USE OF ARTIFICIAL FERTILIZERS IN INDIA

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PREFACE TO THE FIRST EDITION

This bulletin deals with the subject of artificial fertilizers and aims to give, as far as possible, a complete picture of the scope and use of artificial fertilizers in relation to different crops and soils of this country.

The production of fertilizers in India, at present, is inadequate to meet the requirement of the country. Setting up of the Sindri Fertilizer Factory with its expanded programme of production and the proposed setting up of fertilizer factories at Nangal and at other places marks an important step towards the development of the fertilizer industry in India and it is hoped that with the development of various hydro-electric projects in the country new factories will be set up for the manufacture of fertilizers which are now imported in large quantities from foreign countries.

Although efficient use of fertilizers is recognised as one of the potential technical factors conducing to sustained crop production at high level, apprehensions are expressed in some quarters against their use in this country. Most of these fears appear to be connected with the supposed loss in fertility due to their continuous use. The apprehensions can easily be overcome by demonstrating the efficiency of the fertilizers through application in judicious doses, particularly in combination with organic matter. The urgent need of the day is that the production of fertilizers be increased to the level of country's requirement and their equitable distribution at a reasonable price ensured to the farmers.

The author desires to express his sincerest thanks to Dr. B. V. Subbiah and Shri A. B. Ghosh, Assistant Soil chemists, and Dr. N. P. Datta, Special Officer, Soil Testing (T.C.M.), in the Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi, for the considerable amount of assistance rendered by them in compilation of the data and preparation of this bulletin.

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PREFACE TO THE SECOND EDITION

Since publishing of the first edition of this bulletin in 1960 considerable data on fertilizer consumption and use in the country have been published in the various reports and publications of the Indian Council of Agricultural Research, of the different Agricultural Research Institutions and the State Governments. The data have been utilized in revising the present publication. The data of the first edition retained in the second edition have been converted into metric system and the new data are also given in the metric system. New tables showing the data on fertilizers and their efficiencies which are considered important in the recent years but were not included in the first edition have been included in the second edition. Some of these are :

1. Specifications of fertilizers as laid down by the Indian Standards Institutions.
2. Average yardstick for increased yield of different crops by the various fertilizers.
3. Soil test limits of the major available nutrients and of properties like pH and soluble salts.

Special emphasis has been given to the methods of assessment of soil fertility including radioisotope methods. The fertilizer materials which are under contemplation for use in the Fourth Plan have been described and their merits and limitations dealt with. The Soil and Fertilizer Specialists of the Central and State Governments have kindly collaborated in bringing the bulletin up to date and the author expresses his thanks for their help and useful suggestions.

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I. INTRODUCTION

The art of agriculture in India dates back to pre-historic times. The use of dung as manure appears to have been practised since the Rigvedic Age (*Rig Veda* 1, 161, 10,2500–1500 B.C.). The value of green manures like sesamum appears to have been known in periods as far as back as 1000 B.C., as references to the use of stalks and stems of sesamum as manure are found in *Atharva Veda* (II, 8,3). The practice of application of phosphatic fertilizer like bones dates back to about 300 B.C., while the value of excreta of goats and sheep was recognised in post-Vedic age, i.e., between 500 B.C. and 500 A.D. (Kautilya *Arthasastra*). Other manures like oil-cakes, etc., appear to have come into use in this country from 1000 to 1400 A.D. (G.P. Majumdar, *Upavanavinoda*, p. 81-83).

Thus, while organic manures probably found their use in fields from the time the man began cultivating the soils, use of inorganic fertilizers is of comparatively recent origin and has become established only during the last 100 years.

As early as 1840 Justus von Liebig, a German chemist of the University of Giessen, emphasized on the necessity of supplying the plants with phosphoric acid and potash and propounded his famous theory of mineral nutrition. In 1842 J.B. Lawes of the Rothamsted Experimental Station, England, took out a patent protecting treatment of ground phosphate rock with sulphuric acid, and in 1843 he began the manufacture of what he called 'superphosphate' and made a commercial success of the enterprise. It is from this period that the commercial fertilizer industry of today has its beginning. The necessity of supplying plants with nitrogen was, however, not recognized until 1857, when, J.B. Lawes, J.H. Gilbert, and E. Pugh by their classical field experiments at the Rothamsted Experimental Station definitely established the essential nature of this element.

Ground bone, Peresvian guano, Chilean nitrate, German potash salts and rock phosphate were some of the earlier materials put in the market as fertilizers. Since the middle of the 19th century, the first materials to be used as nitrogenous fertilizers were calcium nitrate, calcium cyanamide and the by-product ammonium sulphate as also Chilean nitrate. Since the middle of the 19th century the marked innovation that was made in the fertilizer industry was the development by the German chemists of the economically feasible method for fixing atmospheric nitrogen for the production of nitrogenous fertilizers. The industry has developed considerably in different parts of the world and now nitrogenous fertilizers in various forms like ammonium sulphate, ammonium nitrate, urea, etc., are being produced on a large scale. Compound fertilizers containing nitrogen and phosphate, like ammonium phosphate and nitro-phosphate, are also being manufactured and widely used in various parts of the world.

The total quantity of plant nutrients used in the world in 1959–60 was 28.1 million tonnes and it has been estimated that the world's requirements for plant nutrients would be 49 million tonnes by 1970 and 70 million tonnes by 1980. The world's consumption of nitrogen is expected to be double by 1970, but increased consumption will vary widely in the different countries. In the nutritionally deficient countries, we expect consumption to be about 150 per cent more than it was in 1959–60. In the nutritionally-sufficient countries the growth rate will not be as high but these nations will account for most of the actual increase. Phosphate fertilizer consumption is not expected to increase as fast as that of nitrogen. By 1970, the world is expected to use about 57 per cent more P_2O_5 than it did in 1959–60. The potash consumption is expected to increase at about the same rate as phosphate—57 per cent during 1960's. There is a continued trend towards more highly concentrated fertilizers. The faster growth rate for nitrogen than for phosphate and potash will result in a significant change in the ratios of N to P_2O_5 and K_2O. In 1907, the ratios were 0.34 to 1.00 to 0.47. In 1960 they had become 0.96 to 1.00 to 0.85. By 1970, they should be about 1.20 to 1.00 to 0.85 (Ref. Russell Coleman, 1964). As against this the present fertilizer consumption ratio in India between nitrogen, phosphorus (as P_2O_5) and potash (as K_2O) is generally 1.0 : 0.22 : 0.12.

In India the use of artificial fertilizers was first initiated in 1896 when imported Chilean nitrate was used as a fertilizer. By about 1905 calcium nitrate, calcium cyanamide, ammonium sulphate, superphosphate and potassium sulphate were also imported and used on the Indian soil. After the World War I the Imperial Chemical Industries carried out valuable experiments on different crops particularly paddy with ammonium sulphate during the period 1920–30, which established the general superiority of ammonium sulphate over other nitrogenous fertilizers, particularly for paddy. The manufacture of ammonium sulphate in India was first started at Bellegola in Mysore in 1938 on a small scale, which was followed by the setting up of the factory for manufacture of this fertilizer at Alwaye in 1947. The Government of India set up the fertilizer factory at Sindri in 1951 for production of ammonium sulphate in the public sector. As the availability of high-grade gypsum in India is limited, and there is no deposit of sulphur, attention was paid to the production of new forms of gypsum or sulphur for their manufacture. Accordingly, the fertilizer factory at Sindri was expanded in 1959 to produce also limited quantities of ammonium sulphate nitrate and urea. The soda ash factory at Varanasi in 1960 began production of a limited quantity of ammonium chloride as bye-product for use as fertilizer. The fertilizer factory at Nangal in the public sector was set up in 1961 for the manufacture of calcium ammonium nitrate and that at Rourkela in 1962 for the manufacture of same fertilizers.

Regarding the use of phosphatic fertilizers it goes to the credit of Messrs Parry & Co., Madras, to set up the first factory in 1906 for the production of single superphosphate by the action of sulphuric acid on rock phosphate. Several factories in the private sector also sprang up in due course for the manufacture of single superphosphate. The production of the first compound fertilizer, viz., ammonium phosphate, which contain both nitrogen and phosphate was started at Alwaye in 1961. More factories for the manufacture of fertilizers are being set up at a number of places, namely, Trombay, Neyvelli, Gorakhpur, Durgapur, etc., and the expansion of Sindri and Nangal fertilizer factories is also contemplated for making India self-sufficient in respect of use of fertilizer in the near future.

Role of fertilizers in soil improvement. Soils vary widely due to differences in the formation processes, and usually one or more of plant nutrients are limiting factors in the crop production. Losses of nutrients continuously take place due to cropping, leaching and erosion, and they have to be made up, if soil fertility is to be maintained.

Indian soils have been subjected to cultivation for centuries and although the age-old practice of applying farmyard manure has to some extent checked rapid deterioration in soils, it has not been adequate enough to maintain the soil fertility at satisfactory level. In fact, as pointed out by Stewart (1947), even if all the available organic matter is applied back to the soils, there will still be scope for application of fertilizers, firstly to increase the nutrient status of the soils and secondly to maintain it at a high level of productivity from year to year. It is a sound policy, therefore, to take every reasonable step to ensure supply to the land, all organic waste materials likely to be of value as soil improvers and it is equally sound and necessary to make full provision for supplementing such materials with mineral and other fertilizers which can play an important part in the improvement of soil fertility. The nutrients which are removed by crops depend upon the type of crops.

The nutrients removed from the soil in kg per hectare by an average crop is given in Table 1.

TABLE 1. NUTRIENTS REMOVED FROM THE SOIL BY THE CROP (kg/ha)

Crop	N	P_2O_5	K_2O
Rice	34	22	67
Wheat			
Unirrigated	39	12	44
Irrigated	67	34	90
Jowar	58	116	202
Bajra	36	22	66
Maize	35	20	38
Unirrigated	36	17	29
Irrigated	47	22	44
Groundnut	78	30	62
Sugarcane	1.1	196	325
Potato	37	16	67
Sweet potato	56	56	182
Cabbage	35	17	62
Onion	62	36	62
Cotton	30	17	45
Jute	67	34	67

It has been estimated that the crops in India remove from the soil annually about 4.27 million metric tonnes of nitrogen, 2.13 million metric tonnes of phosphoric acid, 7.4 million metric tonnes of potash and 4.86 million metric tonnes of lime (Mukherjee *et al.*, 1950).

Out of nearly 3,394,170 million cubic metres (2,750 million acre feet*) annual rainfall of India, nearly 1,672,598 million cubic metres (1356 million acre feet) water is drained away to the seas by rivers. Excluding the water used for irrigational purposes and including the amounts contemplated to be utilized under different river valley projects estimated at (357 million acre feet) about 462,555 million cubic metres (River Valley Project in India, 7-year plan CWINC, 1949) about 1,233,480 million cubic metres (1,000 million acre feet) of water are still drained away into the sea carrying with it large quantities of plant nutrients. In India, sound crop rotational practices are frequently not followed and thus losses due to erosion are likely to be considerable.

The nutrients should, therefore, be replenished every year. Otherwise, the soil will be progressively impoverished. Soil analysis will reveal the status of these major nutrients in the soils which will serve as a general guide for application of fertilizers. Some general tentative limits of soil-test values are given in Table 2.

TABLE 2. SOIL TEST VALUES

Nutrient	Low (per cent)	Medium (per cent)	High (per cent)
N (total)	Below 0.05	0.05–0 1	Above 0.1
(Available by alkaline permaganate method)	Below 0.0125	0.0125–0.025	Above 0.025
P_2O_5 (total)	Below 0.1	0.1–0.2	Above 0.2
(Available by Olsen's method)	Below 0.001	0.001–0.0025	Above 0.0025
K_2O (total)	Below 0.6	0.6–1.2	Above 1.2
(Available by Morgan's reagent, 1 : 2 soil and reagent ratio)	Below 0.005	0.005–0.0125	Above 0.0125

Role of nitrogen, phosphorus and potassium in plant nutrition. Deficiency of nitrogen restricts the growth of plants and causes stunted growth. The leaves turn yellowish or light green in colour. Such plants mature early with poor yield of crop. The kernels of cereals and seeds of other crops do not attain their normal size. The leaves of a fruit tree with nitrogen deficiency drop off early. An excess of nitrogen causes more vegetative growth and the leaves acquire a dark-green colour and become thick and soppy. The plant becomes more liable to the attack of certain fungi and its resistence to disease is lowered. In the case of cereal crops excess nitrogen causes the straw to become weak and the crop lodges. In the case of crops such as barley, potatoes, sugarcane and fruits, excess of nitrogen deteriorates the quality of the crop. Also excess of nitrogen induces succulence in the growing fodder crops and certain vegetables.

Phosphorus influences cell division and the formation of fat and albumen. It is concerned with the formation of nucleo-proteins in the plant. In the seedling stage phosphorus increases the root-growth and hastens leaf development and the maturity of the crop. Phosphorus has a special action on leguminous crops, energising the soil bacteria which form molecules necessary for good growth. Phosphorus deficiency causes leaves of cereal plants to become dull greyish-green in colour and slows the growth of the plant and yield.

Potassium helps in photosynthesis, i.e., in the development of chlorophyll and in converting carbon dioxide and hydrogen into sugars. It is of special value for crops like tobacco, sugarcane, potatoes, vegetables and fruits which are rich in sugar and starch. It produces vigour in plant for withstanding adverse climatic conditions and increasing resistance to pests and diseases. Potassium strengthens the straw of cereals and keeps the plant green. Deficiency of this element brings about chlorosis, i e., yellowing of leaves and 'dying back' of the tops of shoots. Excessive potassium does not interfere with the normal development of most crops.

Fertilizers produced and in use in India At present the main chemical fertilizers produced in India are ammonium sulphate, calcium ammonium nitrate, urea, ammonium sulphate nitrate, ammonium chloride and single superphosphate. Besides, the following fertilizers are contemplated to be produced in the future : triple superphosphate, nitrophosphate and ammonium phosphate sulphate. Table 3 shows the nutrient contents of principal nitrogenous fertilizers and manures.

TABLE 3. CONTENTS OF PRINCIPAL NITROGENOUS FERTILIZERS*

Fertilizer/manure	Nitrate nitrogen (per cent)	Ammoniacal nitrogen (per cent)	Amide nitrogen (per cent)	Organic nitrogen (per cent)
1	2	3	4	5
Chemical fertilizer				
Ammonium sulphate	—	20–21	—	—
Ammonium nitrate	17–18	17–18	—	—
Ammonium sulphate nitrate	6.5	19.5	—	—
Ammonium chloride	—	25–26	—	—
Anhydrous ammonia	—	80	—	—
Urea	—	—	46	—
Calcium ammonium nitrate	10	10	10	—
Nitrate of soda	15–16	—	—	—
Organic manures				
Groundnut cake	—	—	—	6–7
Castor cake	—	—	—	4–5
Linseed cake	—	—	—	5–6
Neem cake	—	—	—	4–5
Mahua cake	—	—	—	2–3
Karanj cake	—	—	—	4
Manures of commercial origin				
Dried food	—	—	—	10–12
Fish manure	—	—	—	7–10
Bulky organic manures				
Farmyard manure	—	—	—	0.5–1.5
Compost (urban)	—	—	—	1.0–2.0
Compost (rural)	—	—	—	0.4–0.8
Green manure (various averages)	—	—	—	0.5–0.7

*Taken mainly from *Handbook of Agriculture*, I.C.A.R., 1961, p. 99.

The equivalent acidity produced in the soil by different nitrogenous fertilizers is shown in Table 4.

TABLE 4. EQUIVALENT ACIDITY PRODUCED BY NITROGENOUS FERTILIZERS

Fertilizer	Equivalent acidity as $CaCO_3$*
Ammonium chloride	128
Sulphate of ammonia	110
Ammonium sulphate nitrate	80
Urea	75
Calcium ammonium nitrate	0
Nitrate of soda	Basic

*Indicates the number of parts by weight of calcium carbonate ($CaCO_3$) required to neutralize the acidity resulting from the use of 100 parts of the fertilizer.

Table 5 shows the nutrient contents of phosphatic and compound fertilizers.

TABLE 5. NUTRIENT CONTENTS OF PHOSPHATIC AND COMPOUND FERTILIZERS

Fertilizer	Total P_2O_5	Citrate-soluble P_2O_5	Water-soluble P_2O_5	Total N	Ammoniacal N	Nitrate N
Single superphosphate	16.5	16.5	16.0			
Triple superphosphate	40.0	40.0	40.0			
Dicalcium phosphate	34.0	34.0	Nil			
Kotka phosphate	25.0	16.0	8.0			
Calcium metaphosphate	63.0	63.0	Nil			
Fused magnesium phosphate	22.5	19.0	Nil			
Defluorinated rock phosphate (by calcination)	21.0	18.0	Nil			
Defluorinated rock phosphate (by fusion)	28.1	22.3	Nil			
Rock phosphate	27.0–35.0	10.5–3.5	Nil			

Basic slag (Bessemer)	15.0–18 0	13.5–16.5	Nil			
Basic slag (Indian)	2.5–7.5	2 0–6.5	Nil			
Mono-ammonium phosphate (ammo-phos. A)	48.0	48.0	48.0	11.0	11.0	
Ammo. phos. B	20.0	20.0	20.0	16.0	16.0	
Ammonium phosphate-sulphate	20.0	20.0	20.0	16.0	16.0	
Nitrophosphate (ODDA)	20.0	10.0	10.0	20.0	12.0	8.0
Nitrophosphate (PEC)	14.0	14.0	Nil	16.0	8.0	8.0
Bone-meal (raw)	20.0-25.0	8.0	Nil	3.0–4.0	Nil	Nil
Bonemeal (steamed)	22.0	16.0	Nil	1.0–2.0	Nil	Nil
Ammoniated superphosphate (ordinary)	14 0–20.0	13.0–19.0	Nil	2.0–5.0	Nil	Nil
Potassium metaphosphate	60.1	57.0–60.0	0.5–3.0			

Table 6 shows the approximate price of different fertilizers.

TABLE 6. APPROXIMATE PRICE OF DIFFERENT FERTILIZERS

Name	Nutrient contents (per cent)	Price (approx. Rs. per tonne)	Remarks
Urea	44—46 N	610.00	Pool price f. o. r. destination
Ammonium sulphate	20.6 N	366.00	for 50 kg packing
	25 N	355.00	for 100 kg packing
Ammonium chloride		400.00	Pool price f. o. r. destination
Ammonium sulphate nitrate	26 N	455.00	Pool price f. o. r. destination
Calcium ammonium nitrate	20.5 N	335.00	—do—
Single superphosphate	16 water soluble P_2O_5	213.00	ex-factory
Bonemeal (raw)	20 P_2O_5 (total) and 8 citric soluble (available)	250.00	—do—

Rock phosphate	28 to 35 of total P_2O_5	102.00	Import price
Diammonium phosphate	18 : 46	750.00	Wholesale price at ports
Triple-super-phosphate	40 water soluble P_2O_5	500.00	—do—
Compound fertilizers			
(a) ammonium phosphate	20 : 20 : 0	590.00	Bulk supply f. o. r.
(b) nitro-phosphate	12.9 : 12.9	380.00	Tentative
Chilean nitrate	16 N	283.00	Delivered price to cultivator (within 5 miles of Rly. Station).
Muriate of potash	58—60 N	309.00	Jetty price
	(K_2O)	314.00	Godown price
Potassium sulphate	48 K_2O	377.60	F. O. R. Madras

Production, imports and consumption. Nitrogenous fertilizers are available in the form of ammonium sulphate, ammonium nitrate, calcium ammonium nitrate, sodium nitrate, calcium nitrate, calcium cyanamide, liquid and anhydrous ammonia and urea. So far, mainly ammonium sulphate has been used as the main nitrogenous fertilizer in the country. Phosphatic fertilizers in common use are superphosphate and bonemeal. Rock phosphate, triple superphosphate and basic slag have been used in some cases. Among the combined nitrogen and phosphatic fertilizers, ammonium phosphate is chiefly used while ammoniated superphosphate and nitro-phosphate have been used in some cases. Potassium sulphate and muriate of potash are the common potassic fertilizers.

After completion of some of the river valley projects and a number of other minor irrigation schemes, large areas of dry farm land will be brought under irrigation. Maximum benefits from irrigation can, however, be obtained in the form of increased crop yields only if it is judiciously used in combination with bulky organic manures and chemical fertilizers. There are thus great possibilities of increasing agricultural production through greater emphasis on the use of fertilizers in irrigated farming.

Table 7 shows the internal production, import and consumption of ammonium sulphate since 1952–53. The production and consumption of phosphatic fertilizers and the distribution of potassic fertilizers are also shown in Table 7 (source *Fertilizer Statistics* 1964–65, issued by the Fertilizer Association of India, p. 90).

TABLE 7. PRODUCTION, IMPORTS AND DISTRIBUTION OF FERTILIZERS FROM 1952–53 TO 1964–65 IN TONNES

Year	Nitrogen (1) (2) (N)			Phosphoric-acid (1) (3) (P_2O_5)			Potash (K_2O)	
	Produced	Imported (5)	Distributed (6)	Produced	Imported (8)	Distributed (7)	Imported	Distributed (4)
1952–53	53,067	44,294	57,822	7,445	—	4,552	3,311	—
1953–54	52,905	19,346	89,287	13,831	—	8,261	7,490	—
1954–55	68,478	19,984	94,810	14,345	—	15,027	11,097	—
1955–56	76,850	53,379	107,494	12,365	—	13,018	10,265	—
1956–57	78,788	56,768	123,054	17,585	—	15,874	14,791	—
1957–58	81,144	110,100	149,019	25,785	—	21,922	12,786	—
1958–59	80,766	97,540	171,988	30,987	—	29,490	22,366	—
1959–60	83,694	142,335	229,326	51,407	3,819	53,930	33,103	21,342
1960–61	111,987	171,926	211,685	53,722	128	53,134	24,845	29,052
1961–62	154,326	142,920	291,536	65,360	645	63,932	30,381	27,982
1962–63	194,194	229,462	360,033	88,300	7,959	89,940	44,276	36,503
1963–64	219,072	197,691	406,976	107,836	12,267	116,674	64,060	50,570
1964–65	243,230	256,57	434,473	130,404	12,293	147,652	57,176	70,440

(9) *Note* : (1) Includes complex fertilizers which contain both N and P_2O_5
(2) Excludes ammonium chloride for which data are not available.
(3) Excludes bone-meal and ground rock phosphate for which data are not available.
(4) In the case of sulphate of potash, quantity imported is taken as distributed.
(5) Figures from 1952-53 to 1957-58 are on financial year (April-March) basis.
(6) Figures from 1952-53 to 1957-58 relate to calendar years ending in the first half of the period stated while other figures are on financial year (April-March) basis.
(7) Figures from 1952-53 to 1957-58 relate to calendar years ending in the first half of the period stated while other figures are on financial year (April-March) basis.
(8) In the form of complex fertilizers, viz., ammonium phosphate and nitrophosphate.

The targets and achievements of the production and consumption of chemical fertilizers during the three plan-periods is shown in Table 8.

TABLE 8. N, P, K PRODUCTION AND CONSUMPTION TARGETS AND ACHIEVEMENTS DURING FIRST, SECOND AND THIRD PLANS

	Production (tonnes)		Consumption (tonnes)	
	Target	Achievement	Target	Achievement
First Plan				
N	—	80,000	175.000*	110,000 (63)
P_2O_5	—	12,500	25,000*	13,000 (55)
K_2O	—		10,000*	10,000 (100)
$N+P_2O_5+K_2O$	—	92,500	210,000	133,000 (63)
Second Plan				
N	370,000	109,000	370,000	219,000 (59)
P_2O_5	120,000	53,000 (44)	120,000	53,000 (44)
K_2O	—	—	30,000	35,000 (117)
$N+P_2O_5+K_2O$	490,000	162,000 (33)	520,000	307,000 (59)
Third Plan				
N	800,000	242,000 (30)	1,000,000	540,000 (54)
P_2O_5	400,000	115,000 (29)	400,000	132,000 (32)
K_2O	—	—	200,000	75,000 (37.5)
$N+P_2O_5+K_2O$	1,200,000	370,000 (31)	1,600,000	770,000 (48)

*As fixed by the Standing Committee on Manures and Fertilizers.

Note : Figures in the brackets denote percentage achievement.

II. IMPORTANT FERTILIZERS AND THEIR CHARACTERISTICS

Chemical or inorganic fertilizers form a very wide group of materials which can supply one or more plant nutrients in available form to plants.

The nitrogenous fertilizers are mainly ammonium sulphate, ammonium nitrate, chilean nitrate, calcium cyanamide, calcium nitrate, urea, ammonium sulphate nitrate, ammonium chloride ; among liquids are anhydrous ammonia and calcium ammonium nitrate. The chief phosphatic fertilizers are : superphosphate (ordinary and triple or concentrated), bone-meal, rock phosphate, basic slag and dicalcium phosphate.

Among the combined N and P fertilizers, ammonium phosphate, ammoniated superphosphate, ammonium phosphate sulphate and nitrophosphate are important. The main potassic fertilizers are potassium sulphate and muriate of potash. Potassium nitrate fertilizer is a combination of potassium and nitrogen.

Lime, gypsum and dolomite, the main soil amenders and compounds of iron, manganese, boron, zinc, molybdenum, cobalt, copper and sulphur are used in small quantities to meet the micronutrient deficiencies.

NITROGENOUS FERTILIZERS

1. Ammonium sulphate. Pure ammonium sulphate contains 21.2 per cent nitrogen and 27.5 per cent sulphur. The commercial product contains generally not less than 20 per cent nitrogen and is white in colour, but sometimes carries slight taints of brown, blue, yellow and grey colour imparted to it by impurities. The free acid content does not ordinarily exceed 0.5 per cent. It is a fine crystalline salt, almost moisture-free, as it does not absorb moisture if it is stored in a reasonably dry place. The specifications of this fertilizer as laid down by the Indian Standards Institution are given below. The special feature of ammonium sulphate is that the nitrogen is resistant to leaching (Tidmore and Williamson, 1932). Ammonium sulphate is produced mainly as (i) a by product of the destructive distillation of coal and (ii) by synthetic processes.

REQUIREMENTS FOR AMMONIUM SULPHATE, TECHNICAL AND FERTILIZER GRADES

Characteristic	*Requirement*
Moisture, percent by weight, *Max*	1.0
Ammoniacal nitrogen, percent by weight, *Min*	20.6
Free acidity, (as H_2SO_4), per cent by weight *Max*	0.04
Arsenic (as As_2O_3) per cent by weight, *Max*	0.01
Pyridine (C_5H_5N), per cent by weight, *Max*	0.05

Sulphate of ammonia when added to soil having optimum moisture is converted into nitrates in less than a month under Indian conditions and has proved capable of increasing crop yields from 20 to 100 per cent and over. The response depends on the nature of the soil, crop and climatic conditions. The fertilizer being acid forming in character is not suited for continuous application on acidic soils.

Fixation of ammonia of the fertilizer by soil colloids is another important reaction to note in the practical application of this fertilizer. The extent of this fixation depends on the amount and nature of clay and humus present in the soil ; while this serves to control leaching of the water-soluble nitrogen of the fertilizer, the experiments conducted by Allison (1930) show that a fair part of the fixed nitrogen may become so chemically combined with the soil, as to be unavailable to plants, with the result that the response obtained from a given dose is partly reduced. Comparative trials with sodium nitrate and ammonium sulphate carried out by Russell (1919) showed that under condition of the experiment, sodium nitrate increased the yield of barley slightly more than ammonium sulphate. Russell (1919) thought that although ammonium salts appeared to be inferior to nitrate salts in many experiments, the reverse would be true where the masking effect of acid residues was overcome. Harvey (1925) after a careful study of the data of many experiments reached the conclusion that by adjusting the soil reaction in respect to the preference of given crop, one could show an apparent superiority of ammonium sulphate over sodium nitrate and *vice versa*. He believed that due to the failure to consider all the factors influencing the tests, many experiments have led to erroneous conclusions regarding the relative merits of these two materials. White (1925) in summing the comparative field experiments of 40 years concludes as : "Data from the 40 years' plots with regards to yields from sodium nitrate and ammonium sulphate do not indicate the relative value of these two fertilizers when properly used. The experiments, however, are accurate and give very valuable information, possibly more valuable because of the fact that they point out clearly the improper use of ammonium sulphate. The grower, however, should use these results to point the way to profitable use of ammonium sulphate and not condemn the product which like a fine piece of machinery does not give the best results under misuse."

Response to climatic conditions. To be effective, fertilizers of the type of ammonium sulphate must be applied to the soil in the form of solution ; thus, they are best suited for irrigated areas. Low response or even injury to seedlings may result from lack of adequate moisture at the proper time in rainfed areas. Experimental evidence in India shows that the application of more than relatively light dressings of such nitrogenous fertilizers under conditions of water deficiency may have harmful effect on crops and, it appears fairly definite that the more fully the water requirement of crops is met, the greater is the response from a given dose of manure and greater can be the useful rate of application. For cotton and wheat grown under rainfed conditions, past experiments suggest that nitrogenous dressings should be at only about half the rates for these crops under irrigated conditions.

Results of field experiments. Table 9 gives the results of some field experiments on different crops conducted throughout India with ammonium sulphate for a duration of three years in most cases.

The performance of this fertilizer indicates that except in a few places, there has been a consistent increase at all places in the yield of all crops, viz., paddy, wheat, cotton and sugarcane. The increase in yield over no-manure varied from 11 to 48 per cent in the case of paddy, 7 to 69 per cent in wheat, 4 to 56 per cent in cotton and 12 to 117 per cent in sugarcane. There was no increase in the yield of pulses both in Assam and Bihar, except that in the case of *arhar*, 49.4 per cent increase was obtained in Bihar and in the case of mustard about 69 per cent in Assam.

