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LIMING IN CROP PRODUCTION IN INDIA

BY

M. CHAKRABORTY, B. CHAKRAVARTI AND S. K. MUKHERJEE

PROJECT DIVISION, FERTILIZER CORPORATION OF INDIA LTD.,

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I. AGRONOMIC ASPECTS OF LIMING

The use of lime is in no way less important than the application of properly recognised and conventional fertilizers *viz.*, nitrogenous, phosphatic and potassic. The latter provide the corresponding nutrient elements to the plants whilst lime furnishes calcium, another important nutrient, for the plant growth. In addition to providing calcium, it has other beneficial effects on soils. The role of lime can broadly be divided into three categories *viz.*, (1) soil antacid, (2) improver of soil structure and (3) plant nutrient.

LIME AS SOIL ANTACID

Optimum pH : Very few plants can thrive favourably in strongly acid soils. The soil micro-organisms which are indispensable for contributing to soil fertility do not flourish well in that condition. Nitrogen, phosphorus and potassium become less available if the soil is strongly acid. Besides, plant roots are adversely affected if the soil acidity exceeds the limit of tolerance for a particular crop. The approximate optimum pH ranges (Ignatieff, 1958) of a number of crop plants are presented below :

Crop	*Optimum pH range*
Barley	6.5—8.0
Beets, Sugar	6.5—8.0
Banana	6.0—7.5
Coconut-palm	6.0—8.0
Cotton	5.0—6.0
Groundnut	5.3—6.6
Maize	5.5—7.5
Rice	5.0—6.5
Soybean	6.0—7.0
Sugarcane	6.0—8.0
Sunflower	6.0—7.5
Tobacco	5.5—7.5
Wheat	5.5—7.5

The figures quoted above are not precise, as the optimum pH for the plant growth varies with the type of the soil and climate. "Climatically adapted crops grow better on soils of somewhat lower pH (more acid) in the subarctic and cool temperate regions than on soils of the temperate and warm temperate regions" (Ignatieff, 1958). A high percentage of crop plants, it has been observed, have their optimum ranges around pH 6.5. The neutrality of the soil is a pre-requisite for the maximum yield in most cases, and more so in an warm-temperate region like India.

Causes of acidity : Lime, the major contributor of calcium to the soil is depleted by various processes and its place taken up by hydrogen ions which make the soil acidic. Some of the processes which contribute to the depletion of calcium in the soil are discussed below.

(i) Lime is very susceptible to leaching. Carbon dioxide dissolved in rain water and in soil reacts with lime to form calcium bicarbonate which being soluble is likely to be leached out of the soil.

The acidic oxides in atmosphere like NO_2 and SO_2 are also returned to the earth with rain water in the form of acids. These acids react with soil bases to produce salts which are mostly liable to be washed out. Sulphur dioxide from the combustion products of coal, as has been reported for some parts of U. K., might also create a problem in contributing to soil acidity, particularly in places where a large number of industries are concentrated.

Decomposition of humus gives rise to acidity in the soil. The presence of sufficient amount of lime in the soil is thus necessary to counteract the effects of these acids.

A considerable amount of lime present or applied is thus leached out and carried down to the sub-soil by rain or irrigation water. It has been estimated that a rainfall of about 750 mm. (30 in.) leaches out about 136.4 kg. of CaO *i.e.* 242.0 kg. of $CaCO_3$ per acre per year from an uncropped soil at Rothamsted, U. K. (Russell, 1951). The rate of loss of lime depends, besides rainfall, on the type of the soil, lime applied in relation to the requirement and the vegetation. Lime is likely to be leached out more rapidly from sandy soil than from the clayey type. The average annual rates of losses by leaching, depending on the lime applied in relation to the requirement, are presented in table 1 (Russell, 1952).

TABLE 1

Average annual rates of losses from soil with different amounts of lime applied against the requirement of 2036 kg./acre

Lime applied to soil (kg. of $CaCO_3$/acre)	Annual loss of lime (kg. of $CaCO_3$/acre)	Percentage of annual loss of lime
1273.0	51.0	4.0
2550.0	153.0	6.0
5100.0	306.0	6.0

It can be seen in the table that the losses of lime are more for the higher lime status. It appears that lime is not retained permanently in the soil. Calcium of the soil is not converted into any form comparable with the so-called fixed or slowly available form of potassium. Soil is thus prone to become deficient in calcium, more so in an area of heavy rainfall.

(ii) As calcium is retained in exchangeable form on the soil particle, it is replaced by other soluble cations in solution. Calcium is thus exchanged for sodium, potassium, hydrogen or ammonium ions. These are retained in the soil and ultimately available to the plants with the release of calcium from the soil. The ammonium fertilizers, in general, develop acidity in soil owing to the removal of calcium by cation exchange.

'Equivalent acidity' [a] of some of the commonly used fertilizers are given below (Ignatieff, 1958).

Fertilizer	*Per cent N*	*Equivalent acidity*
Ammonia, anhydrous	82.0	148
Ammonium chloride	24.0	128
Ammonium nitrate	33.5	60
Ammonium nitrate-limestone [b]	20.5	0
Ammonium sulphate	20.5	110
Ammonium sulphate-nitrate	26.0	93
Urea	45.0	80

(a) 'Equivalent acidity' is the number of parts by weight of calcium carbonate required to neutralize the acidity resulting from the use of 100 parts of the fertilizer material. For example, ammonium sulphate has an equivalent acidity of 110. It takes, therefore, 110 kilograms of calcium carbonate to neutralize the acidity developed in the soil by the use of 100 kilograms of ammonium sulphate fertilizer.

(b) Cal-Nitro, A-N-L, calcium ammonium nitrate and other names.

It can be seen from the table that even anhydrous ammonia, like other ammonium fertilizers, leads to acidity due to the displacement of calcium from the soil. For every kg. of such fertilizer consumed, a certain quantity of calcium carbonate is required to maintain the lime status of the soil. For example, about 1100 kg. of calcium carbonate should be applied to maintain the original lime status for the use of every 1000 kg. of ammonium sulphate in the soil.

Indirect effects of neutralizing acidity : Besides directly neutralizing acidity of the soil including the resultant acidity of the nitrogenous fertilizers, liming brings about other beneficial effects.

(i) The efficiency of utilization of water soluble phosphates is reduced in absence of suitable base status of the soil. The solubility of such interfering elements as aluminium and iron is reduced at a higher pH consequent on liming and thereby phosphorus is made more available to the plants.

(ii) Trace elements e.g. boron, manganese, copper, zinc, etc. may exert toxic effects when their concentrations are more than certain limits. Judicious liming helps in keeping them available in sufficient but not in excess amounts.

(iii) Nitrifying bacteria thrive well at a pH of 6.0-6.5. Nitrogen is, therefore, made more readily available to the plants if the soil is properly limed to this pH.

(iv) Nitrogen fixation processes—both symbiotic and non-symbiotic—are favoured in the soil at neutral pH. At such pH the soil nitrogen is enhanced and in this way liming may reduce the need for nitrogen fertilizers.

As the legumes, in general, are lime-loving, the growth of the plants are enhanced because of the increased amounts of nitrogen fixed. Consequently, larger quantities of both organic matter and nitrogen are returned to the soil and the soil fertility is improved to a considerable extent. It has been observed that richer the soil is in lime, phosphorus and potash, the greater is the gain in nitrogen from the growth of legumes. "On the average, there may be a gain of 50-100 pounds (23-45 kg.) nitrogen per acre of soil due to the growth of legumes" (Waksman, 1952). The growth of legumes which thrive well only in properly limed soil has thus got a practical value of immense significance in reducing the requirement of nitrogenous fertilizers.

It has been observed by Dhar and Ghosh (1955) that by the use of calcium carbonate (or phosphate), even under absolute sterile conditions, carbonaceous matter undergoes more rapid oxidation leading to a greater fixation of atmospheric nitrogen in soils so that C/N ratio decreases and the fertility is increased.

The experimental results obtained by them are reproduced in the following table (table 2).

TABLE 2

Fixation of atmospheric nitrogen in presence of calcium carbonate in sterile condition in light

pH of the soil—8.0 ; Temp. of the soil—25.0°C
Per 100 gm. of the mixture

Period of exposure in days	Total carbon present in gm.	Total carbon oxidised in gm.	Total nitrogen present in gm.	Gain in total nitrogen in gm.	Efficiency (mg. of nitrogen fixed per gm. of carbon oxidised)
		1 gm. soil+0.0275 gm. starch			
0	2.6227	0.0	0.2334	0.0	—
100	2.0950	0.5277	0.2608	0.0274	51.92
		1 gm. soil+0.0225 gm. starch+0.0025 gm. Cal. carbonate			
0	2.6227	0.0	0.2334	0.0	—
100	1.8582	0.7645	0.2931	0.0597	78.09

Table 2 shows that there is appreciable oxidation of carbon and fixation of nitrogen in presence of calcium carbonate even under sterile condition. The amount of nitrogen fixed per gm. of carbon oxidised is reported to be 108 mg. under unsterile condition.

Since this type of nitrogen fixation is more in light than in the dark, it is believed that the process of nitrogen fixation in soils is partly due to surface and photo-oxidation of all kinds of energy materials which are aided by calcium carbonate (or by phosphate). It has been suggested that the loss of nitrogen from nitrite, the intermediate compound in the fixation of nitrogen, is checked by the presence of calcium carbonate due to the formation of more stable nitrate, and thus the overall gain in total nitrogen in the soil is more.

