomite.

Liming materials are used on the basis of "Neutralising Value", which is a figure that measures the use of a product for neutralising soil acidity. This is expressed in terms of calcium oxide (CaO). If a product has a neutralising value of 90, it means that 100 kg of the product has the same effect on soil acidity as 90 kg of burnt lime (calcium oxide).

The fineness of the material should also be specified. The finer a limestone (or liming material), the quicker will it neutralise soil acidity. The amount of ground limestone, and ground magnesium limestone that will pass through a 100 mesh British Standard Sieve (B.S.S) should be specified.

The value of a liming material is simply its effect in neutralising soil acidity. Ground limestone

($CaCO_3$) is just as effective as the chemically equivalent amount of burnt lime (CaO) or slaked lime ($Ca(OH)_2$), and there is no advantage from any of these latter materials that are often more expensive per unit of lime (CaO). Magnesium liming materials are as effective as ordinary burnt lime or limestone, when they are applied at equivalent rates, although they are usually considered to be less soluble and act more slowly than calcium limes.

Burnt lime contains 85 % of lime (CaO);

Hydrated lime (i.e. slaked lime) contains about 70 % lime;

Ground limestone contains about 50 % lime;

Dolomite contains about 30 % lime.

One tonne of burnt lime is approximately equivalent to 1.5 tonnes of slaked lime, 2.0 tonnes of ground limestone and to 3.0 tonnes of dolomite. Besides being cheaper per unit of lime, ground limestone and dolomite are more convenient and pleasant to handle and easy to spread than burnt or slaked lime.

Limestones store indefinitely and they are usually ground to a state that 60 % goes through the 100-mesh B.S.S. In this state they will act quickly enough and be as satisfactory as burnt lime. In general, ground limestone can be considered to have the right mesh size if all the material pass through a 30-mesh sieve.

The specification for Dolomite ($CaCO_3$, $MgCO_3$) is that the material should have not less than 20 % magnesium oxide (MgO) and the mesh size should be such that 50 to 70 % should pass through a 100 mesh B.S.S. whilst all the material should pass through a 30 mesh B.S.S.

Method of Timing of Lime Applications

Lime may be applied any time during the year. There should be a clear interval of about six to eight weeks between liming and the next nitrogenous fertilizer application. Liming is best done soon after pruning. Once the bigger prunings have been removed after leaf fall, the lime should be distributed as evenly as possible. The number of labourers should be so adjusted so that each one spreads not more than 250 to 300 kg of liming material.

Besides distributing the lime as evenly as possible, it is also necessary to ensure that the lime is mixed very thoroughly with the soil. When the lime dissolves, it does not move to any appreciable extent horizontally and only to a very limited extent vertically. This natural movement is inadequate to ensure good mixing of the lime with the top layer of soil containing the feeder root zone (rhizosphere). One way of ensuring a good mixing is by tillage operations. It is best that following an even broadcasting of the lime, the field be forked to help vertical mobility of the added lime.

Caution against Over-Liming - A Warning

When the soil pH is around 4.5 or over, one should exercise caution in determining the required quantity of lime. For good growth and high productivity of tea, there is no need for liming when the pH has reached 5.0. In fact liming of tea soils with a pH of 5.0 and over is harmful to a crop such as tea, which thrives best in soils with some degree of acidity. Excess lime reduces the availability of phosphorus and the trace elements boron, copper, zinc and iron. Excess lime could also suppress the availability of potassium.

It is in areas where soils have a very low cation-exchange capacity that the effects of over-liming could be seen quite readily. Tea soils in the low-country in general have a low cation-exchange capacity (in the order of about 6 to 8 meq). Hence one should exercise caution in liming such soils.

Lime plus an adequate supply of decomposing organic matter are basic to the maintenance of good soil fertility. Either one of the practices alone will not prove beneficial in acid soils. Lime stimulates the decomposition of organic matter, thereby hastening the exploitation of nutrients held in organic combination. Thus an adequate supply of organic matter should be returned to the soil at regular intervals. Liming without an adequate supply of organic matter will lead to a gradual impoverishment of the soil fertility status.

Besides determining the soil pH, it is necessary to estimate the organic matter status of the field, before one adds the estimated required quantity of lime. In the event the organic matter content is below the optimum level for the location, it is desirable to split the calculated amount of lime to two doses, with the second dose being applied after proper soil amelioration to elevate the organic matter status. It is desirable to apply not more than two metric tonnes of dolomite in one application. If the calculated dosage exceeds this amount, two tonnes may be applied after pruning and the balance may be applied around mid-cycle.

Liming of Uprooted Tea Fields Prior to Rehabilitation with Grasses

Since the pH in many of the old seedling tea fields that are being uprooted for replanting is relatively low, the current recommendation of applying dolomite at 1.25 metric tonnes/ha is grossly inadequate. Both Mana and Guatemala grass require large amounts of both calcium and magnesium and hence, to meet with such heavy demands on the one hand and to buffer the soil pH from declining further, such uprooted fields are likely to need a far greater quantity than what is being presently recommended. In the case of such uprooted fields, the lime requirement should be calculated to raise the pH to 5.5 from whatever level it has declined to. Thus, depending on the total CEC and the base saturation of the soil, the amount of lime needed is likely to be in the region of two to four metric tonnes/ha.

Besides applying a greater quantity, what is even more important is to ensure the uniform distribution of the lime as evenly as is possible. Having applied the lime, it is preferable to even fork the lime into the soil for greater vertical mobility.

Liming of Pruned Tea Frames

The practice of applying lime on pruned tea frames has many advantages. This is an old practice that was routinely carried out following pruning but had been given up over the past 15 to 20 years. As the trade name of the hydrated lime that was in use was "Limbux", this routine practice was even referred to as "limbuxing of pruned frames".

Liming of pruned tea frames helps to check the growth of moss and lichen; the appropriate concentration helps to soften the bark and significantly helps bud break; the resultant bleaching effect helps to reflect the hot rays of the sun and thereby reduces sun-scorch damage.

The recommended concentration is 10 to 12 kg of the specified hydrated lime in 50 litres of water. On the basis of this concentration, one would need about 200 kg/ha in 1,100 litres of water.

The specification for hydrated lime is:

Calcium oxide content not less than 70 %;

Calcium carbonate content not more than 1 %;

Moisture content not more than 3 %;

Maximum carbon dioxide content 4 %;

All the material should pass through a 200 mesh British Standard Sieve.

SUMMARY

Increasing soil acidity has now become a matter for concern in many tea fields in Sri Lanka (more particularly in the up-country and in the Uva). As such, quick remedial action is warranted to arrest this rate of acidification. The quantum of lime needed could be worked out on the basis of one of two methods. The amount could be calculated to raise a given soil pH to a level above 4.5 or, by estimating the lime requirement just sufficient to decrease the exchangeable soil aluminium level below the critical upper limit for tea, which upper limit needs to be established by further studies.

When liming is to be carried out, due consideration has to be given to soil organic matter. If the level is below the required optimum, it is best to apply half the calculated dosage of lime following pruning and the balance applied at mid-cycle, after having elevated the level of soil organic matter. Further, it is known that at low soil pH, increasing levels of organic matter help to reduce the exchangeable soil aluminium levels quite significantly. Thus, a high level of soil organic matter could help mitigate to some extent the ill-effects of high soil acidity.