Optimum rate of application of ammonium sulphate for getting maximum increase in yield with minimum investment on the fertilizers is an important aspect. The increase in yield and response per kg of N applied when averaged from the results given in Table 9, indicate that for paddy, ammonium sulphate gives profitable results, both in respect of percentage increase in yield and per kg response at the rate of 22 kg N per hectare. However, in many States, higher doses are recommended depending on the local conditions. High doses of nitrogen are used in the Japanese method too. In the case of irrigated wheat application at the rate of 22 kg has given

TABLE 9. RESULTS OF FERTILIZER EXPERIMENTS

State	Farm	Nature of soil	Period
			PADDY
Bihar	Sabour and Gaya	—	1935–37 (3 years)
Bombay	Alibagh	Sticky clay	1916–18 (3 years)
	Karjat	Sandy loam to loam	1925–29 (5 years)
Madhya Pradesh	Adhartal	Light sandy loam	1926–30 (5 years)
	Raipur	Clay loam	1939–43 (5 years)
Madras	Manga nalore	Deficient in N and P	1916–21 (5 years)
Andhra Pradesh	Samalkot	Rich in N and K_2O	1909–13 (4 years)
Mysore	Nagenhalli	—	—
Punjab	Gurdaspur	Loam	1946–47
Orissa	Berhampur	—	—
,,	Jeypore	—	—
,,	Sambalpur	Superficially fine and rocky below surface. Fairly rich in P_2O_5.	1929–30
			WHEAT
Bihar	Pusa	Calcareous sandy loam	1934–41 (4 crops)
	Sabour	Light loam to heavy def. in N	1930–31
Madhya Pradesh	Adhartal	Sandy loam	(1945–49) (4 years)

WITH AMMONIUM SULPHATE

Treatment (kg/ha)		Yield kg/ha	Per cent increase over no-manure	Response (kg/kg N)	Remarks
Amm. sulphate	45	1,317	34	7.4	
—do—	67	1,243	26	3.8	
No manure		986			
Amm. sulph.	25	2,576	15	14.1	
No manure		2,393			
Amm. sulph.	67	4,066	36	15.9	
No manure		3,002			
Amm. sulph.	22	2,016	48	29	
No manure		1,366			
Amm. sulph.	22	1,681	19	25.7	
No manure		1,107			
Amm. sulph.	75	2,441	15	4.2	
No manure		2,128			
Amm. sulph.	45	3,752	15	10.8	
No manure		3,270			
Amm. sulph.	17	2,279	13	20	
Amm. sulph.	34	3,158	20	16	
Amm. sulph.	56	1,203	24	40	Irrigated crop.
No manure		973			
Amm. sulph.	34	2,150	20	10.7	
No manure		1,792			
Amm. sulph.	34	2,668	20	13.3	
Amm. sulph.	50	2,668	20	8.9	
No manure		2,240			
Amm. sulph.	22	2,839	20	21.5	
No manure		2,357			
Amm. sulph.	22	415	36	5 (I)	New Permanent
No manure		304			Manurial Experiments
Amm. sulph.	28	750	26	5.6 (I)	Unirrigated
No manure		594			
Amm. sulph.	22	623	46	8.4 (U.I)	
No manure		433			

TABLE 9. *contd.*

State	Farm	Nature of soil	Period
Madhya Pradesh	Jubbulpore	*Kabar II* Black	1942–45 (3 years)
	Labhandi	*Kankar* (clay loam)	1923–30 (7 years)
Madras	Coimbatore	Black and red soils	1910–20 (4 crops)
Punjab	Patiala	Loamy to heavy loam	1946–49 (3 years)
	Jullundur	Loam	1946–48 (3 years)
Uttar Pradesh	Gorakhpur	Light loam	1925–29 (4 years)
			SUGARCANE
Bombay	Fadegaon		1939–50 (11 years)
	Arbhavi	Black silts and gritty reddish, sand, alk. patches	1910–14 (4 years)
Bihar	Purulia Upland	Thin gravelley uplard	1930–31 (2 years)
	Kanke	Poor and unproductive, between loam and clay	1924–28 (4 years)
Punjab	Gurdaspur	Heavy loam, well irrigation	1926–30 (3 years)
	Gurdaspur	Loam	1948–49 (2 expts.)
			COTTON
Bombay	Surat	Black cotton soil 1.22–1.52 m, yellowish alluvium below. Deep black soil	1933–49 (6 years)
	Nagpur	Morand II clay loam. Black cotton soil—Uniform	1903–10 (7 years) 1921–27 (6 years)
Madhya Pradesh	Powerkheda	Lighter clay-loam	1926–30 (4 years)

Treatment (kg/ha)		Yield kg/ha	Per cent increase over no-manure	Response (kg/kg N)	Remarks
Amm. su ph.	17	1,024	69	25 (U.I)	
No manure		606			
Amm. sulph.	13	694	22	20.9 (I)	
Amm. sulph.	25	721	56	10.7 (U. I)	
No manure		458			
Amm. sulph.	26	2,046	26	16.6 (I)	
No manure		1,620			
Amm. sulph.	112	2,355	26	4.3 (I)	
No manure		1,894			
Amm. sulph.	25	2,206	21	15.5 (I)	
No manure		1,829			
Amm. sulph.	336	71,250	117	114	
No manure		22,656			
Amm. sulph.	168	6,467	20	88 (*Gur*)	Results expressed as yield of jaggery
No manure		4,990			
Amm. sulph.	22	2,229	11.5	10.5 (U.I.)	
No manure		1,994			
Amm. sulph.	36	1,971	38.8	16 (*Gur*) (U. I)	
No manure		1,411			
Amm. sulph.	25 (*Gur*)	3,053	23.3	7 (*Gur*) (I)	
No manure		2,877			
Amm. sulph.	84	47,665	46	117 (*Gur*) (U.I)	
Amm. sulph.	45	747	35	4.4	
do.	22	594	7	1.9	
No manure		552			
Amm. sulph.	34	1,534			
No manure		1,366	12	5	
Amm. sulph.	22	672	28	6.5	
No manure		526			
Amm sulph.	22	1,467	21	11.5 (I)	
No manure		1,210			

TABEL 9. *Concluded*

State	Farm	Nature of soil	Period	Treatment (kg/ha)		Yield kg/ha	Per cent increase over no-manure	Response (kg/kg N)	Remarks
Madras	Coimbatore	Wetland, loam	1924–32	Amm. sulph.	25	1,781	36	19.6 (I)	
			(8 years)	No manure		1,299			
			PULSES AND OIL SEEDS						
Bihar	Pusa	Clay sandy loam	1932–48	Amm. sulph.	45	678	49	4.9 (U. I)	
		(Crop—*Rahar*)	(6 crops)	No manure		460			
Assam	Kokilamukh	Highland sand and silt deposits	1947–49	Amm. sulph.	45	1,138	69	10.3	
		(Crop—Mustard)	(3 years)	No manure		668			

References : Vaidyanathan, 1933 ; Allan 1933 ; Stewart, 1947 ; Sethi *et al.* 1953 ; *Report of the Expert Fert. Committee*, 1953.

Note : In column 8 (I) means irrigated and (U. I) Unirrigated.

maximum increase in yield per kg while a rate of application lower than 22 kg N for unirrigated wheat appears to give the best return for the investment on fertilizer. In the case of cotton, however, a higher dose at 45 to 67 kg N is preferable in getting a higher increase in the yield. In balanced manuring programme, under irrigated conditions, the above doses can be increased with profitable returns.

As observed from the field experiments conducted at Padegaon for 11 years, a dose of 336 kg of N gave about 117 per cent increase in the case of sugarcane and thus a very high dose of N of this order will be necessary for this crop.

In the experimental trials conducted in India and reviewed by Stewart (1947), the responses of different crops to ammonium sulphate have been shown to be of the following order :

		per kg N
Wheat	—	6.7—17.25
Jowar	—	3.8—15.7
Bajra	—	13.9
Maize	—	13.2
Groundnut	—	13.4
Paddy	—	13.4—15.7

The Institute of Agricultural Research Statistics has brought out data on average yardsticks of additional production of certain food-grains and commercial crops from the use of nitrogenous fertilizers (1964) on the basis of experimental data in cultivators' fields (Table 10).

TABLE 10. YARDSTICKS OF ADDITIONAL PRODUCTION WITH THE USE OF NITROGENOUS FERTILIZER

Crop	Yardstick (tonnes per tonne of N)
Rice	10.8
Wheat (irrigated)	14.0
Wheat (unirrigated)	7.6
Ragi (irrigated)	12.6
Ragi (unirrigated)	9.1
Maize	12.0
Gram	5.5
Sugarcane (N. India)	171.2

These results indicate the value of the nitrogenous fertilizers in increasing yield of some of the crops grown under different soil conditions in India. Ammonium sulphate as a fertilizer is particularly useful for tea manuring because of its sulphate radical as tea requires an acid soil reaction.

Response in combination with phosphatic and potassic fertilizers. While conflicting results have been obtained in a number of trials conducted in India with phosphatic fertilizers alone, it has been found that many areas, where phosphate by itself has a little effect on yield, a combination of nitrogen and phosphorus may be markedly superior to nitrogen. This indicates that the utility of other fertilizers becomes perceptible only after the existing primary deficiency of nitrogen in Indian soils is made good. The additional response in some cases obtained with a supplementary dose of phosphorus was as high as with nitrogen (Idnani, 1952).

The soils in India are generally well provided with potash and there is at present not much demand for potassic fertilizers. For most crops it is felt that when nitrogen and phosphorus deficiencies are made good, the reserves of potash are bound to get depleted and will show up in course of time. The interaction of nitrogen with other nutrients is evident from the comparatively few trials conducted in India in which nitrogen, phosphorus and potash combination has sometimes been found to be superior, to either of these alone and to the combination of nitrogen and phosphorus.

Effect of continuous use. Associated with nitrogen in ammonium sulphate is a quantity of sulphate radical which is left as residue in the soil and reacts with an equivalent of lime forming calcium sulphate. The conversion of nitrogen of the fertilizer into nitric acid is responsible for another equivalent of lime combining with this acid so that the net residue from the use of the fertilizer is an amount of acidity corresponding to two equivalents of lime. In practice, it has been found that each application of 100 kg of ammonium sulphate per hectare roughly corresponds to a depletion of 130–140 kg of soil lime. Ordinarily, this is not a heavy loss, but when the acidity in soil is greatly increased due to low initial lime status followed by heavy doses of ammonium sulphate many beneficial soil processes are likely to be interfered with. The rate of nitrification in particular is decreased, for nitrification does not proceed extensively in the soil when the pH falls below 6. In soils deficient in lime and magnesium, iron, aluminium and maganese are rendered soluble which may be further aggravated when heavy doses of ammonium sulphate are applied to the same soil for a number of years. On the other hand, soils fairly rich in lime will stand protected against the deleterious effect of continuous use of ammonium sulphate as is shown by experiments on Broad-balk soils where with a content of about 4 per cent lime, the use of sulphate of ammonia by itself for 80 years did not affect the crop growth (Mann and Barnes, 1940). Idnani (1949) calculated that with a lime content of 10 per cent in Sind soils, it would take some 2,500 years to neutralize the reserves of lime before any adverse effect of continuous use of ammonium sulphate becomes perceptible. On the Woburn soils, however, which were initially deficient in lime, crop yields started declining after 20 years and at the end of 40 years the soils had become unproductive. The entire damage was, however, found to get restored by the addition of enough lime to such soils to neutralize the acidity. It is thus important that a judicious dose of lime should invariably be combined with each application of ammonium sulphate to prevent the deterioration of soils, particularly those that are deficient in lime. In India, acidic soils occur in some places only, and in general, there is no serious problem arising due to continuous use of ammonium sulphate. A few experiments conducted in India, however, show that although high yields are obtained during the few years of application of ammonium sulphate, the yields are found to decrease in the later years. Mukherjee (1951) observed that in the alluvial soils of central and western Uttar Pradesh, increase in yields of sugarcane could be obtained by sulphate of ammonia alone ; the increase showed a distinct downward trend in succeeding years after about first three years and the deterioration in the tonnage of cane, increase in soil acidity, reduction in total exchangeable bases and depletion of humus content were most pronounced in the case of heaviest application of nitrogen as sulphate of ammonia. Thus single application of ammonium sulphate for many years may lead to soil deterioration.

Rege (1941) concluded from a 12-year's experiment on the cane crop using sulphate of ammonia and organic manures alone and in combination that there was a considerable fall in the yield in ammonium sulphate-treated plots. On wheat in Delhi, similar observations have been made by Desai and Subbiah (1952), who showed that nitrogen applied half in the form of ammonium sulphate and the other half in the form of farmyard manure or compost gave the maximum yields. The necessity of the use of organic manures with sulphate of ammonia has been shown by many Indian investigators (Rege, 1941 ; Basu, 1953 ; Mukherjee, 1951 ; Sanyasi Raju, 1952).

Reponse to sulphate of ammonia. While the major part of nitrogen assimilated by plants enters the roots as nitrate, it has been shown by Shive (1926) that young seedlings absorb ammonia, and as they become older the absorption ratio of nitrogen as ammonia, to nitrogen as nitrate becomes smaller until finally it is less than unity. According to Russell (1932), plants which are relatively rich in carbohydrates such as barley, maize and potatoes readily utilize ammonia. Jolly (1911) showed that rice grown on submerged soils absorbs nitrogen in the ammoniacal form and that this nutrient should be applied to rice as an ammonium salt or as organic nitrogen. He also showed that when nitrates are applied to rice on submerged soils they are partly reduced to nitrite which may cause injury to seedlings.

An excess of ammonium sulphate has often been found to be harmful. Raheja and Misra (1955) showed that excess of nitrogen caused loss of 62 per cent in wheat grain and 36 per cent in straw by lodging, thereby each kilogram of nitrogen bringing about a decrease of 4.5 kg in the grain yield. Similar observations on the effect of excessive manuring with nitrogenous fertilizers on lodging and yield of wheat have been recorded by Singh (1952). Grain yield increased with the increasing nitrogen doses up to 67 kg. per hectare, and thereafter decreased with higher levels. The crop lodged after the first emergence with 84, 112 and 118 kg N per hectare and the percentage of area lodged also increased ; lodging reduced grain yield by 46.2 per cent which is rather a very heavy loss.

2. Ammonium nitrate. *Ammonium nitrate is one of the con*centrated nirtogenous fertilizers, the amount of nitrogen present in the material being nearly 35 per cent as against 20 per cent in the sulphate of ammonia. The nitrogen in the nitrate form is easily available to plants. Besides, ammonium nitrate is less acidic causing a much smaller drainage on calcium than ammonium sulphate, the equivalent acidity being 60 parts of calcium carbonate required to neutralize the soil acidity resulting from the use of 100 parts of the fertilizer material. Ammonium nitrate is being produced in Canada and by a number of plants in the U. S. A. and Europe. The Canadian product is known under the trade name 'Nitra-prills'.

Two properties of ammonium nitrate, viz., (i) hygroscopicity, and (ii) its tendency to cake in storage have tended to discourage its use as a fertilizer. Further, being explosive in nature, it has not been recommended for wide use.

The first two shortcomings in the use of ammonium nitrate as fertilizer have largely been overcome by granulation of the product to give it a round shape with elimination of most of the fine particles and coating the resultant granules with suitable materials to reduce moisture absorption and caking which was found not to adversely affect the fertilizing property of ammonium nitrate. As a further precaution against moisture absorption, ammonium nitrate fertilizers are stored and despatched in moisture-proof bags. These bags may be of polyethylene burlap or cotton lined with paper. Double layers are also used.

A series of experiments on the use of ammonium nitrate as a fertilizer were conducted at the Indian Agricultural Research Institute, New Delhi, at Madras, Uttar Pradesh, Bihar and West Bengal with and without varying amounts of T.N.T. (2 to 5 per cent) and in comparison with the organic and inorganic nitrogen fertilizers and the results are given in Table 11 (Sen *et al.*, 1952; Raychaudhuri *et al.*, 1955).

Ammonium nitrate was found to be as good as, or slightly better than, ammonium sulphate for cereals like wheat and maize in experiments at Motipur and for paddy, perhaps ammonium sulphate is a better fertilizer than ammonium nitrate but more systematic experiments than those conducted at Karnal and West Godavari are needed for confirmation. For both cotton and *jowar* fodder, ammonium nitrate has been found as good as ammonium sulphate or rather slightly better than ammonium sulphate in experiments conducted at the I A R.I., New Delhi. With sugarcane at different stations in Bihar, Uttar Pradesh, Madras and Karnal ammonium nitrate proved as good as ammonium sulphate (Sen *et al.*, 1952).

It appears that ammonium nitrate is a good fertilizer for crops of short duration like wheat and maize. For a crop of long duration like sugarcane with which experiments have been conducted in Uttar Pradesh, Bihar, Madras and Karnal all that can be said is, that its behaviour was as good as that of ammonium sulphate in most cases, and in some cases it proved even superior to ammonium sulphate. In addition, because it contains nitrogen in both nitrate and ammoniacal forms, it is idealy suited for grass crops and other crops that prefer nitrogen in both forms. It is more resistant to leaching than sodium nitrate but less so than ammonium sulphate. Its properties are somewhat similar to that of a 50 : 50 mixture of sodium nitrate and ammonium sulphate.

3. Urea. Urea contains about 44 per cent nitrogen and theoretically, is almost an ideal nitrogeneous fertilizer for crops. In manufacture, pure ammonia is combined with carbon dioxide gas under high pressure to produce an unstable intermediate carbamate which loses molecule of water forming urea. Synthetic production of fertil-

TABLE 11. SOME RESULTS OF FERTILIZER EXPERIMENTS WITH AMMONIUM NITRATE

State	Centre	Duration of Experiment (years)	Rate of N application kg/ha	Yield in kg/ha	Per cent increase over control	Response kg/ha N
			WHEAT			
Delhi	I.A.R.I.	1944–46	45	2,563	44	18.3
		(2 years)	control	1,844		
Bihar	Motipur	1947–49	34	1,023	50	10.1
		(2 years)	control	682		
	Motihari	1947–49	34	1,115	48	10.7
		(2 years)	control	756		
			PADDY			
Punjab						
	Karnal	1944–46	45	2,509	—	—
		(2 years)	control	2,600		
Andhra	W. Godavari	1945	17	1,619	—	—
		(1 year)	34	2,074	13	7.2
			control	1,832		
			MAIZE			
Bihar	Pusa	1948–49	34	863	36	6.9
		(2 years)	control	636		
	Motihari	1948–49	34	1,907	41	16.4
		(2 years)	control	1,355		
			COTTON			
Delhi	I.A.R.I.	1944–46	45	1,049	24	4.8
		(2 years)	control	835		
			SUGARCANE			
Bihar	Sabour	1947–49	67	37,061	20	9.2
			control	30,890		
U. P.	Muzaffar-nagar	1945–49	67	66,449	25	199.2
		(4 years)	134	75,029	48	188
			control	5,310		
U. P.	Gorakhpur	1946–49	56	38,437	15	89.0
		(3 years)	56	37,884	13	39.5
			control	33,460		

lizer grade urea has been undertaken under the expansion programme of the Sindri Fertilizer Factory.

Urea is converted into ammonia in the soil after one or two days of its application and this conversion into ammonia helps in preventing it from being leached away (Allison, 1939). Owing to the rapidity with which certain types of bacteria convert urea into carbamide urea, great care must be taken not to apply urea in too large amounts at any one time in close proximity to germinating seeds or roots of plants, otherwise, injury may result. The initial influence of urea on the soil reaction is alkaline like that of the protein organics, but as urea contains no residual base, its continued use may turn soil slightly acidic. This fertilizer will produce acidity in the soil, and the use of small amounts of dolomitic limestone along with urea is likely to increase the efficiency of the material.

Urea is frequently used in commercial fertilizers. For use as fertilizer, it is frequently employed in combination with superphosphate, the product being called as 'Phosphazote'. The complex salt with calcium nitrate is also recommended for agricultural purposes.

A large number of trials have been conducted in India with urea. In six trials on wheat at Labhandi it gave a poor response of 3 3 kg per kg N compared to 6 to 12 kg obtained with ammonium sulphate. Urea in dilute solution (1 to 3 per cent) can be applied to paddy and wheat as foliar spray with remarkable beneficial results. It has been found that by foliar application of urea plants use nitrogen better than when urea is put as soil application, The protein content as also the yields of rice and wheat crops increase significantly by foliar application of urea than by soil application. Field experiments on a large scale in different parts of the United States, for studying the comparative value of urea and other fertilizers, indicate that the yields of crops with urea are as good as those obtained with ammonium phosphate or ammonium sulphate (Merz and Brown, 1943).

Comparative studies with ammonium sulphate, ammonium sulphate niterate, calcium ammonium nitrate and urea at various centres throughout the country in cultivators' fields and Government farms from 1953 to 1965 reveal that broadly there is no consistent trend of differance between these sources of nitrogen (Ref. Reports of I.C.A.R. on Fertiliser Trials on paddy and on wheat, 1953–56, and on coordinated simple fertiliser trials in cultivators' fields and Model Agronomic Experiments, year-wise, during the Second and Third Plan periods).

Nitrogenous chemical fertilizers being completely water-soluble are likely to suffer losses due to leaching and in this respect are inferior to organics which are characterised by their slow nitrifiability, and the consequent gradual availability to the crop. In recent years, some new compounds with slow nitrogen availability, prepared by the reaction of urea with formaldehyde are coming into use (Yee and Love, 1946 ; Clark *et al.*, 1948). These have been found to be quite comparable with the prevailing nitrogenous materials and sometimes superior to them in maintaining the supply of available nitrogen over a long period of time.

4. Calcium cyanamide. This fertilizer contains about 21 per cent N and 54 per cent CaO and is basic in nature. One hundred parts of this fertilizer will produce basicity equal to 63 parts of calcium carbonate. As a fertilizer, calcium cyanamide is applied to the soil before seeding or planting so that no injury due to cyanamide occurs to the plants.

Decomposition of calcium cyanamide in soil. In the soil, urea and dicyanamide are the only primary decomposition products that calcium cyanamide can form. This conversion of calcium cyanamide usually takes place in two to seven days, and hence it should be applied to crops at least one to two weeks before sowing.

During the decomposition of calcium cyanamide in the soil, Joshi and Singh (1938) observed a lag period before the commencement of nitrification. Dicyanamide formed as decomposition product is, however, not toxic to nitrifying organisms in the concentration in which it is present in the soil. The observed delay occurring between accumulation of ammoniacal nitrogen and its conversion into nitrate, is attributed to the toxicity of the insoluble decomposition products of calcium cyanamide, particularly to the fraction which is extractable by 1 per cent HCl.

Results of field experiments. The number of field experiments conducted with calcium cyanamide are small as compared to those with ammonium sulphate. The few experiments conducted with this fertilizeer indicate good increases varying from 16 to 56 per cent, in the yields of wheat and paddy (Table 12).

TABLE 12. RESULTS OF FERTILIZER EXPERIMENTS WITH CALCIUM CYANAMIDE

Farm (State)	Soil type	Crop	Years	Dosages per hectare of calcium cyanamide	Yield in kg. per hectare	Increase over control (per cent)	Res. pons kg/kg N.
Labhandi (M. P.)	Light laterite	Paddy	1905–16 (11 yrs.)	34 kg N. No manure	1,187 717	65.6	14.0
Coimbatore (Madras)	Fairly fertile. Both red black	Paddy	1923–26 (3 yrs.)	45 kg N. No manure	3,382 2,854	18.6	11.8
Kanpur (U. P.)	Medium loam	Wheat	1909–12 (3 yrs.)	30 kg N. No manure	1,837 1,580	16.2	8.5

5. Sodium nitrate. Sodium nitrate occurs as natural deposit in Chileand is imported in this country. In recent years, it has also been produced synthetically from atmospheric nitrogen, by oxidizing ammonia into oxides of nitrogen and absorbing these in a solution of sodium carbonate. Sodium nitrate carries about 16 per cent nitrogen. The Chilean sodium nitrate contains as impurities a large number of elements like potassium, boron, magnesium, iodine, calcium, chlorine and sulphur (Collings, 1947). It is readily soluble in water and hence immediately available. The chief drawback in this fertilizer has been the poor physical condition brought about in the soil by its continued use due to the deflocculation of soil colloids by the sodium present in this fertilizer. In India, where majority of the soils have either nearly neutral or slightly alkaline reaction, its liberal use is likely to produce considerable damage in the long run.

The results of fertilizer experiments (Table 13) indicate generally a positive response on all the crops, the response being higher particularly with oilseed crops. Continuous use of sodium nitrate for 18 years at Powerkheda (Madhya Pradesh) has, however, led to a negative response. More recent co-ordinated experiments carried out at different centres throughout India show that this fertilizer gives positive response on cotton.

A report from the Tocklai Tea Experiment Station, Assam (1949), shows that Chilean nitrate when applied to sandy well-drained soil initially produced increased yields but on continuous application for a number of years spoiled the tilth. This can be corrected by applying three parts of ammonium sulphate to two parts of sodium nitrate. On heavy soils, sodium nitrate produced harmful effects in the year of application itself. However, experiments were conducted from 1925–26 to 1932–33 in the Central Farm, Coimbatore, to find out the effect of application of Chilean nitrate alone and in combination with organic nitrogen on paddy. The total dosage of nitrogen applied was 56 kg per hectare. *Dhaincha (Sesbania* sp.) and cattle manure formed the source of organic nitrogen. The results indicate that Chilean nitrate in combination with cattle manure in a ratio of 3 : 2 gives best results.

6. Ammonium sulphate nitrate. Ammonium sulphate nitrate (double salt) contains about 26 per cent N and is made by mixing hot solutions or moist salt of ammonium sulphate and ammonium nitrate and then drying the mixture. The double salt results in a soft crystalline material in which about one-fourth of the total nitrogen is in the nitrate form and three-fourths in the ammoniacal form. This double salt no longer has the hazardous character

TABLE 13. RESULTS OF FERTILIZER EXPERIMENTS WITH SODIUM NITRATE

State	Farm	Nature of Soil	Crop	Period	Treatments (kg N/ hectare)	Yield kg/ hact	Per cent incr-ease over no manure	Res-ponse kg/kg N
Assam	Khasi and Jaintia Hills	Acidic, rich in organic matter	Paddy	1925–30	Sodium nitrate 19	2718	15	19
				(6 years)	No manure	2355		
Madras	Aduthurai	Rich in K_2O, deficient in N and P_2O_5	Paddy	1925–28	Sodium nitrate 56	3528	18	9.5
				(3 rears)	No manure	2998		
		Wet lands, supplied with all elements of plant food	Paddy	1925–31	Sodium nitrate 56	3091	9	4.4
				(6 years)	No manure	2845		
Madhya Pradesh	Labhandi	Kankar (clay loam)	Wheat	1923–30	Sodium nitrate 17	963	19	9.3
				(7 years)	No manure	806		
Maharashtra	Nagpur	Black soil	Wheat	1906–20	Sodium nitrate 22	517	92	11.1
				(15 years)	No manure	269		
,,	Nagpur	Heavy clay loam	Saff-lower	1896–02	Sodium nitrate 22	862	19	6
				(5 years)	No manure	728		
			Til	(5 years)	No manu e	347	69	6.5
						202		
			Linseed	(3 years)	No manure	190	54	3
						123		
			Mustard	(4 years)	No manure	291	36	3.5
						213		

References : Vaidyanathan, 1933 ; Allan, 1933.

of ammonium nitrate and is perfectly safe for handling. There is about 50 per cent saving in sulphur or sulphuric acid and manufacture of this fertilizer has been undertaken in the expansion programme of the Sindri Fertilizer Factory.

Ammonium sulphate nitrate is less hygroscopic than ammonium nitrate and may, therefore, be more suitable for storage and transport to long distances. The acid equivalent (85) rated as carbonate of lime, is comparatively less than that of ammonium sulphate. Fertilizer tests conducted in agricultural experiments in foreign countries have shown that the product compares favourably with many of the leading nitrogenous materials (Collings, 1947). Recent field experiments in India on paddy and wheat also show that, on equal nitrogen basis, this fertilizer is equal in efficiency to ammonium sulphate *(Fertilizer Trials on Paddy, ICAR, 1959 ; Fertilizer Trials on Wheat, ICAR, 1959.)*

7. Ammonium chloride. Ammonium chloride, also known as muriate of ammonia, is synthesized by combining ammonia with hydrochloric acid. As it can be a suitable outlet for the by-product chlorine from the caustic industry, its cost of production on an industrial scale can be quite low. It is also produced by treating sodium chloride with ammonia and carbon dioxide to form sodium bicarbonate and ammonium chloride, and the resulting ammonium chloride is then separated from the solution. The procedure adopted in the industry for the manufacture of soda ash is similar to the process used for the manufacture of ammonium sulphate from gypsum. Ammonium chloride contains about 26 per cent of nitrogen, and has very good physical condition especially when granulated. Ammonium chloride may be used in mixtures of superphosphate and potash without caking. It is an acid fertilizer and 100 kg of this fertilizer will produce an acidity equivalent to 128 kg of calcium carbonate ; this figure is comparatively higher than that of ammonium sulphate when considered in terms of nitrogen added to soil. For those crops which are susceptible to chlorine toxicity, ammonium chloride has been found to be inferior to ammonium sulphate. Russell's (1932) results at the Rothamsted Experimental Station show that ammonium sulphate is superior to ammonium chloride as a source of nitrogen for potatoes, but less effective for barley. Skinner and Buie (1926) found ammonium chloride to be equal in value to ammonium sulphate in the production of cotton. In India it has been tried in very few cases in the past (Chatterjee, 1953 ; Gadre, 1954). In an experiment with wheat at Kanpur conducted for five years (1882–86), ammonium chloride at 34 kg N along with 36 kg of P_2O_5 as super per hectare and the calcium sulphate, gave on an average 97 per cent increase over the control (Vaidyanathan, 1933). A fairly large number of trials carried out in India during recent years also point out its high fertilizing value comparable to that of sulphate of ammonia (Ghosh *et al.*, 1956 Desai, 1956 ; Khanna 1956).

8. Calcium nitrate. This fertilizer usually contains about 15 to 16 per cent nitrogen and is very hygroscopic in nature. This defect has largely been overcome by producing it, in a granular form and packing in moisture-proof multi-walled paper bags cemented with asphalt to keep the material dry. It is an excellent nitrogenous fertilizer particularly for those crops which require large amounts of nitrogen and calcium (Collings, 1947). The experiments conducted with wheat in Kanpur and cotton in Surat indicate its good performance with 15 to 19 per cent increases in yields over the control (Table 14).

TABLE 14. RESULTS OF FERTILIZER EXPERIMENTS WITH CALCIUM NITRATE

Farm (State)	Soil type	Crop	Years of experiments	osages	Yields in kg hectare	Per cent increase over control	Response kg/kg N
Kanpur (U.P.)	Medium loam	Wheat	1909–12 (3 yr)	Cal. nitrate 28 kg N/ha.	1,879	18.9	10.7
				No manure	1,568		
Surat (Gujarat)	Black cotton soil yellowish alluvium below deep black	Cotton	1908–14 (5 yr)	Cal. nitrate 11 kg N/ha.	605	15	7.0
				No manure	526		

9. Calcium ammonium nitrate. Calcium ammonium nitrate is prepared by mixing ammonium nitrate with either precipitated calcium carbonate or ground limestone or ground dolomitic limestone. The purpose of adding calcium carbonate to ammonium nitrate is to make it safe for handling and less hygroscopic. It is a granular fertilizer and contains 15.5 per cent nitrogen and 27 per cent CaO (Ignatieff, 1949). The products A.N.L., Nitrochalk (I.C.I.) and Cal-Nitro, are prepared in a similar way but have a composition of about 20.5 per cent N (half in the nitrate and the half in the ammoniacal forms), 9 per cent lime and 7 per cent MgO (Collings, 1947). Experiments so far conducted with this fertilizer in this country have given good results, particularly on acid soils. It may be mentioned that it is one of the most important nitrogenous fertilizers which is under production in large amounts in India.

Relative performance of different forms of nitrogenous fertilizers. The main reasons for differences in the effectiveness of different forms of nitrogen for specific crops could be due to (i) the loss by leaching from the soil, (ii) mobility or immobility of the source, (iii) effect of soil reaction on availability, (iv) effect of sources on soil reaction and other soil properties, (v) secondary elements, and (vi) form of nitrogen required by the plants.

The superiority of one source of nitrogen on the other is sometimes due to the accompanying ion or element. For instance, with inadequate potassium fertilization the sodium nitrate might prove beneficial to some extent in the nutrition of plants on soils poor in potassium as sodium substitutes for potassium. Similarly. if calcium, magnesium and sulphur levels in the soil are below a critical level, sources containing these elements might prove superior to others.

Results of field studies in the United States with cotton, corn, small grains and vegetable crops have shown that one source of nitrogen is generally as efficient as any other where the soils were adequately supplied with potassium and limed properly. These experiments, however, indicate that a mixture of different forms of nitrogen is generally superior to any single form of application. This may be due to the fact that some crops thrive better on ammoniacal form of nitrogen, while some others prefer nitrate form. However, in normally well-aerated soils, whatever may be the source of nitrogen applied, nitrate form will predominate

In India although experiments indicate that ammonium sulphate is slightly superior to other forms of nitrogen in most of the soils, as pointed out by Stewart (1947) and corroborated by observations made by Sethi *et al.* (1953) and Basu (1953), the primary necessity of most of the soils is that application of nitrogen in any form that can be easily obtained and the choice of the form probably is only subject to the consideration of economics.

Vachhani (1952), Gupta (1952) and Chandnani (1952) found that among all the other nitrogenous fertilizers ammonium sulphate was the best. Chandnani (1954) experimented on wheat with Chilean nitrate, ammonium nitrate, ammonium sulphate and urea and observed that these fertilizers could be rated as under :

TABLE 15

Level of nitrogen	Ammonium sulphate	Ammonium nitrate	Chilean nitrate	Urea
23 kg per hectare	1.00	0.88	0.84	0.66
45 kg per hectare	1.00	0.88	0.87	0.65
Average net profit in rupees per rupee invested	2.01	2.98	1.01	2.22

These experiments were conducted over a period of three years. At current prices ammonium nitrate was found to be the cheapest source of nitrogen for fertilizing wheat.

In the fertilizer trials on paddy, conducted under the Indo-U.S. Technical Co-operation Agreement, on Soil Fertility and Fertilizer Use Project, nitrogen as ammonium sulphate in cultivators' fields gave good response at all the centres, the average response of paddy to 22 kg N being 4–5 kg per hectare. With increase in nitrogen level to 45 kg there was an additional response of 190 kg per hectare. On an average, the response to ammonium sulphate and urea was nearly the same at either 22 or 45 kg N per hectare. In complex experiments at selected centres, the average respose to urea was 85 kg per hectare less than that due to ammonium sulphate at 45 kg N level, while at 22 kg N, urea gave 62 kg per hectare less than ammonium sulphate. Ammonium nitrate also showed a lower response than ammonium sulphate at the 45 kg N dose, the average difference at 45 kg N level being 185 kg per hectare (*Fertilizer Trials on Paddy*, I.C.A.R., 1959). Raychaudhuri *et al.* (1955) reviewed the results of a large number of trials on different important agricultural crops carried out during 1944 and 1949 in various parts of India with salvaged ammonium nitrate, with a view to ascertaining its manurial value. It has been observed that ammonium nitrate is an excellent nitrogenous fertilizer for short-duration crops like wheat, maize and *jowar*, and is fully comparable to ammonium sulphate, but for paddy the latter seems to be somewhat better. For a long-duration crop like sugarcane it can be placed on equal merit with sulphate of ammonia.