(v) Loss of nitrogen from acid soils by decomposition of nitrate fertilizers has also been reported (Bridger, 1960). Neutral reaction of the soil is thus essential to reduce the loss of valuable nitrogen in this manner.

(vi) Organic matter is decomposed into easily assimilable compounds of nitrogen, phosphorus etc. and humus more rapidly by micro-organisms at neutral pH than under acidic conditions.

(vii) Potassium is also more available in the neutral pH of the soil.

Thus, in short, it can be said that better utilization of plant nutrients and fixation of atmospheric nitrogen by symbiotic and non-symbiotic processes are secured with proper liming. Trace elements are also available to an optimum extent without any toxic effect.

Types of liming material: Limestone, burnt lime, hydrated lime and by-product lime from various industries are generally used as liming materials.

By-product lime from industries like sugar, paper and ammonium sulphate fertilizer by gypsum process is very effective, because it is mostly chemically precipitated calcium carbonate and thus is in fine form.

Of all the liming materials, limestone is most widely used because of its availability in abundance and due to some advantages over the other liming agents. The major advantages of limestone over burnt lime (CaO) and hydrated lime [$Ca(OH)_2$] are discussed below.

(i) It is available as a mineral in abundance almost in every country including India and is used as such only after size reduction.

(ii) The main chemical constituent of limestone being calcium carbonate it is unlike burnt lime and hydrated lime and is non-caustic, non-irritant, non-hygroscopic, non-corrosive and completely harmless to the plants.

(iii) The chances of overliming and consequent deleterious effects of high pH are rather less with limestone; the pH of $CaCO_3$ as such is about 8.4. Many of the productive soils have a reaction in this range.

(iv) Limestone, unlike burnt lime or hydrated lime, can be mixed with nitrogenous fertilizers and manures without causing loss of ammonia.

Dolomitic limestone is preferred on soils specially deficient in magnesium. Despite higher neutralizing value, the rate of solution of dolomitic limestone is much lower than that of calcitic limestone and as such the danger of overliming is far less with the former.

Quantity of liming materials: The determination of the optimum amount of lime required to neutralize the soil acidity needs a careful study.

Some of the factors on which this rate of application of lime to the soil depends are as follows :

(i) *The pH or the intensity of soil acidity.*

(ii) *The total acidity of the soil :* The total acidity to be neutralized or the capacity factor depends on the type of the soil. Soils having more clay and organic matter have generally more total acidity than sandy soils of the same pH ; the requirement of lime is thus larger for the former.

(iii) *The pH of the plough layer* : If acidity is developed only in the surface layer, smaller amount of lime is required for neutralization.

(iv) *The requirement of lime for crops* : Some crop plants such as maize, sugarcane, groundnut and other legumes, tobacco etc. require sufficient amounts of calcium for their growth. The presence of adequate lime is consequently necessary for these kinds of plants. The requirement of lime is also in this way related to the number of crops in the culture or rotation.

(v) *The type and purity of the liming material* : The requirement of liming materials depends on their neutralizing values. The higher the neutralizing value, the less is the requirement. The relative neutralizing values of some common liming materials are shown in table 3.

TABLE 3

Relative neutralizing values of some pure liming materials

Liming material	Relative neutralizing values
Calcium carbonate ($CaCO_3$)	100 (standard)
Calcium oxide (CaO)	178
Calcium hydrate [$Ca(OH)_2$]	135
Magnesium carbonate ($MgCO_3$)	119

It can be seen in table 3 that the requirement of burnt lime (CaO) or hydrated lime [$Ca(OH)_2$] is less than that of limestone ($CaCO_3$) for neutralizing the same acidity.

The liming materials containing impurities like silica and other inert materials are naturally low in their neutralizing values and hence larger amounts of such materials are required for counteracting the acidity. The use of liming material containing less than 80 per cent $CaCO_3$ or equivalent is generally not economical.

(vi) *The particle size of the liming material* : The finer particles are more readily available than the coarser ones ; the requirement of liming materials consequently decreases with the fineness of the particles. The relation of the particle size with the availability (Thompson, 1957) is presented in table 4.

TABLE 4

Relative availability in the soil of limestone particles of different degrees of fineness

Fineness of particles	Percentage available within	
	1–3 Yrs.	8—12 Yrs.
Held on 20-mesh screen	20	50
Through 20-mesh screen but held on 60-mesh screen	60	100
Through 60-mesh screen[a]	100	100

(a) "The Association of American Fertilizer Control Officials requires that ground limestone should pass a 10-mesh sieve and at least 50 per cent should pass a 100-mesh sieve" (Blanck, 1955).

Limestone product of the size 'through 60-mesh screen' is 100 per cent available within 1 to 3 years. Since both availability and leaching loss increase with the fineness, the frequency of application should be more.

Thus, the requirement of liming materials depends on the intensity of acidity and the total acidity of the soil, type of the liming material and the particle size. Table 5 (Ignatieff, 1958) is recommended as a very general guide to liming but field trials on local soil types are needed to give more precise predictions.

The amounts suggested in the table are for initial application. As lime is leached out of the soil, particularly from the sandy soils, further amounts of lime may be necessary over a period of years to maintain the neutrality.

Besides acid soils, the neutral and sodium soils may also require to be limed. Recommended soil tests should be carried out to determine the actual requirement of lime for a particular soil. In other words, soils of all textures must be limed periodically to maintain optimum growing condition usually determined by soil tests.

The amounts mentioned in the table are for limestone; burnt lime and hydrated lime, due to their higher neutralizing values, would require about one half and three quarters respectively of the amounts so indicated.

The acid soils of cool-temperate and temperate regions require more lime in view of higher total acidity than those in hot countries.

TABLE 5

Approximate amounts of finely ground limestone[a] needed to raise the pH of an 18 cm. layer of soil

Soil regions and texture	Limestone requirements		
	From pH 3.5 to pH 4.5	From pH 4.5 to pH 5.5	From pH 5.5 to pH 6.5
		kg. per acre[b]	
Soils of warm-temperate and tropical regions[c]			
Sandy and loamy sand	243	243	364
Sandy loam	(*)	446	610
Loam	(*)	688	890
Silt loam	(*)	1100	1300
Clay loam	(*)	1375	1740
Muck	2260	3040	3480

(a) All through a 2 mm. screen and at least one half through a 0.15 mm. screen. With coarser materials application need be greater.
(b) The suggestions for muck soils are for those essentially free of sand and clay. For those containing much sand or clay the amounts should be reduced to values midway between those given for muck and the corresponding class of mineral soil. If the mineral soils are unusually low in organic matter, the recommendations should be reduced by about 25 per cent; if unusually high, increased by about 25 per cent.
(c) Red-Yellow Podzolic, Red Latosol, etc.
(*) No recommendation given.

LIME AS IMPROVER OF SOIL STRUCTURE

Amelioration of the physical characteristics of the soil is one of the major functions of lime. The soil structure depends to a considerable extent on the cations predominating in the soil. Soil predominant in sodium manifests a gelatinous nature ; it is not flocculated and shrinks too badly on drying, producing wide cracks in the soil. This kind of soil is stiff, difficult to work and not very responsive to cultivation. Examples of such soils are the vast tracts of saline and alkali lands in many parts of India.

On the other hand, soils containing calcium are flocculated. This flocculation (aggregation of soil particles) facilitates better aeration by rendering a crumb structure which is considered to be the desired physical state of the soil. Thus lime, providing calcium to the soil, plays a vital part in improving the structure of the soil.

The properties of a few typical soils with recommended methods of improvement are presented in table 6 (Remington & Francis, 1955).

TABLE 6

Type of soil and the conditioning treatment required

Soil type	Nature	pH	Conditioning treatment
Peaty	Light, acid, moist	5.0	Lime or chalk-potash
Sandy	Light, acid, dry	5.5	Humus (farmyard manure), lime, clay, or marl, salt, wood ash
Loam	Medium light, acid or neutral	6.5	Humus (farmyard manure or compost), chalk or limestone
Clay	Heavy, sticky, neutral or acid	6-7	Humus (peat, compost or green manure), chalk or gypsum
Marl	Heavy, neutral or alkaline	6.5-7	Humus (peat or green manure), gypsum
Calcareous	Medium or heavy, neutral or alkaline	7-8	Humus

Lime or chalk is suitable for all types of soil except for the marl and calcareous ones. Lime in presence of organic matter (humus etc.) acts as a better ameliorant than lime alone for all soils and in that condition it exerts a binding effect even on the sandy soil particles.

LIME AS A PLANT NUTRIENT

Lime mainly provides calcium to the soil where it is changed into a form available to plants. Calcium is one of the essential nutrient elements[a] to plants.

Some of the main functions of calcium in plant metabolism are to influence :

(i) water economy of the plants,
(ii) neutralization of acids in plants,
(iii) synthesis of proteins,
(iv) transfer of nutrients,

(a) '......the functions of calcium in plant metabolism are to a very large extent of a colloid-chemical nature ; together with other ions it controls the state of swelling of the plasma colloids which is necessary for normal metabolic reactions. In this way calcium influences the water economy of the plant, the protein-carbohydrates in fat metabolism as well as in many other physiological processes. Calcium plays a certain part in the neutralization of organic acids in the plant and seems to be of importance in the absorption of nitrogen.'
'As a structural element in the combined form calcium is only present in the calcium pectin of the middle lamella of the cell-wall. In this connection the beneficial effect of calcium on the strength of the stem may have some importance as was observed, for instance, in rice. The presence of certain amounts of calcium is necessary for normal root development' (Jacob & Uexkull, 1958).

(v) absorption of nitrogen,
(vi) strength of the stem and
(vii) proper root development.

Actually, man or animal derives directly or indirectly calcium salts from plants for their growth. Cattle fed on grass poor in calcium manifest consequent calcium deficiency in their systems. Plants, in turn, derive calcium from soil and so if the soil does not contain adequate quantity of calcium the yield and quality of the produce become poor. The uptake of calcium by some crop plants are shown in table 7.

TABLE 7

Uptake of calcium by some crop plants

Plant species	Average yield in kg. per acre		Quantity of calcium removed (in kg. per acre)	
			Ca	$CaCO_3$
Berseem	18,636	(Entire crop)	52.3	130.7
Coffee	For 100	Young *C. arabica* bushes during 5th year of growth	5.5	13.7
Cotton	2,727	(Cotton and stick)	20.4	51.0
Groundnut	1,682	(Entire crop	29.5	73.7
Lemon	For 160	Trees	103.0	258.0
Maize	2,727	(Grain & straw)	40.0	100.0
Orange	For 160	Trees	90.8	227.0
Paddy	2,727	(Grain & straw)	14.5	36.2
Pineapple	For 32	Tons	128.0	310.0
Potato	11,363	(Entire crop)	34.0	85.0
Sugarcane	18,636	-do-	16.3	41.0
Tea	For 1,000	kg. of made tea	5.0	12.5
Tobacco	773	(Dry leaves & stalk)	63.6	159.0
Wheat	1,818	(Grain & straw)	10.0	25.0

(a) Magnesium is an indispensable constituent of chlorophyll in plants. It promotes the absorption and transfer of phosphoric acid. 'Magnesium participates in the production of carbohydrates, proteins and fats as well as in certain catalytic reactions in the enzyme systems and in the formation of vitamins' (Jacob & Uexküll, 1958).

It is evident from the above table that a substantial amount of calcium is removed by crops from the soil. To follow the well-proved maxim (Teiwes, 1956) in soil management, "Return to the soil at least the quantities of nutrients which the crop has removed from the soil in the harvest", a certain amount of lime is to be added only to compensate for the removal of calcium by plants like other nutrients.

Most of the liming materials contain, in addition to calcium, some other elements particularly magnesium[a], and these elements of great significance for the proper growth of plants are also thereby furnished by lime.

II. ECONOMIC RETURNS ON THE APPLICATION OF LIME AND PROSPECTS OF ITS USE IN INDIA

In many countries of the world the benefits of liming are increasingly derived by using it as one of the fertilizers. Lime would also produce better yield response in soils in India as is revealed by experimental results. The yield substantially increases, particularly when lime is applied in conjunction with NP or NPK fertilizers.

In this part of the paper the experiences gained in other countries on the application of lime and the prospects of liming in India, including the economic returns, are reviewed.

Liming Practices in Different Countries

U. S. A.

In the United States liming is practised probably in the most organised and systematic way and is considered as important as the application of other principal plant nutrients, N, P and K. Lime-meter has been introduced to determine the requirements of lime which, instead of soil pH, indicates directly the quantity of lime per acre necessary to neutralize the acidity of a particular soil. Table 8 shows the progressive increase in the use of lime for soils in U. S. A. (Blanck, 1955).

Table 8

Consumption of liming agents for soils[a] in the U. S. A.
(Million tons)

Year	Limestone	Burnt lime	Hydrated lime	Total (including other liming materials)
1920	1.8	0.2	0.14	2.6
1930	2.9	0.07	0.27	3.4
1935	2.3	0.09	0.20	3.2
1940	12.2	0.18	0.20	13.4
1945	20.8	0.13	0.27	22.3
1950	25.2	0.12	0.20	26.5
1951	25.0	0.13	0.20	26.5
1952	24.9	0.13	0.20	26.4

(a) Total area used for agriculture in U.S.A. is about 1100 million acres.

Of the total quantity of liming agents used limestone constitutes about 95 per cent. Up to 1936, most of the limestone used to be delivered to farmers in bags. The farmers can now have limestone in bulk and uniformly spread on their field by the suppliers' trucks fitted with centrifugal type of spreaders for about the same cost as bagged lime earlier delivered to them. A few, however, prefer to mix limestone with manure and spread themselves. Such application of limestone requires little labour and is less costly.

Substantial returns obtained by liming acid soils are shown in table 9 (Worther & Aldrich, 1956).

TABLE 9

Extra yield on raising the soil pH from 5.5 to 6.0 by liming at Wooster, Ohio during 1939-1944

Rotation	Increase in yield per acre			Value per acre per year
	Corn (bu)	Wheat (bu)	Hay (tons)	
Corn, wheat, red clover	10.8	14.3	0.33	14.78
Corn, wheat, alfalfa	13.3	16.5	1.22	23.03

An annual investment on limestone of about $1.35 per acre yielded a net benefit in red clover and alfalfa rotation of about $ 13 and $ 22 respectively. In fact, money spent on good seed, fertilizer and farm labour would give little return on strongly acid soils unless they are appropriately limed.

Ceylon

Although the use of fertilizers for food crops is in its infancy, yet Ceylon has recognised the necessity of extensive liming of her soil. Coral lime is usually recommended as liming agent mainly due to its availability in abundance. The recommended dosage of application is 6 tons per acre of slaked coral lime or 8 tons per acre of ground coral lime as soil ameliorant on brown clayey and loam, acid and lateritic rice soils. Increase in yield, it is reported, is about 16 bushels per acre and nitrogen application is unnecessary in the season of liming. The target drawn up for liming is 50,000 acres by 1961 and 100,000 acres by 1963 (Anonymous, 1958). In view of the small area of Ceylon, the total land under agriculture being only 3.7 million acres, the target area for liming is significant.

Philippines

A considerable area of soil in Philippines is acid. More attention is being given to liming, particularly on sugarcane and coconut soils. The yields of legumes have been increased several times by liming. A dosage of 2.4 tons per acre gave extra yield of tapilum and soybean of about 3.4 and 8.5 tons of green materials per acre respectively.

India

Liming is not generally practised in India as yet except in some experimental farms. The growing effect of non-liming is the gradual deterioration of the soil productivity and responsiveness to fertilizers.

Fertilizers containing ammoniacal nitrogen (NH_4-N) render the soil acidic, particularly due to the displacement of soil calcium by ammonium ion. The ammonium fertilizer is thus usually available to the plant at the cost of calcium. With the increase in consumption for acid forming nitrogenous fertilizers year to year, the need of liming becomes all the more imperative. Calcium carbonate equivalent for neutralizing the acidity due to the use of fertilizers since 1950 is shown in table 10 and graph (Fig. 1). About 0.7 million tons of calcium carbonate is required only to neutralize the combined effect of all nitrogenous fertilizers consumed in 1958-59 even with the present low level of fertilizer usage in the country.

It has been estimated that about three million tons of calcium carbonate would be required to offset the undesirable effects of nitrogenous fertilizers that are planned to be used at the end of the Third Plan. This quantity does not necessarily mean that the entire 3 million tons are to be

TABLE 10

Calcium carbonate equivalent[(a)] for the different fertilizers consumed in India since 1950 (in thousand metric tons)

Year	Ammonium sulphate		Urea	Ammonium sulphate nitrate	Ammon. nitrate	Total
	Imported[(b)]	Indigenous				
1950	429	83	—	—	—	512
1951	154	84	—	—	—	238
1952	225	264	0.8	—	—	490
1953	83	362	2.4	—	1.8	450
1954	73	372	72.0	7.4	—	525
1955	223	414	11.2	14.8	—	663
1956	250	430	8.0	12.4	—	700
1957-58*	374	430	47.2	27.9	—	880
1958-59	176	474	60.0	58.0	—	770

(a) 'Equivalent acidity' for Ammon. sulphate, Urea, Ammon. sulphate-nitrate and Ammon. nitrate are 110, 80, 93 and 60 respectively.
(b) Urea, Ammon. sulphate-nitrate and Ammon. nitrate are all imported except small amount of Urea and Ammonium sulphate-nitrate produced at Sindri in the later part of 1958-59.
* Figures are for fifteen month period.

applied every year on this account only, because the soils in some parts of India contain sufficient lime to take care of the resultant acidity. It merely implies that a greater amount of lime would be used up from the soil, with the increase in consumption of nitrogenous fertilizers. The soil with low lime content would become further depleted due to the use of nitrogenous fertilizers unless the soil is limed at intervals as indicated by soil tests.

A considerable amount of lime is also removed by the crops grown in the country. Table 11 gives an idea of the total calcium uptake by the crops in less than half of the total cultivated area (1955-56).

TABLE 11

Total lime removed by the principal crops in India

CROP	Area under cultivation (1955-56) (million acres)	Ca removed, million metric tons of $CaCO_3$ equivalent (a)
Paddy	75.0	2.76
Wheat	29.0	0.72
Maize	9.0	0.90
Cotton	20.0	1.02
Groundnut	12.5	1.00
Sugarcane	4.4	0.18
Tobacco	0.9	0.14
Total	150.8	6.72

(a) Calculated on the basis of uptake by average yield per acre for the single crop (vide table 7).