The results of fertilizer trials on wheat conducted during 1953–56 showed that, on an average, the response to ammonium sulphate and urea at levels of 22 and 45 kg N per hectare were nearly the same at higher levels of application, but at the lower level the urea was found to give an additional response of 62 kg per hectare over ammonium sulphate under irrigated conditions. Under unirrigated conditions slightly better response was indicated for ammonium sulphate. In complex experiments at selected centres, comparison of urea, ammonium nitrate, ammonium sulphate nitrate and ammonium chloride was made with ammonium sulphate. On an average, urea gave about 24 kg less response than ammonium sulphate at both the levels of nitrogen. Ammonium nitrate also showed a response lower than that to ammonium sulphate, the average difference being nearly 24 kg at 22 kg N level and 32 kg at 45 kg level (*Fertilizer Trials on Wheat*, I. C. A. R., *1959*).

Mahapatra and Sahu (1963), working on the efficiency of nitrogenous fertilizers in sandy loam lateritic soil of Bhubaneswar, have shown that all the five forms of nitrogenous fertilizers, viz., ammonium sulphate, ammonium sulphate nitrate, ammonium chloride, calcium ammonium nitrate and urea, gave significantly higher grain yield of rice than the control. Their findings indicated that the application of the above fertilizers at three levels gave an increase in yield varying from 22.4 kg per hectare to 908 kg per hectare and that there was no significant difference between the different forms. A summary of the above study for the years 1955–56 to 1958-59 is given in Table 16.

The residual effect of nitrogenous fertilizers, according to Karunakar (1948), is almost nil and there is need for renewed application of fertilizers every time.

It has been found by Sen (1953) that in calcareous soils containing 30 to 35 per cent calcium carbonate, rate of nitrification of ammonium nitrate is greater than that of ammonium sulphate. In non-calcareous soils, on the other hand, the rate of nitrification remains the same.

It was reported by Dastur and Malkani (1933), Dastur and Pirzada (1933), and Dastur and Kalyani (1934) that during the earlier stages of life-cycle, rice plants absorbed more of ammonium ion and at later stages more of nitrate ion In continuation of Dastur's work, Bamji (1938), however, did not notice any perceptible variation of total nitrogen in two plots treated with 90 kg nitrogen as ammonium sulphate or ammonium nitrate.

Finfrock and Donahue (1962) have shown that for pound for pound of nitrogen, ammonium nitrate and calcium ammonium nitrate are equally as efficacious as urea or other ammonium forms of nitrogen such as ammonium sulphate and ammonium chloride on all upland crops on most soils, but not efficient when used on paddy. Also for most efficacious use, fertilizers for paddy should be placed 5 to 10 cm.

TABLE 16. GRAIN YIELD IN KG PER HECTARE (AVERAGE OF ALL YEARS)

Form of fertilizer	Levels of N in kg./hactare			Mean	% over control	Relative rating	Remarks
	N_{20}	N_{40}	N_{60}				
Ammonium sulphate	2,338	2,655	2,615	2,536	127.78	100.00	Average of 4 years
Ammonium chloride	2,295	2,282	2,648	2,409	121.34	94.96	Average of 4 years
Urea	2,256	2,202	2,557	2,338	117.79	92.18	Average of 3 years
Ammonium sulphate nitrate	2,012	2,645	2,893	2,517	126.82	99.24	Average of 2 years
Calcium ammonium nitrate	2,238	2,318	2,583	2,379	119.87	93.81	Average of 2 years
Average	2,228	2,421	2,660				
Control (no manure)				1,985			

deep in the soil. Mitsui (1950) has shown that recovery of ammonium nitrogen for upland crops amounted to 50 to 60 per cent, but for paddy only 30 to 40 per cent. The low recovery of ammonium nitrogen for paddy is explained by Finfrock and Donahue (1962) as follows :

"If ammonium nitrogen is broadcast on the surface of soil or in the water, the ammonium attaches to the clay particles of surface soil. This surface layer contains enough oxygen, which is carried by the water from the air, so that the ammonium nitrogen can be changed by nitrifying bacteria to nitrate nitrogen just as occurs in well-aerated upland soils. This converted nitrate nitrogen, however, dose not attach itself to the clay particles in the soil as does ammonium nitrogen, but moves freely with the water. Thus, the nitrate nitrogen is carried by the water into the deeper layers of the soil where oxygen is not present and denitrification takes place. The applied nitrogen is thus lost from the soil as nitrogen gas escapes to the atmosphere".

The growing popularity of anhydrous ammonia (82 per cent N) as a source of nitrogen for crops in the United States has prompted a few workers in this country to find out the possibilities of substituting ammonium sulphate with this fertilizer in view of its low cost. Govindarajan (1956) has been able to show from the small-scale trials on *ragi* that liquor ammonia outyields ammonium sulphate to a considerable degree. In the field experiments, carried out on paddy at three government farms using 34 kg of nitrogen per hectare as liquor ammonia and ammonium sulphate, differences in yield of grain and straw were not significant. In certain large-scale experiments, carried out in cultivators' fields, both grain and straw yields were distinctly higher under liquor ammonia treatment. In the case of sugarcane the yields were not significantly different between treatments.

The recent experiments, that have been conducted with aqueous ammonia on the fertilization of cotton at the Surat Agricultural Station in Gujarat State, have shown that aqueous ammonia is as efficacious as ammonium sulphate as a nitrogenous fertilizer (Bhat *et al.*, 1955).

Liquid ammonia applied with irrigation water was tried as a fertilizer for rice in small-scale pot experiments at Cuttack. Sulphate of ammonia was found to be superior at both 22 and 45 kg N *(Rep. C. R. R. I, 1950–51)*.

A general statement of the position in respect of the relative manurial values of nitrogen in different forms appears to be that, when compared in magnitude with the reponses obtained or obtainable from the application of nitrogen in some readily available form, the differences in response to different forms of readily available nitrogen are small and relatively unimportant. In other words, the result suggests that the factor of prime importance to crop yield in the country is the application of nitrogen in some form, which will become available to the plant in a reasonably short period. Evidence on these and other aspects of nitrogenous manuring is by no means conclusive and the response to individual forms may vary with the crop, soil and climate.

For sugarcane, in certain experiments, a mixture of sulphate of ammonia and oilcake appears to be superior to either source of nitrogen by itself. On the other hand, sulphate of ammonia with mustard cake, groundnut cake and *neem* cake are all equally good for cotton. That the application of nitrogen in some readily available form is the factor of major importance and that the experimental evidence for and against individual cakes and sulphate of ammonia is conflicting, are well illustrated by the results of Ramiah and Sahasrabuddhe (1947).

Experiments with other soluble forms of nitrogen, such as sodium nitrate, calcium cyanamide, ammonium nitrate and urea, are still not many in number to permit strict generalizations being made on their relative manurial values. Ammonium sulphate in a few cases seems to be somewhat superior to other forms of inorganic nitrogen. Much more experimental evidence is still required to be obtained from all over the country.

The relative efficacies of seven nitrogenous fertilizers supplying about 22 to 34 kg of nitrogen have been worked out for paddy by Ramiah *et al.* (1952). The figures are as follows : ammonium sulphate —100, ammonium phosphate—86 ; calcium cyanamide—64, sodium nitrate —40, ammonium nitrate—92, urea—82, and potassium nitrate—44.

The relative efficacies of ammonium chloride, ammonium sulphate, urea and ammonium nitrate at 22 and 45 kg nitrogen doses per hectare on paddy (variety T. 1145) have been studied at Cuttack with the following results : at 22 kg N dose per hectare the responses in yield in percentage per kg of N applied have been 24.7, 21.3, 17.1 and 16.4 for ammonium chloride, ammonium sulphate, urea and ammonium nitrate respectively. There was proportional increase in yield on raising the N dose to 45 kg and the corresponding response in percentage were 21.0, 26.6, 18.1 and 20.7 per kg of N applied.

With the object of finding out the relative performance of different kinds of nitrogenous fertilizers, experiments were conducted at Sabour (pH 6.8; $CaCO_3$ 0.5 per cent), Pusa (pH 8.0 ; $CaCO_3$ 32.5 per cent) and Kanke (pH 5.6 ; $CaCO_3$ traces) at Government Farms in Bihar, representing the three broad soil divisions of the State having treatments of two levels (28 kg and 56 kg N) each of ammonium sulphate, urea, ammonium sulphate nitrate, calcium ammonium nitrate and ammonium chloride over a basal dressing of 33.6 kg of P_2O_5 and 33.6 kg K_2O per hectare. The test crop was wheat. In *kharif*, maize was tried with suitable modifications of doses. The results of these experiments show that different forms of nitrogenous fertilizers do not differ significantly in their effect on the yield of the crops.

Some trials have also been conducted on paddy and wheat on cultivators' fields in Bihar under the I.C.A.R. demonstration scheme, with the object of studying the behaviour of new nitrogenous fertilizers, viz., urea, ammonium sulphate nitrate and calcium ammonium nitrate in comparison to the commonly used nitrogen fertilizer—ammonium sulphate. Simple randomised block design was followed in such trials, the treatments being (i) control, (ii) 22.4 kg N + 22.4 kg P_2O_5, and (iii) 22.4 kg N+22.4 kg P_2O_5+22.4 kg K_2O per hectare. Nitrogen was applied as ammonium sulphate, urea, calcium ammonium nitrate and ammonium sulphate nitrate, P_2O_5 as single superphosphate and K_2O as muriate of potash. The dose of nitrogen in trials conducted during 1960–61 was 28 kg per hectare. At these levels of nitrogen the responses to all these nitrogenous fertilizers on both paddy and wheat are again almost of the same magnitude. The average figures for three years (1960–61 to 1962–63) for paddy and wheat are given in Table 17.

TABLE 17. DEMONSTRATION TRIAL RESULTS OF DIFFERENT NITROGENOUS FERTILIZERS* (q./ha)

Type of nitrogenous fertilizer	Crop	Control	Response to	
			28 kg N	22.4 kg P_2O_5
	1960–61			
SA	Paddy	15.68	5.90	3.50
Urea	Paddy	15.87	5.90	3.87
ASN	Paddy	14.48	4.61	4.06
CAN	Paddy	16.67	6.64	2.49
S/A	Wheat	8.95	4.52	1.56
Urea	Wheat	9.13	3.96	0.74
AS/N	Wheat	10.24	4.33	2.30
CA/N	Wheat	9.68	3.96	1.75
	1961–62			
SA	Paddy	13.74	5.25	8.48
Urea	Paddy	14.11	5.07	7.84
ASN	Paddy	14.39	5.16	7.84
CAN	Paddy	13.65	5.81	8.39
SA	Wheat	7.33	4.79	5.62
Urea	Wheat	7.56	4.33	5.90
ASN	Wheat	7.56	4.89	6.45
CAN	Wheat	7.65	5.53	6.55
	1962–63			
SA	Paddy	13.38	6.82	8.39
Urea	Paddy	13.10	5.81	7.84
ASN	Paddy	13.28	5.99	7.94
CAN	Paddy	13.28	6.36	7.75
SA	Wheat	7.84	4.52	5.81
Urea	Wheat	7.84	4.42	5.53
ASN	Wheat	7.84	4.33	5.25
CAN	Wheat	7.65	4.61	5.53

*Sinha, 1963 (Private communication).

A point worth keeping in mind is that while in any experimental programme priority should certainly be given to the study of those manures which are available locally, there is also a need for experimental work with other manures or fertilizers which could possibly be manufactured or otherwise obtained, if the evidence in their favour should prove sufficiently strong.

Time and method of application. Although many conflicting and contradictory results have been obtained in various experiments on the time of application of fertilizers, the bulk of the evidence appears to suggest that (i) for crops of long growing period, such as sugarcane, part of the nitrogenous dressings should be given at planting time and the remainder in the form of top-dressing, e g., at earthing-up time ; similarly for potato top-dressings are found to be beneficial, and (ii) for cotton grown under irrigated conditions, nitrogenous top-dressing at the time of flowering is beneficial and superior to application at other times. Otherwise, in general, nitrogenous manure in readily available form may usually be given with greatest advantage as an early application at the time of sowing. It will, of course, be realized that there are many individual exceptions to such generalization.

Ammonium sulphate when applied to paddy two weeks after transplanting yielded better results than at the time of transplanting (*Ann. Rep. I.C.A R.* 1937–38). Narsing Rao (1954) reported that the application of ammonium sulphate four weeks after transplanting at 22 kg N per hectare was the best treatment which increased the yield of paddy by 395 kg per hectare. Singh (1952) obtained best results on wheat with the application of nitrogen in two instalments, one at germination 12 days after sowing and the other at tillering 30 days after sowing. Single application at the time of flowering was not beneficial. According to Khan (1946) the best time for application of ammonium sulphate is when plants enter the reproductive phase, i. e., at the time of development of buds and flowers. Ammonium sulphate application after stand was distinctly superior to the application at the time of sowing. Thus 32.5 kg nitrogen per hectare after stand yielded 104 per cent increase as compared to 69 per cent when applied at sowing.

Application of urea and sulphate of ammonia to paddy at different stages of the crop growth, beginning from about four days before planting to a week before flowering, indicated, in general, a rather insignificant effect of the time of application on crop yield. On a heavy clay soil area, split-dose application, however, showed a much higher response than a single-dose application (*Fertilizer Trials on Paddy,* *I.C.A.R., 1959*). The two fertilizers, when applied to wheat, either at the sowing time or at the time of first irrigation, did not show any significant effect due to different time and method of their application (*Fertilizer Trials on Wheat, I.C.A.R., 1959*).

From the limited amount of experimental work on the comparison of different methods of applying nitrogenous manures, there are indications that under rainfed conditions drilling or placement of cakes at the sides and slightly distant from the plant rows may be superior to ordinary broadcast application. There is some evidence that this finding may be applied also to dressings of ammonium sulphate. For cotton, sulphate of ammonia may be applied either by broadcast or by placing round the stem of plants (Khan, 1946). The experiments conducted at the Rice Research Institute by Ramiah *et al.* (1952) showed that, by applying two-third portion of nitrogen as ammonium sulphate at 50 to 75 mm depth in dry soil a day before water was let in and one-third portion later in the form of pellets at the same depth, the response per kg of nitrogen was 19.5 kg in dry soil and 32 kg while applied in wet soil. It was pointed out by Ramiah *et al.*, (1953) that under waterlogged conditions in rice soils, the upper oxidizing layer converts ammonia to nitrate, which on passing down to the immediately lower reducing zone gets changed to nitrate and nitrogen, whereas in sub-surface application the ammonium ions remain fixed and unchanged and can be available to plants. They obtained significantly higher yields of paddy by subsurface application than surface broadcast.

More experiments on the subject are, however, necessary. For crops grown under irrigated conditions, there appears to be no evidence that drilling or placement of nitrogenous manures has any advantage over broadcast application. These observations, however, do not apply to crops like sugarcane and potato, where earthing up operation is involved. In respect of other methods of providing crops with nutrients, some work has been done in studying the effects of coating the seed with nitrogenous fertilizer. Kalamkar (1942) reported promising results by this method in trials on cotton. There is, however, a danger that such treatment may adversely affect germination and later experiments may not yield encouraging results.

PHOSPHATIC FERTILIZERS

The phosphatic fertilizers in common use are superphosphate (ordinary or concentrated), nitrophosphate and dicalcium phosphate which are produced by the action of acid on rock phosphate or bones, basic slag, metaphosphate, etc., produced by fusion methods. The production methods of these fertilizers, their properties and their performance in Indian soils on different crops are discussed below.

Production methods. The naturally occurring rock phosphates and bones contain the phosphates as tricalcium phosphate, which is practically not available to plants. Some of the earliest methods for converting phosphate rock into a more available form of phosphatic fertilizer was by treatment with strong sulphuric acid, by which method the superphosphate is being manufactured even today.

It is believed that the use of a valuable heavy chemical like sulphuric acid for super phosphate production is rather wasteful. Therefore, the problem of preparing other suitable forms of phosphatic fertilizers consists in the use of acids other than sulphuric acid or in the use of high temperatures for fusing rock phosphates with suitable materials to give useful phosphatic fertilizers, like water-soluble mono-calcium phosphate or citrate-soluble dicalcium phosphate.

Relative merits of water-soluble and citrate-soluble phosphate. The available phosphate content of artificial fertilizers may be either in water-soluble form as in single superphosphate, triple superphosphate and ammonium phosphate or in citrate soluble form as in dicalcium phosphate. The relative merits of water-soluble and citrate-soluble phosphate with reference to the response to crop yield has been a subject of discussion.

From the results obtained in several countries and in India, it can be said that the relative value of water-soluble and citrate-soluble phosphatic fertilizers would be guided by several known and unknown factors, viz., the type of the fertilizer, the soil type, its reaction, humus content, microbiological activity, water supply, etc. On the two following factors, however, there is general agreement : (i) citrate-soluble phosphatic fertilizer is more effective as a source of phosphorus in acid to near-neutral soils and a high degree of water-solubility appears to be of importance in alkaline soils. The optimum soil pH range for maximum availability of water-soluble phosphates is 6.5–7.0, (ii) in natural and alkaline soils citrate soluble phosphate may be as efficacious as water-soluble phosphate, if applied along with organic matier, (iii) in short-duration crops water-soluble phosphate is more beneficial than citrate-soluble form whereas citrate-soluble phosphate is suitable for crops with long growing season or those which are biennial or perennial. As has been shown by experiments with radioactive phosphorus, it is essential to supply easily soluble phosphorus to the young plants and also to the plants with a limited root development. Also, more soluble form of phosphorus appears to hasten maturity which is of importance to short-duration crops.

In view of the high prices of imported sulphur and sulphuric acid in India, efforts were made at National Chemical Laboratory

(Gupta, 1951) to produce dicalcium phosphate containing 40 per cent P_2O_5, of which about 95 per cent is citric soluble, by using hydrochloric acid and rock phosphate. The production of semi-acidulated rock phosphate of the *kotka* type was also investigated (Gadre and Gupta, 1953) in which only alternate layers or batches of rock phosphate are acidulated with sulphuric acid. On maturing, this results in a fertilizer of high citrate-soluble phosphate, with about 50 per cent economy in sulphur requirement.

A simple method of obtaining dicalcium phosphate from raw bones on a cottage-industry basis (Gulati *et al.*, 1955) is to treat the raw bones with dilute hydrochloric acid. The organic residue rich in glue, gelatin and nitrogen is separated and the soluble fraction is treated with the calculated amount of lime to precipitate out dicalcium phosphate.

High-temperature phosphates such as the silicophosphate (Fox, 1946; Hignett and Hubuch 1946; Macintre *et al.*, 1944), calcium metaphosphate (Freer and Hall, 1941), phosphate rock-magnesium silicate glass (Hill *et al.*, 1947) and Rhenania phosphate can also be very useful fertilizers, but further experiments with them are necessary to establish their fertilizer efficacy.

The rock phosphate deposits of India, either at Trichnopoly or in Singhbhum, contain high amounts of calcium carbonate and iron or aluminium and present a great difficulty for their economic utilization. However, it may be possible to use the Trichy rock phosphate for dicalcium phosphate production (Gadre and Gupta, 1953).

N. Jayaraman, Director of Essen & Co., Malleswaram, Bangalore (1953, 1963), claims that he has been able to evolve a process of ultilization of indigenous rock phosphate. The process consists in the fusion of the ground phosphatic nodules and magnesia-bearing rocks in suitable proportions at 1000°C in a oil-fired rotary kiln, and quenching in water which produces a granular grey-coloured material 'fused calcium magnesium phosphate fertilizer' with 16 to 18 per cent P_2O_5 which is almost entirely soluble in 2 per cent citric acid and is, therefore, in an available form. High cost of electricity in the country is one of the main handicaps in the utilization of this invention. The fertilizing value of the 'fused calcium magnesium phosphate fertilizer' on acid soils needs examination.

One way of utilizing indigenous rock phosphate would be to use in fertilizer mixture after grinding, and this is a straight forward way of utilizing the material for fertilizer use. But the nodules are very hard and grinding to a fine mesh is expensive. The possibility of grinding these hard materials at the quarries should be explored.

The phosphatic nodules of the Trichinopoly district, Madras : Krishnan (*Rec. Geol. Surv. India* 1949, 77, Professional Paper No. 9, 22-23) states that the resources of this mineral may be taken to be about 8.13 million tonnes, which are substantially the same as were previously estimated by Warth, if reckoned to a depth of 200 ft and about 2 million tonnes if exploitation to a depth of only 50 ft is contemplated.

Apatite deposits of Singhbhum, Bihar : It has been generally estimated that some 700,000 tonnes of minerals carrying on an average 20–25 per cent P_2O_5 may be extractable from this deposit. A representative sample of phosphatic nodules from Trichinopoly on analysis gave the following values : $Ca_3(PO_4)^2$, 56.7 ; P_2O_5, 26.0; $CaCO_3$, 13.5; mixed oxides (Fe_2O_3 and Al_2O_3), 8. 9 ; and CaF_2 5.3 per cent. The material coarsely ground was extracted with 27.5 per cent commercial hydrochloric acid free from phosphate at 80°C. The product obtained had an average P_2O_5 content of 44-45 per cent, 41-42 per cent P_2O_5 being soluble in neutral ammonium citrate solution. The yield obtained by extracting a 500 gm sample of the nodule was about 235 gm of dicalcium phosphate, giving an overall efficiency of about 80 per cent.

Phosphorite deposits located in Laccadive Island : Very recently, large deposits of low-grade phosphorite accumulations of recent origin have been located in the Laccadive, Amindivi group of islands, which occupy an area of about 2,752 hectares off the south-west coast of India. These small coral islands number 20 in all. A preliminary appraisal of the deposits of phosphatic material in these islands carried out by the Indian Bureau of Mines, resulted in the following tentative conclusions.

(a) There is evidence for the occurrence of both Guano deposits and phosphorites, the latter resulting from the phosphatic acid reaction (derived from the Guano) with coral sands and coralline limestone originally present in the islands.

(b) Out of the total area of 2,752 hectares, comprising 20 islands, only about 30 per cent (i. e., about 810 hectares) is available for detailed investigation.

(c) Preliminary work has indicated that a total area of 200 hectares, spread over six islands, has phosphates of commercial value The tentatively estimated reserves in this area are of the order of 8.5 million tonnes with 12 per cent P_2O_5, up to an average depth of 3 metres.

(d) The present data are inadequate to come to any definite conclusions. It is probable that another 200 hectares, out of the remaining area of 600 hectares, may prove to be promising.

(e) The phosphates available from this source being generally of low grade, they cannot be readily used in the manufacture of superphosphate and, therefore, they require to be beneficiated.

(f) Out of the 8.6 million tonnes of reserves tentatively estimated, about three million tonnes are likely to yield a grade of little over 16 per cent P_2O_5, which in terms of tricalcium phosphate average around 35 per cent SPL (superphosphate of lime) and can be used with soil as a direct fertilizer after grinding.

(g) If the deposits are finally proved to contain at least three million tonnes of phosphatic materials of superphosphate grade (30 per cent P_2O_5) as anticipated, they can sustain an annual production of 0.1 million tonnes for 30 years, contributing to an annual production of 0.203 million tonnes of superphosphate fertilizer.

(h) Detailed analysis of five samples have shown that the CaO content ranges from 25.16 to 50.19 per cent, FeO content varies from 0.33 to 4.33 per cent, and K_2O, MgO, Na_2O and nitrogen contents are all low. The properties of the different fertilizers and their performance in Indian soils on different crops are discussed below in the order of their importance.

1. Superphosphate. *(i) Ordinary superphosphate.* Ordinary superphosphate is an established phosphatic fertilizer, containing 14.5 to 20 per cent water-soluble P_2O_5, 25 to 30 per cent lime, and 28 to 30 per cent sulphate. A typical sample contains about 50 per cent gypsum, 26.6 per cent monocalcium phosphate, 4.6 per cent di-and tricalcium phosphates, 7 per cent silica, 4 per cent iron aluminium sulphates, and 1.5 per cent calcium fluoride (Collings, 1947). The Indian standard specifications prescribed for this fertilizer are as follows: There shall be two grades of the material, namely Grade I and Grade 2. The material shall be free from excessive lumps and shall not form a hard cake on storage. The material shall also comply with requirements given in the Table 18.

The fertilizer value of the superphosphate is due to the water soluble monocalcium phosphate which is in an immediately available form.

Results of Field Experiments. The results of some typical field experiments conducted in India with superphosphate (Table 20) show increases in yields from 8 to 30 per cent with an average of about 18 per cent and a response of 7.7 kg per kg of P_2O_5 in the case of paddy. In the case of rainfed wheat from a poor and negative response to a high per cent increase of 93.3 has been obtained. Wheat under irrigation, however, show a consistent increase in the yields ranging from 7 to 16 per cent. At Coimbatore, wet lands gave as much as 61 per cent increase which could not be obtained normally in the wheat-growing areas. The average percentage increase in yield and response per kg of P_2O_5 excluding the above particular case work out to 11.1 and 5.4 respectively. In the case of rainfed sugarcane the response to superphosphate has been insignificant and in some cases negative, but with irrigated crop, increase ranging from 10 to 105 per cent have been obtained. The responses in cotton yields were not consistent and from negative to increase up to 27 per cent over control has been indicated from the field experiments.

TABLE 18. REQIRMENTS FOR SUPERPHOSPHATE

Sr. No.	Characteristics	Requirements	
		Grade 1	Grade 2
(i)	Moisture, per cent by weight, max.	12.0	12.0
(ii)	Free phosphoric acid (as P_2O_5) per cent by weight, max.	4.0	4.0
(iii)	Water soluble phosphates (as P_2O_5), per cent by weight, min.	18.0	16.0
(iv)	Available phosphates (as P_2O_5), soluble in neutral ammonium citrate solution and water soluble phosphate (as P_2O_5) by weight, min.	18.5	16.5

The effect of superphosphate on the yield of pulses (leguminous crop) has been quite conspicuous. High increases ranging from 46 to 163 per cent over control have been obtained with an average response of 7.7 kg per kg of P_2O_5 applied.

The Institute of Agricultural Research Statistics has brought out data on average yardsticks of additional production of certain food-grains and commercial crops from the use of phosphatic fertilizers on the basis of experimental data in cultivators' fields (1964), a statement of which is given in Table 19.

The optimum dose of application so as to give maximum economic returns is an important aspect. Application of superphosphate at a rate exceeding 22-34 kg P_2O_5 per hectare has not been much profitable.

Concentrated superphosphate. This is also known as triple superphosphate. This concentrated form of phosphatic fertilizer, containing as much as 45 to 50 per cent water-soluble P_2O_5 and 17 to 20 per cent lime, is produced by treating phosphate rock with

TABLE 19. YARDSTICK OF ADDITIONAL PRODUCTION

Crop	Yardstick in tonnes per tonne of P_2O_5
Rice	7.1
Wheat (irrigated)	8.7
Wheat (unirrigated)	4.0
Ragi (irrigated)	5.8
Ragi (unirrigated)	6.6
Maize	6.8
Gram	6.4
Blackgram	3.5
Horse gram	4.7
Green gram	3.4
Pea	6.8
Sugarcane (N. India)	136.2
Sugarcane (S. India)	44.6

phosphoric acid produced by wet process from sulphuric acid. The main advantage in producing this fertilizer lies in the utiltzaion of low-grade phosphate rock (Collings, 1947) is the reduction in the overhead costs of transport, etc., which is a distinct advantage in this country. However, due to the presence of larger amount of free acidity, its physical condition is not suitable, but these defects have been largely removed by the development of a product in a relatively dry, granular condition from concentrated phosphoric acid obtained from electrical methods (Walthal, 1941, 1946).

In fertilizer trials with paddy on cultivators' fields, an application of triple superphosphate at the rate of 22 kg P_2O_5 per hectare alone gave, on an average, 3·3 quintals of extra grain over no manure. With wheat, with the same dose of phosphate, the average response worked out to 2·1 quintals of grain per hectare. Increasing the dose to 45 kg P_2O_5 per hectare gave a further increase in yield by about 92 kg both in the case of paddy and wheat (*Fertilizer Trials on Paddy/Wheat I.C.A.R., 1959*).

2. **Basic slag.** Basic slag is obtained as a by-product from steel industry and ranks next to superphosphate as the leading phosphatic fertilizer. In the manufacture of high quality steel, the impurities like silicon, sulphur and phosphorus combine with calcium and rise to the top in the furnace and are poured off as slag which when solidi-

TABLE 20. RESULTS OF FERTILIZER EXPERIMENTS

State	Farm	Nature of soil	Period
			PADDY
Bihar	Sabour and Gaya	Alluvial, sandy loam	1935–37 (3 years)
Maharastra	Alibagh	Sticky clay, containing grit stone	1916–18 (3 years)
Madras	Mangalore	Deficient in N and P	1921–24 (4 years)
Orissa	Sambalpur	Superficially fine and rocky below the surface	1926–27
Uttar Pradesh	Pratapgarh	Medium loam, poor in fertility	1914–30 (16 years)
W. Bengal	Chinsurah	Alluvial, clay loam	1937–40 (4 years)
			WHEAT
Bihar	Pusa	Calcareous sandy loam	1933–39 (6 crops) 1934–37 (4 crops)
Madras	Coimbatore	Wet lands, red and black	1916–20 (4 years)
Punjab	Jullundur	Alluvial, loam	1946–48 (3 years)
	Gurdaspur	Alluvial, heavy loam	1925–29 (2 years)
Uttar Pradesh	Aligarh	Loam, deficient in N and P	1915–21 (5 years)
			SUGARCANE
Bihar	Gaya	Calcareous clay, deficient in N and P	1928–29
Uttar Pradesh	Pratapgarh	Alluvial, poor in fertility, silty loam	1918–22 (4 years)
Madhya Pradesh	Indore	Black	1947-48
			COTTON
Maharastra	Akola	Black cotton	1909–22 (12 years)

References : Allan (1933), Vaidyanathan (1933)

WITH SUPERPHOSPHATE

Treatment kg P_2O_5/ha		Yield kg/ha	Per cent increase over no-manure	Response kg/kg P_2O_5
Superphos.	22	1,114	20.5	9.1
Superphos.	45	1,184	20.0	4.4
Superphos.	67	1,277	29.4	4.3
No manure		986		
Superphos.	25	2,632	13	12.3
No manure		2,330		
Superphos.	26	2,206	18.5	13
No manure		1,882		
Superphos.	36	2,318	14.3	8.1
No manure		2,027		
Superphos.	7	1,702	46.2	80
No manure		1,165		
Superphos.	45	2,244	8	3.8
No manure		2,073		
Superphos.	45	521	93.3	5.6
No manure		276		
Superphos.	45	326	7	0.5
No manure		305		
Superphos.	67	737	61	4.2
No manure		455		
Superphos.	140	2,029	7.2	1
No manure		1,894		
Superphos.	34			7.7
Superphos.	45			5.2
Superphos.	70			4.9
Superphos.	63	1,728	9.5	2.4
No manure		1,578		
Superphos.	39	1,568	10.6	3.8
No manure		1,417		
Superphos.	20	1,991	15.6	13.3
No manure		1,719		
Superphos.	34	2,240	53.9	140
No manure		8.736		
Superphos.	140	42,907	105	157
No manure		20,728		
Superphos.	22	306	9.6	1.2
No manure		281		
Superphos.	45	—	27	

Stewart (1947) ; Rep. Expert Fert. Committee (1953).

fied are finely ground and are put into market as basic slag, some grades of which may contain as much as 17 per cent P_2O_5. According to International Standards, it should contain at least 13 per cent P_2O_5 out of which 80 per cent should be citric-soluble and should be finely ground so that 80 per cent of the material passes through 100-mesh sieve. Its chemical formula most commonly accepted is : $(CaO)_5$, P_2O_5, SiO_2. Due to its high lime content it should not be used in mixed fertilizers.

The basic slags so far produced in India are of low grade with an average P_2O_5 content of 3-8 per cent and are uneconomical because of transport costs (Mehta, 1945). A typical slag from the Martin Burn Steel Factory (near Asansol), West Bengal, was found to have the following composition. Other slags, obtained from the Indian Steel factories, examined at the Indian Agricultural Research Institute contained much lower percentages of phosphate.

TABLE 21. COMPOSITION OF BASIC SLAG FROM MARTIN BURN STEEL FACTORY

Constituent	*Per cent*
Total P_2O_5	7.12
2 per cent citric acid-soluble P_2O_5	6.26
Fe_2O_3	13.53
Al_2O_3	4.85
CaO	43.50
MgO	7 43
MnO_2	6.50
SiO_3	17.05

As 80 per cent of the total phosphate in basic slag is citric soluble, crop response is likely to be much greater than that with rock phosphate. Basic slag contains varying quantities of magnesium and manganese and it may be used for correcting soil deficiencies with respect to these elements. Its performance compares favourably with superphosphate particularly on acid soils and with leguminous crops (Collings, 1947). In India, experiments with this fertilizer are few and in one experiment at Akola (black cotton soil) in Madhya Pradesh 28 per cent increase in yield of groundnut was obtained even on non-acid soils (Vaidyanathan, 1933).

Dhar and Sharma (1955) working on four phosphatic fertilizers found that Tata Basic Slag was comparatively superior to Trichinopoly rock phosphate, Algerian rock phosphate and Kulti basic slag.