From the above figures it can be observed that calcium equivalent to 6.7 million metric tons of calcium carbonate is taken up by crops in about 150 million acres. Probably for the entire cultivated area of about 360 million acres, calcium equivalent to 16 million metric tons of calcium carbonate is removed by the crops and plants. Although a part of this lime goes back to the soil by way of manures and vegetable wastes and in some soils addition of lime may not be initially necessary, the application of lime is nevertheless necessary to compensate for the depletion of lime. A precise estimate is not possible due to the lack of reliable data but probably several million tons of agricultural lime should be used to obtain optimum plant growth.

EXPERIMENTAL OBSERVATIONS IN DIFFERENT CENTRES IN INDIA

Mysore

The effect of liming on the yield of paddy in acid soil is indicated from the following typical experimental data (table 12).

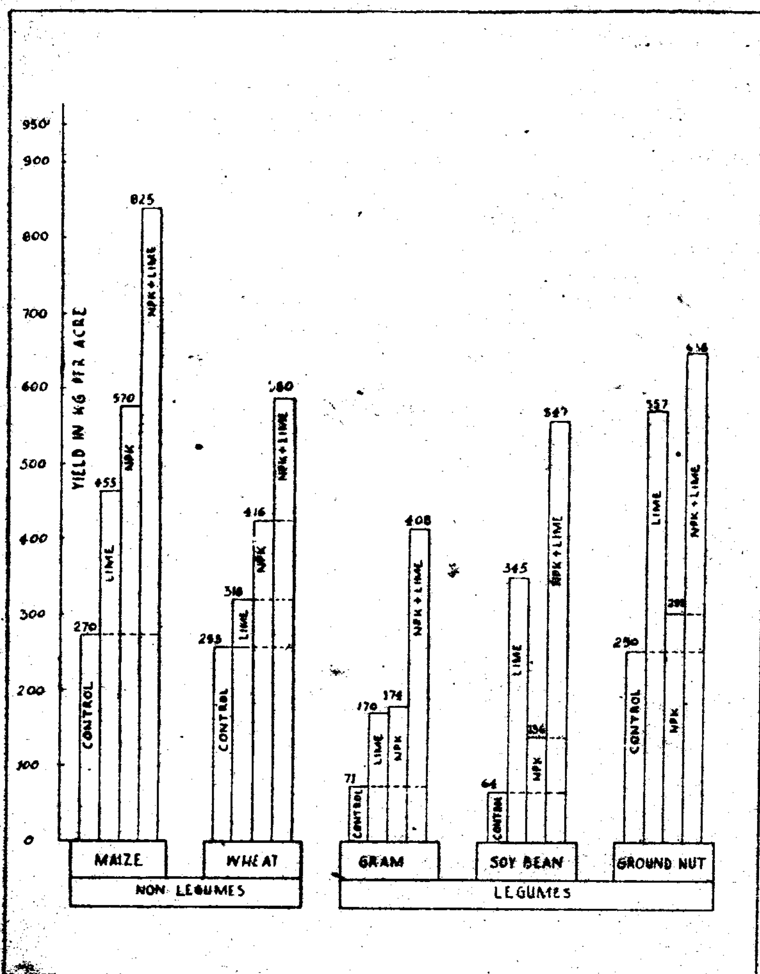

Figure 2 : Average yield of crops during 1958-60 for different treatments on the uplands of Ranchi (pH 5.3—5.6)

TABLE 12

Average response to the application of lime to acid soils (averaged over levels of N and P_2O_5 at 9.10 and 18.18 kg./acre respectively for paddy (Anonymous 1959)
(in kg. per acre)

Centre of conducting Expt.	Year	Yield without lime kg.	Response (extra yield) to levels of lime		Ave. per 1000 kg. of lime kg.
			500 kg./acre	1000 kg./acre	
Ponnampet	1954-55	1050.0	67.7	366.0	276
	1955-56	1185.0	11.2	186.5	
			1000 kg./acre	2000 kg./acre	
Shimoga	1954-55	904.0	93.4	231.0	116
	1955-56	950.0	164.0	231.0	

In Ponnampet and Shimoga the average increase in yield were 276 and 231 kg./acre for the application of 1000 kg. and 2000 kg. of lime per acre respectively. Average response of these centres to 1000 kg. of lime amounts to 196 kg. of paddy.

Sufficient data of the effect of liming on Indian soils are not available. However, the following extracts (Anonymous, 1957) will indicate, though in a qualitative way, the significant response to and other congenial effects of liming in soils of different parts of India.

Assam

(1) The old alluvial soils of Assam with high acidity are generally unsuitable for the *rabi* crops such as mustard, pulses, etc. An application of 20 md. (764 kg.) or more lime per acre, according to the necessity, corrects soil acidity and in return gives a very high increase in yield of the crop which is difficult to grow without lime.

(2) Lime is added to help decomposition of green manure in sugarcane fields.

(3) There is a significant increase in yield in potatoes by green manuring with '*matikalai*' (*Phaseolus mungo*) or sunflower and the yield is greater when lime is added to the green manure.

Madras

(1) Liming seems to be essential in West Coast area and in the Nilgiri tracts for miscellaneous crops like pepper, potato, sannhemp, etc.

(2) The application of ammonium sulphate at quarter lb. (0.114 kg.) and superphosphate at quarter lb. in presence of leaf mould at 20 lb. (9 kg.) and lime at half lb. (0.228 kg.) per vine has considerably enhanced the yield (pepper) at Taliparamba.

A very useful investigation on the effects of liming is being conducted since 1956 at the Agricultural Research Institute at Ranchi. These experiments have already revealed very encouraging results (Mandal, 1960). Lime (30% Ca) has been tried on various crops in the uplands of Ranchi having a pH range from 5.3—5.6. Lime was applied to soils of pH 5.3 and 5.6 at the rate of 3600 lb. (1636 kg.) and 2400 lb. (1091 kg.) per acre respectively as determined by soil tests for lime requirement. It is reported that the residual effect of liming on wheat and maize after 4 years from the date of application is still persisting.

In case of other crops like soybean, groundnut, *rahar*, cotton, etc. the experiments were started in 1958. Two crops already harvested revealed very encouraging results and the residual effect of liming is believed to be existent for further two to three years.

Average yield of crops for two years (1958-60) with control, lime, fertilizer and both in combination are reproduced in table 13 and in fig. 2.

TABLE 13

Average yield of crops during 1958-60 for different treatments on the uplands of Ranchi (pH 5.3-5.6)

(in kg./acre)

Treatment	Maize pH 5.6	Wheat(a) pH 5.6	Gram pH 5.5	Soybean pH 5.3	Groundnut pH 5.3
Control	270	253	71	64	250
Lime alone(b)	455	318	170	345	557
NPK fertilizers alone(c)	570	416	174	136	295
NPK+Lime	825	580	408	547	636

(a) Average yield of three years (1957-60).
(b) Lime applied : 1636 kg. for pH 5.6 and 1091 kg. for pH 5.3.
(c) For legumes: N-4.5 kg., P_2O_5 and K_2O 18.18 kg. of each per acre per year (for every crop). For non-legumes: 18.18 kg. of each per acre per year (for every crop).

The responses to liming as observed in experiments with *jowar* (millet), *moong, rahar, masoor, marua* (pulses), cotton, pea, barley, linseed, mustard, etc. were also very encouraging.

In years of normal rainfall and favourable weather conditions the yield of crops were more significant than the data produced in the table. Although the yields may ordinarily be less prominent in the later part of the liming period than in the initial year of application, table 13 would reveal the trends of responses of liming compared to other treatments.

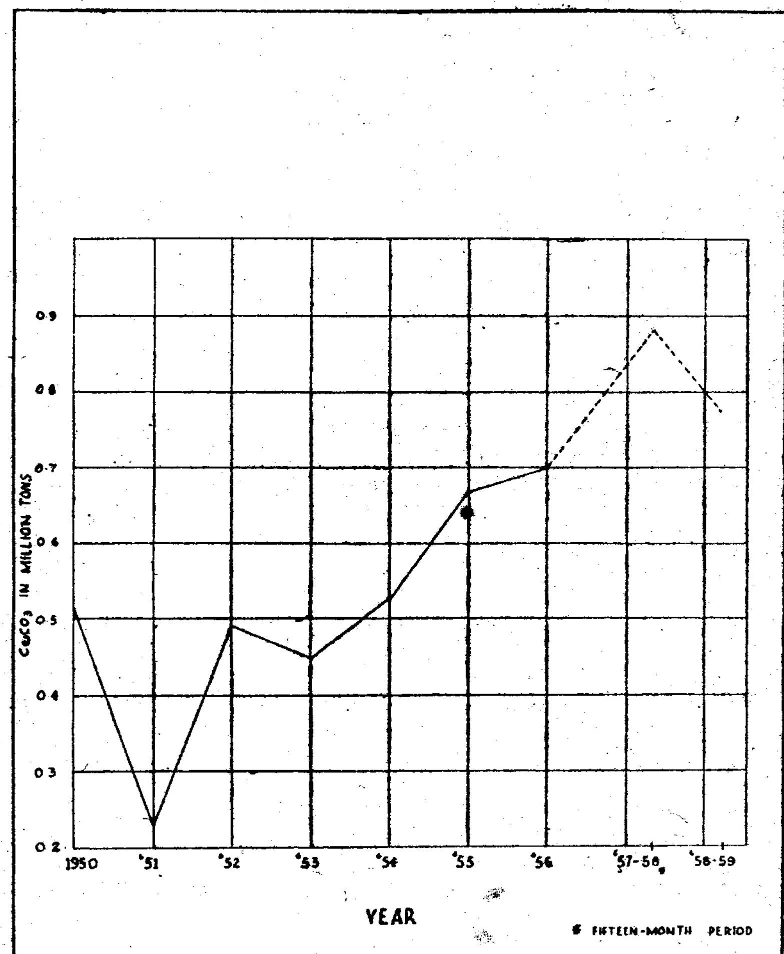

Figure I : Total $CaCO_3$ equivalent for fertilizers consumed in Indias ince 1950

It has also been reported that surface application is better than deep placement and is as effective as combined surface and deep placement.

Percentage increases in yields for different treatments are presented in the following table and in fig 3.

TABLE 14

Percentage increase in yields for different treatments on the uplands of Ranchi (pH 5.3-5.6)[a]

Treatment	Per cent increase in yield				
	Maize	Wheat	Gram	Ground-nut	Soybean
Lime alone	68	26	139	123	440
NPK fertilizers	111	64	146	18	112
Lime+NPK (combined effect)	206	129	475	154	755
Effect of lime alone over the levels of NPK fertilizers	45	40	135	116	300

(a) Calculated on the basis of average yields of crops (vide table 13)

It can be seen from table 14 that for different crops lime when used alone increases the yield over control by 26 to 440 per cent, NPK fertilizers alone by 18 to 146, and lime in conjunction with fertilizers by 129 to 755 per cent. Lime over levels of NPK fertilizers increases by 40 to 300 per cent. This extra yield over the levels of fertilizers is mainly due to the increased efficiency of fertilizers and enhanced activity of micro-organisms in the limed soil. The significant response to lime particularly in conjunction with NPK fertilizers is, therefore, sufficiently indicative of the promising prospects of substantial returns from the use of lime in acid soils.

ECONOMIC RETURNS ON THE APPLICATION OF LIME

On the basis of the yield data obtained at the Agricultural Research Institute, Ranchi, the economic returns have been estimated in tables 15, 16, 17, 18 and 19. As it has been suggested that lime should be applied once in every four or five years, the calculation of economic returns is based on the frequency of lime application being once in four years only. If there be residual effect even after four years, the returns would be still more favourable. Economic returns are estimated for a single crop per year. In cases where irrigation facilities exist, it may be possible to grow more than one crop by rotation and thereby yielding larger profits.

(i) *Maize :* Table 15 shows the economic returns from the investment on various treatments on maize. The profit by the investment on lime alone works out to 66 per cent, whereas the corresponding profit from NPK fertilizers alone is nil. The percentage return rises to 34 per cent for the investments on the combined application of lime and fertilizers, indicating that the functions of fertilizers in acid soils are limited unless applied in conjunction with lime. When the investment on lime alone over the levels of NPK fertilizers is considered the profit amounts to 126 per cent.

TABLE 15

Economics on the use of lime on maize[(a)]

Treatment	Yield kg./acre	Response kg./acre	Value of response[(b)] Rs.	Profit per acre Rs.	Returns from investment in per cent	Remarks
Control	270	—	—	—	—	—
Lime alone [c]	455	185	50	20	66	
NPK fertilizers alone [d]	570	300	80	0	0	No profit
NPK+Lime (combined effect) [e]	825	555	148	38	34	
Effect of lime alone in presence of NPK fertilizers (over the levels of NPK) (4-3)	—	255	68	38	126	Significant profit

(a) Calculated on the basis of average yield of crops (vide table 13).
(b) At the rate of Rs. 268 per 1000 kg. (Rs. 10/md.) of maize.
(c) pH of the soil—5.6 ; Lime requirement 1091 kg./acre. Assuming lime is to be applied after every 4 years, investment on lime works out to Rs. 30/year @ Rs. 112 per 1000 kg. of lime including the cost of transportation and application to the soil.
(d) N, P_2O_5 and K_2O—18.18 kg. each per acre for each crop. Total cost—Rs. 80 (Anonymous, 1959).
(e) Cost of NPK+Lime—(Rs. 80+Rs. 30)=Rs. 110.

(ii) *Wheat* : Profits accrued by the investments on various treatments on the yield of wheat are estimated and shown in table 16. Both lime and NPK fertilizers when used alone do not fetch any profit ; on the contrary, there are losses to the extent of 6.6 and 12.5 per cent respectively. Application of lime, on the other hand, yields profits of 28 and 137 per cent respectively, when considered in conjunction with or over the levels of NPK fertilizers.

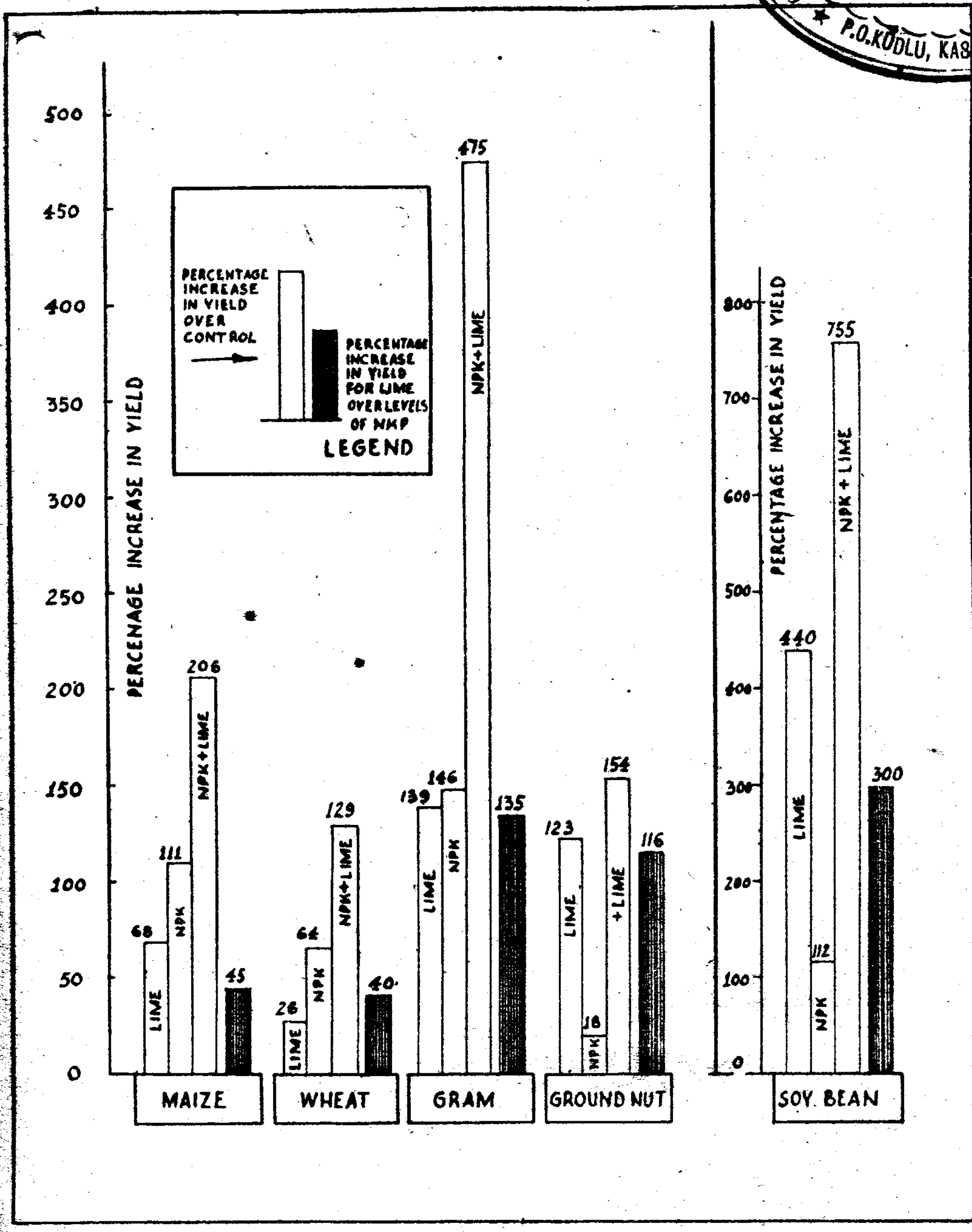

Figure 3 : Percentage increase in yield for different treatments on the uplands of Ranchi (pH 5.3—5.6)

TABLE 16

Economics on the use of lime on wheat[a]

Treatment	Yield kg./acre	Response kg./acre	Value of response[b] Rs.	Profit per acre Rs.	Returns from investment in per cent	Remarks
Control	253	—	—	—	—	—
Lime alone[c]	318	65	28	—2	—6.6	Loss
NPK fertilizers alone[d]	416	163	70	—10	—12.5	Loss
Lime+NPK[e] (combined effect)	580	327	141	31	28	
Effect of lime alone in presence of NPK fertilizers (over the levels of NPK) (4-3)	—	164	71	41	137	Significant profit

(a) Calculated on the basis of average yield of crops (vide table 13).
(b) At the rate of Rs. 430 per 1000 kg. (Rs. 16/md.) of wheat.
(c) pH of the soil—5.6; Lime requirement—1091 kg./acre. Assuming lime is to be applied after every 4 years, investment on lime works out to Rs. 30/year @ Rs. 112/1000 kg. of lime including the cost of transportation and application to the soil.
(d) N, P_2O_5 and K_2O—18.18 kg. each per acre for each crop. Total cost—Rs. 80 (Anonymous, 1959).
(e) Cost of NPK and lime—(Rs. 80+Rs. 30)=Rs. 110.