Results of experiment on Tata Basic Slag and other phosphatic fertilizers at the Government Agricultural Farm, Kanke, are shown below. The composition of Tata Basic Slag is shown in Table 22.

TABLE 22. COMPOSITION OF THE BASIC SLAG USED AND OBTAINED FROM TATA IRON AND STEEL COMPANY, JAMSHEDPUR

	S.M. No. 2
SiO_2	15.08
Al_2O_3	4.03
FeO	12.20
Fe_2O_3	4.03
MnO	7.25
CaO	43.3
MgO	6.87
P_2O_5	7.24

Paddy (lowland) and maize upland : Significant under lime and no limes. No significant effect of basic slag or other phosphate.

Peas (upland) : acid soil (pH 5.5)—two years (1961-63)

NO LIME : Phosphate gives response ; basic slag better than single superphosphate, D. C. P., Ca glycerophosphate, rock phosphate and bonemeal.

WITH LIME : Phosphate gives greater response than no lime. Single superphosphate was the best.

The data are given in Table 23.

TABLE 23. DATA REGARDING PEAS.

SUB-PLOT SIZE 1,988 HECTARE

DESIGN : RANDOMISED BLOCK REPLICATIONS : 5

Treatment	Yield of grain/hectare (quintals)			
	1961–62		1962–63	
	No lime	Lime	No lime	Lime
Control	2.73	7.32	0.76	5.04
Single superphosphate	5.35	13.02	2.62	14.36
Rock phosphate	3.54	9.42	2.09	9.09
Bonemeal	5.00	9.82	3.29	8.65
Dicalcium phosphate	5.23	12.50	2.34	10.95
Basic slag	7.44	9.20	5.38	10.47
Calcium glycerophosphate	3.89	15.12	1.92	7.74

3. Dicalcium phosphate. Since the water insoluble phosphate in dicalcium phosphate will not undergo reversion in the soil as rapidly as mono-calcium phosphate contained in superphosphate and as it is also available to plants, it is claimed to be superior to other forms of phosphates at least for long-duration crops like sugarcane, although on short-duration crops like paddy and wheat water-soluble phosphate is generally considered to be somewhat better than citrate soluble phosphate. Dicalcium phosphate has an excellent physical condition and due to high P_2O_5 content overhead costs of transportation, etc., become less.

The dicalcium phosphate prepared in the National Chemical Laboratory (Gadre and Gupta, 1953) contained about 38-40 per cent P_2O_5 soluble in neutral ammonium citrate solution (total P_2O_5 : 40-42 per cent). With Indian phosphatic nodules (from Trichinopoly), a product of similar nature but containing the total fluoride content 2-3 per cent of the nodules, was obtained. This product contained 40-44 per cent total and 38-42 per cent citrate-soluble P_2O_5, the latter figure remaining unchanged after a storage for 12 months. It is thus evident that the presence of fluoride did not materially affect the citrate solubility of this product during storage. Evidence is, however, not available regarding the possibility of a similar behaviour in soils.

Experiments to test the fertilizer value of dicalcium phosphate have been carried out at the Indian Agricultural Research Institute on wheat and paddy. Results indicate that this is as good as superphosphate in its fertilizing value (*Scient. Rep. I. A R. I , 1953-56*).

4. Calcium meta-phosphate. A general method developed by Tennessee Valley Authority consists in burning phosphorus furnace gases and passing them directly into contact with finely ground phoshate-rock at temperature of 1200°C (Collings, 1947). The hot phosphorus vapour and the phosphate rock unite to form liquid calcium meta-phosphate. Calcium meta-phosphate contains 63 per cent available phosphoric acid and appears to be a very good form of phosphate. The results reported by Das (1944) indicate its good fertilizing value and further, sodium meta-phosphate is less liable to be fixed by soil bases.

As pointed out by Stewart (1947), most of the experimental work on phosphates in India has been done with superphosphate, and with other products sufficient data are not yet available to permit any generalisation on the relative merits of different forms of phosphate but the following tentative conclusions can be drawn on the basis of the field experiments so far conducted in India.

With paddy, bonemeal on an average, gave the highest percentage increase of about 37 per cent over control. Superphosphate and rock phosphate were equal in increasing the yield of paddy by about 18-19 per cent over control.

With wheat and sugarcane (irrigated and unirrigated) the experiments are only available with superphosphate and ammonium phosphate and in all cases ammonium phosphate proved to be better.

In the case of cotton, although the response with superphosphate varied widely, on the average, both ammonium phosphate and superphosphate with ammonium sulphate equalled in their effect.

With oilseeds, ammonium phosphate gave 62 per cent increase and was followed by basic slag (28 per cent). The results with bonemeal varied widely from negative to increase up to 29 per cent at different places, giving on the whole an average increase of 8.0 per cent over the control.

Further experiments are needed not only with indigenous phosphatic fertilizers but also with new phosphatic fertilizers like dicalcium phosphate and nitrophosphate as well. It may be worthwhile to examine, in brief, comparative results with different phosphatic fertilizers obtained in foreign countries.

Field tests with many of the less common phosphate carriers have been reported by the Tennessee Valley Authority (Walthal, 1941). The tests conducted at Mississippi (Anthony and Pitner, 1940) show that basic slag with the most effective source of phosphorus, concentrated superphosphate, dicalcium phosphate and ordinary superphosphate were about equally efficient and tricalcium phosphate and raw rock phosphates usually were less effective. Results obtained at Tennessee (Anthony and Pitner, 1940) indicated that dicalcium phosphate, concentrated superphosphate and meta-phosphate proved every year superior to fused rock phosphate. Fudge and Graps (1945) reported that the application of ground rock phosphate increased yields in a few cases but were not comparable with those obtained with superphosphate. The phosphoric acid in ammonium phosphate, calcium meta-phosphate, defluorinated rock phosphate and basic slag applied to a slightly acid but phosphorus-deficient soil was nearly as available as that in 20 per cent superphosphate.

However, as pointed out by Hartwell and Damon (1947) the comparative efficiencies of phosphorus carriers differ significantly with crops. According to Crowther (1950) some of the new fertilizers may be very useful on most soils for most crops, but there is need for trials on a wider range of soils and crops before their limitations can be established.

In India, Basu and Kibe (1943) investigated the phosphate status of black cotton soil which had been continuously fertilized with phosphatic fertilizer under irrigated conditions for ten years. They found that the amount of available phosphoric acid was highest in plots fertilized with superphosphate, next came the basic slag and bonemeal the last.

*Interaction of source of phosphates with methods of placement** : Significant interaction was observed at Powerkheda where the wheat crop was not irrigated.

TABLE 24. RESPONSE OF WHEAT TO PHOSPHATE AT DIFFERENT METHODS OF PLACEMENT OF PHOSPHATE (QUINTALS/HECTARE)

CENTRE : POWERKHEDA (UNIRRIGATED)

Type of phosphates	Yield without phosphate	Broadcast	6.4 cm below seed	Band placement
Single superphosphate	3.4	0.83	2.4	1.6
Ammonium phosphate	3.4	1.1	4.1	2.2

Ammonium phosphate was significantly superior to single superphosphate when applied 6.4 cm below the seed and placed in bands. The differential response was higher in the case of placement 6.4 cm below the seed. There was no difference between the two fertilizers when applied broadcast.

COMBINED PHOSPHATIC AND NITROGENOUS FERTILIZERS

1. Ammonium phosphate. Ammonium phosphate fertilizer is available as mono-ammonium phosphate and diammonium phosphate. It is usually manufactured by adding ammonia in phosphoric acid in correct amounts necessary to secure the desired grade. The pure monoammonium phosphate which is slightly acidic in reaction contains 61.7 per cent P_2O_5 and 12.17 per cent nitrogen, and the pure diammonium phosphate which is slightly alkaline has 53.35 per cent P_2O_5 and 21.07 per cent of nitrogen. Another method of preparing commercial monoammonium phosphate consists in replacing with ammonium sulphate about one-third of the sulphuric acid used in acidulating the phosphate rock.

Ammo-phos, the trade name for commercial monoammonium phosphate mixed with various amounts of ammonium sulphate or other fertilizers to give different N to P ratios is usually sold in two

Fourth Report of Model Agronomic Experiments, I.C.A.R. Rabi, 1957-58, pp. 26-27.

grades containing 10.7-11.0 per cent N : 48 per cent P_2O_5 and 16 per cent N : 20 per cent P_2O_5 (Collings, 1947). The fertilizer maintains an excellent physical condition during storage and handling.

Ammonium phosphate being a combined nitrogen and phosphatic fertilizer is likely to find greater use in areas where phosphoric acid requirement proportional to nitrogen is relatively high. In India, the deficiency of phosphorus is secondary to that of nitrogen so that a supplementary response to the application of phosphorus along with nitrogen has been obtained in several areas, notably in Punjab, Madhya Pradesh, Bihar, Maharashtra, Andhra Pradesh, Mysore and Uttar Pradesh. There is evidence that phosphorus deficiency is a factor of importance in many of the red soils, particularly the texturally lighter types. It may be incidentally mentioned that recent experiments with radioactive phosphorus have revealed that at least 40-50 per cent of Indian soils respond to phosphate manuring after the basal nitrogen requirement of the soil is met with.

The large volume of experimental evidence so far obtained in India shows that nitrogenous fertilizers constitute a major need for Indian soils and phosphates as a supplement to nitrogen would be very useful in some tracts for some specific crops. A combined NP fertilizer like ammonium phosphate could be equally useful purely as a nitrogenous fertilizer on the soils deficient in nitrogen, but it is adequately provided with phosphorus that would entail useless addition of this element. This fertilizer is thus likely to prove useful in many areas on which deficiencies of both nitrogen and phosphorus exist simultaneously.

Field experiments with ammonium phosphate and allied materials have given consistently positive results with all the crops in all areas (except in acid soils of Assam) possibly due to the fact that it is a combined NP fertilizer. Thus, on the average, the percentage increase in yield of paddy was 33 per cent, irrigated wheat 35.5 per cent, unirrigated wheat 28.5 per cent, irrigated sugarcane 27.5 per cent, unirrigated sugarcane 62.5 per cent, cotton 15 per cent and oilseeds 62 per cent. Some of the typical results are given in Table 25.

In large number of field experiments conducted in India with paddy and wheat, either on cultivators' fields or in complex experiments at selected centres, no significant difference could be observed on crop yields due to the application of ammonium phosphate or superphosphate as the source of phosphorus (*Fertilizer Trials on Paddy/Wheat, I.C.A.R., 1959*).

2. **Ammonium Superphosphate.** Ammoniated superphosphate is one of the important fertilizer materials containing combined nitrogen

TABLE 25. RESULTS OF SOME FERTILIZER

State	Farm	Nature of soil	Crop	Period
Assam	Jorhat	In the upland, poor in P_2O_5, acidic in reaction	Paddy	1928–31 (3 years) (2 trials)
Assam	Khweda	Low level laterite, markedly deficient in P_2O_5, clayey	Paddy	1929–31 (2 trials)
W. Bengal	Chinsurah	Clay loam	Paddy	1936–41 (5 years)
Orissa	Cuttack	Light and sandy loam with heavy sand	Paddy	1926–27
Madhya Pradesh	Adhartal	Sandy loam	Wheat	1945–49 (4 years)
	Chindwara	Morand (loam)	Wheat	1935–40 (5 years)
	Powerkhera	Morand (lighter loam)	Wheat	1940–45 (5 years)
	Tharsa	Inferior clay loam	Wheat	1940–49 (9 years)
Punjab	Jullundur	Clay loam	Wheat	1945–48 (3 years)
Bihar	Sepaya	Loam, alkaline, poor fertility	Sugarcane	1928–30 (2 years)
Punjab	Gurdaspur	Loam	Sugarcane	1948–49
Mysore	Bangalore	Dark red, gravelly loam	Sugarcane	1929–33 (4 years)

EXPERIMENTS WITH AMMONIUM PHOSPHATE

Treatment (kg/ha)	Yield (kg/ha)	Per cent increases over no-manure	Response kg/ha N or kg/kg P_2O_5	Remarks
Diammophos. 15 kg N+35 kg P_2O_5	3016	17.4	30.8	
No manure	2568			
Ammophos. 15 kg N+18 kg P_2O_5	3169	10.4	22.7	
No manure	2839			
Ammophos. 15 kg N and 18 kg P_2O_5	3102	21.9	44.6	
No manure	2452			
Niciphos. 22 kg (N+P_2O_5)	2819	22.2	22.9	
No manure	2308			
Ammophos. 28-29 kg N and 32= 36 kg. P_2O_5	3965			
No manure	3388	17	20.4	
Ammophos. 11 kg (N+P_2O_5)	607	40.1	15.5	
Am. Sul. 11 kg N	556	28.2	10.9	
No manure	433			
Niciphos. 22 kg (N+P_2O_5)	995	16.9	6.4	Dry
No manure	851			
Niciphos. 11 kg (N+P_2O_5)	575	30.9	12.1	Irrigated
Niciphos. 17 kg (N+P_2O_5)	654	48.9	13.5	
No manure	439			
Niciphos. 28 kg N	710	33	6	Irrigated
No manure	534			
Amm. phosphate 112 kg N	2353	24.3	4.1	
No manure	1894			
Diammophos. 45 kg N+112 kg P_2O_5	56214	77.9	549	Dry
No manure	31606			
Ammophos. 84 kg N	32787	47	125	Dry
No manure	22317			
Ammophos. 84 kg N	51890	37	167	Irrigated
No manure	37872			
Niciphos. 60 kg (N+P_2O_5)	71071	18	137	Irrigated
No manure	60534			

TABLE 25. RESULTS OF SOME FERTILIZER

State	Farm	Nature of soil	Crop	Period
Bombay	Nagpur	Morand II, clay loam	Cotton	1903-10 (7 years)
Assam	Kokilamukh	Highlands ; sand and silt deposits	Mustard (*Brassica* sp.)	1947-49 (2 years)
			Ground-nut (*Arachis hypogaea*)	
Madhya Pradesh	Diff. Centres		Oilseeds	15 trials
Madras	Diff. Centres		Oilseeds	6 trials
	Eastern part		Oilseeds	4 trials

EXPERIMENTS WITH AMMONIUM PHOSPHATE (contd.)

Treatment kg/ha	Yield kg/ha	Percent increases over no-manure	Response kg/g N or N and P_2O_5	Remarks
Niciphos. II. 34 kg N and P_2O_5	1568	14.7	6	Dry
No manure	1344			
Ammophos. 45 kg N	1080	26	9.2	Dry
No manure	668			
Ammophos. 45 kg N			9.1	Dry
Niciphos. I, 8–47 kg N			17.7	Dry
Niciphos. 18–47 kg ($N : P_2O_5=1 : 32$)			14.3	Dry
Niciphos. II. 11–22 kg N ($N : P_2O_5=1 : 1$)			10.2	Dry
Niciphos. I. 11–22 kg N			22.5	Irrigated

and phosphoric acid. It is prepared by treating ordinary superphosphate (Bear, 1942 ; MacIntre *et al.*, 1944) with ammonia or ammonia containing liquors. It contains monoammonium phosphate, mono- and dicalcium phosphates and ammonium and calcium sulphates as well. It has about 2.4 per cent nitrogen and between 16 and 18 per cent P_2O_5. No results of field experiments in India are so far available with this fertilizer.

3. Nitrophosphate. Nitrophosphate is a comparatively new complex fertilizer to this country. Nitrophosphate has a great scope for widespread use in this country where sulphuric acid position is not very satisfactory. The material produced in the Netherlands (Pluste, 1951) contains 20.5 per cent N and 20 per cent P_2O_5.

The material is obtained by the decomposition of phosphatic rock by nitric acid. The reaction of nitric acid with phosphate rock produces a solution containing calcium nitrate and phosphoric acid or monocalcium phosphate according to reactions (1) or (2).

$$Ca_{10}F_2(PO_4)_6 + 20\ HNO_3 \rightleftharpoons 10Ca(NO_3)_2 + 6H_3PO_4 + 2HF \text{—(1)}$$
$$Ca_{10}F_2(PO_4)_6 + 14\ HNO_3 \rightleftharpoons 3CaH_3\ PO_4)_2 + 7Ca(NO_3)_2 + 2HF \text{—(2)}$$

In some nitrophosphate processes, sulphuric acid or phosphoric acid is added in addition to nitric acid. These processes are sometimes called sulphonic or phosphoric processes. In other processes part of the calcium nitrate is removed by cooling, crystallization and centrifuging. The purpose of these steps is to balance the amount of calcium that is available for combining with phosphate, so that upon ammoniation no calcium phosphate more basic than dicalcium phoshate will form. The ratio of CaO : P_2O_5 in dicalcium phosphate is 2, and as in practice some water-soluble P_2O_5 is usually desired in the final product the ratio of available CaO to P_2O_5 is adjusted to less than 2 ; under such conditions part of the P_2O_5 form water-soluble ammonoium phosphate or monoammonium phosphate upon ammoniation. It must however, be noted, that if the water solubility is raised by using increasing amounts of sulphuric acid or phosphoric acid, less sulphur is saved (T.P. Hignett. *Nitrophosphate processes, advantages and disadvantages*, Proceedings, National Seminar on Fertilizer, 1965-p. 206).

In India the material was tried at several centres on paddy and wheat during 1953–56. This fertilizer gave a significantly lower yield of paddy in comparison to superphosphate on equal phosphate level. In the case of wheat, the response to nitrophosphate was much lower than that to superphosphate (*Fertilizer Trials on Paddy/Wheat, I C.A.R., 1959*).

There are two products, viz., 20-20-0 produced by O.D.D.A. process and 16-14-0 produced by P.E.C. process (with carbon dioxide). The 20-20-0 nitrophosphate fertilizer produced by the O.D.D.A process contains 12 per cent ammonia nitrogen, 8 per cent nitrate nitrogen, 10 per cent citrate-soluble P_2O_5 and 10 per cent water-soluble P_2O_5 and also an equivalent quantity of nitrochalk of 21 per cent nitrogen, half of which is nitrate nitrogen. This method has, therefore, the advantage that a concentrated nitrophosphate fertilizer is obtained, in which half of the P_2O_5 is in water-soluble and half in citrate-soluble forms. An equivalent quantity of calcium ammonium nitrate of about 21 per cent nitrogen is also obtained as a bye-product.

The other complex nitrophosphate fertilizer 16-14-0 is produced by the P.E.C. process in which the excess of calcium (excess over total available P_2O_5 as dicalcium phosphate) is precipitated as calcium carbonate by passing carbon dioxide in the mixture. The product contains all the P_2O_5 in citrate soluble form, and half of the nitrogen is in ammonia form and half in the nitrate form.

Results of trials with ODDA and PEC nitrophosphate on paddy crop in different soil types of Bihar are given in Table 26.

TABLE 26. EFFECT OF NITROPHOSPHATE ON PADDY CROP

(YIELD IN Q/HA)

Soil type	Control yield	S/A**	S/A** +S/P***	S/A** +ODDA	S/A** +PEC	Remarks
Old alluvium	14.29	18.84	24.96	22.64	19.15	Irrigated
Old alluvium	13.62	18.87	22.33	20.56	19.64	Unirrigated
Sandy alluvium (young)	11.87	16.86	20.18	17.89	16.53	Unirrigated
Sedentary (mixed)	11.52	14.54	19.00	16.49	14.76	Unirrigated

* Sinha, M.P. 1963. Private communication.

** S/A=Ammonium sulphate.

*** S/P=Single superphosphate.

Phosphate in the form of single superphosphate gives the highest response in all broad soil divisions of the state. PEC nitrophosphate gives the least responses while ODDA gives average but poor response in comparison to single superphosphate.

Nitrophosphate containing P_2O_5, half in water soluble form and half in cstrate-siluble form, was compared with superphosphate in trials with paddy, sugarcane and groundnut in Maharashtra. Results obtained show that nitrophosphate is as good as superphosphate on long duration crops like sugarcane. Encouraging results were not obtained on paddy because of nitrogen being present in nitrate form in nitrophosphate. The response on groundnut was also not encouraging (Raychaudhuri, S.P. *Fert. news.* 1965, 10, No. 12, p. 84). On the basis of several experiments in the country the broad conclusion has been made that ammonium phsophate is better so far as its keeping quality and response to crop is concerned than nitrophosphate (Donahne, Roy L. Ammonium phosphate or nitrophosphate for India.*A Technical Assessment, Second Draft*, 1965, June 10). The report of the field experiments with nitrophosphate on rice at Sindri farm of the Fertiliser Corporation of India, however, indicates that under the conditions existing at Sindri, nitrophosphate gives good response on rice.

4. **Ammonium phosphate sulphate.** It is obtained when a mixture of phosphoric acid and sulphuric acid is treated with ammonia. It consists principally of a mixture of amm. phos. and amm. sulphate and is available in two grades, viz, 16 : 20 : 0 and 20 : 20 : 0. These are excellent fertilizers of good keeping quality and have the entire quantity of phosphate in water soluble form. It has great possibilities of use in this country directly to the soil where the plant requirements of nitrogen and phosphorus are in equivalent amounts.

*Direct, residual and cumulative response to phosphate**. To study the direct, residual and cumulative response of paddy to the application of phosphate at 22 kg and 44 kg P_2O_5 per hectare a long-term experiment was started in *kharif*, 1954, at Aduthurai centre. An additional treatment of phosphorus at 11 kg P_2O_5 per hectare was also included for the study of cumulative effects. Two crops of paddy were taken each year, both crops being manured. Basal manuring with 4400 kg of green leaves per hectare was given to all plots. Nitrogen at 22 kg N per hectare was given as a basal dose in all experimental plots except the pure control plots. The results are summarized in Table 27.

Significant direct response of 5.3 quintals per hectare to the application of 22 kg N per hectare was observed while response to higher levels of nitrogen was not significant. The residual responses were not obtained at this centre. Cumulative responses to 22 kg and 44 kg P_2O_5 per hectare were significant, being 2·3 and 3·8 quintals per hectare,

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respectively, to the two doses. The results of this experiment at Aduthurai were in conformity with those in the preceding year.

TABLE 27. DIRECT, RESIDUAL AND CUMULATIVE RESPONSE OF PADDY TO PHOSPHATE (Q/HA)

(BASAL DRESSING OF 22 KG N/HA AND 4,400 KG GREEN LEAF)

ROTATION : PADDY—PADDY. YEAR OF COMMENCEMENT : *Kharif*, 1954-55

State	Centre	Control yield	Direct response per ha		First residual response per ha		Second residual response at per ha		Cumulative response per ha		S.E. of response
			22 kg P_2O_5	44 kg P_2O_5	22 kg P_2O_5	44 kg P_2O_5	22 kg P_2O_5	44 kg P_2O_5	2 2kg P_2O_5	44 kg P_2O_5	
Madras	Aduthurai	38.8	5.3	1.8	—1.10	—0.64	—1.56	0.27	0.09	2.12	1.29

Mention may be made of the beneficial effects observed at several places of the application of phosphates to legumes, specially berseem, in increasing the yield of the legume and the residual crop following it and in improving the fertility status and physical properties of the soil (Parr and Bose, 1944 ; Sen and Sundara Rao, 1953 ; Patel *et al.* 1962 ; Sen, 1964).

*Interaction of nitrogen with phosphorus**. Significant interactions at the Model Agronomic Experimental Centre during *rabi*, 1957-58 on wheat were obtained at Powerkheda in Madhya Pradesh, at Bichpuri in Uttar Pradesh, and at Reura Farm in Madhya Pradesh. The response to nitrogen at both 33 and 67 kg N per hectare in the absence of phosphorus was moderate at Powerkheda and was increased by about 2·2 q/ha in the presence of 33 kg P_2O_5 per hectare. With the increase in level of phosphorus to 67 kg P_2O_5 per hectare, the responses to nitrogen remained stationary. Application of 67 kg N per hectare in conjunction with 33 kg P_2O_5 appears to be the best combination in this experiment.

The response to 22 kg and 44 kg N per hectare in the absence of phosphorus were identical and on the verge of significance at Reura Farm. In the presence of 22 kg P_2O_5 the response was doubled. At the highest level of phosphate, the response to 44 kg N showed a further increase of about 3·6 quintals per hectare but the response to 22 kg N remained stationary. A comparison of the results with those obtained under the T.C.M. Fertilizer Use Project, showed complete uniformity of results with those in 1954–56.

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At Bichpuri the response to initial application of 33 kg N per hectare without phosphate was about 3·6 quintals per hectare. The response curve was approximately linear in the range of nitrogen applied. In the presence of phosphate at 33 kg P_2O_5 per hectare, 33 kg N gave a further increase of about 4.1 quintals per hectare while 67 kg N application registered a fall. Further increase in the phosphorus levels tended to bring down the nitrogen responses. Application of 33 kg N plus 33 kg P_2O_5 or 67 kg N alone appears to be the best.

Interaction of nitrogen with potash. In the presence of 33 kg K_2O the response of wheat to 67 kg N increased substantially at the Model Agronomic Experiment *rabi* 1957-58 at Bichpuri. Table 28 is given as an illustration.

TABLE 28. RESPONSE OF WHEAT (Q/HA) TO NITROGEN AT DIFFERENT LEVELS OF POTASH

Level of potash (kg/ha)	Average yield of plots without nitrogen	Response to nitrogen at		S.E. of response
		33 kg N/ha	67 kg N/ha	
		Bichpuri		
0	13.7	4.7	2.8	1.37
2.7	13.8	2.9	8.0	1.37
55.3	13.3	5.0	5.1	1.37

Interaction of nitrogen with bulky organic manure. The response to nitrogen in the absence of bulky manure was moderate at Bichpuri. At 5605 kg FYM level, the response to nitrogen increased substantially. From the result of experiment No. 2 at Bichpuri, the best combination appears to be 67 kg N+33 kg P_2O_5+33kg K_2O+ 5605 kg FYM. (Table 29).

TABLE 29. RESPONSE TO NITROGEN AT DIFFERENT LEVELS OF FARMYARD MANURE (Q/HA)
CROP : WHEAT

Levels of FYM (kg/ha)	Average yield of plots without nitrogen	Response to nitrogen at		S.E. of response
		33 kgN/ha	67 kgN/ha	
		Bichpuri		
0	12.9	2.4	2.7	1.12
5605	14.3	5.9	8.0	1.12

IV. POTASSIC FERTILIZERS

Among the potassium-bearing fertilizers, namely, muriate of potash and potassium sulphate, the latter has been used extensively in field experiments as compared to the former in India. Saltpetre (potassium nitrate) is a combined potassium and nitrogenous fertilizer and is the only potassic fertilizer produced in India by recovery from the soils of old village sites in Uttar Pradesh, Bihar, the Punjab, Kashmir, Madhya Pradesh, Maharashtra, Madras and Andhra Pradesh. About 25000 tonnes of saltpetre (Saxena, 1951) is thus being obtained annually in this country. So far the amount of potassic fertilizer required is met with from imports.

According to Saxena's 1951 estimates, the following quantities of potash-bearing materials could be produced in India from sources which are only incompletely tapped at present.

TABLE 30

Source of potosh	*Estimated production per annum in tonnes*
Saltpetre	25,900
Distillery waste	25,000
Flue dust	5,000
Bitterns	80,000
Ash of cotton seed	75,000
Wool washing	400

1. Muriate of potash (potassium chloride). Muriate of potash occurs naturally in the American, French and German deposits in the mineral form known as sylvite, which contains also sodium chloride, magnesium sulphate or chloride. The marketed muriate of potash is a refined product. Muriate of potash may contain 48 to 62 per cent of K_2O and 47 per cent of chlorine. This form of potassic fertilizer finds extensive use and accounts for the 90 per cent of the potassium fertilizer consumed in the world (Collings, 1947).

Sanyasi Raju (1952) observed that potassium sulphate was better than muriate of potash.

2. Potassium sulphate. Potassium sulphate was formerly manufactured in Germany from kainite mineral, but it is now prepared by dissolving any double sulphate of potassium and magnesium in water and then adding to it a concentrated solution of potassium chloride (Collings, 1947) Potassium sulphate precipitates itself and is separated from the solution by simple decantation. The sulphate is then dried, screened, ground and sacked for shipment. One American plant produces potassium sulphate through interaction of potassium chloride and sodium sulphate ; another through the action of caustic potash and sodium sulphate. High-grade potassium sulphate contains at least 48 per cent K_2O and not more than 2.5 per cent of sodium sulphate. Potassium sulphate has a better physical condition than most of the potash salts and is much more finely divided. The market value of potassium sulphate is comparatively high due to high expense in its production and thus its general use is limited. The earlier field experiments conducted with potassium (Table 32) indicate no great beneficial effects either alone or in combination to justify its application economically. However, the results indicate a better effect in combination with nitrogen and phosphates.

3. **Potassium nitrate.** Potassium nitrate contains 13 0 per cent nitrogen and 44 per cent K_2O. This is the only indigenous source of potash in India which is obtained by refining crude nitrate earth. Due to the presence of nitrogen it has often given good response in crop yields. However, this fertilizer is likely to find more use on crops like tobacco and chillies, which have high potassium requirements.

Performance of potassium fertilizers. The field experiments conducted in India (Table 32) indicate that potassium is not generally needed at the present level of crop production. On the basis of the permanent manurial experiments conducted at Coimbatore, Sanyasi Raju (1952) concluded that there was not much response for potash either alone or in combination. Parthasarathy (1952) reviewed the manurial experiments in sugarcane in Madras State and found that potassium did not influence either yield or quality and in certain cases it even depressed the yield. The experiments at Delhi (Desai and Subbiah, 1952) showed that addition of potassium depressed the nitrification of nitrogenous manures and also the nitrogen recovery by the crop. Kadam (1952) reviewed fertilizer experiments on tobacco and reported that Virginia tobacco responded only to nitrogen and did not benefit in any way from phosphorus or potash. Ramanujam and Mukhtar Singh (1952) concluded from multi-factor experiments on potatoes that potash as muriate or sulphate gave very little or no response, but in some cases the muriate actually depressed the yields of potato.

TABLE 31. RESULTS OF SOME FERTILIZER EXPERIMENTS WITH POTASSIUM SULPHATE

Farm (State)	Nature of soil	Period	Treatment Dose per hectare	Yield kg/ha	Increase in yield over control per cent
1	2	3	4	5	6
			Paddy		
Coimbatore (Madras)	Wet land	1908-16 (8 years)	Bonemeal+pot. sulph. (18 kg N+129 kg P_2O_5+56 kg K_2O)	—	13
			Bonemeal (18 kg N+129 kg P_2O_5)	—	26
Manganallur (Madras)	Def. in N and P	1916-22 (7 years)	Amm. sulph.+super+pot. sulph. (11 kg N+49 kg P_2O_5 +21 kg K_2O)	2139	4.2
			Amm. sulph.+super 11 kg N+49 kg P_2O_5)	2117	3.0
			Control	2050	
Coimbatore (Madras)	Wet lands red and black	1908-16 (6 years)	G.M.+super+pot. sulph. (22 kg N+22 kg P_2O_5+56 kg K_2O)	4021	15.3
			G.M.+super (22 kg N+22 kg P_2O_5)	3741	7.3
			No manure	3843	
Manganullur (Madras)	Def. in N and P	(6 years)	Green leaf plus super+K_2O (11 kg N+22 kg P_2O_5+ 22 kg K_2O)	2050	56
			Green leaf plus super	2173	66
			No manure	1310	
			Wheat		
Pusa (Bihar)	Calcareous sandy loam	1933-49 (6 crops)	Amm. sulph. (22 kg. N)+ 45 kg P_2O_5	642	138
			Amm. sulph.+Super+Pot. Sulph. 22 kg N+45 kg P_2O_5+28 kg K_2O)	668	147
			Amm. sulph. (22 kg N)	289	7.1
			Super (28 kg P_2O_5)	521	93.4
			Pot. sulph. 28 kg P_2O_5)	516	8.0
			No manure	270	—
		1943-47 (4 crops)	Amm. sulph.+Super (22 kg N+22 kg P_2O_5)	507	66.5
			Amm. sulph.+super+pot. sulph. (22 kg N+45 kg P_2O_5+28 kg K_2O)	522	71.3
			Super (45 kg P_2O_5)	326	7
			Amm. sulph. (22 kg N)	416	36.4
			Pot. sulph. (28 kg K_2O)	311	2
			No manure	305	—

TABLE 31. (Contd.)