(iii) *Gram :* Table 17 represents the returns for gram, a legume, from the investments on lime, NPK fertilizers and combination of lime and NPK. Treatments with lime alone or in conjunction with NPK fertilizers yield a substantial profit, whereas investment on NPK fertilizers alone incurs a loss of 25 per cent. When the application of lime is considered as investment over the levels of NPK fertilizers, the returns amount to a profit of 168 per cent. It is thus apparent that the investment on fertilizers is of little use unless the soil is adequately limed.

TABLE 17

Economics on the use of lime on gram[a]

Treatment	Yield kg./acre	Response kg./acre	Value of response[b] Rs.	Profit per acre Rs.	Returns from investment in per cent	Remarks
Control	71	—	—	—	—	—
Lime alone[c]	170	99	40	5	14	
NPK fertilizers alone[d]	174	103	41	—13.5	—25	Loss
NPK+Lime[e] (combined effect)	408	337	135	45.5	51	
Effect of lime alone in presence of NPK fertilizers(over the levels of NPK) (4-3)		234	94	59	168	Significant profit

(a) Calculated on the basis of average yield of crops (vide table 13).
(b) At the rate of Rs. 400 per 1000 kg. (Rs. 15/md.) of gram.
(c) pH of the soil—5.5 ; Lime requirement—1273 kg./acre. Assuming lime is to be applied after every four years, investment on lime works out to Rs. 35/year at the rate of Rs. 112/1000 kg. of lime including the cost of transportation and application to the soil.
(d) N—4.5 kg ; P_2O_5 and K_2O—18.10 kg. each per acre for each crop. Total cost—Rs. 54.50. (Anonymous, 1959).
(e) Cost of NPK+Lime—(Rs. 54.50+Rs. 35)=Rs. 89.50.

(iv) *Soybean* : Table 18 shows the economic returns from the use of lime compared to other treatments on the yield of soybean, another leguminous plant. Legumes are lime-loving and can make use of atmospheric nitrogen particularly in presence of sufficient lime. The investment on NPK fertilizers incurs a loss of 41 per cent, whereas investments on lime alone and in conjunction with NPK fertilizers yield significant profits to the extent of 163 and 107 per cent respectively. Investment on lime over the levels of NPK, as in case of other crops, produces promising returns.

TABLE 18

Econonrics on the use of lime on soybean [a]

Treatment	Yield kg./acre	Response kg./acre	Value of response [b] Rs.	Profit per acre Rs.	Returns from investment in per cent	Remarks
Control	64	—	—	—	—	
Lime alone [c]	345	281	121	75	163	Significant profit
NPK fertilizers alone [d]	136	72	32	—22.5	—41	Loss
NPK+Lime [e] (combined effect)	547	483	208	107.5	107	Significant profit
Effect of lime alone in presence of NPK fertilizers (over the levels of NPK (4-3)		411	177	131	284	Significant profit

(a) Calculated on the basis of average yield of crops (vide table 13).
(b) At the rate of Rs. 430/1000 kg. (Rs. 16/md.) of soybean.
(c) pH of the soil—5.3; Lime requirement—1636 kg./acre. Assuming lime is to be applied after 4 years, investment on lime works out to Rs. 46/year @ Rs. 112/1000 kg. of lime including the cost of transportation and application to the soil.
(d) N—4.5 kg., P_2O_5 and K_2O—18.18 kg. each per acre for each crop. Total cost—Rs. 54.50 (Anonymous, 1959).
(e) Cost of NPK+Lime—(Rs. 54.50+46)=Rs. 100.50.

(v) *Groundnut*: Table 19 represents a comparison of returns for groundnut from investment on different treatments. As groundnut is a legume like gram and soybean, the investment on lime alone or in conjunction with NPK fertilizers yields significant returns, while there is a loss of 56 per cent from investment on NPK fertilizers alone. Application of fertilizers is thus prohibitive unless the acidity of soil is corrected by liming.

TABLE 19

Economics on the use of lime on groundnut [a]

Treatment	Yield kg./acre	Response kg./acre	Value of response [b] Rs.	Profit per acre Rs.	Returns from investment in per cent	Remarks
Control	250	—	—	—	—	
Lime alone [c]	557	307	165	119	258	Significant profit
NPK fertilizers alone [d]	295	45	24	—30.5	—56	Loss
Lime+NPK [e] (combined effect)	636	386	208	107.5	107	Significant profit
Effect of lime alone in presence of NPK fertilizers (over the levels of NPK) (4-3)		341	184	138	300	-do-

(a) Calculated on the basis of average yield of crops (vide table 13).
(b) At the rate of Rs. 536/1000 kg. (Rs. 20/md.) of groundnut.
(c) pH of the soil-5.3, Lime requirement—1636 kg./acre. Assuming lime is to be applied after every 4 years, investment on lime works out to Rs. 46/year @ Rs. 112/1000 kg. of lime including the cost of transportation and application to the soil.
(d) N—4.5 kg., P_2O_5 and K_2O—18.18 kg. each per acre for each crop. Total cost—Rs. 54.50 (Anonymous 1959).
(e) Cost of NPK+Lime—(Rs. 54.50+46)=100.50.

Percentage returns of the crops—maize, wheat, gram, soybean and groundnut—from the investments on lime or NPK fertilizers, combination of both and also lime over the levels of NPK fertilizers are summarised in table 20.

TABLE 20

Summary of the economic returns

Treatment	Maize	Wheat	Gram	Soybean	Groundnut
Lime alone	66	—6.6	14	163	258
NPK fertilizers alone	0	—12.5	—25	—41	—56
NPK+Lime	34	28	51	107	107
Lime over the levels of NPK fertilizers	126	137	168	284	300

Graphical representations of the economic returns are presented in fig. 4.

It can be seen that the investments on lime in conjunction with NPK fertilizers are substantially encouraging and the returns range from 28 to 107 per cent for the crops shown in the table. The investments on NPK fertilizers when used alone do not yield such significant returns and in most cases, particularly with legumes, there are losses. Symbiotic process of nitrogen fixation through legumes is favoured in presence of sufficient lime. Efficiency of fertilizers and activities of micro-organisms are increased as a result of liming acid soils. The returns are, therefore, more economical when lime is applied in conjunction with NPK fertilizers.

REQUIREMENT OF AGRICULTURAL LIME FOR WHOLE OF THE COUNTRY

Determination of the requirement of lime for a particular soil is not possible without proper soil test. However, a rough idea of the requirement of lime can be had on the basis of acidity and physical condition of the soil.

(i) Acid soils, as discussed earlier, urgently require to be limed for the better yield of crops.

(ii) Neutral soils which are at present extended to a considerable portion of eastern and southern India, are liable to develop acidity due, besides leaching, to repeated uptake of lime by plants and use of increasing amounts of acid forming fertilizers. Lime should in practice be applied to neutral soils at regular intervals to maintain the lime status. Equivalent amount of lime should at least be applied to counteract the effect of the use of acid forming fertilizers.

(iii) Clay soils, deficient in calcium base, present a deflocculated structure which are too stiff to work and have restricted air circulation.

The exact area of these types of soil is not available and in the estimation of lime requirement, the clay soils could not be considered.

Acid soils of India : It has been observed that the soils under heavy rainfall become acid due to the leaching out of the bases. The upland soils, in particular, are subjected to the continuous washing down of bases and thus develop strong acidity, limiting crop production unless regularly limed. The soils of whole of Assam ; Manipur ; Tripura ; the Jalpaiguri, Bankura, Burdwan, Hooghly and Midnapur districts of West Bengal ; the Santal Parganas, Hazaribagh, Ranchi, Palamau, Singhbhum districts of Bihar ; the Dhenkanal, Keonjar, Mayurbhanj and Sundargarh districts of Orissa ; the Sirguja, Raigarh and eastern parts of Bilaspur districts of Madhya Pradesh ; the whole of Kerala ; the Mysore and Shimoga districts of Mysore ; the Salem district of Madras ; and Ratnagiri district of Bombay are distinctly acid. Lime should be applied to these soils at regular intervals for deriving better yield of crops, as is proved by the experiments conducted at Ranchi and Shimoga.

The areas of different types of soil as estimated by planimetering from the pH map of India (Indian Agricultural Research Institute) are tabulated below and the lime requirements at the expected rates are incorporated in table 21.