1	2	3	4	5	6
Coimbatore (Madras)	Wet lands	1924–30 (6 years)	Amm. sulphate+super (25 kg N+67 kg P_2O_5)	1019	144
			Amm. sulphate+super+pot. sulphate (22 kg N+67 kg P_2O_5+56 kg K_2O)	1141	174
			Amm. sulphate 22 kg N	571	38
			Super phosphate 67 kg P_2O_5	627	52
			Pot. sulphate 56 kg K_2O	571	38
			No manure	414	—
			Cotton		
Coimbatore (Madras)	Wet lands supplied with all plants	1924–32 (8 years)	Amm. sulphate+super (25 kg N+67 kg P_2O_5)	1825	43
			Amm. sulphate super+pot. sulphate (25 kg N+67 P_2O_5+56 kg K_2O)	1730	35
			Amm. sulphate (25 kg N)	1780	36
			Super (67 kg P_2O_5)	1590	23
			No manure	1299	—
			Pulses		
Pusa (Bihar)	Calcareous sandy loam	1930–47 (7 crops)	Amm. sulphate+super (22 kg N+45 kg P_2O_5)	547	187
			Amm. sulphate+super+pot. sulphate (22 kg N+45 kg. P_2O_5+28 kg K_2O)	515	170
			Pot. sulphate (28 kg K_2O)	168	2
			No manure	190	
		1933–45 (4 crops)	Amm. sulphate+super (22 kg N+45 kg P_2O_5)	601	89
			Amm. sulphate+super+pot. sulphate (22 kg N+22 kg P_2O_5+28 kg K_2O)	612	93
			Pot. sulphate at 28 kg K_2O	352	10
			No manure	317	—
			Gram		
		1935–47 (4 crops)	Amm. sulphate+super (22 kg+45 kg P_2O_5)	564	40.8
			Amm. sulphate+super+pot. sulphate (22 kg N+45 kg P_2O_5+28 kg K_2O)	505	26
			Pot. sulphate at 28 kg K_2O	348	
			No manure	400	
			Rahar		
		1932–48 (4 crops)	Amm. sulphate+super (45 kg N+90 kg P_2O_5)	1163	153
			Amm. sulphate+super+pot. sulphate (45 kg N+90 kg P_2O_5+56 kg K_2O)	790	72

TABLE 31. (Contd.)

1	2	3	4	5	6
			Pot. sulphate (56 kg K_2O)	508	10
			No manure	460	—
			Jowar		
Coimbatore		1924–29	N+P+K : 25+67+56	2038	143
(Madras)		(5 years)	N+P : 25+67	2027	142
		(13 crops)	N 25	963	16
			P 67	1467	76
			K_2O 56	1064	27
			No manure	840	—

Out of the 52 experiments on paddy conducted upto 1931 (Vaidyanathan, 1933), the application of potash gave, on an average, a negative response of 4.76 kg of paddy per kg of K_2O.

Recently Mukherjee and Sinha (1953-54) reported the response of 2.3 quintals of paddy for 44 kg K_2O per hectare applied as muriate of potash. This is an average of 624 simple trials conducted on cultivators' fields in various districts of Bihar. All of the 17 districts showed some response, although magnitude varied from district to district. Low response, (below 1.8 quintals per hectare) was obtained in Champaran, Bhagalpur and Saran, medium response (1.8-2.7 quintals) in Patna, Gaya, Muzaffarpur, Saharsa, Monghyr, Ranchi, Palamau, Hazaribagh and Singhbhum, high response(2.7—3.6quintals) in Shahabad and Purnea and very high response (above 3.6 quintals) in Santhal Parganas and Manbhum.

Trials to study the response to levels of K_2O were conducted on cultivators' fields during 1954-55 and 1955-56 in nine Community Project Centres. In some of the projects, the application of 22 and 44 kg K_2O per hectare applied on 22 kg N+22 kg P_2O_5 proved (Table 32) very economical (I.A.R.I., 1959).

The simple trials conducted on cultivators' fields have shown that fertilization of paddy with potash was profitable in Bihar, Kerala and Madhya Pradesh at 22 and 44 kg K_2O per hectare.

In Southern and Central India, Potascheme of India, conducted a large number of fertilizer demonstrations on cultivators' fields on paddy in collaboration with local fertilizer companies.

The trials conducted in South India indicated the response of 3.7 quintals of paddy with 44 kg N+44 kg P_2O_5+44 kg K_2O. However, the response was not profitable.

TABLE 32. RESPONSES OF PADDY TO LEVELS OF POTASH IN CULTIVATORS' FIELDS AND THEIR ECONOMICS

Name of the Centre and State	22 kg K_2O per hectare		44 kg K_2O per hectare	
	Respon e quintals/hectare	Net profit or loss (Rupees)	Response quintals/hectare	Net profit or loss (Rupees)
Agartala (Tripura)	2.12	46.9	0.36	26.1
Mangalore (Mysore)	0.73	4.69	2.12	30.1
Samalkot (Andhra Pradesh)	0.18	24.9	1.2	3.4
Raneshwar (Bihar)	2.7	69.90	2.9	56.81
Chalakudy (Kerala)	1.9	43.22	2.9	56.81
Raipur (M.P.)	1.8	40.2	2.5	41.99
Bodhan (Hyderabad)	0.6	1.72	0.8	11.36
Pusa (Bihar)	2.3	58.04	1.2	34.58
Nilokheri (Punjab)	1.1	54.58	1.3	82.49

During 1955-56, 368 demonstration trials were conducted in Andhra Pradesh, Bombay, Hyderabad, Madras, Mysore and Kerala States. The results of these trials have confirmed the findings of the experiments conducted during 1953-54 and 1954-55. Responses obtained in various states along with economics are given in Table 33 (Annoymous, 1956).

TABLE 33. RESPONSES IN VARIOUS STATES OF PADDY

Name of the State	Dosages in kg/hectare		Response to K over a dressing of NP (quintals/ha)	Net Profit per hectare due to addition of K to NP (Rupees)
	NP	NPK		
Andhra Pradesh	34N+42P	34N+42P+44K	3.22	59.5
Maharashtra	37N+29P	37N+29P+50K	2.52	35.5
Hyderabad	53N+40P	53N+40P+41K	3.21	59.7
Madras	38N+41P	38N+41P+41K	2.98	52.3
Mysore	60N+40P	60N+40P+40K	2.96	54.0
Kerala	35N+43P	35N+43P+43K	1.93	24.2

The application of potash has given a good profit over a dressing of nitrogen and phosphoric acid in all the demonstration centres.

In Andhra Pradesh, Hyderabad, Madras and Mysore, the net profit due to application of potash amounted to more than Rs. 49.40 per hectare which was more than 100 per cent of the investment on potassic fertilizer.

The above data have brought out clearly that there is a need to apply potash over and above the combined optimum dose of nitrogen and phosphate to increase the profits on the present rates of fertilization of paddy. The experiments conducted so far indicate that potash fertilization may be profitable in Bihar, Andhra Pradesh, Madras, Kerala and Mysore.

In some of the West Bengal acid soils, the manurial schedule included 224 kg of muriate of potash in addition to lime, cowdung, and bonemeal. The stem rot was effectively checked by muriate of potash and also by lime, the attack decreasing proportionately with the amount of potassium applied. In the acid soils of South Canara and West Malabar, the need for potassium fertilizers is felt for plantains, chillies and tobacco. Travancore soils also appear to be poor in available potash. In Cochin, application of potash in the shape of ashes is deemed quite sufficient to meet the needs of this nutrient. In Mysore, the need for potash is felt for coffee, arecanut, sugarcane and tobacco. However, one important point may be kept in view that with increased crop yields with nitrogen and phosphatic manuring, shortage of potash may be felt in some soils in the near future.

Results of certain NPK trials and demonstrations carried out in the Thanjavur district have shown Table 34 that substantially high responses to potash application in conjunction with nitrogenous and phosphatic fertilizers have been obtained with short, medium and long

TABLE 34*. RESULTS OF POTASCHEME DEMONSTRATION TRIALS CONDUCTED ON CULTIVATORS' FIELDS IN THANJAVUR DIST. DURING 1955-56

Seasonal crop	Fertilizer applied in terms of nutrients kg/ha			Yield of paddy kg/ha		Response NPK–NP	Additional profit
	N	P_2O_5	K_2O	N.P.	N.P.K.	kg/ha	NPK–NP
Single crop	33.6	50.4	50.4	3,571	3,951	381	Rs. 45.00
First crop	33.6	33.6	33.6	3,693	3,872	179	Rs. 15.00
Second crop	44.8	44.8	44.8	2,747	3,044	397	Rs. 32.00

*Bhaumik, H.D. 1966. Potassic fertilizers give higher paddy yields in Thanjavur District, *Fertilizers news* **11**, 7-9.

duration varieties of paddy grown in the Old Delta (alluvial soils), the main paddy growing region of the district (Bhaumik, 1966).

The results of Potascheme demonstration trials conducted on the cultivators' fields in Thanjavur District during 1955-56 are given in Table 34.

Potassium fixation in Indian soils and its availability to the crops. The importance of K fixation in nature lies in the fact that it, not only regulates the supply of the soil K for the plants and prevent its leaching, but also regulates the available Ca/K balance in the soil. Lamb (1935) showed that wide Ca/K ratio leads to serious disturbance in plants as was evident from experiments of Ramamoorthy and Desai (1946). The theoretical significance of this fixation phenomenon seems to be in opposing the normal weathering sequence of minerals as discussed by Nagelsch-midt (1949). Viswanath (1925) is reported to have studied availability of K as influenced by liming of acid soils of India. Nandy (1946) studied both K fixation or its release while liming acid soils of West Bengal. He concluded that K fixation or its release by liming occurred only between pH 6.0 and 7.0. Pathak *et al*, (1949) and Pathak (1950) studied potassium fixation in manured and unmanured soils at different depths and in different fractions, both before and after destruction of organic matter. They confirmed that micaceous soils have high fixation capacity and that organic matter reduces this amount. As they find high values for silt also, it may perhaps be presumed that the primary micas are taking part in this. They make the interesting observation that the manured wheat soil (type not mentioned by the authors) had the maximum K-fixing capacity in the surface only, while the unmanured soil had maximum K-fixing capacity at 60 cm layer. It will be of interest if this confirmed the experimental results in a large number of manured and unmanured wheat soils.

Kibe and his co-workers (1953) reported that black cotton soils released potash by the application of sodium chloride.

V. MISCELLANEOUS FERTILIZERS

Lime. Besides being an essential plant nutrient, calcium is found useful in neutralizing the soil acidity and in improving the physical condition of the soil. For this purpose, limestone and dolomitic stone are being used, the latter being used where magnesium is also deficient. By-product liming materials suitable for soil treatment, viz., dust from marble works, precipitated calcium carbonate from sugar mills and ammonium sulphate factory, sludge from paper mills, and waste from gas works can be available from a number of industrial concerns. Plant wood ash (hard wood) contains about 30 to 40 per eent lime (CaO) and equal high grade limestone in its neutralizing value. Blast furnace slag, a by-product of pig iron industry, and basic slag, a by-product of the steel industry contain chiefly calcium silicate and after pulverisation have a neutralizing effect on acid soils comparable to that of limestone. Laccadive phosphate which contains about 37 per cent calcium can also be used as a liming material.

In India, the acid soils are confined mainly to Assam, some parts of West Bengal, in southern parts of Bihar (Chota Nagpur) and in South Canara and Malabar. Mandal (Mandal, S.C., 1960, unpublished) has established the great beneficial effect of liming the acid red soils of Ranchi for increased yield of crops.

All crops do not respond to liming to the same extent. In order to find out the degree of response of different crops in the acidic uplands, experiments have been conducted at the Bihar Government Farm at Kanke in three successive years, 1958–61. The degree of response of some *kharif* and *rabi* crops is given in Table 35.

TABLE 35. RESPONSE OF *kharif* AND *rabi* CROP TO LIMING

Crop	Mean yield (three years' average) in q/ha			
	Control	Lime	NPK	Lime + NPK
Soyabean	1.45	7.34	2.98	11.48
Rahar	0.52	5.89	2.14	10.0
Groundnut	4.17	12.63	8.12	13.90
Cotton	0.20	1.92	2.98	4.45
Jowar (Fodder)	86.1	172.4	184.3	297.7
Maize	2.61	5.28	11.19	17.21
Wheat	6.10	6.67	13.11	16.32
Gram	1.89	6.11	4.83	11.45
Pea	2.07	4.22	6.41	12.34
Barley	7.11	7.23	18.84	23.31

In addition to the crops listed above, lentil, linseed, *kalai* and *mung* also responded very well to liming. The crops that did not respond to liming are *gora* paddy, *marua*, *gondli*, *surguja* and mustard.

The dose of lime required will depend on the pH of the soil, texture of the soil, type of clay minerals, etc. Assuming that the type of clay mineral is not widely variable, a tentative schedule of lime requirement has been worked out for different textures and pH values as shown in Appendix V (Kanwar and Bhaumik, 1959).

Chakraborty, Chakravarti and Mukherjee (1961) have shown that 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. 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 shown in Table 36.

TABLE 36

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
Soyabean	6.0—7.0
Sugarcane	6.0—8.0
Sunflower	6.0—7.5
Tobacco	5.5—7.5
Wheat	5.5—7.5

(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 no equivalent acidity of 110. It takes, therefore, 110 kilograms of calcium carbonate to neutralize the acidity developed n the soil by the use of 100 kg of ammonium sulphate fertilizer.

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

'Equivalent acidity' of some of the commonly used fertilizers are given in Table 37 (Ignatieff, 1958).

TABLE 37. EQUIVALENT ACIDITY OF FERTILIZERS

Fertilizer	Percent N	Equivalent acidity (a)
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 considerable amount of lime is also removed by the crops grown in the country. Table 38 gives an idea of the total calcium uptake by the crops in less than half of the total cultivated area (1955-56).

TABLE 38. TOTAL LIME REMOVED BY THE PRINCIPAL CROPS IN INDIA

Crop	Area under cultivation (1955-56) (million acres)	Ca removed, million tones 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	

2.47 acre = 1 hectare

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

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 17 million metric tonnes 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 ıor the depletion of lime. A precise estimate is not possible due to the lack of reliable data but probably several million tonnes of agricultural lime should be used to obtain optimum plant growth.

Experimental observation in different centres in India

Sufficient data of the effect of liming on Indian soils are not available. However, the following will indicate the significant response to and other congenial effects of liming in soils of different parts of India.

Mysore. The effect of liming on the yield of paddy in acid soil is indicated from the typical experimental data of Table 39.

TABLE 39. DATA INDICATING EFFECT OF LIMING ON YIELD OF PADDY IN ACID SOIL, 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/HA RESPECTIVELY FOR PADDY (ANONYMOUS, 1959)
(IN KG/AH)

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

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

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 1900 kg or more lime per hectare, 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.

(4) The results of manurial experiments in Assam show that an application of 18.5 quintals of lime per hectare or more (according to necessity) corrects the soil acidity and in return increases yields of crops like mustard, pulses, etc., which will not otherwise grow without liming.

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 0.114 kg and superphosphate at 0.114 kg in presence of leaf mould at 9 kg and lime at 0.228 kg per vine has considerably enhanced the yield of pepper at Taliparamba.

Kerala. Soils in Kerala are highly acidic in nature. Most of the soils in Kerala show a pH below 5.5 About 81000 hectares under rice in the State have a pH below 4.5. These rice lands are situated in the Districts of Alleppey and Trichur. The Kuttanad rice lands situated mostly in the Alleppey District and the *kole* areas of Trichur District are highly acidic. The lime contents of these soils is very low. Liming in such areas improves the soil conditions for the production of paddy. Trials have been conducted in the State with lime particularly in the highly acidic soils of the Kuttanad with a pH varying from 3.5 to 4.5. It has been proved that the response of the fertilizer application increases with the judicious use of lime.

Different kinds of liming materials such as unburnt, half-burnt and fully-burnt lime were tried on these soils. It has been found that the burnt lime is the most effective and the best results are obtained when burnt lime is applied in two doses—the first dose before sowing and the second dose about three to four weeks after sowing, i e., at the time of thinning out and transplanting. On an average 560 kg of burnt lime per hectare will be necessary. It has also been estimated that with such a dose of lime over the usual recommended

N.P.K. dose, an additional yield of 450 kg of paddy per hectare could normally be obtained.

The lateritic areas of the State also require liming in view of the acidic nature of the soils.

The results of manurial experiments in Assam show that an application of 18.5 quintals of lime per hectare or more (according to necessity) corrects the soil acidity and in return increases yields of crops like mustard, pulses, etc , which would not otherwise grow without liming. In parts of West Bengal where acid soils exist, the manurial schedule includes 9.2 quintals of lime in addition to cowdung, bonemeal and muriate of potash. The stem-rot was effectively checked in these areas by lime and muriate of potash. Application of lime seems to be essential for miscellaneous crops like pepper, potato, sugarcane, etc., in Nilgiri tract of Madras State. Nair (1952) reported that in the acid soils of South India, where thousands of acres are under banana cultivation, the crop responded well to liming and there was an increase in yield ranging from 100 to 1000 per cent. The importance of liming to paddy soils of South Canara has been suggested by Anantha Krishna Rao and Hanumanta Rao (1952), whose results showed that application of lime in doses of 1121 to 3363 kg per hectare resulted in increased grain yields of 10 to 20 per cent during the second and third year of application.

Gokhale *et al.* (1954) found that liming increased the phosphorus fraction soluble in carbonated water and thus decreased the percentage of added phosphorus unavailable to plants.

Rai, Prasad and Mandal (1963) found that liming the acid soil (pH 5.5 or so) to neutral point distinctly resulted in higher uptake of phosphorus by crops.

Leguminous crops require large amounts of lime. Data reported by Padhi (1942) suggest that liming of most soils growing cotton would be a beneficial practice.

Gypsum. Gypsum as a fertilizer supplies calcium and sulphur nutrients. It is extensively used in the reclamation of saline and alkali soils. Gypsum reserve of 86.9 million tonnes is estimated to be available ; in Bikaner (46.3) and Jodhpur (16.6) in Rajasthan, Madras (16.2), Saurashtra (4.1), Kutch (2.0), and Himachal Pradesh (1.8). There are considerable reserves also in Kashmir, the former Jaisalmer State and in adjoining areas of Bhutan. There are other places, but full particulars about them are not yet known.

In India, there are millions of hectares of *usar* lands which can be made cultivable by extensive applications of gypsum. They are found especially in the west and central parts. In Maharastra State, though saline and alkaline soils are generally met with but badly affected lands are found in Karnataka and in the Deccan. Talati (1931) divided these soils into (i) mixed saline soils, which contain a mixture of calcium, magnesium and sodium salts, with pH higher than the mixed saline soils and (iii) alkali soils with varying degrees of alkalisation between 20 to 60 per cent. The first type improves with simple leaching but saline soils after leaching turn alkaline. Application of gypsum and sulphur in combination with FYM has been found to be the best soil treatment. Islor (1941) has suggested burning the soil with field wastes, followed by the application of gypsum and green manures.

This *usar* problem is very acute in the gangetic alluvium soils due to continued irrigation resulting in rise of salts to the surface which turns fertile lands useless for crop growth. About 0.85 million hectares are affected by *usar* in Uttar Pradesh alone. Agarwal (1957) has shown that gypsum requirement of mild alkaline soils is 2.5—12.5 tonnes per hectare. About 30 per cent of the total *usar* area of the State consists of such milder types. Worst alkali-affected lands require 25 tonnes or more per hectare. The soils of Punjab plains also have become alkaline. Sodium salts are usually present in soil crusts and control of their movement has become a problem for the State. Dalip Singh and Nijhawan (1932) have pointed out that application of gypsum or calcium chloride at the rate of two tonnes per hectare is only remedy to improve these soils.

Willis and Rankin (1930) demonstrated the value of gypsum in superphosphate and showed that it counter-acts the free ammonia produced as a result of the decomposition of organic matter. Willis and Pilland (1931) recommended the use of gypsum as a supplement to all the fertilizers or soil improving treatments which supply free ammonia to soils in high concentrations.

Fertilizers dealing with micronutrients. It is now more or less clearly established that the plants also need, in addition to major plant food elements, small quantities of manganese, zinc, copper, boron and molybdenum. Supply of these elements below or above certain limits is reflected in the health of plants through characteristic symptoms and this may ultimately lead to the decrease in yield or, in severe cases of total failure of the crops.

Quite a number of instances of possible deficiencies of boron, manganese, zinc, etc., exist in India (Stewart, 1947). Mukherjee (1949) reported a deficiency disease due to deficiency of manganese and zinc in the case of citrus in Coorg, and Madras. Daji (1948) attributed 'band disease' of arecanut trees to the manganese toxicity. Das and Motiramani (1949) observed top yellowing of gram to be due to manganese deficiency. Rama Moorthy and Desai (1946) found that all minor-element-deficiency diseases of tobacco, wheat, barley, citrus and betelnut were associated with the excess of some elements which created deficiency of other elements manifesting in a wide range of deficiency symptoms.

As pointed out by Rama Moorthy and Desai (1946), and Nair (1952), boron, from the agricultural point of view, is perhaps the most important of all the above trace elements, especially in relation to the nutrition and yield of the cereal and oilseed crops. Boron is also considered to exert considerable influence in the absorption and availability of various other plant nutrients.

Rama Moorthy and Viswanath (1946) showed that boron content of the cultivated soils differ considerably from that of the corresponding virgin soils and it was shown to be dependent, amongst other things, on the nature of irrigation water and the manurial treatments employed. The manganese status of Indian soils (Biswas, 1950), was found to vary considerably, depending on the soil and climatic factors. Such studies help in preparing a proper manurial schedule of micronutrients to be applied in these soils.

It is a common practice to incorporate these microelements in proper proportions in mixed fertilizers to get good results. Agarwal (1950) suggested the possibility of the use of blast furnace slag as a soil corrective for the deficiencies of manganese and phosphate.

The deficiency of these microelements is usually due to low availability and not due to absolute lack of the elements. Sprays are often used as a temporary corrective measure (Ignatieff, 1949). To correct iron deficiency, a solution of about 1.8 kg of ferrous sulphate and 0.9 kg of lime per 200 litres of water could be used. To correct zinc deficiency in some parts of Australia, zinc is applied by swabbing pruned canes and vines, or by spraying citrus and pine trees with a dilute solution of zinc sulphate. Under suitable conditions, soil application of 9–27 kg of zinc sulphate per hectare might meet the needs. Manganese deficiency could be corrected by sprays using 0.9 to 1.8 kg of manganese sulphate with an equal amount of lime in 200 litres of water. Soil applications of 22.4 to 89.7 kg of manganese sulphate per hectare were often satisfactory for correcting manganese deficiency in slightly acid soils

Boron and copper deficiency could be corrected by applications of 4.28 lb. of borax and copper sulphate per acre applied broadcast mixed with fertilizers. Regarding molybdenum, addition of small quantities of commonly used fertilizers could be effective but very diluted sprays of molybdenum compounds (ie., 28 gm of sodium molybdate in 480 litres of water per acre) could also be used.

Essentiality of sulphur in crop production particularly in legumes has been recognised. In India, the study of the effect of different types of phosphatic fertilizers on *berseem* has revealed that superphosphate, a sulphur bearing fertilizer has given significantly higher yield compared to other fertilizers on equal phosphoric acid basis. Aiyar (1945) reports that sulphur deficiency in rice plants, results in chlorosis reduction in height, leaf area and tillering and failure to reach maturity. This can be corrected by the application of sulphur to the soil.

In general, deficiencies of boron and copper have been found to exist in calcareous soils, soils of high pH, highly leached sandy soils and peaty soils.

The deficiencies of these microelements is usually due to low availability, rather than an absolute lack of the element. Sprays are often used as a temporary corrective measure (F.A.O. *Efficient Use of Fertilizer*, 1949). Boron and copper deficiency could be corrected by applications of 4.9 to 31.4 kg of borox and copper sulphate per hectare applied broadcast or mixed with fertilizers.

Sadaphal and Das (1956 a) reported that micronutrients like copper, manganese, zinc and magnesium, whether applied singly or in combination to Delhi soil, significantly increased the yield of wheat, the maximum increase being with manganese. The results of a field trial with application of 5.6 kg per hectare of copper and zinc and 11.2 kg per hectare of manganese and magnesium are presented in Table 40.

TABLE 40. EFFECT OF MICRONUTRIENTS ON YIELD OF WHEAT

Treatment	Yield of wheat grain kg/hectare
NPK*	1428
NPK+copper	1665
NPK+mangnese	1861
NPK+zine	1597
NPK+magnesium	1726
NPK+Cu+MO+Zn+Mg	2605

*N—33.6 kg/ha P_2O_5—56 kg/ha K_2O—22.4 kg/ha

Raychaudhuri and Datta Biswas (1964) have summarised broadly the results of field experiments indicating responses with micronutrients till 1963 in the country which is shown in Table 41.

TABLE 41. TRACE ELEMENT DEFICIENCY FOR GROWING CROPS AS REPORTED FROM DIFFERENT PLACES IN INDIA*

Element	Crop	Place
Manganese	Sugarcane	Bihar
	Soyabean	Allahabad
	Sweet orange	Madras
	Citrus	Punjab
	Citrus	Coorg
	Gram	Delhi
	Paddy	Ranchi (Bihar)
Copper	Sweet orange	Madras
	Paddy	Ranchi (Bihar)
Zinc	Betelnut	Maharashtra
	Urid	Sepaya, Dt. Saran (Bihar)
	Citrus	Madras
	Citrus	Punjab
	Citrus	Coorg
	Citrus	Ajmer
	Paddy	Palampur (Punjab)
	Wheat	Jullundur (Punjab)
	Wheat	Mehsana (Gujarat)
	Wheat	Ahmedabad (Gujarat)
	Wheat	Bassi (Rajasthan)
Boron	Cauliflower	Baroda
	Cauliflower	Delhi
	Cauliflower	West Bengal
	Virginia tobacco	Baroda
	Maize, wheat,	Bihar
	Pea, barley, Maize, groundnut	Islampur (Bihar)
	Berseem	Delhi
	Wheat	Ahmedabad (Gujarat)
	Wheat	Bassi (Rajasthan)
Molybdenum	Berseem	Punjab
	Berseem	Delhi
	Berseem	Nagpur
Iron	Sugarcane	Punjab
	Sugarcane	Burdwan (West Bengal)
	Sugarcane	Nadia (West Bengal)
Sulphur	Groundnut	Samrala (Punjab)
	Sugarcane	Burdwan (West Bengal)
	Jute	Burdwan (West Bengal)

*Source: Trace Element Status of Indian Soils, Raychaudhuri, S.P. and Datta Biswas, N.R. 1964. *J. Indian Soc. Soil Sci.* 12 : 207-14.

III. BEHAVIOUR OF FERTILIZERS IN RELATION TO CROP, SOIL, CLIMATE AND STORAGE

Manures and fertilizers in relation to quality of crops

The nutritive value of plant-food elements, viz., nitrogen, calcium and phosphorus has been described by many investigators and a fertilizer programme should aim at increasing these nutritive elements. The increased application of fertilizers generally leads to increased absorption of a particular nutrient, this in turn affects the absorption of other elements. Thus, Subbiah and Desai (1952) observed that because of the increased availabiliy of nitrogen due to fallowing, the ratio of nitrogen and phosphate uptake markedly increased in wheat after fallow as compared to that in wheat after a *kharif* maize crop. Subbiah (1952) observed that increased application of nitrogen to *jowar* led to considerable decrease in the absorption of silica.

Some of the recent studies have shown certain general inter-relationships of major elements in plants. Subbiah (1951) showed that in all the seeds of different plants, the ratio of sum of nitrogen, phosphorus and sulphur and the sum of calcium, potassium, magnesium and sodium expressed in equivalents tended to be constant (about 0.2), showing thereby that the seeds high in nitrogen are also proportionately high in minerals.

Parkar and Truog (1920) observed that the plants high in nitrogen were generally high in calcium content, It was observed by Subbiah (1946) and Desai and Subbiah (1951) that the ratio of nitrogen to cations tended to remain fairly constant, irrespective of the application of fertilizers at each stage of the growth. Similar observations have been made by Bear (1950). These relationships are likely to be of great use in drawing up proper manurial schedules to raise crops of high nutritive quality.

Gupta and Das (1954) observed a significant increase in the percentage protein content of wheat grain due to the application of N, NK and green manure in the Pusa Permanent Manurial Experiments, whereas, a depression in its content resulted from P application. The phosphate content in wheat was increased under P, PK, NP, NPK, FYM and green-manure treatments and the percentage calcium was higher under FYM, oil-cake, NP and NPK treatments.

Manures and fertilizers in relation to crop, soil and climate. No systematic soil survey has so far been carried out in India to fix the soil type for fertilizer trials. Information about the distribution of broad soil classes are, however, available, viz. (a) alluvial, (b) laterite, (c) red and (d) black. The responses of paddy, wheat (irrigated and unirrigated), and sugarcane to (1) inorganic nitrogen, (2) inorganic phosphate, (3) combination of N and P, (4) oilcakes, (5) bulky organics, (6) green manures, and (7) organics plus inorganics in these soil classes are discussed below. It must, however, be pointed out that any soil class may have a number of soil types showing different responses to manures and fertilizers and as such only very general conclusions can be drawn. The available data have been averaged for this purpose on the basis of the soil classes of the different experimental stations.

PADDY

Alluvial soils. In alluvial soils, the maximum percentage increase in the yield was obtained with a combination of inorganic N and P (107.8 per cent increase over the control) followed by organics plus inorganics (44 per cent increase over the control). The response to phosphate has not been appreciable in most cases, possibly due to nitrogen becoming a liming factor. The effect of bulky organic manures on yield was least.

Laterite soils. On laterite soils, bulky organic manures and oilcakes proved most effective in increasing the yield (52 per cent and 64 per cent respectively) and were followed by organic plus inorganic and green manures (percentage increases 37.8, 33.6 respectively). There were few experiments with phosphate on these soils and, in general, the increase in yield due to phosphate alone and with inorganic N had been small.

Red soils. From the point of view of percentage increase in yield over the control, bulky organic manures and green manure appeared to be superior to other treatments (percentage increase 67 and 41.5 respectively). N plus P proved to be superior to either N and P singly.

Black soils. Experiments with paddy on these soils had been very few and thus no conclusion can be drawn,

N alone (inorganic). The percentage increase in yield with inorganic N on paddy has been best in the laterite soils followed by alluvial and red soils. The response per lb. of N applied has been maximum in red soils followed by laterite and alluvial soils. The average percentage increase over no manure and response per kg of N applied are (1) laterite, 33.6 and 13.2 kg, (2) black, 27.0 and 17.5 kg, (3) alluvial, 21.3 and 10.0 kg, and (4) red soil, 18.9 and 16.6, kg respectively.

P alone. The general response in alluvial soils was also fairly good with 22.6 per cent inerease over the control. The numl er of experiments in red, black and laterite soils has been small and general indications show that only 10 per cent increase in the yield could be obtained by phosphate manuring.

N plus P. The average increase in yield with N plus P combination has been generally more than either of them singly in almost all cases and in all soil types.

Organic and inorganic. The combination of organics with inorganics appeared to be more beneficial in alluvial and laterite soils than in red soils.

WHEAT

Wheat growing has been mostly confined to red, black and alluvial soils, most of the unirrigated crop being grown in black soils.

Alluvial soils. In most of the irrigated trials made in alluvial soils, a combination of nitrogen and phosphate (artificial) appears to have given highest increase in yields (60.6 per cent over control). This trend is followed by the organic plus inorganic treatment with an average increase of 37 per cent over the control. Bulky organic manure, or artificial N alone has given an average increase of about 22 per cent over the control. The number of trials with unirrigated wheat in alluvial soils has been small and the results indicate that organic plus inorganic produced good results (average increase 427 per cent) followed by bulky organic manure (159 per cent) and oilcake (71 per cent) over the control. Generally, inorganics have given lower response.

Red soils. In irrigated wheat bulky organic manures and oilcakes have given better yields (47.3 and 54.4 respectively) than inorganic N (20 per cent) over the control or inorganic P (9.5 per cent over the control or inorganic P (0.5 per cent over the control). Trials conducted on unirrigated wheat had been very few to draw any definite conclusion. A combination of inorganic N and P appeared to be best resulting in an increase in yield of 102 per cent over the control. This was followed by oilcakes (43 per cent over the control).

Black soils. Trials conducted with irrigated wheat too, had been very few and most of the trials were made with organic manures. Bulky organic manures increased yields by 61 per cent over the control. In the case of unirrigated wheat a combination of inorganic N and P showed best increase in yields. Each of the treatments (a) inorganic N, (b) inorganic phosphates, (c) oilcakes and (d) bulky organic manures, gave an approximately equal increase of 20 to 25 per cent over the control.

SUGARCANE

Sugarcane is generally grown as irrigated crop, except in Bihar and a few other places. In black soils at Padegaon an average increase of as much as 255 per cent over control was obtained by a treatment with organics plus inorganics, and equally good results with application of cakes. Application of inorganic N gave 117 per cent yield over the control and ranks next to the above.

In red soils, the best yield of 102 per cent over the control was obtained with oilcakes and was followed by P (artificials 56 per cent over the control). N or N plus P have given on an average 25 per cent increase over the control. In the alluvial soils, inorganic N has proved to be the best (average increase in yields 78 per cent over the control), oilcakes (29 per cent) and green manure (13 per cent). The results of application of phosphate alone in alluvial soils indicate no beneficial effect.