TABLE 21

Agricultural lime requirement for different types of soils in India

Soil	pH	Total area [a] million acres	Cultivated area in million acres	Lime requirement for acid soils only, million metric tons/year
Strongly acid [b]	below 5.5	64.0	16.0 [c]	5.5 [e]
Slightly acid	5.6-6.5	58.4	20.4 [d]	4.6 [f]
Neutral	6.6-7.5	114.0	—	—
		236.4 [g]	36.4	10.1

(a) Approximate area estimated by planimetering.
(b) The Naga Hills of Assam, though the soils are highly acidic, has been excluded.
(c) Cultivated area, as it includes some hilly tracts of eastern and southern parts, has been assumed to be 25% of the total area of strongly acid soils.
(d) Cultivated area assumed to be only 35% of the total area (average cultivated area of India is about 42% of the total area).
(e) Estimated at the average rate of 1364 kg. (3000 lb.)/acre/4 yrs. i. e. 341 kg./acre/yr.
(f) Estimated at the average rate of 910 kg. (2000 lb.)/acre/4 yrs. i. e. 227 kg./acre/yr.
(g) Rest includes strongly alkaline soils, slightly alkaline soils, desert soils of Rajasthan, the State of Jammu and Kashmir and other unsurveyed (as to pH) lands.

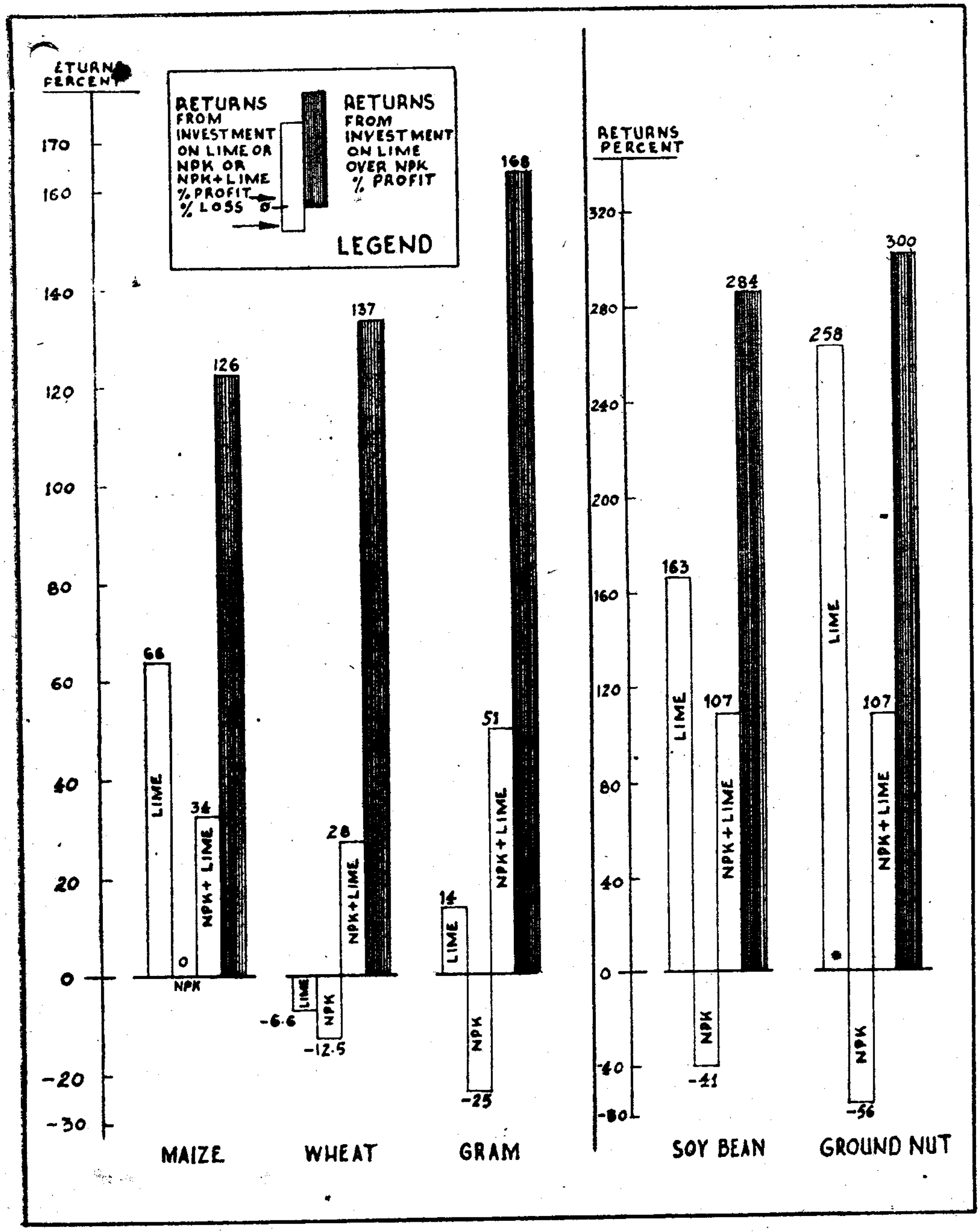

Figure 4 : Economic returns from investment on different treatments

It can be seen in this table that about 10 million tons of agricultural lime per year would be required for 36 million acres of the present acid soils in India. This excludes the quantity that might be required for the maintenance of lime status in neutral soil and conditioning of clayey and other similar types of soils. The area of acid soils would be gradually extended if the lime losses are not replenished in the soils at present neutral or near neutral.

RETURNS FROM THE APPLICATION OF AGRICULTURAL LIME TO THE STRONGLY AND SLIGHTLY ACID SOILS

(i) *Over the levels of NPK fertilizers* : Ten million metric tons of agricultural lime when used over levels of NPK on 36 million acres of acid soils would yield, taking wheat as an example, an additional amount of 5.9 million metric tons per year @ 164 kg. of wheat/acre per/year (*vide* table 16), as experimentally observed at Ranchi. For other crops the yields would be more (vide table 15-19). The value of the additional response of 5.9 million metric tons of wheat would be about Rs. 2500 million at the present market rate of Rs. 430/1000 kg. (Rs. 16/md.). If even one half of the 36 million acres of the cultivated acid soil is limed at the first stage the additional amount of about 2.9 million metric tons of wheat worth nearly Rs. 1250 million would be produced over the levels of NPK fertilizers.

(ii) *Agricultural lime alone* : By the use of agricultural lime alone in the 36 million acres of acid soils, the yield of wheat per year would be about 2.4 million metric tons valued at Rs. 1030 million. If it is presumed that 18 million acres i.e. 50% of total acid soils be limed at the initial stage, the extra yield would be about 1.2 million metric tons of wheat for 5 million metric tons of agricultural lime. The value of this additional response of 1.2 million metric tons of wheat would be Rs. 515 million.

The returns are summarised in table 22.

TABLE 22.

Returns from the application of agricultural lime to 36 million acres of total (strongly and slightly) acid soils

Agricultural lime over the level of NPK fertilizers		Agricultural lime alone	
Extra yield (a) per year million metric tons	Value of the yield (b) million Rs.	Extra yield c per year million metric tons	Value of the yield (b) million Rs.
5.9	2500	2.4	1030

(a) Extra yield of wheat estimated @ 164 kg. per acre per year. For other crops the yield would be more (vide tables 15-19).
(b) Price of wheat is taken as Rs. 430/metric ton (Rs. 16/md.) (Anonymous, 1959).
(c) Extra yield of wheat estimated @ 65 kg. per acre per year (table 16).

Even for wheat these significant returns of Rs. 515 million for lime alone and Rs. 1250 million for lime in conjunction with NPK per year from only 50% of the cultivated area of the total (strongly and slightly) acid soils speak for itself of the enormous prospects of liming in the country.

Although slightly acid soils might not respond to liming in the same manner and degree as strongly acid soils, it can be mentioned here that wheat which gives the least response has been taken into consideration for the estimation of these returns. As the experimental data on liming slightly acid soils are not available, estimates for such soils could not be presented here.

Requirement of Agricultural Lime Exclusively for Strongly Acid Soils

(i) It can be further seen in table 21 that for the total cultivated area of strongly acid soils, 16 million acres, the requirement of agricultural lime would be 5.5 million metric tons. This has been estimated at the rate of 341 kg. of lime per acre per year as was used in the experiments at Ranchi for similar soil pH. Although the rate of lime would vary from soil to soil and should be determined by soil test, this rate of 341 kg. per acre per year appears to be conservative for the initial application to soils other than sandy or sandy loam.

(ii) If 50 per cent of the cultivated area of strongly acid soil is taken into consideration at the first stage, 2.8 million metric tons of agricultural lime would be required for 8 million acres of soil. The requirements are tabulated in table 23.

TABLE 23

Requirement of agricultural lime for strongly acid soils only

The whole of the cultivated area of strongly acid soil (pH below 5.5)		50% of the cultivated area of strongly acid soil (pH below 5.5)	
Area (million acres)	Agricultural lime (million metric tons)	Area (million acres)	Agricultural lime (million metric tons)
16	5.5	8	2.8

Returns from the Application of Agricultural Lime to the Strongly Acid Soils only

For 16 million acres of cultivated area of strongly acid soils, as shown in table 23, 5.5 million metric tons, and for 8 million acres (50% of the cultivated area of strongly acid soils), 2.8 million metric tons of agricultural lime would be required. The returns from the application of lime to strongly acid soils are shown in table 24.