No experiments with unirrigated sugarcane have been reported from black-soils area. In red soils, N and P artificials gave an average increase of 41 per cent over the control and was followed by N alone (27.8 per cent). Phosphate alone gave the least increase (3.3 per cent over control). In alluvial soils, N plus P has given an average increase of 78 per cent, followed by artificial N (54 per cent) and organics plus inorganics (29.30 per cent over control).

In general, organics plus inorganics, oilcake and inorganic nitrogen have given the best increase in yields in most of the soil types.

Storage of fertilizers. Increasing use of fertilizers for stepping up crop production in India involves problems of storage of fertilizers from the manufacturing stage to the stage of their application by cultivators. In addition to ammonium sulphate and superphosphate, other fertilizers like urea, ammonium nitrate, ammonium sulphate nitrate, triple superphosphate, ammonium phosphate, and nitrophosphate have been imported into the country under the Indo-U.S. Technical Co-operation Project for examining their performances on Indian soils and for their domestic production, if found suitable. This is particularly important in view of the scarcity of sulphur or its other compounds needed in the manufacture of ammonium sulphate or superphosphate.

The physical condition of a fertilizer is of primary importance in its efficiency. If the fertilizers cake or become sticky, or if their drillability is impaired due to season, it will be difficult to properly apply them to crops. The following factors are likely to operate on fertilizers under different conditions of storage.

1. Humidity, which affects the absorption of moisture by the fertilizers

2. Effect of moist fertilizers on bag rot

3. Caking of fertilizers as a result of stocking and change in humidity

4. Loss or reversion of manurial constituents in storage under different climatic conditions

5. Fire hazards or effect of fire on the physical conditions and chemical composition of fertilizers

6. Damage to packing bags during storage

7. Toxicity when ingested by animals.

Poor physical condition of fertilizers can usually be largely or completely overcome by one or more of these methods : (i) controlling initial moisture content, (ii) proper curing to ensure completion of chemical reactions before shipment, (iii) use of right kind and quantity of conditioning agent to hinder coalescence of the individual particles, (iv) granulations of the fertilizers or with mixtures and use of ingredients having uniform or relatively large particle size, (v) protection from extremes of atmospheric temperature and humidity, and (vi) transport in moisture resistant packages.

Granulation of fertilizers, whereby the particles are converted into pellets of nearly uniform size or composition, has been found to promote good physical condition. Most of the fertilizers like ammonium nitrate, ammonium phosphate, calcium cyanamide, calcium nitrate, sodium nitrate or superphosphate are at present produced and sold in granular form.

The granulation of fertilizers of like size prevents the segregation of the individual fertilizers and reduces their tendency to cake or to become sticky. Further, granulated fertilizer will not film fertilizer distribution machinery and may be distributed uniformly and introduced in the soil at the correct depth by most fertilizer distributors, unlike the pulverised fertilizers which usually film the fertilizer distribution machinery. One particular advantage in granules in fertilizer mixture containing superphosphate is that the phosphate in granules is maintained in a water soluble form longer than in regular superphosphate. In U.S.A., granulated superphosphate has proved superior to pulverised superphosphate for crops like hay and pastures where the fertilizer is broadcast. In case, however, where the fertilizer is drilled in narrow bands and high amounts of phosphate are used, as in the case of cotton, granulated superphosphate has not proved superior to the pulverised fertilizer. If, however, the soils are deficient in plant nutrients and limited quantities of fertilizers are used, it is likely that even with drilling, the granulated fertilizer will show better response than the pulverised mixed fertilizer, as the phosphate in the granule will come in contact with less soil and fixed in a less available form to a smaller extent. Although the absorption by roots of nutrients from the mixed fertilizers of somewhat large sized granules may be delayed in the initial stage of growth of crop, the effect of this form of fertilizers is more lasting than of the powdered form as the granular fertilizer may be less readily leached and may not be denitrified even when applied near the surface. Recent experiments in Japan have shown that the granulation of compound fertilizers containing 10 per cent of ammoniacal nitrogen, 8 per cent of soluble phosphate and 5 per cent of soluble potash had a good effect on the growth and yield of paddy and large granules of fertilizers (10—13 mm diameter) increased the yield of paddy by about 11 per cent above that compared with the powdered form (less than 2 mm diameter).

While granulation of single or compound fertilizers may be carried out at the production stage, granulation of mixed fertilizers is done only after the individual fertilizers are manufactured and, therefore, granulation of mixed fertilizers involves comparatively more cost. The additional cost of commercial granulation of mixed fertilizers, however, may be gradually brought down by spraying and rotary drying techniques.

On the whole, it may be stated that under Indian conditions, where fertilizers are usually broadcast and also limited quantities are used, granulation of mixed fertilizers is likely to be advantageous and the increased cost of granulation will be made up partly by the increased yield and partly by the saving in the losses by wind action during the application of the fertilizer to the field and by the saving of cost of powdering the cakes which frequently form with pulverised fertilizers.

The Indian Council of Agricultural Research sanctioned a scheme in 1952 to examine the physical properties of certain chemical fertilizers under storage conditions in the country. The ferrtilizers tried were, (i) ammonium sulphate, (ii) urea, (iii) ammonium nitrate, (iv) triple superphosphate, (v) ammonium phosphate, and (vi) nitrophosphate. In order to examine the storage behaviour of the above fertilizers under a variety of climatic conditions, 20 centres were selected at different parts of the country for conducting the storage trials (Idnani, *et al.*, 1956).

Among nitrogenous fertilizers, urea absorbed moisture upto 5 per cent in open packing. Alkathene liners reduced moisture absorption. Ammonium sulphate absorbed 0.5 to 1 per cent moisture in jute bags and even this much of moisture was sufficient to produce heavy lump formation. Repacking in alkathene linres did not prevent lump formation. Ammonium nitrate, which was in the prilled form, absorbed less than 1 per cent moisture.

There was 100 per cent lump formation in the case of both ammonium sulphate and urea, irrespective of the type of packing ; lump formation could be effectively prevented by mixing ammonium sulphate and urea with 5 per cent saw dust. It may be pointed out that at the United Planters' Association of South India, (*Ann. Rep.* 1952—1953), urea mixed with 10, 15, 20, 25, and 30 per cent by weight with groundnut cake, flour phosphate and steamed bonemeal could be satisfactorily stored for one year. There was slight increase in moisture in the groundnut cake mixture, but not in the other two.

Ammonium sulphate was stable in its composition during storage ; urea under humid condition underwent slight decomposition. Ammonium nitrate was quite stable when kept in 6-ply paper bags or alkathene liners.

Ammonium sulphate and urea did not damage the jute bags under dry conditions. Damage to jute bags could in all cases be avoided by packing the fertilizers in alkathene liners inside jute bags.

IV. RELATIVE VALUE OF ORGANIC AND INORGANIC MANURES

The actual role of organic manures in maintaining soil fertility has been the subject of controversy for some years. Keen (1946) holds the view that because of the rapid decomposition of organic matter in tropical conditions, the beneficial effect of bulky organic manures lies, not so much in securing physical improvement of the soil as in supplying plant nutrients that are contained in the manure. He quotes a number of experiments on green manuring to show that large increases in yield were obtained by applying their ashes rather than by digging in the green-manure crop (Faulkner, 1934 ; Lewin, 1931). Doyne (1937) found that a marked increase in the carbon and nitrogen contents of the soil was brought about by green manuring but the effects were transitory. Within less than a year of being ploughed in, the plant residues decomposed so effectively that there was hardly any trace left of them. Bear (1949) has cited field experiments carried out at the Virginia Experimental Station to show that the application of a complete inorganic manure (NPK) increased the organic matter content of the soil over a period of 15 years.

One of the important functions of organic matter in soil is to build up a structure resistant to erosion. Stewart, who examined the available evidence in India up to 1946, states in his report (1947), "In many of the heavy deltaic soils under paddy, where the application of green leaf and similar organic manures is of particular value, the beneficial effects of the supplements appear to be associated with the improvement of tilth and other physical properties rather than of the chemical properties of the soils, whilst in many of the texturally lighter soils such as those in Mysore and in some of the paddy areas in Travancore, both physical and chemical improvements appear to be involved".

There is a belief that organic manures possess fertilizing properties in addition to various plant nutrients that they contain. Convincing scientific evidence in support of the above is, however, lacking. The value of auximones, vitamins and such compounds in composts, which are said to improve the quality of the crops and confer immunity from disease to plants, requires further confirmation.

There is evidence that the use of suitable and balanced fertilizer mixtures gives good crop yields comparable to those obtained by the application of large doses of organic manures. At Rothamsted, soils receiving heavy applications of fertilizers for 100 years are still in excellent condition and high yields have been maintained as shown in Table 42 (quoted by F.E. Bear, 1949).

TABLE 42

Periods	Plot No.				
	3	2B	8	7	13
	Annual application/hectare				
	None	Manure 39.4 tonnes	Fertilizer 2166 kg	Fertilizer 1336 kg	Fertilizer 1110 kg
	Yield (ha)				
1852–61	39.3	86.0	86.5	85.5	81.3
1862–71	35.6	92.6	100.0	63.7	86.0
1932–41	31.4	64.5	76.6	66.4	63.5
1942–46	38.8	77.3	95.6	87.2	76.1

The 2166 kg of fertilizers used on plot 8 supplied about 145 kg N, 74 kg P_2O_5, 114 kg MgO and 16 kg Na_2O. On plot 7, the N was reduced to 96 kg. Plot 13 received the same fertilizer as plot 7 except that no MgO and Na_2O were used.

It has, however, been pointed out by Howard and other workers that the seed used every year in the above experiments was purchased from outside market and might have been grown on the soil treated with organic manures. Behaviour of the seeds grown in plots treated with artificial fertilizers when resown in similar plots or fields is worth examining.

In the permanent manurial experiments at Pusa (Bihar) during the period 1908–30, it was found that the complete fertilizer treatment gave yields which were equal to those obtained by applying FYM or green manure. The new manurial series at Pusa laid out in 1932–33 confirm the above observation that N and P fertilizers, have proved to be as efficient as heavy doses of farmyard manure. In this connection, the following paragraph in Stewart's report (1947) would be read with interest : "It is impossible to assess the value of organic manures in a single year or short-term experiments and more detailed work of a long-term nature is required. The long-term aspect of such work has been stressed by Viswanath (1931) who has described results of experiments with farmyard manure and mineral fertilizers conducted over a long period at Coimbatore. It is pointed out that the effect of farmyard manure on the first 36 crops was generally inferior to that of complete mineral fertilizers, while average yields for the 37th to 56th crops favoured the farmyard-manure treatments. Whilst short-term work is essential for a variety of purposes, the long-term and cumulative aspects of soil fertility must also be kept in mind.

It is still felt in some quarters that fertilizers, though they contain plant nutrients in readily available and concentrated form, spoil the land and make it unproductive for a long time to come. They, therefore, advocate the use of only organic manures. In the absence of manure they prefer to leave the land unmanured. As pointed out by Sanyasi Raju (1952) this is a most suicidal policy to be adopted at a time when the fertility of Indian soils is low and the supply of indigenous manure inadequate to satisfy the needs.

The results of permanent manurial experiments conducted at Coimbatore (Sanyasi Raju, 1952) are very illustrative to show that no deleterious effects are observed with continued use of artificial fertilizers.

This experiment started in 1909 and 81 crops were taken up to 1950. The major nutrients, i.e., nitrogen, phosphoric acid and potash were applied singly and in combination. Cattle manure at the rate of five tonnes per acre was also included as one of the treatments. The field was originally irrigated till September, 1937 and it was left fallow till November, 1939 and, therefore, treated as rainfed. The following amounts of chemical fertilizers were added annually.

Fertilizer	Quantity applied per hectare	Kg of ingredient supplied per hectare
Ammonium sulphate	125.5 kg	25.1 kg N
Superphosphate	376.5 kg	72.6 kg P_2O_5
Potassium sulphate	125.5 kg	60.5 kg K_2O

Average yields of grain of each variety of crop grown during the period (1910-1951) are given in Table 43.

The data presented in Table 43 show that when the total yield of all the crops is taken into account, the following is the descending order of treatments in their responses : N plus P plus K ; N plus P ; cattle manure ; K plus P ; P ; K ; N plus K ; N ; and no manure.

TABLE 43. AVERAGE YIELD OF CROPS IN OLD PERMANENT MANURIAL PLOTS, COIMBATORE

Name of the crop	Number of crops (1910-51)	No manure	N	N+K	Average yield in kg. grain per hectare					
					N+P	N+K+P	K+P	K	P	Cattle manure
RAGI (*Eleusine coracana*)	15	474	552	601	1681	1738	1472	821	1016	1492
Per cent on control		100	116	127	354	365	310	172	214	315
CHOLAM (*Jowar*) (*Sorghum vulgare*)	15	716	790	820	2114	2104	1812	958	1198	2219
Per cent on control		100	110	115	294	293	253	133	167	310
WHEAT (*Triticum* sp.)	6	372	514	536	1017	1144	862	576	632	903
Per cent on control		100	138	144	273	307	232	154	170	243
PANIVARAGU (*Panicum miliaceum*)	7	861	671	596	1254	1146	1098	764	1039	1199
Per cent on control		100	78	69	145	133	127	88	121	139
CUMBU (*Bajra*) (*Pennisetum typhoides*)	3	140	185	221	357	348	236	188	163	303
Per cent on control		100	132	158	322	248	168	134	116	217
Total of yield for all crops		1563	2712	2714	6425	6477	5482	3309	4050	6118
For single crops		513	542	555	1284	1295	1096	661	810	1224

Reference : Sanyasi Raju (1952)

There is not much response to potash, either alone or in combination. It may be noted in this connection that the ingredients were not added on equal basis. For instance, cattle manure contains nearly 2¼ times the amount of nitrogen added in the form of ammonium sulphate and about twice the amount of potash than potassium sulphate. Thus, except for phosphoric acid, cattle manure contained double the dose of the artificials added. Yet it did not show its superiority over the inorganic fertilizer.

The same experiment was repeated in duplicate under gardenland conditions from the year 1925 and continued up to date. Forty crops were grown till 1951. One set of plots was found to be giving lower yields than other. It, therefore, received a basal dressing of 2242 kg. of cattle manure per hectare since 1931. The average results of crop yields with and without basal dressing from 1925 to 1951 are given in Table 44.

TABLE 44. RESPONSE OF EACH TERATMENT IN THE NEW PERMANENT MANURIAL EXPERIMENTS, COIMBATORE

Rank	Without basal dressing of cattle manure	With basal dressing of cattle manure
1.	Cattle manure	
2.	N+P+K	N+P+K
3.	N+P	N+P
4.	P	P
5.	K+P	K+P
6.	N+K	N+K
7.	No manure	N+K
8.	N	N
9.	K	Basal dressing alone

Under irrigated conditions, cattle manure responded best. The complete inorganic fertilizer closely followed cattle manure. As in the previous experiment under rainfed conditions, phosphate was the best single plant nutrient that increased the crop yield very markedly. There was little response to potash application either alone or in combinations. The applications of basal dressing of 2242 kg of cattle manure containing 13 kg N, 8.4 kg P_2O_5 and 20 kg K_2O per hectare increased the response of inorganic fertilizers in a field of low fertility. The dosage of nitrogen in both the experiments was very low.

The analysis of soils of the permanent manurial plots (both old and new) is given in Table 45.

There was a definite increase in the yield in the soil in which ingredients were added as manure, especially in the available form. The percentages of nitrogen and potash were double in the cattle-manure treatment in the old permanent manurial plots. This was due to the large supply of these ingredients as mentioned before.

There was a marked loss in the total lime in the cattle-manure treatment. The organic matter seems to be responsible for the mobilization of lime and the consequent loss due to leaching. There was a fall in pH from 7.9 to 7.5 in the N+P treatment. This was also noted in cattle-manure treatment and thus the fall cannot be attributed to the evil effect of inorganic fertilizers. A loss in total calcium was also observed in the new permanent manurial plols in the cattle-manure treatments. The results disprove the impression that inorganic fertilizers, if judiciously used, render the soil acidic and unproductive if used without the use of bulky organic matter continuously for a long time such as 40 years. It is true the microbiological populations and activity are not as high in the NPK treatment as in the case of cattle-manure treatment, but nevertheless, the values were far higher than those in the no-manure plot In no case did the NPK treatment depress either the microbial population or their activity.

In the Old Series of a Permanent Manurial Experiments at Pusa (Bihar) laid out in 1908 it was found that complete fertilizer treatment gave yields which were equal and in some cases more than those obtained by applying FYM or green manure. The New Manurial Series at Pusa laid out in 1932 confirm the above observations. Combination of N and P fertilizers have proved superior to N alone (Bhaumick and Raychaudhuri, 1953). In the 'Old Series' the green-manure treatment with sannhemp in conjunction with phosphate gave highest yield of crops, in as much as the loss incurred in crop yield by missing a crop in the year when sannhemp was grown, was amply compensated by high yields of subsequent crops obtained after green manuring. None of the treatments was able to maintain the crop yields in these long-term experiments. But the rate of decline in the yield was found to be less in the plots receiving organic manures than that in the plots under inorganic fertilizer treatments.

Carpenter (1938) observed that with tea in Assam, sulphate of ammonia is at least as efficient, if not more than an equivalent of organic manure, in maintaining both quality and the quantity of the crop.

TABLE 45. ANALYSIS OF SOILS FROM PERMANENT MANURIAL PLOTS, COIMBATORE

Treatment	Old Permanent Manurial Series (Percentage)						pH	New Permanent Manurial Series (Percentage)						pH
	Lime	Nitrogen	Total P_2O_5	Available P_2O_5	Total K_2O	Available K_2O		Lime	Nitrogen	Total P_2O_5	Available P_2O_5	Total K_2O	Available K_2O	
1. No manure	1.14	0.0295	0.032	0.0088	0.275	0.0198	7.9	0.975	0.060	0.083	0.0253	0.623	0.0269	8.1
2. N	1.33	0.0358	0.035	0.0099	0.003	0.0211	7.7	1.937	0.061	0.088	0.0225	0.666	0.0295	8.2
3. N+K	1.21	0.0371	0.032	0.0096	0.331	0.0288	7.6	1.947	0.061	0.085	0.0238	0.636	0.0360	8.2
4. N+P	1.17	0.0414	0.098	0.0544	0.286	0.0180	7.5	1.886	0.064	0.101	0.0378	0.618	0.0271	8.1
5. N+K+P	1.01	0.0367	0.109	0.0548	0.430	0.0265	7.6	1.843	0.062	0.094	0.0357	0.611	0.0275	8.2
6. K+P	0.89	0.0349	0.098	0.0614	0.461	0.0252	7.7	1.920	0.061	0.098	0.0367	0.613	0.0316	8.2
7. K	0.95	0.0343	0.037	0.0152	0.458	0.0264	7.8	1.832	0.064	0.089	0.0277	0.596	0.0308	8.2
8. P	0.99	0.0316	0.088	0.0612	0.358	0.0150	7.6	1.795	0.087	0.094	0.0340	0.578	0.0273	8.3
9. C.M.	0.86	0.0437	0.035	0.0119	0.640	0.0348	7.6	1.730	0.100	0.088	0.0290	0.568	0.0315	8.2

Ref. Sanyasi Raju (1952)

The deleterious effect of the injudicious use of sulphate of ammonia has been clearly brought out in the Permanent Manurial Experiments at Woburn (Wales) where 50 years continuous use of this fertilizer resulted ultimately in making the area totally unsuitable for growth of wheat or barley. Application of calcium carbonate in this case resulted in restoring the crop yield to normal. Successful results were also obtained by application of FYM alone as a corrective (Mann and Barnes, 1940). Similar results were obtained from the long-term experiments carried out in Pennsylvania, U.S.A. (quoted by Collings, 1947) since 1882 with sodium nitrate and ammonium sulphate on equal nitrogen basis. The results showed that sodium nitrate and ammonium sulphate gave nearly equal results in the first few years. Continued use of ammonium sulphate brought about deterioration in yield at an alarming rate but when this was used in conjunction with lime to correct the acidity, bad effects could not be observed. The yield obtained was even higher than that with sodium nitrate.

In the Permanent Manurial Experiments at Kanpur, considerable deterioration in soil was observed in the plots treated with sodium nitrate and sodium nitrate plus super. Cowdung and sheep-penning treatments preserved the soil from deterioration.

The use of organic manures alone has been found to be definitely beneficial in acid soils. In experiments at Karimganj, during a four-year cycle, ammonium sulphate at 56 kg N per hectare gave a negative response as compared to organic manure. In the case of lighter soils like those of Mysore and in some paddy areas in Travancore, both physical and chemical improvements were observed. Experiments in Maharashtra State showed that the soil productivity improved by the use of heavy doses of organic manure.

Sethi (1938) presenting data on the manuring of sugarcane showed that when FYM was supplemented by ammonium sulphate, significantly higher yields were obtained over FYM alone, indicating the necessity for application of an available form of nitrogen. Castor cake gave better yields than FYM but was not superior to FYM plus ammonium sulphate. At Mysore, a mixture of groundnut cake and ammonium sulphate was found to be better than ammonium sulphate. Deterioration of soil has been found to occur in the long run by continued use of inorganic fertilizer not supplemented by organic manure (Kalamkar and Sripal Singh, 1935).

The usually high yield of rice in Italy is the subject of interest throughout the world. Among the factors contributing to this are (1) application of FYM at the rate of 25-125 tonnes per hectare before planting of rice, (2) heavy application of fertilizer mixtures of ammonium sulphate, superphosphate and potassium chloride at the rate of 785 kg/ha, (3) long-term rotation to include several years of a legume-hay crop preceding the plan of planting of rice. In Japan, the yield of rice per acre has increased by 70 per cent during the 65 years (1878-1942). Two factors appeare to have been principally responsible for this, viz., liberal use of fertilizers along with organic manures and better varieties of paddy (Ghose *et al.*, 1960).

The addition of bulky organic matter obviously will influence the phosphorus fertility status of soils. The effect of organic-matter addition to soils in this regard is two fold : direct and indirect. Bulky organic matter contains phosphorus, 0.45 kg per tonne is good average for FYM. There is plenty of evidence to show that phosphorus in manure is just as available as phosphorus in superphosphate. Organic matter also increases both inorganic and organic phosphorus in soils. The indirect effects are through decomposition products of organic matter, e.g., CO_2 hydroxy acids as citric, tartaric, malonic, malic, etc., which act by making native soil phosphorus more available and also modifying the phosphate fixing capacity of the soil. As early as 1935 Ramaswami (1925) recorded the importance of FYM and turning under of green-manure crops in making phosphorus more soluble in calcareous soils. Singh and Nijhawan (1943) found an increase in available phosphorus in alkaline and calcareous soils by application of manures and green plants. Basu and Kibe (1945) showed that application of FYM and cake at the rate of 336 kg N per hectare increased the water soluble phosphorus even higher than the phosphorus fertilizer treatment. They noted that total phosphorus supplied by FYM and cake was very much less than that by fertilizer, yet they raised the available phosphorus status to a considerable extent. Sen and Bains (1955) added phosphorus in the form of FYM and showed marked increase in available soil phosphorus over that in no manure treatment. Khanna and Roy (1956) found that in calcareous soils of Bihar increase in soluble phosphate by the application of organic matter modified also the phosphate fixing characteristics of the soils. Considering the diversity of soil types in the country attemps to evaluate their phosphorus fixing characteristics are comparatively few (Raychaudhuri and Mukherjee, 1941 Patel and Srivastava, 1946 ; Singh and Das, 1945 ; and Pathak *et al.*, 1950). Srivastava (1960) using p^{32} as a tracer has confirmed that the effect of organic matter in mobilizing phosphorus is marked in all soil types. It reduces the intensity of binding, increases the movement of phosphorus and makes phosphorus more available.

Flooding a soil for a long time, as is usual for rice growing conditions induces marked reducing conditions as well as increased hydrolysis of soil phosphates. In laterites or soils containing predominently iron phosphate system, reduction of ferric iron to the ferrous state will reduce fixation and consequently lead to greater movement of the applied phosphates. Incidentally these processes will increase available soil phosphate also (Datta and Srivastava, 1958). Very little work on physico-chemical investigations on soil phosphorus behaviour under flooded rice soils has been conducted and this phase of work needs emphasis in future investigations.

Influence of liming on phosphorus status of soils and its availability depends on soil, the nature of crop and its rotation. Proper liming of acid soils promotes the availability of phosphorus —whether native or applied. Very little Indian work is available on the subject.

The bulk of the evidence on this important aspect of the problem indicates that under Indian conditions the use of combination of organic manure and fertilizer would give the optimum results both in long and short-term planning for improving soil productivity and maintaining soil fertility. Every attempt should, therefore, be made to conserve and utilize indigenous resources of organic manures. Further investigations are necessary to show the optimum combination of organic and inorganic manures needed for different crops and soils in the country.

TABLE 46. ADJUSTMENTS IN FERTILIZER DOSES FOR BULKY ORGANIC MANURE

Bulky organics	When basal dose of bulky organics is recommended but not added for each 454 kg recommended, increase the fertilizer dose as	When basal dose of bulky organics is not recommended but added for each 454 kg added, decrease the fertilizer dose as
Farmyard manure or compost (wet weight)	0 45 kg N and 0.45 kg P_2O_5	0.45 kg N and 0.45 kg P_2O_5
Legrminous green manures not grown *in situ* or non-leguminous green-leaf manures (green weight)	1.82 kg N and 0.91 kg K_2O_5	1.82 kg N and 0.91 kg K_2O
Leguminous green manures grown *in situ*	1 36 to 2.72 kg N (depending upon species of legume)	1.36 to 2.72 kg N (depending upon species of legume)

The suggestions for adjustments in fertilizer doses for bulky organic manures by Roy L. Donahue and his co-workers (*Fertilizer News*, 1966) for efficient use of fertilizers in the Intensive Agricultural District Programme are given in Table 46.

Green manuring. Panse *et al.*, (1965) have recently reviewed the work of green manuring of crops in the country. The review has brought out that the extent of green manuring in North India is practically nil. In the district of West Godavari in South India the survey in 1954–1955 indicated that 10.1 per cent of the area under rice was green manured, of which green manuring through forest leaves contributed 1.5 per cent. No green manuring was done on any other crop in the district. The 1954–1955 survey in Coimbatore district showed that 33.4 per cent of the area under rice was green manured, the contribution of forest leaf manuring towards the total being 16.3 per cent. Nearly 1.3 per cent of the cotton area and 1.9 per cent of sugarcane area were shown to be green manured. A resurvey in this and West Godavari districts, after a period of five years in 1961–1962 showed that the extent of green manuring is not materially changed. In Thanjavur district, which is one of the most important rice-growing areas in Madras, the extent of green manuring is estimated to be about 20.24 per cent for the different rice crops. More than half of this percentage was covered by greenleaf manuring. The average response of rice to green manure is 236 kg per hectare. Green manuring of sugarcane has shown a response of about eight tonnes per hectare. On irrigated wheat an average response of about 1.5 kg per hectare was obtained. Green manuring of cotton has given variable response with occasional depression in yield.

V. MIXED FERTILIZERS

Mixed fertilizers are combinations of different fertilizers distributed in the field in one operation. Equally good or better agronomic results can be obtained by applying fertilizer materials separately, but the use of mixed fertilizers has the following advantages: (i) fewer man-hours are required to apply a mixture than to apply its various materials separately; this is an important factor in areas where farm labour is scarce and expensive, (ii) mixtures may have better physical condition and are more easily applicable than many individual fertilizer materials, (iii) the residual acidity of fertilizers can conveniently and effectively be controlled by the use of a proper quantity of dolomitic liming material in the mixtures, (iv) plant nutrients required in small amounts can be applied more evenly by being incorporated in mixed fertilizers and, (v) if a proper mixture is used for the particular soil type and crop, less care on the part of the farmer is needed to assure the right proportion of plant nutrients in the soil than when the various fertilizer materials are applied separately.

Mixed fertilizers have some disadvantages too, viz., (i) their use does not permit application of individual nutrients at specific times which may best suit the needs of crops, (ii) the total concentration of and specific plant nutrient in a mixture is usually much less than that in the materials from which it is made, so that for a given weight of any specific nutrient more fertilizer need be handled and transported in the form of a mixture than in the ingredient materials, (iii) the unit cost of plant nutrients in mixture is usually higher than in the ingredient materials because of cost of mixing and (v) farmers are often led to use some mixture without careful study of their needs, thus using too little of some nutrients and more than necessary of others.

The formula of mixed fertilizer shows the kind and quality of each material contained therein. By the formula one is able to judge the type and quality of the nutrients and their suitability for specific soils and crops, and to determine roughly the quantity of sand and other inert materials used in its preparation.

In making a mixture of a specified grade, it is seldom practicable to obtain the exact quantities of nitrogen, phosphoric acid, and potash desired by the use of only fertilizer materials themselves. To assure that the mixture contains quantities of the nutrients specified by the grade, addition of material containing neither nitrogen, phosphoric acid, nor potash is usually necessary. Such material is called filler. It may serve only as a make-weight to balance out the formula to an even grade or it may serve also (i) as a conditioning agent to reduce caking and improve drillability, an important factor in the preparation of mixture from high analysis materials, (ii) as a corrective of the residual acidity of the fertilizer and (iii) as a source of other nutrient elements. These are legitimate uses of filler within the limits of conditions prevailing in the area of intended use. Indiscriminate addition of filler solely as a make-weight unnecessarily increases the cost of plant nutrients.

If the mixture does not contain a natural organic fertilizer material, it is advisable to add a conditioning agent. Although some inorganic substances, such as dolomitic limestone are suitable for this purpose, use is made chiefly of vegetable products and wastes which usually contain small percentages of plant nutrients. Addition of limestone or dolomite to mixed fertilizers to correct residual acidity is justified for those areas where use of calcium and magnesium liming materials has been adequately established.

The preparation of satisfactorily mixed fertilizers requires detailed knowledge of the chemical and physical characteristics of the individual materials and of their behaviour in the mixtures under different conditions of storage, transportation, and use as well as under varying circumstances of temperature and humidity.

Chemical reactions causing actual loss of plant nutrients or their conversion into less available forms may occur in mixed fertilizers. For example, calcium cyanamide, basic slag, slaked lime and other highly basic materials cause loss of nitrogen from ammonium salts. Except in limited quantities, these materials, as well as anhydrous and aqueous ammonia, also decrease the availability of the phosphoric acid in superphosphate. Hygroscopic materials, notably ammonium nitrate, calcium nitrate, and urea, may impart poor physical condition to mixed fertilizers. Such materials can be utilized in only limited quantities unless the other ingredients are low in moisture and the mixture is well protected from the atmosphere. Some other materials, for example, ammonium sulphate, may cause serious caking in improperly cured mixtures.

Some fertilizer materials can be bought and mixed satisfactorily at the farm without the use of special equipment. Home mixing may be more economical than the use of factory made mixtures. Especially in communities distant from the sources of supply, considerable saving may be made by purchasing the high analysis materials, and mixing them in local farm cooperatives. This practice also has definite educational values. It encourages study and experimentation to ascertain the mixture best adapted to particular soil and crops ; it serves as an incentive towards acquiring knowledge of different fertilizer materials and their values, and it assures precise knowledge of ingredients and the ability to duplicate mixtures that may prove particularly effective.

In India, the list of ingredients used in the preparation o. manure mixtures by different firms are as follows : (i) sulphate of ammonia, (ii) nitrate of soda, (iii) ammonium sulphate nitrate, (iv) calcium cyanamide, (v) urea, (vi) single superphosphate, (vii) groundnut-cake powder, (viii) tobacco-seed cake, (ix) granular ammonium phosphate, (x) bonemeal, (xi) mineral phosphate, (xii) sulphate of potash, and (xiii) muriate of potash.

Some of the fertilizer mixtures recommended or in common use in different parts of the country and for different crops are as follows :

For paddy in Madras, the recommended schedule in these areas includes 4484 to 6726 kg of green manure or green leaves, 112 to 168 kg of super and bonemeal and 112 kg of sulphate of ammonia. Parthasarathy (1952) reviewing sugarcane experiments in Madras State reported that although experiments showed the superiority of ammonium sulphate to cakes and cattle manure in increasing the yields, but beyond certain levels it depressed juice quality. If high yields and good juice quality were to be obtained, he recommended mixing of cakes with fertilizers in proportions varying from 1 1 to 3.2 between cake and ammonium sulphate.

For sugarcane in Uttar Pradesh, the manuring schedule comprises 101 kg. N as green manure and FYM per hectare, together with 16.8 to 22.4 kg N as castor cake plus 112 kg N as sulphate of ammonia. For wheat, application of 56 kg N per hectare, half as *ammonium sulphate and half in organic form is recommended.*

In North Bihar, a mixture of 9.2 quintals of castor cake plus 1.85 quintals of ammonium sulphate per hectare at planting is recommended. In south Bihar, 9.2 quintals of castor cake plus 1.4 quintals of ammonium phosphate at planting plus 9.2 quintals of ammonium sulphate or .69 quintal of ammonium nitrate, per acre at earthing up in June was found to be optimum dose. In Bombay, a total dose of 672-840 kg of ammonium sulphate, about 4480-5600 kg of cake and 280 kg of superphosphate are recommended for application at different stages of growth like planting, after 8 weeks, after 18 weeks and finally at the time of earthing up. In Punjab, 112 to 156 kg of nitrogen, is applied in the form of FYM and sulphate of ammonia at the rate of half organics and half inorganics. In Assam, ammonium sulphate to paddy is applied over a basal dose of FYM or compost. In Madhya Pradesh, in addition to basal dose of organic manure, 112—168 kg of nitrogen as sulphate of ammonia and cakes in the ratio of 1 : 1 are applied at three intervals.

Thus it would appear that in view of the very poor organic matter status of Indian soils, most of the State recommendations are based on the application of artificial fertilizers along with organic manures.

There is no doubt that good crop yields and higher net returns from lands can be obtained by using chemical fertilizers to provide balanced nutrition according to the requirements of the crops grown. The use of ready-made mixtures to suit the needs of the crops would be welcome to the majority of the cultivators. However, farmers are often puzzled by the multiplicity of fertilizer mixtures in the markets, the differences in analysis and prices and many are unable to decide which brand to purchase. To make matters easier and with the object of popularising the use of mixed fertilizers, State Governments are specifying standard fertilizer mixtures for specific crops. Some common grades of fertilizer mixtures which will be useful for use under specific soil climate crop conditions are : N : P_2O_5 : K_2O as 1 : 1 : 0 ; 1 : 1 : 1 and 2 : 1 : 0. Further, the intensified soil fertility programme now being sponsored in India, particularly in respect of the high yielding varieties of paddy and wheat, should not overlook the need of trace elements in the fertilizer mixtures. Plant food elements are a chain of essential nutrients and a missing link in the chain may be disastrous, particularly because the deficiency of trace elements have been reported from a number of field experiments and from soil analysis in the country.

VI. DETERMINATION OF SOIL FERTILITY AND FERTILIZER USE

The methods of assessing soil fertility can broadly be divided into six classes : (1) field trials, (2) greenhouse pot-culture and lysimeter experiments, (3) micro-biological methods, (4) chemical methods and rapid soil tests, (5) plant analyses and tissue tests, and (6) radio tracer technique.

Field trials. Direct field experiments form one of the oldest and most important methods for the assessment of soil fertility. One of the great merits of this method is that it takes into account all factors that actually affect crop production and thus gives a direct estimate of soil-plant-fertilizer relationship. In conducting field experiments, a typical field fully representative of the soil conditions and as uniform as possible should be selected. The treatments depending upon the type of information required are randomly assigned within each replication. Usually the soil is divided into blocks of plots. Each treatment is applied to one plot in each of the blocks. The average of all plots treated alike is considered the best value in estimating the effect of that treatment.

Most of the field experiments in India were earlier conducted on government farms, where the general level of fertility was usually high due to improved land management practices. Stewart (1947) while reviewing the work on soil fertility conducted on various crops in India, recommended that side by side with the fertilizer trials on government farms and other specially selected representative centres, simple fertilizer trials should be conducted in cultivators' fields all over the country. Following these recommendations, the Government of India initiated a scheme under which a series of three-plot trials in cultivators' fields were conducted for three years. As a result of these results from these experiments, it was further felt that the scope and coverage of these experiments needed to be enlarged considerably for obtaining specific information on several aspects of fertilizer use. A series of fertilizer experiments known as Simple Experiments in Cultivators' Fields and Complex Experiments in selected centres were initiated on a comprehensive scale practically in all the States. The objectives of these agronomic experiments may briefly be stated as : (i) to investigate the relative performance of some nitrogenous and phosphatic fertilizers intended for indigenous production, (ii) to evaluate fertilizer response to varying levels of nitrogen, phosphorus and potassium applied separately and in combination, (iii) to study relative response on various broad soil classes, (iv) to correlate responses from the field trials with soil data obtained by rapid soil-tests as a preliminary to starting the soil testing service in the country, and (v) to demonstrate to the cultivators the economic value of fertilizers for profitable nutrient combination for each of the different major soil classes in the country.

In complex experiments, besides responses to fertilizers, studies on their inter-relationship to varieties, irrigation levels, methods of application, time of application, etc., were also included.

The field trials are, however, costly and time consuming and in view of the changing fertility pattern, they cannot indicate the fertilizer requirements of the succeeding crops. It is not possible to conduct adequate field experiments on all fields and the different crops, soil types and management conditions. Cheaper and quicker tests have been developed to extend the results obtained from the field experiments.

Green-house pot-culture and lysimeter experiments. In green-house pot-tests, plants grow in pots in the greenhouse. Usually 0.45 to 4.5 kg of bulk soil sample is weighed into individual pots. Clean white sand or washed gravel is mixed with the soil to improve its physical condition. Nutrient solutions or fertilizers are added at different rates to the soil in some of the pots. In this case also it is desirable to replicate each treatment. These pot-culture tests have been conducted with most field and vegetable crops such as wheat, rice, maize, tomato, tobacco, etc. The plants are seeded or transplanted into the pots and allowed to grow for 3 to 6 weeks Water is added to keep the soil moist. The plants are harvested, dried and weighed. The plant samples are analysed for determining the nutrient uptake. Pot-culture experiments have the following advantages : (i) plants are grown under uniform conditions and a comparison of plant responses on different soils can be made, (ii) they often furnish the best estimates of nutrient availability and for comparing the reliability of different chemical tests and (iii) each pot is like a plot in the field experiments and data similar to that of the field experiments can be obtained. The following are some of the different types of pot and green-house tests usually conducted :

Mitscherlich's pot-culture technique. This method is essentially a fertilizer test in pots in which the soil requirements for nitrogen, phosphorus and potassium are determined simultaneously. In each test there are ten specially designed enamelled pots (20 cm in diameter and 20 cm deep, each constructed with a drainage hole of

8 cm in diameter and provided with a metal plate to cover the hole). Oats are used as test-plants and grown to maturity. Approximately 6 kg of soil at the rate of about 2.7 kg for each pot are required. The treatments given are as follows : one pot no N ; three pots no K_2O; three pots no P_2O_5 and three pots complete fertilizer. The yield under complete fertilizer" is taken as maximum yield and the percentage ratio of the yield from the unfertilized soil to this maximum yield is found from the experiment. From the tables prepared by Mitscherlich (using his equation $Y = A(1 - 10^{-cx})$, where Y=yield produced by a given quantity of growth factor 'X' ; A is the maximum yield possible ; and c is a constant depending upon the nature of the growth factor. It will be possible to calculate the percentage increase in yield corresponding to a given addition of plant nutrient and thus serve as a basis for calculating the profit that can be expected from fertilizers.

Jenny's lettuce pot-culture technique. Jenny (1950) developed a modified Mitscherlich technique to determine the nutrient requirements using Romaine lettuce as the test crop. In this technique various combinations of nutrients (nitrogen, phosphorus and potassium) are added to pot culture ; Romaine lettuce is grown for six weeks and relative yields are calculated for partial treatments (N+P ; N+K and P+K) on the basis of yield with full treatment (all three nutrients). In Californian soil, calibration of pot tests with field tests reported by Jenny showed that nitrogen application could be expected to increase the yields of pasture and field crops if the relative yield of no nitrogen treatment in pot tests is 30 per cent or less (provided water, other nutrients and soil conditions are not limiting) ; phosphorus application could be expected to increase the yields of the crops if the relative yield of no-phosphorus treatment is 20 per cent or less. From the percentage yield values, the soils are classified into three categories ; definite deficiency, probable deficiency and uncertain deficiency.

Neubauer seedling method. In this method one hundred carefully selected seeds of rye, wheat or barley are weighed and planted in 100 gm of soil diluted with quartz sand. Similarly 100 seeds are planted in quartz sand alone. After 14 to 18 days of growth, the roots and tops of the seedlings are harvested and analysed.

The difference in the amount of nutrients in the seedlings grown in the soil and those grown in the sand indicates the amount of nutrients the seedlings obtained from the soil. This amount expressed as milligrams per 100 gm of soil is referred to as Neubauer number. These numbers may be interpreted in relation to certain limit values. which are assumed to be the minimum values for satisfactory yields of crops. The technique is useful for both major and trace elements.

Sunflower pot-culture technique for boron. Several modifications of this test have been used. In the Colwell method, 0.45 kg of soil is placed in a tall fruit can and treated with a complete nutrient solution without boron and five sunflower seeds are planted. The criterion of boron deficiency is the number of days required for the first of five plants to show symptoms of boron deficiency. The boron status of the soil is judged as follows :

No. of days required for the appearance of boron deficiency symptoms	*Status of the soil with respect to boron*
Less than 28 days	Marked deficiency
28 to 36 days	Moderate deficiency
Greater than 36 days	Little or no deficiency

By comparing with the standards grown in sand cultures to which are added increasing quantities of boron, an estimate of the absolute amounts of available boron can be made.

Lysimeter (drain gauge) method. This represents a great advance over simple pot-experiments in view of the complete profile that is imitated in a small scale, and the nutrient lost in percolating water is taken in the study. The conditions of these experiments are so very different that the results should be translated with caution.

Microbiological Methods. The crop producing power in soils as well as the microbial activity is influenced by physical, and chemical factors like texture, moisture content, aeration and available nutrients and hence microbiological analysis is likely to be a good index of soil fertility. Madhok (1942) pointed out that microbiological methods are more logical than the chemical methods but little use has been made of them in India.

These methods are based on the relationship of soil micro-organisms and soil fertility on the one hand and the micro-organisms and higher plants on the other.

These methods are of two types, (i) based on the close relationship between the activity of different groups of soil micro-organisms and soil fertility, and (ii) based on the recognition that soil micro-organisms have the same general requirement as the plants. Instead of making pot-culture experiments to ascertain soil deficiencies it suffices if culture experiments with bacteria and related micro-organism are made.

Two methods usually employed for studying soil and microbiological activities are (i) solution method and (ii) soil method. The biological activities generally studied are : (a) ammonifying power, (b) cellulose decomposing power, (c) the respiratory power of the rate of evolution of carbon dioxide, (d) nitrogen fixing power and (e) nitrifying power.

(i) *Ammonifying power.* Christensen's (1924) investigations showed that weak power of peptone decomposition under all circumstances indicated decidedly unfavourable soil conditions. However, according to Waksman (1923) the degree of ammonia production is a function of too many variable factors to serve as a useful index of soil fertility.

(ii) *Cellulose decomposing power.* The cellulose decomposing power of a soil may serve as an index of soil fertility. The amount of cellulose decomposed is governed by the amount of available nitrogen and phosphate in the soil.

(iii) *The respiratory power of the rate of carbon dioxide evolution.* Since all microbiological processes are accompanied by carbon dioxide evaluation, this phenomenon can readily be considered to be an index of soil fertility. Stoklasa and Ernest (1911) found that proper measurement of the carbon dioxide evolved by a soil furnished a reliable and accurate method of determining the bacterial activities. The curves for bacterial numbers, nitrate content and carbon dioxide evolved were found to be similar by Russell and Appleyard (1915), thereby showing that all these phenomena are interrelated.

(iv) *Nitrogen fixing power.* A definite correlation is found to exist between nitrogen fixation by soil organisms in culture medium to which energy source has been added and crop producing capacity of the soil.

Azotobacter has a definite need of available phosphoric compounds. Based on this, Christensen (1922) and Niklas and Hirsch Berger (1924) developed a biological test for determining the easily soluble phosphoric acid compounds in the soil. As such, nitrogen fixation studies may be more usefully employed for studying the phosphoric acid deficiencies than to obtain an indication of soil fertility in general.

(v) *Nitrifying power.* Correlation was obtained between the nitrifying capacity and soil fertility by Ashby (1907), Lohnis (1905), Gutzeit (1906), Kellermann and Allen (1911), Greaves (1913), Lipman (1914) and others. Alikante (1927) utilized the results obtained to determine the fertilizer requirement of sugarcane soils. A low nitrifying capacity was found to indicate a good response to the addition of inorganic nitrogen and *vice-versa*.

(a) DETERMINATION OF LIME DEFICIENCY. This method is based on the sensitiveness of azotobacter to acidity. It is known that *Azoto-*

bacter chroococcum cannot tolerate acidity of higher than pH 6.0 and, therefore, the extent of its activity in an otherwise normal soil serves as an indication of its lime requirements.

(b) PHOSPHORIC ACID REQUIREMENTS. Here again azotobacter is the indicator organism chiefly used because it is very sensitive to deficiencies of available phosphate in soil.

Aspergilus niger and *Cunnighamella* have also been used for the purpose. In the case of the former the weight of the mycelium forms the criterian while in the later it is extent of growth on a soil plaque that gives an indication of the sufficiency or otherwise of phosphates in soil.

(c) POTASH REQUIREMENTS. Here too, *Azotobacter* and *Aspergilus niger* are used as indicator organisms.

In practice, these methods are, therefore, limited to a few elements and a general way of approach will be to take into account the solvent action of agents occurring in natural soils so as to cover the complete range of mineral nutrients.

Chemical methods.

A. Soil test methods. Chemical soil tests, unlike the biological methods are much more rapid and are being extensively used in the U.S.A. and other countries of the world. Many countries have well developed soil testing programmes.

Under Indo-U. S. Project on Soil Fertility and Fertilizer Use, a start has been made by setting up 24 soil testing service laboratories at different locations. Besides the above, the State Government of Bihar has established three new laboratories of their own which are located at Ranchi, Patna and Pusa. Similarly, the State Government of Punjab has established one more soil testing laboratory at Palampur and another at the Government Agricultural College, Hissar. These laboratories have been equipped so as to analyse 10,000 soil samples a year. Recently, the laboratories at Ludhiana, New Delhi, Bangalore and Sambalpur have been remodelled with the help of U. S. aid and every one of these laboratories is capable of analysing 30,000 samples a year. Plans to set up more soil testing laboratories in the intensive agricultural areas are underway. There is a proposal to strengthen the well equipped centres in the various soil climatic regions for working on the soil test and crop correlation work more intensively. These laboratories have been rendering free advisory service to the farmers. Apart from this objective of giving advice on fertilizers and soil amendments (if needed) to be used for getting most profitable and increased crop yields, soil tests provide data of great value in several other ways. The preparation of soil fertility maps and soil test summaries have been of help to planners, fertilizer industry and fertilizer production, distribution and consumption of the country. The All India soil test summaries prepared on the basis of 246134 soil samples analysed by all the centres in 1965 showed that 54.3% of soils were low, 30.3% medium and 15.4% high with respect to available phosphorus ; 43.4% of soils were low, 33.7% medium and 22.9% high with respect to available potassium ; and 57% of soils were low, 33% medium and 17% high with respect to nitrogen.

Soil testing kits (Raychaudhuri and Subbiah, 1958) are also in use for the ready estimation of the nutrients in the farmers' fields. Soil testing kits have, however, got their limitations in the sense that the data obtained by soil testing kits require careful interpretation for the recommendation of manurial schedules.

Chemical tests of soil samples may be made to determine the total amount of an element in the soil or to show the amount of an element that is soluble in some reagent, like a weak acid or salt solution. The total analysis generally does not help much in estimating its availability to plants.

In the most widely used soil tests, a reagent is used to extract a small, more readily soluble of the total amount of the nutrient in the soil. Reagents like dilute sulphuric acid, dilute hydrochloric acid plus ammonium fluoride, sodium carbonate or water saturated with carbon dioxide have been used. If suitable reagents are used, a good correlation can be obtained between the amount extracted and availability of the nutrient. Suitable reagents have to be evaluated for a particular nutrient and particular group of soils.

Further, these soil tests to be of any value as a guide, might be capable of distinguishing between soils of different nutrient levels. This will be possible only if the soil-testing methods are carefully calibrated against crop responses in pot culture and field experiments and (Tamhane and Subbiah, 1962).

Tests for phosphorus. Use of chemical extractants for estimating available phosphate and assessing the need for the phosphate fertilizers has been made in the past by several workers and among all the methods, Dyer's 1 per cent citric acid method received greatest attention. Leather (1907) working on some representative Indian soils obtained the limits of phosphate response by the Dyer's method to be below 0.05 per cent, except in the case of laterite soils for which a much higher limit of 0.11 per cent was fixed. In calcareous soil, Das (1926) found extraction with potassium carbonate to give more satisfactory results. The earlier studies, however, lacked systematic attempts to correlate the analytical results with crop responses to fertilizers, In recent years, more intensive work was carried out in India to evaluate the methods of estimating the available phosphorus and for determining the limits of response or lack of response. In red and laterite soils of pH varying from 5 to 7, significant coefficient of correlation between available phosphate by Truog method and responses of rice crop to superphosphate was obtained (Raychaudhuri *et al.*, 1955). Later Datta and Kamath (1955) found that for many soils, available phosphate by Olsen's method using sodium bicarbonate as the extractant gave the highest correlations with crop responses in the case of wheat and paddy both in pot and field experiments. On the basis of this work, Datta and Kamath (1958) fixed the limits for low, medium and high values for available P_2O_5 as follows : less than 22.4 kg/hectare low ; 22.4-56 0 kg/hectare medium ; and above 56.0 kg/hectare high. These limits are practically the same as suggested by Olsen *et al.* (1954), for soils of the United States. The usefulness of Olsen's method in soils of pH above 6 and of Bray's method for soils of pH below 6 for assessing phosphate fertilizer needs in India was furthur confirmed by Tamhane *et al.* (1958) in pot experiments.

Available potassium. Leather (1907) using Dyer's method reported that responses to potassic fertilizers were only slight in Indian soils even with 0.0(2 per cent available K_2O. Sen *et al.*, (1940) found that all lateritic soils which were studied by them, with very few exceptions, contained much less than 15-20 mgm. equivalent exchangeable K per 100 gram of soil and that they were likely to respond to fertilizers. Mukherjee, Mandal and Mukherjee (1955) concluded on the basis of their work in Bihar soils that percentage potassium saturation will be a more reliable index for potassium response than the net amount of exchangeable potassium. Recent correlation studies by Tamhane *et al.* (1958) in both pot and field experiments on all Indian soils indicated that no single extractant is likely to be suitable for all-India soils and exchangeable potassium as determined by ammonium acetate appears to be no good index of the soil to supply potassium to crops. Potassium extracted by Morgans extractant, percentage saturation and dilute nitric acid soluble potassium showed moderately good correlation with crop responses to the applications of potassic fertilizers in red and lateritic soils of Bihar, acid alluvial soils of Kerala and West coast alluvial soils of Mangalore respectively.

Nitrogen. The increasing awareness of the importance of nitrogen in crop production has led many workers in recent years to evaluate the capacity of soils to supply nitrogen to crops. Richardson (1952) working at Rothamsted reported that mineralisable nitrogen produced under standard conditions was correlated with crop responses to nitrogenous fertilizers and that the relationship was as good as that obtained for phosphate or patash. The nitrogen availability to Indian soils was evaluated in the past on the basis of total nitrogen values. As Indian soils are very poor in carbon and nitrogen, a value of less than 0.03 per cent of nitrogen was taken as poor, 0.03 to 0.06 as fair, 0.06 to 0.1 as good and above 0.1 as rich.

In recent years, attempts have been made to eharacterise the nature and decomposibility of organic nitrogen by using alkaline permanganate as the reagent. The method developed for the assessment of available nitrogen involves the use of 0.32 per cent $KMnO_4$ and 2.5 per cent alkali (Subbiah and Asija, 1955). The available nitrogen values by this method correlated well with total mineralisable N obtained by standard incubation method and also with paddy and wheat yield responses. Further studies coducted by Subbiah and Bajaj (1961) showed that in rice soils, the ammonia release under water-logged conditions after a week's incubation may be a better index of nitrogen availability than the available nitrogen values obtained by other methods.

Test for liming the acid soils. Soil factors other than pH which are most important in indicating lime requirement are :

(1) Cation exchange capacity
(2) Organic matter
(3) Exchangeable hydrogen
(4) Clay content.

The precipitation of Al_{+++} or $Al\ (OH)^{+++}$ or $Al(OH)^{+2}$ as hydroxides thus reducing aluminium toxicity, is one benefit that accounts for liming. Another is of easily available calcium from the exchange complex. As is well known, the calcium held by kaolinitic group of clay minerals becomes available only after about 40 per cent of the calcium saturation of exchange complex.

One can determine the lime requirement of soil to a given pH in the laboratory but if one then applies this amount of lime to the soil in the field, the field pH doses not rise as much as expected. This was first shown by Christensen and Jensen (1926) in two Danish soils which showed that soil in the field needed 2 to 3 times more lime to bring its pH to a selected value than that indicated by the laboratory titration curve. This factor is known as liming factor. This factor was found to vary from unit to three by various workers.

According to Jackson (1958) the calcium carbonate equivalence of exchangeable hydrogen of soil is considered as a first approximation to the lime requirement of soil. In other words, it is the amount of lime required for a soil to bring it to a normal productivity where deficiency of liming is no limiting factor. But according to modern concept of liming, it has been defined as the amount of lime needed to give maximum economic return from the crop rotation we wish to follow.

The method for determining lime requirements of an acid soil may be classified into five following different classes :

Electrometric methods. This includes all the methods which are based on the principle of titration curve. pH is measured in soil suspension with different chemical solutions and titration curves are prepared.

Titrimetric methods. It includes all the methods working on the principle of acid base titration.

Buffer methods : Buffer is prepared and is adjusted to a certain pH and change in pH with soil will tell the lime requirement of the soil.

Exchangeable hydrogen methods. It is based on the principle of replacement of exchangeable hydrogen by other cations and concentration of hydrogen ions is measured with alkali titration.

Exchangeable calcium methods. It is just similar to exchangeable hydrogen methods. Here calcium equivalance to exchangeable hydrogen is measured by calcium determination in soil leachate.

Puri (1936) has developed a method for lime requirement determination. The method is based on the principle of replacement of exchangeable hydrogen by calcium ; exchangeable calcium is determined in the treated and untreated soil samples and the difference in the exchangeable calcium quantity of treated and untreated samples gives the calcium equivalance to exchangeable hydrogen.

Sampling the soil for soil tests. One of the most important aspects of soil testing is the collection of a representative sample for the area being tested. To obtain a composite sample adequately representative of the field, small portions of surface soil from 15 to 20 borings taken at several spots over the entire field from a depth of 15 cm are collected, mixed well and about 500 gm of representative soil is sent to the soil testing laboratory.

Calibration of soil tests. The reliability of any of these soil tests depends upon the data showing the relationship between the test results and the results of the experiments in the field. Different methods may be used for developing a relationship between the results of laboratory and green house tests and their results obtained from the field experiments and use this to predict from test results as to what increase in crop production can be expected from the added nutrients.

One method is to express the yields obtained in field experiments as percentage of the yield that would have been obtained, had the nutrient been present in adequate amount. This percentage yields are essentially a method of expressing the yield data obtained in the field experiments in terms of nutrient availability and thus these can be correlated with the soil tests, if the latter can differentiate the nutrient levels.

A direct method depends upon the use of the actual yield increases obtained in the field experiments. A curve can be fitted by the data showing the relationship between the test results and the yield increases obtained in each rate of nutrient applications. Such curves for different rates of nutrient applications will indicate the yield increases to be expected at any test level from different rates of fertilizer application.

In view of the wide variety of soils, climatic conditions, crops grown and method of applying nutrients that influence the test correlations and the amounts of nutrients required, Tamhane and Subbiah (1962) pointed out the necessity of developing correlations on each region basis for each crop so as to build good fertilizer recommendations on the basis of soil tests.

Importance of soil tests to fertilizer industry. Although soil targets are not infallible they are of great assistance in reducing guess work in lime and fertilizer use practices and in assisting the farmer to select the fertilizers needed before the sowing of the crop. In addition to making individual fertilizer recommendation to farmers, soil tests summarised over an area are useful to administrators and planners in deciding the trends and amounts of fertilizer and fertilizer mixture most suitable in each area or district and determining the policy of fertilizer production, distribution and consumption in different regions. These summaries of soil test data are also of use to fertilizer associations, fertilizer industries and extension workers in promoting their programmes and to research workers particularly from the point of view of changes in fertility levels, conditioned by different fertilizer use or by different soil and crop management practices.

These summaries of soil data for any particular area indicate the percentage of soils testing as low, medium and high. Circular diagrams of such summaries are prepared for each area for educational purposes.

In Delhi State, out of 4775 soil samples analysed up to 31st March 1959 (Tamhane and Subbiah, 1962), 28.0 per cent were low, 40.8 per cent medium and 31.4 per cent high in available P. In order to compare the levels of soil fertility of one area with those of another, it is necessary to obtain a single value for each nutrient. In order to evaluate this Parker *et al.* (1951) suggested a procedure according to which a weighted average is obtained by multiplying the percentage of low samples by 1, medium group by 2, and high group by 3. The products thus obtained divided by 100 gives the weighted average nutrient index. This value can vary only from 1 to 3, higher the value, greater the fertility with respect to the particular nutrient. In the above example, the nutrient index from Delhi State for available P works out to 2.03 showing thereby that the fertility status for the area as a whole for P is medium.

In determining the ratio of fertilizers needed for a given area, two-way soil test summary tables can be prepared as suggested by Fitts *et al* (1956) for any two nutrients. This is done through the summary of the phosphorus and potassium data in two-way table (Table 47).

TABLE 47. TWO WAY SOIL TEST SUMMARY TABLE

Percent number of soil samples falling under different gradations with respect to P and K (Delhi State)

Available potassium per cent

		L	M	H	Total for phosphate
	L	7.8	7.8	1.4	17.0
Available phosphate per cent	M	13.3	22.9	3.3	39.4
	H	7.2	25.3	11.0	43.5
Total for potassium		28.3	56 0	15.7	10 0

(unpublished data of Tamhane and Subbiah 1958)

In the above illustration, 17.0 per cent of the samples are low in P ; of these samples, 7.8 per cent are low, 7.8 per cent medium and 1.4 per cent high with respect to potassium.

Soil-test summaries and maps can have bias because soil samples are usually sent by more progressive farmers who follow better management practices. Bias may also be present because samples from troubled areas flow in a larger number to the laboratories and because samples are received from soils under particular crops in preference to others.

Plant analyses methods. The chemical composition of plants varies according to the availability of the nutrient in the soil and the per cent composition of any nutrient in the plant follows a response curve as nutrient availability is increased. As the plant composition reflects all the factors that affect the nutrient availability, plant analyses data are likely to give information which may not be obtainable from the soil tests.

Tissue testing can be broadly classified as (i) laboratory analyses of the whole or selected part of the plant and (ii) quick tests carried out directly in the field.

Total analyses. In fertility experiments, total analyses for many elements is carried out by chemical procedures or by spectrographic means. The elements usually determined are N, P, K, Ca, Mg, Mn, Zn, B, Fe and Mo. Analysis is carried out on the selected plant part like *recently matured material* or *petioles.* These plants indicate most accurately the nutrient condition of the plant. This type of analyses coupled with standardisation of the analytical results against yield response to fertilizer applications in the field experiments help in evaluating the nutrition status of the plant. If one element is lacking and other elements are adequate, simple courses can be developed to show the relationship of the nutrient content to the maximum yield. The lowest nutrient content associated with near maximum yield is termed the critical level. Any nutrient content in excess of the critical level is known as 'luxury consumption' of the elements.

Quick tests. These tests are made directly in the field and involve simple chemical tests that produce a colour proportionate to the amount of certain soluble forms of the nutrient present. Such tests are usually made on the mid ribs or stalks of the plants like corn and in the petioles or leaves of crops like potatoes or sugar beets. The test simply measures the amount of certain forms of the nutrient flowing in the 'blood stream' of the plant. Usually nitrate nitrogen, phosphorus, and potassium can usefully be estimated by this technique.

These quick tests provide only semi-qualitative estimates of the amounts of nutrient present in a particular form. A person who knows how to use and interpret the tests can get much help from them in the diagnosis of nutrient deficiencies.

Crop logging. This is a special case of plant analyses in which a graphic record of the progress of the sugarcane crop obtained by a series of chemical and physical measurements is maintained (Clements, 1948). These measurements indicate the condition of the plant and suggest the changes in management necessary to produce maximum yields.

The measurements include the weight of the young sheath tissue and the analysis of the crop, sampled every 35 days after sowing, for nitrogen, sugar, moisture, phosphorus or potassium. Knowledge of the per cent moisture enables proper irrigation. It has been found that yields gradually increase when crop-logging is undertaken.

SYMPTOMS IN PLANTS FOR NUTRIENT DEFICIENCIES

Nitrogen

1. A sickly yellowish green colour
2. A distinctly slow and dwarfed growth
3. Drying up or 'firing' of leaves which starts at the bottom of the plant, proceeding upward. In plants like corns, grains and grasses, the firing starts at the tip of the bottom leaves and proceeds down the centre or along the midrib
4. Premature ripening of the plant
5. Seeds do not attain their normal size and become shrivelled and light in weight.

Phosphorus

1. Leaves of cereals become dull greyish green in colour
2. Slow growth and maturity
3. Soft, weak stems with no strength and poor root growth
4. Small slender stalk in case of corn. In small grains lack of stooling
5. Low yields of grain, fruit and seed.

Potash

1. Mottling, spotting, streaking or curling of leaves, starting on the lower levels
2. Lower leaves scorched or burnt on margins and tips. These dead areas may fall out, leaving ragged edges. In corn, grains and grasses firing starts at the tip of the leaf and proceeds down from the edge, usually leaving the midrib green
3. Premature loss of leaves and small, knotty, poorly-opened bolls on plants like cotton
4. Plants, like corn, falling down prior to maturity due to poor root development.

Calcium

1. Young leaves in terminal bud become 'hooked' in appearance and die back at the tips and along the margins

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*Taken from *Fertilizer Guide*, Extension Pamphlet No. 1, Directorate of Extension and Training, Ministry of Food and Agriculture, New Delhi, October, 1955.

2. Leaves have wrinkled appearance
3. In some cases, young leaves remain folded
4. Short and much-branched roots.

Sulphur

1. Young leaves light green in colour, have lighter veins
2. Short slender stalks
3. Slow, stunted growth
4. Spotting of leaves, as with potatoes.

Magnesium

1. General loss of green colour which starts in the bottom leaves and later moves up the stalk. The veins of the leaf remain green
2. Cotton leaves often turn purplish-red between the green veins
3. Weak stalks with long branched roots
4. Definite and sharply defined series of yellowish-green, light yellow, or even white streaks throughout entire leaf as with corn
5. Leaves curve upward along the margins.

Foliar fertilization of crops. Foliar fertilization of crops has gained considerable importance recently. This importance is primarily due to the availability of concentrated fertilizers and secondly to a greater economy in the fertilizer use. There are certain conditions of soil and plant growth under which it would be fruitful to adopt the new method of foliar fertilization of crops. If the pH of the soil is very high or very low, certain nutrients although present in the soil may not be available to the plants.

Much of the biological activity of soils and plants is associated with ionic exchange complexes. This exchange can take place through the foliar membranes as well as through the root cell structure. The plant sap moves by capillary action to the surface of leaves and evaporation of water takes place from the foliar cells. Plant nutrient in the right proportion can be applied to the leaves and therefore, the question of absorption of nutrient through the leaves and utilization of plant nutrient through leaf fertilization is important.

Sadaphal and Das (1956), while reporting the results of spraying urea on wheat, state that spraying at a concentration as low as 1 per cent level, in the absence of the basal dressing of NPK resulted in a significant increase of the yield of wheat. Results of their field experiments are given in Table 48.

TABLE 48. EFFECT OF SPRAYING UREA ON WHEAT

Treatment	Yield of wheat kg /hectare
1% Urea sprayed once 4.76 kg N/hecta e	2033
1% Urea sprayed twice 9.5 kg N/hectare	1942
2% Urea sprayed once 9.5 kg N/hectare	2073
2% Urea sprayed twice 19.0 kg N/hectare	2014
No spray	1716

Different concentrations of urea were sprayed at the rate of 93 gallons per acre on wheat during the reproductive phase.

Sadaphal and Das (1956 b) have tried the foliar applications of micronutrients. They have reported that while soil application of manganese was more efficient than foliar application, zinc showed better results when sprayed on the leaves. Generally, the effect of foliar application of micronutrients was noticed in increasing the yield of wheat grain. In conclusion it can be safely stated that foliar sprays can be effectively utilized as a supplementary method of fertilization of wheat.