TABLE 24

Returns[a] from the application of agricultural lime exclusively to 16 million acres of strongly acid soils

Agricultural lime over the levels of NPK fertilizers		Agricultural lime alone	
Extra yield, million metric tons	Value of the yield, million Rs.	Extra yield, million metric tons	Value of the yield, million Rs.
2.6	1120	1.0	430

(a) Estimated as in table 22.

The extra yield shown in table 17 would be for wheat, for other crops the additional yields due to the application of lime over the levels of NPK fertilizers or alone would be more (vide tables 15-19).

The additional yield for paddy in 16 million acres of strongly acid soils due to lime over the levels of 9.1 kg. of N and 18.18 kg. of P_2O_5, according to experiment conducted at Ponnampet and Shimoga in Mysore (vide table 12), would be about 3.0 million metric tons. The corresponding value of the yield @ Rs. 335 per metric ton (Rs. 14/md.) would be Rs. 1000 million.

These substantial returns could be successfully derived with the application of agricultural lime, the sources of which are also fortunately available in abundance all over the country.

III. RESOURCES OF AGRICUTURAL LIME IN INDIA

It has been observed that under certain conditions lime when applied in conjunction with NPK fertilizers increases the yield by about 130 to 750 per cent. If only 16 million acres of cultivated area of strongly acid soils are taken into account for liming, the additional yield of wheat over the levels of NPK fertilizers would be 2.6 million metric tons per year worth Rs. 1120 million.

Despite virtually inexhaustible natural resources of agricultural lime and the significant response to it, liming is as yet not practised in India in any organised manner.

In India, liming material is available in abundance and deposits are scattered all over the country. This lime, in addition to its other uses, could easily be processed to agricultural lime. In this part of the paper, the resources of agricultural lime in India are described.

Natural sources of lime : India has got virtually unlimited natural resources of lime (limestone) scattered all over the country. Relatively very small amount of it, about 23 million tons, is expected to be consumed at the end of Second Five Year Plan and that too mainly for metallurgical work, cement making and for the production of quicklime. In view of this vast reserves of limestone the chance of its getting exhausted within a few centuries to come is probably remote. "Limestone quarrying is a growing industry in India and the vast quantities of available stones of all descriptions in the country as a whole are more than sufficient to meet all the demands of the future" (Dey & Brown, 1955). The quality of limestone varies, as in case of other minerals, from place to place. Some are highly pure chalk, while others are of impure siliceous variety. Limestone deposits in different States of the country are shown in table 25.

Limestone is also reported to be available in Kerala and Kashmir. Orissa is the largest supplier of limestone at present, followed by Bihar where it is mainly processed to cement. Limestone of Gujarat appears to be one of the best ($CaCO_3$ content 92.0—94.5 per cent).

By-product lime : Besides these natural sources of lime, liming materials are also produced as by-products in some industries like paper,

TABLE 25

Location and quality of limestone available in India

State	District	Analysis (per cent)			Remarks
		SiO_2	CaO	MgO	
Andhra	Kurnool Hyderabad Vishakapatnam	10-13	46-47	Trace-0.9	
Assam	Khasi Hills Garo Hills	0.5-2	50-53	0.7-1	
Bihar	Sahabad Hazaribagh Palamau Singhbhum	8-15	44-50	0.5-2	Siliceous
Gujarat	Junagadh Banas	0.8-4	51-53	0.6-0.9	Chalk
Madhya Pradesh	Jabalpur Durg Bilaspur	1-9	40-53	0.2-2	
Madras	Tiruchirapalli Nellore, Salem Madura Ramanathapuram	0.5-2	53-54	0.2-8	Crystalline limestone
Maharashtra	Yoetmal	1-6	50-54	Trace-3	
Mysore	Shimoga Chitaldrug Tumkur, Mysore Bijapur	0-2	49-50	0-1	Crystalline
Orissa	Sundargarh Sambalpur Koraput	1-10	49-53	0.5-3	Dolomitic
Punjab	Patiala Ambala	0.3-3	51-53	0-1	
Rajasthan	Bundi Jodhpur Udaipur	7-15	44-45	0.1-0.9	
Uttar Pradesh	Mirzapur Dehra Dun	—	—	—	
West Bengal	Darjeeling (Western Duars)	—	—	—	Crystalline (at present inaccessible), dolomitic

sugar and ammonium sulphate by the gypsum process. These are, as chemically precipitated calcium carbonate, in fine form and are considered agronomically superior. In many parts of the world, these by-product liming materials are widely used for agricultural purposes. A considerable amount of by-product lime is obtained in India. With the increase of such industries, the amount of the by-product lime would significantly increase and could profitably be used for liming of soils in India.

Sindri is producing lime as by-product in the production of ammonium sulphate fertilizer by the gypsum process. Some other fertilizer projects that are now being planned will also make such liming material available in significant quantities.

Besides, the under-size products from the limestone crushing plants for metallurgical purposes can be utilized as agricultural lime.

Requirement of agricultural lime in India: In Part II of this paper, the total agricultural lime requirements for the cultivated areas of the total (strongly and slightly) acid and also exclusively of the strongly acid soils in India have been estimated. This production plan for lime fertilizer is based on the need for the strongly acid soils only.

Assuming again that only 50 per cent of the cultivated area of strongly acid soils, i. e. 8.0 million acres, would use lime to begin with, the requirement of agricultural lime would work out to about 2.8 million metric tons. This is a very conservative estimate as:

(i) only 25 per cent of the total area of the strongly acid soils is assumed to be cultivated, the all-India average percentage of cultivated area being about 42 per cent of the total area ;

(ii) out of about 36 million acres of cultivated area of strongly acid and slightly acid soils that require to be limed, only half of the cultivated area of strongly acid soil has been taken into consideration as a preliminary step for the application and production of agricultural lime ;

(iii) the 50 per cent of the cultivated area of the strongly acid soils, 8 million acres, is only about 22 per cent of the total (strongly and slightly) acid soils that urgently need to be limed and about 2.2 per cent of the gross cultivated area (360 million acres) ;

(iv) the requirement of lime for 8 million acres of strongly acid soils has been estimated at 2.8 million metric tons @ 341 kg. of lime per acre per year. For clay and clay loam type of soils the rate would probably be more.

The amount of agricultural lime, 2.8 million metric tons, for only 8 million acres of strongly acid soils is, therefore, a very conservative—rather low—estimate in view of the total requirements for the soils of India.

SUMMARY

1. The effects of liming on soil and plant are to :
   (i) neutralize soil acidity,
   (ii) stimulate bacterial decomposition of organic matter,
   (iii) promote nitrification,
   (iv) enhance fixation of nitrogen by symbiotic and free-living organisms,
   (v) render water-soluble phosphates more available,
   (vi) help the availability of potash and make trace elements available without any toxic effect,
   (vii) provide Ca and Mg ions to the soil which are mainly responsible for desirable crumby structure and ion exchange,
   (viii) exert a binding effect on sandy soil; and
   (ix) furnish essential nutrient elements—calcium and magnesium —to the plants.

2. Experimental data from the Agricultural Research Institute, Ranchi, prove that lime is essentially necessary for the better yield of crops in acid soils. The application of agricultural lime as such increases the yield under certain conditions by 25 to 400 per cent, whilst in conjunction with NPK fertilizers by 130 to 750 per cent. The use of NPK fertilizers alone, in many cases, is not so economical but when lime is used in conjunction, the profit is highly significant and promising.

In India, about 36 million acres of acid soils would require to be limed at the present state of the soils. This is a conservative estimate. The application of agricultural lime in conjunction with NPK fertilizers to these soils would yield, taking wheat for example, an additional amount of 5.9 million metric tons worth Rs. 2500 million. With agricultural lime alone the yield would be 2.4 million metric tons of wheat valued at Rs. 1030 million.

To start with, if strongly acid soils which should be limed urgently are considered, the additional yield over the levels of NPK fertilizers would be about 2.6 million metric tons of wheat worth Rs. 1120 million. With agricultural lime alone, the yield is computed at 1.0 million metric tons worth Rs. 430 million.

For other crops such as maize, gram, soybean etc. the returns owing to the application of agricultural lime would be more. With legumes like soybean, groundnut, etc., the requirement of nitrogenous fertilizers may be reduced as these plants can make better use of atmospheric nitrogen in limed soils.

The figures indicate decisively the prospects of using agricultural lime in India. Apart from the economic gains, lime should, in any case, be applied to offset the unfavourable effects of nitrogenous fertilizers which are increasingly being consumed in the country. Lime would prevent continual degradation of soils and for this cause alone liming would be of inestimable value.

3. In India, natural deposits of liming material (limestone) are available in every State and virtually in abundance. In addition, by-product lime is also available from industries like sugar, paper and ammonium

sulphate fertilizer by gypsum process. The natural raw material (limestone) can be easily processed to agricultural lime by only quarrying the material and crushing it to a product of the size through 60-mesh screen.

If, at the outset, only 50 per cent of the cultivated area of the strongly acid soils (pH below 5.5) i. e. 8 million acres is taken into account for liming, 17 agricultural lime production plants of 500 metric tons per day capacity each, would require to be installed at a total investment of Rs. 68 million. The annual returns thereof, only by way of additional yield of wheat over the levels of NPK fertilizers, would be about Rs. 560 million which are significantly more than the returns from the investment on the installation of one nitrogenous fertilizer plant (70,000 ton capacity).

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