In an experiment where micro-nutrients were applied on wheat (Koraddi and Seth, 1964) although the soil application to boron and manganese gave maximum increases in yield the foliar application of zinc gave a maximum response of Rs. 4.65 per rupee invested. An improvement in the protein quality of wheat grain can definitely be brought about by spraying urea on wheat before heading of the wheat crop (Seth *et al.*, 1960 ; Seth, 1963). Significant increases in the yield of wheat and barley grown under *barani* conditions have been obtained due to partly soil application and partly foliar spray of urea (Vainetheyn, 1962 ; Prasad, 1963). Evidently there was a more efficient utilization of nitrogen through foliar spray when crops were grown under limited moisture conditions in the soil. Similarly, phosphate fertilization of legumes especially *berseem (Trifolium alexandrinum)* partly through soil and partly through foliar spray resulted in the saving of about 40 per cent of the phosphatic fertilizer in the form of triple superphosphate (Anonymous, 1962, 1963). This might be because of the fact that when phosphate fertilizer is applied in the soil about 80 90 per cent of the total fertilizer applied gets fixed up. This result is of significance because at present there is a short supply of fertilizers in our country. Work on foliar fertilization has conclusively shown that a starter dose of half the required quantity of the fertilizer must be added to the soil before sowing of the crop, to be supplemented later on by the remaining half by foliar fertilization. Soil application of fertilizers cannot be replaced entirely by foliar fertilization. In growing of cash crops, it might be economical and useful to mix fertilizers with insecticides and fungicides and apply them as mixed sprays on plants. A highly concentrated fertilizer must be selected for sprays, otherwise either the frequency of sprays will have to be increased or the total volume of the solution to be sprayed, will have to be increased. The former will result in increasing the cost of cultivation of the crop, while the latter will result in dropping of the spray solution on the ground. The concentration of the spraying solution is an important factor to be borne in mind. Usually spraying must be done at 3 per cent or at a lower concentration in respect of urea and triple superphosphate. Higher concentrations of the solution will result in scorching of leaves which will adversely affect the yield. Plants may be sprayed with fertilizer solution at a time when there is sufficient foliage. Spraying may be done on a day when it is neither windy nor cloudy.

Spray fertilization in respect of micro-nutrients on horticultural crops has shown promise in the various trials which have been conducted in different parts of the country. *J. Indian Soc. Soil Sci.* 1964, vol 12 , No. 4, pp. 203-466).

Radio-tracer technique and evaluation of 'A' values. One of the newest techniques in soil fertility research is the use of isotopically labelled compounds to investigate problems such as comparative availability of the fertilizer materials, effect of granulation of fertilizers on availability, effect of time and placement of fertilizer, availability of materials applied as foliar sprays, effect of lime, nitrogen, potassium supply on phosphorus availability, effect of irrigation on phosphorus availability, comparison of crop species in utilization of phosphatic fertilizers, and the residual value from phosphate in rotation or permanent fertilizer experiments or availability of phosphates.

In using tracers, either stable or radio-active isotopes can be employed in any desirable chemical form, but in the case of radio active tracers the amount used is wholly small and the radiations do not interfere with the natural course of the process under study. A detailed development of the concepts peculiar to tracer methodology is beyond the scope of the book but a brief background is provided in the following page for an understanding of the technique.

Isotopes are atoms which vary in nuclear mass but not in chemical nature. Most of the naturally occurring elements consist of a mixture of stable isotopes. Radio-active isotopes are unstable atoms which continuously undergo a process of active disintegration or decay to stable atoms by the liberation of energy and emission of α or β or γ rays or their combinations. When a small quantity of radio isotopes is used to follow a biological or chemical form, it is called a radio-active tracer. Since the stable and radio-active isotopes of an element have essentially the same chemical properties and the radio-active ones are detected, the movement and behaviour of the stable atoms can be traced by following the radio-activity. In this case, the compound under observation is said to be labelled as 'Radio-active isotopes'.

Radio-active disintegration or decay and the energy of the radiation emitted are the characteristic functions of a given radio-isotope. For a single radio-active substance the decay curve or rate of decay is exponential and follows the equations ;

$N_t = N_o. e^{-\lambda t}$ where N_t = the number of radio-active atoms at time t, N_o = the number of radio-active atoms at time zero, and λ = the characteristic disintegration or decay constant for the atom. The half life of an isotope is simply defined as the time in which the amount of radio-isotope is reduced to half of its initial value. The half life of radio-isotope can be expressed mathematically by the relationship $T_{\frac{1}{2}} = 0.693/\lambda$. Where $T_{\frac{1}{2}}$ = the half life of a particular radio-isotope, usually expressed in seconds, minutes, days or years.

The curve is the most common unit for expressing radio-activity and is generally accepted to be equivalent to 3.7×10^{10} disintegrations/sec. Radio-active isotopes prepared by neutron radiation in atomic piles are being widely used in agricultural research and other branches.

Preparation of radio-active fertilizers. Fertilizers cannot be labelled uniformly with a tracer merely by adding the isotope to commercial fertilizers. For example p^{32}—labelled superphosphate, must be prepared by adding a small quantity of phosphoric acid labelled with P^{32}, to the sulphuric acid to dissolve mineral phosphate. Only in liquid medium, the uniform labelling can be brought about on atomic scale.

Evaluation of 'A' values using tracer technique. As mentioned earlier, one of the major problems in soil management is the evaluation of the available nutrient status of the soil for prediction of fertilization requirements. The chemical and biological methods have met with varying success as means of predicting the available plant nutrients in the soils. *The radio-tracer technique offers another tool for evaluating* the available nutrient status of the soils.

In the early work with radio-phosphorus in soils many investigators pointed out that the per cent phosphorus in the plant derived from the fertilizer varied with the level of available nutrient in the soil. Subsequently, Fried and Dean (1952) on the basis of the assumption that plants absorb nutrient from two sources in direct proportion to the amounts available, developed a mathematical expression for calculating the amount of available nutrient in soil in terms of a standard fertilizer material:

$$A = \frac{B\,(1-Y)}{Y}$$

Where A = amount of available nutrient in the soil
B = the amount of fertilizer nutrient (standard) applied
Y = proportion of the nutrient in the plant derived from the standard

As these authors state, the method simply involves the introduction of a standard source of nutrient under consideration into a soil, growing the desired crops, determining the proportion of the total nutrients absorbed that was derived from the standard source and calculating the amount of available nutrient in the soil-A by the use of the above equation. The main restriction that the authors placed on the procedure was that the two sources of nutrient under consideration, namely, the soil and the standard, must be equally accessible to the plant.

The laterite soil having predominently iron-phosphate system showed maximum fertilizer phosphorus utilisation from mono- and di-ammonium phosphates followed by calcium metaphosphate. On black cotton soil, maximum phosphorus was utilized from the soluble mono-calcium and mono-ammonium phosphates and the least from dicalcium and ammoniated superphosphate. On calcareous soil, rice obtained maximum phosphorus from mono- and di-calcium phosphates, to a high extent from calcium metaphosphate and mono-ammonium phosphate followed by superphosphate. Trial or small field plots growing paddy indicated better utilization of superphosphate as surface broadcast rather than placement applications. In the case of wheat placement *application was superior (Datta, 1961).*

By labelling the superphosphate and compost with P^{32} separately, it was found that digesting of superphosphate with composting material reduced the phosphorus of the superphosphate non-availability particularly for the rice crop and the movement of superphosphate digested P was also greater as revealed by radio-autographic method (Subbiah and Mohan, 1964). Using S^{35}, the 'A' values of sulphur in typical rice-growing soils were found to vary from 81 to 245 ppm indicating generally a high supply of available sulphur (Subbiah and Venkateswarlu, 1963).

By placing P^{32} labelled superphosphate, it was found by Subbiah and Manniker (1964) that *dhaincha* green-manuring crop could take up more superphosphate as compared to *guar* or sunnhemp under similar conditions. As pointed out by Fried (1956), this isotope technique has certain advantages over non-isotopic procedure. The 'A' in the above equation is independent of the amount of nutrient applied. Thus one rate of fertilizer application is sufficient to obtain the desired result in contrast to the large numbers of rates needed to define a curve. Secondly, the plants do not have to be grown under abnormal conditions of severe nutrient stress. This means that the indicator plants are healthy and normal plants. A third consideration is that the value obtained is not an extra-polated value and thus the error of estimate is not appreciably increased. A fourth and major consideration is that the amount of growth does not affect the results. The 'A' value presumably changes only when the environments affect either the actual amount of available nutrient in the soil or the availability of nutrient standard.

The first use of radio-isotopes in soil and fertilizer investigation was made in India as early as 1949 at the Indian Agricultural Research Institute, New Delhi, where a commercial product 'Alphatron' was tested as a radio-active soil stimulant. No beneficial effect was observed.

By using P^{32} labelled superphosphate it has been possible not only to show that crop species differ in the utilization of added phosphorus but also that it differs from soil to soil for the same species.

VII. POTENTIALITY OF CHEMICAL FERTILIZERS IN INCREASED PRODUCTION

Generally the soils and climate of India are favourable to greatly increased production. It is true that under rainfed conditions the climate in some instances may be less favourable, especially during the dry period between monsoons. But with better soil management, as in any of the leading agricultural countries, the production is bound to go up.

The most serious of the factors limiting production is the very low level of chemical fertilizer use. When chemical fertilizers are made available in adequate amounts and farmers are taught how to use them, along with other good farming practices Indian yields can be very greatly increased.

The data assembled by the Fertilizer Association of India from results of crop contests (Table 49) are indicative of the Indian potential for agricultural production by all round package practices including intensive use of chemical fertilizers.

TABLE 49. CROP YIELD POTENTIAL IN INDIA AS INDICATED BY CROP CONTEST RESULTS*

Crops	Indian average kg/ha	Crop contests' winner yields kg/ha	% increase
Rice	1,C09	9,376	929
Wheat	888	6,618	745
Cotton	105	612	583
Sugarcane	40,578	2,51,100	619

**Fertilizer proposals for increased Agricultural Production*, 1964, United States Agency for International Development Mission to India, American Embassy, New Delhi.

VIII. FERTILIZER RECOMMENDATIONS

One of the major reasons for the low level of agricultural production in India is due to inadequate fertilizer consumption which is indicated in Table 50.

TABLE 50*

Name of the country	Fertilizer consumption in terms of $N+P_2O_5+K_2O$ Kg/hectare of arable land	Yield in kg/hectare		
		Paddy	Wheat	Maize
1	2	3	4	5
Netherlands	463.86	—	4,200	4,260
Belg um	532.31	—	3,770	4,330
W Germany	311.61	—	3,510	3,640
Japan	297.68	5,240	1 230	2,670
Taiwan	210.81	3,500	1,300	1,800
U S A.	51.59	4,440	1,700	4,240
India	3.68	1,540	790	1,000

It is recognized that use of fertilizers constitutes the single major factor contributing to increased agriculture production. Japan is supporting over 5½ times the population per unit area of arable land in India by following scientific farming practices including the use of heavy doses of plant nutrients.

The State Governments have worked out certain general fertilizer recommendations for the various crops grown both under irrigated as well as under rainfed conditions. These recommendations are reviewed from time to time on the basis of the latest results of fertilizer trials conducted by the State Agricultural Departments and by the Indian Council of Agricultural Research.

High yielding varieties. A significant step towards the intensive agriculture based on high level technology has been the introduction on the high yielding varieties of paddy, wheat, *bajra*, *jowar* and maize during the last *kharif* season. These high yielding varieties produced high yields only with high level of fertilization and other inputs which have to be used according to recommendations. These are mostly dwarf varieties and do not lodge even with heavy doses of nitrogenous fertilizers. The target of coverage by the end of the Fourth Plan under the different varieties would be around 13.16 million hectares (32.5 million acres). The achievements and targets for the year 1966–67 is given in Table 51.

TABLE 51. TARGET OF COVERAGE DURING 1966–67 (MILLION HECTARES)

Crop	4th Plan target	1966-1967	
		Coverage during *kharif*	Target of coverage during *rabi* season
Paddy	5.06(12.50 million acres)	0.51(1.258 million acres)	0.63(1.565 million acres)
Wheat	3.24(8.00 ,,)	0.00(—)	0.50(1.225) ,,)
Maize	1.62(4.00 ,,)	0.14(0.342 ,,)	0.10(0.242) ,,)
Jowar	1.62(4.00 ,,)	0.05(0.116 ,,)	0.24(0.585) ,,)
Bajra	1.62(4.00 ,,)	0.04(0.102 ,,)	0.04(0.093) ,,)
Total	13.16(32.50 ,,)	0.74(1.818 ,,)	1.51(3.710) ,,)

The experience gained during one season has given very encouraging results. The area under high yielding varieties could be extended further if adequate quantities of fertilizers were available. The schedule of general fertilizer recommendations is given in Table 52 which may have to be varied on the basis on soil analysis and experience.

TABLE 52. FERTILIZER RECOMMENDATIONS FOR THE HIGH YIELDING VARIETIES OF MAIZE, *jowar*, *bajra*, PADDY AND WHEAT*

Name of the crop	Fertilizer Recommendations kg/ha			Remarks
	N	P_2O_5	K_2O	
Hybrid Maize	45	30	45	Apply 1/3rd of N and all phosphate and potash at planting time 8 cm below and 8 cm away from the seeds. Apply rest of the N as top-dressing when the plants are 30-60 cm high.

Hybrid *Jowar* (C.S.H)	30** 60***	15 25	15 15	Apply ½ of N and all the phosphate and potash as basal dose 7 cm below and 7 cm away from the seed at planting time. Apply the rest of N as top-dressing 40 days after planting.
Hybrid *Bajra* (C.B.H. No. 1)	40	25	15	Apply as above as basal dose. Apply the remaining N 30—45 days after planting as side-dressing in a shallow 8-10 cm away to one side of the row.
Paddy : T.N.-1 Taichung-65 Tainan-3	40	16	15	Use 2,000 to 5,000 kg green manure or FYM or compost (5 cartloads) per acre as basal dressing during land preparation. Apply 3/4th of N and all the phosphate and potash during planting. Rest of the nitrogen should be used as top-dressing five weeeks after transplanting.
Wheat Sonora-64 Lerma Rojo	36-46	18	15	As above.

*Reference : H.D. Bhaumik, fertilizers requirements for paddy and other cereal crops, 1966, unpublished.

** Rainfull crop

***Irrigated crop

APPENDIX I

SPECIFICATIONS OF INDIAN STANDARDS INSTITUTION

Ammonium sulphate

i.	Moisture, per cent by weight (maximum)	1.0
ii.	Ammoniacal nitrogen, per cent by weight (minimum)	20.6
iii.	Free acidity (as H_2SO_4), per cent by weight (maximum)	0.04
iv.	Arsenic (as As_2O_3), per cent by weight (maximum)	0.01
v.	Pyridine (C_5H_5N), per cent by weight (maximum)	0.05

Bonemeal (steamed)

i.	Free moisture per cent by weight (maximum)	7.0
ii.	Total phosphates (as P_2O_5) per cent by weight (dry basis) (minimum)	22.0
iii.	Available phosphates (as P_2O_5), soluble in 2 per cent citric acid solution, per cent by weight (dry basis) (minimum)	16.0

Bonemeal (raw)

i.	Moisture, per cent by weight (maximum)	8.0
ii.	Acid-insoluble matter, per cent by weight (maximum)	12.0
iii.	Total phosphates (as P_2O_5), per cent by weight (minimum)	20.0
iv.	Available phosphates (as P_2O_5), soluble in 2 per cent citric acid solution, per cent by weight (minimum)	8.0
v.	Total nitrogen, per cent by weight (minimum)	3 0

Dicalcium phosphate

i.	Moisture, per cent by weight (maximum)	8.0
ii.	Available phosphates (as P_2O_5), soluble in neutral ammonium citrate solution, per cent by weight (minimum)	34.0
iii.	Chlorides (as Cl), per cent by weight (maximum)	1.0
iv.	Fluorides (as F), per cent by weight (maximum)	0.5

Kotka phosphate

i.	Moisture, per cent by weight (maximum)	8.0
ii.	Water soluble phosphates (as P_2O_5), per cent by weight (minimum)	8.0
iii.	Available phosphates (as P_2O_5) soluble in neutral ammonium citrate solution plus water soluble phosphates as (P_2O_5), per cent by weight (minimum)	16.0

Superphosphate (tentative)

		Requirements	
		Grade 1	Grade 2
i.	Moisture content, per cent by weight (maximum)	12.0	12.0
ii.	Free phosphoric acid (as P_2O_5), per cent by weight (maximum)	4.0	4.0

iii. Water soluble phosphates (as P_2O_5), per cent by weight (minimum)	18.0	16.0
iv. Available phosphates (as P_2O_5) soluble in neutral ammonium citrate solution and water soluble phosphates (as P_2O_5), per cent by weight (minimum)	18.5	16.5

Triple superphosphate

i. Moisture, per cent by weight (maximum)	12.0
ii. Free phosphoric acid (as P_2O_5), per cent by weight (maximum)	3.0
iii. Water soluble phosphates (as P_2O_5), per cent by weight (minimum)	40.0

Ammonium chloride

i. Moisture, per cent by weight (maximum)	2
ii. Ammoniacal nitrogen, per cent by weight (on dry basis) (minimum)	24.0
*iii. Heavy metals including iron (as Pb) per cent by weight (individual metallic impurities not to exceed 0.01 per cent by weight, calculated as metal) (maximum)	0.1
*iv. Sulphates as $(NH_4)_2$ SO_4), per cent by weight (maximum)	0.5
*v. Chlorides other than ammonium chloride (as NaCl), per cent by weight (maximum)	2.0
*vi. Carbonates (as $NaHCl_3$), per cent by weight (maximum)	0.2
*vii. Matter insoluble in water, per cent by weight (maximum)	0.2

*These requirements may not apply to material intended for use as a fertilizer.

Ammonium sulphate nitrate

i. Total nitrogen (as N), per cent by weight (minimum)	26.0
ii. Ammoniacal nitrogen (as N), per cent weight (minimum)	19.25
iii. Nitrate nitrogen (as N) per cent by weight (maximum)	7.00
iv. Moisture, per cent by weight (maximum)	0.3
v. Free acidity (as HNO_3) per cent by weight (maximum)	0.015

Calcium ammonium nitrate

i. Total nitrogen (as N), per cent by weight (minimum)	20.5
ii. Ammoniacal nitrogen (as N), per cent by weight (minimum)	10.25
iii. Moisture, per cent by weight (maximum)	1.0
iv. Calcium nitrate, per cent by weight (maximum)	0.5

Potassium chloride (Muriate of potash)

i. Potash content (as K_2O), per cent by weight (minimum)	58.0
ii. Sodium (as NaCl), per cent by weight, (on dry basis) (maximum)	3.00

Potassium sulphate (Fertilizer grade)

i. Potash content (as K_2O), per cent by weight (maximum)	48.0
ii. Totalchorides (as Cl), per cent by weight (on dry basis) (maximum)	2.5
iii. Sodium (as NaCl), per cent by weight (on dry basis) (maximum)	2.0

Castor seed cake (for fertilizer purposes)

	Type 1 Decorticated	Type 2 Undecorticated
*i. Moisture, per cent by weight (maximum)	8.0	8 0
*ii. Water insoluble organic nitrogen, per cent by weight (minimum)	4 5	3.5
*iii. Total ash, per cent by weight (maximum)	9 5	10.5
*iv. Acid insoluble ash, per cent by weight (maximum)	2.4	2.5

Urea

	Fertilizer grade		Technical grade
	Coated	Uncoated	
i. Moisture, per cent by weight (maximum)	1.0	1.0	0.50
ii. Total nitrogen, per cent by weight (on dry basis) (minimum)	44.0	45.0	46.0
iii. Biuret, per cent by weight (maximum)	1.5	1.5	1.5
iv. Free ammon a (as NH_3), per cent by weight (maximum)	—	—	0.01
v. Ash, per cent by weight (maximum)	2.5	—	—
vi. Iron (as Fe), per cent by weight (maximum)	—	—	0.002
vii. pH of 10 per cent solution	—	—	7.0–9.5

*On moisture free basis

APPENDIX II

YEAR-WISE BREAK-UP OF FERTILIZER DEMAND IN THE FOURTH PLAN AND IMPORTS (IN MILLION TONNES)

Year	N			P_2O_5			K_2O
	Minimum requirements	Indigenous production	Import requirements	Minimum requirements	Indigenous production	Import requirements	Import requirements
1966–67	1.00	0.400	0.600	0.370	0.238	0.132	0.20
1967–68	1.35	0.525	0.825	0.500	0.269	0.231	0.30
1968–69	1.70	1.100	0.600	0.650	0.506	0.144	0:45
1969–70	2.00	1.400	0.600	0.800	0.629	0.171	0.56
1970–71	2.40	1.700	0.700	1.000	0.737	0.263	0.70

(Economic Times, Bombay, 18.3.1966)

APPENDIX III

THE SOIL TEST LIMITS (APPLICABLE TO CEREAL CROPS ONLY) ON ALL INDIA BASIS FOR THE PLANT NUTRIENTS

S. No.	Nutrient	Method used	Limits		
			Low	Medium	High
1.	Available phosphate (as P_2O_5 kg per hectare)	Olsen's method	Below 22.4	22.4–56	Above 56
2.	Available potassium (as K_2O kg per hectare)	Extraction with Morgan's reagent, 1 : 2 soil and reagent ratio	Below 121	121–280	Above 280
3.	Available nitrogen (kg per hectare	Alkaline per-manganate method	Below 280	280–560	Above 560
4.	Organic carbon	Walkley and Black's method	Below 0.5%	0.5–0.75%	Above 0.75%
5.	Total nitrogen	Kjeldahl method	Below 0.03%	0.03%–0.06%	Above 0.06%
6.	Total lime (as CaO)	HCl soluble	Below 0.1%	0.1%–0.25%	Above 0.5%
7.	T.S.S. in terms of conductivity (milliomhos per cm at 25°C)	Soil water ratio 1 : 2	Normal 1.0	Tending to become critical for crops, 1.0–2.5	Critical for crops above 2.5
8.	pH	Soil water ratio 1 : 2.5	Acidic below 6	Normal 6.0 to 8.5 Tending to become alkaline 8.5 to 9.3	Alkaline above 9.3

APPENDIX IV

The following table gives an estimate of the cost of producing one ton of nitrogen in four different carriers in India as determined by the U.N. team in 1961*.

	Rs.
Ammonia (82% N)	454
Urea bagged (45% N)	810
90/10 Ammonium nitrate limestone (30.5% N) bagged	1030
Ammonium sulphate bagged (20.5% N)	1320

Pressure tank wagons and some other equipments would be necessary for the transport and use of ammonia. The depreciation of these items would add to the cost of the ammonia, but even with these added costs ammonia would be a cheaper source of nitrogen.

*'Planning for the Production of Commercial Fertilizers in India During the Third Plan', Department of Economic and Social Affairs, United Nations, September 1961.

APPENDIX V

THE RECOMMENDED DOSES OF LIMESTONE FOR THREE SOIL TYPES AND FOR EIGHT pH RANGES.

(KANWAR, J.S. AND BHUMBLA, D.R. 1959. *Indian Fmg.* **2**(2), pp. 27-28).

Soil pH	Kg of limestone required per hectare for different soil types		
	Sandy loam	Loam	Clay loam
5.0	1260	1889	2940
5.2	1092	1637	2548
5.4	924	1385	2156
5.6	756	1133	1764
5.8	588	881	1372
6.0	420	629	980
6.2	252	377	588

REFERENCES

AGARWAL, R R. 1955. *Sci. & Cult.* **16** : 61.

———— 1957. *Indian Fmg* **7** : 6-8.

AIYAR, S.P. 1945a. *Curr. Sci.* **14** : 10-1.

———— 1945b. *Indian J. agric. Sci* **15** : 283-97.

ALIKANTA, N.M. 1927. *Philipp. J. Sci.* **32** : 1-27.

ALLAN, R.G. 1932. *Quin. Rep. Dep. Agric. Madhya Pradesh (1925-30).*

———— 1933. A consolidated record of the field experimental work carried out by the Department of Agriculture in the Central Provinces between 1900-1930. pp. 1-399.

ALLISON, F.E. AND COLAMAN, D.A. 1930. *Soil Sci.* **3** : 499-505.

ANANTAKRISHNA RAO, P.N. AND HANUMANTHA RAO, K. 1952. *Madras agric. J.* **39** (3) : 173-82.

ANONYMOUS. 1920-25. *Report (Scientific) Indian agric. Res. Inst.* 1920-25.

———— 1937-44, 1949-56. *Indian Coun. agric. Res.* 1937-44 ; 1949-56.

————, 1953. *Report of the Expert Committee on Manures and Fertilizers.* Ministry of Food and Agriculture, Government of India.

————, 1950-51, 1952-53. *Annu. Rep., C.R R.I.* 1950-51 and 1952-53.

————, 1953. *Report (First) on Agronomic Trials on Paddy and Wheat, 1953-54.* Technical Cooperation Mission.

———— 1952-53. *ibid.* 1954-55.

————, 1952-53. *Report (Annual), United Planters' Association of South India* 1952-53.

CWINC, 1949. *Report (Seven-Year Plan) on River Valley Projects in India.*

ANONYMOUS. 1956. First Report of the Potascheme Fertilizer Demonstrations on paddy in India for the year 1953-54 and 1954-55. *Potascheme, Bangalore.*

———— 1957. N.P.K. Scheme, Punjab. Results of simple fertilizer trials in cultivators' fields (1956-57). *ibid.*

———— 1963. Relative efficiency of soil and foliar application of phosphate on berseem. *Rep. Agron. Div., I.A.R.I. 1962-63.*

ANTHONY, J.L. AND PITNER, J. 1940. Results of co-operative tests of T.V.A. plant food materials by the land grant colleges. *Bulletin* **1** 30-45.

ARLANDS, A. 1933. *Zeitschrift Pflanzanernahrung und Dungung und Bodenkunde.* **28** : 172.

ASHBY, S.F. 1907. *J. agric. Sci.* **2** : 52-67.

BAMJI, N.S. 1938. *Indian J. agric. Sci.* **8** : 839-47.

BASU, J.K. 1942. *Proc. 4th Meet Crops Soils Wing, Indian Coun. agric. Res.*

——— 1953. *Proc. nat. Inst. Sci. India.* **19** : 29.

BASU, J.K. AND KIBE, M.M. 1943. *Bull. Indian Soc. Soil Sci.* **5** :

———— AND ———— 1945. *J. Univ. Bombay* **14** (A) : 29-34.

BEAR, F.E. 1942. *Soils and Fert.*

———— 1949. *Agric. Chem.* **4** : 39-41.

———— 1950. *Agron. J.* 42 (4) : 176-8.

BHAT, N.P., INGERJI, K.B. AND PATEL, M.H. 1955. *ibid.* **9** : 27.

BHOWMIK, H.D. AND RAYCHAUDHURI, S.P. 1953. *Proc. nat. Inst. Sci. India* **19** : 35-43.

BISWAS, T.D. 1951. *Indian J. agric. Sci.* **21** : 97-107.

CARPENTER, P.H. 1938. *Emp. J. exp. Agric.* **6** : 1-10.

CHANDNANI, J J. 1952. *J. Sci. Tech. India.* **1** (1) : 35.

CHAKRAVARTY, M., CHAKRAVARTY, B. AND MUKHERJEE, S.K. 1961. Liming in crop production in India. *Bull. Indian Soc. Soil Sci.* **7** : 1-33.

CHANDNANI, J J. 1954. *Indian J. agric. Sci.* **24** : 195-211, 213-25.

CHATTERJEE, B. 1953. *Sci. & Cult.* **18** : 421-2.

CHRISTENSEN, H R. 1922. *Z. Pfl Ernahr. Dung* A. **1** : 265.

——— 1924. *Proc. 4th int. Soc. Soil Sci.* **2** (4) : 309.

CLARK, K G., YEE, J.Y. AND LOVE, K.S. 1948. *Indian Engng. Chem* **40** : 1178.

CLEMENTS, HARRY, F. 1948. Better crop with plant food. Vol. 32.

COLEMAN, RUSSELL. 1964. World fertiliser requirements. *Fertil. News* **9** : 7-13 ; 32.

COLLINGS, G.H. 1947. *Commercial Fertilisers.* 4th Edn, pp. 1-522. The Blackiston Co., Philadelphia.

COMMITTEE ON NATURAL RESOURCES, PLANNING COMMISSION. 1963. Report on the Study on Survey and Utilisation of agricultural and industrial by-products and wastes. XI-Basic slag. pp 92-96.

CROWTHER, E.M. 1950. *Chem. & Ind.* **69** : 763-6.

DAJI, J.A. 1948. *Curr. Sci.* **17** : 259.

DALIP SINGH, AND NIJHAWAN, S.D. 1932. *Indian J. agric. Sci.* **21** : 1-18.

DAS, S. 1926. *Mem. Dep. Agric. India* (*Chem. Ser.*) 8-69.

——— 1944. *Indian J. agric. Sci.* **14** : 268-72.

DAS, S.C. AND MOTIRAMANI, D.P. 1949. *Curr. Sci.* **18** : 46-47.

DASTUR, R H. AND MALKANI, 1933. *Indian J. agric. Sci.* **3** : 157.

——— AND KALYANI, 1934. *ibid.* **4** : 803-71.

———, AND PIRZADA, A.R. 1933. *ibid.* **3** : 963.

DATTA, N.P. 1961. Radio-isotopes, Fertilisers and Cow-dung Gas Plant. (Report) *Indian Coun. agric. Res.* pp. 58-63.

——— AND GOSWAMI, N.N. 1962. Effect of organic matter and moisture levels on the up take and utilisation of soil and fertiliser phosphorus by wheat. *J. Indian Soc. Soil Sci.* **10** (4) : 263-7.

——— AND KAMATH, M.B. 1961. Radio-isotopes, fertilisers and cowdung gas plant. (Report). *Indian Coun. agric. Res.* pp. 1-22.

——— AND ——— 1959. *Indian J. agric. Sci.* **29** : 11-18.

———, AND SRIVASTAVA, S. C. 1958. Proceedings 2nd International Conference on peaceful uses of Atomic energy, Geneva, 27: 190-2.

DAUEBENY, C.B 1845. Philosophical Transactions, Royal Society London. **135** : 179.

DAVIS, C.R. 1951. *Nature, Lond.* **167**: 793.

DESAI, S.V. 1956. *J. Indian Soc. Soil Sci.* **4** (1) : pp 3-9.

———and SUBBIAH, B V. 1951. *Proc. Indian Acad. Sci.* **32** (B) : 75.

——— AND——— 1952. *ibid.* **16** (B) : 180-90.

DHAR, N.R. 1961. "Nitrogen Problem", General presidential Address. *Proc. 58th Indian Sci. Congr. Ass.* pp. 1-32.

DHAR, N.R. AND SHARMA, D. 1955. Comparative value of Indian rock phosphate and basic slag. *J. nat. Acad. Sci.* **25** (6) : 511-4.

DIRECTORATE OF EXTENSION AND TRAINING, MINISTRY OF FOOD AND AGRICULTURE. 1955. *Ferti. Guide.* Extension Pamphlet No. 1.

DOYNE, H.C. 1937. *Emp. J. exp. Agric* **5**: 218-53.

ENGBERG, C.A. AND SPURWAY, C H. 1933. *J. Amer. Soc. Agron.* **5** : 304.

FAULKNER, O.T. 1934. *Emp. J. exp Agric.* **2** : 93-102.

FERTILISER ASSOCIATION OF INDIA. 1965. *Fertiliser Statistics.* 1964-65.

FINFROCK, D.C. AND DONAHUE, ROY L. 1962. The efficiency of various nitrogenous fertilisers for paddy. Intensive Agricultural District Programme. Staff working paper No. 6204.

FITTS, J.W. AND NELSON, E.C. 1956. *Advanc. Agron.* **8** : 242-82, Academic Press. Inc., New Yoik.

FOX, E.J., HILL, W L., JACOB, K.O. AND RAYNOLDS, D.S. 1946. *Industr. Engng. Chem.* **38** : 329-34.

FREAR, G.L. AND HULL, L H. 1941. *ibid.* **33** : 1560-6.

FRIED, M. AND DEAN, L.A. 1952. *Soil Sci.* **73** : 263-71.

FRIED, M. 1956. Atomic energy in agriculture. *American Association for the Advancement of Science*, pp. 1-8.

FUDGE, J E. AND FRAPS, G S. 1945. *Bull. Texas agric. exp. Sta*, pp 672.

GADRE, G.T. AND GUPTA, J. 1953. *J. sci. Industr. Res. India* **12** (B) : 173-4.

GADRE, G.T. 1954. *Sci & Cult.* **19** ; 328-30

GHOSH, A.B., RAYCHAUCHURI, S.P. AND BHURE, N.D. 1956. *J. Indian Soc. Soil Sci.* **4** : 23-39.

GOVINDARAJAN, S.V. AND VENKATARAO, B.V. 1957. *ibid.* **5**(3) : 133-140.

GULATI, K.C., JUNEJA, P.C. AND RAYCHAUDHURI, S.P. 1955. *Indian J. agric. Sci.* **25** : 29-30.

GUPTA, J.1951. Report of the proceedings of symposium on chemicals for agriculture, July, 1951. *Nat. chem. lab. Poona, India.*

GUPTA, Y.C. 1952. *Indian Fmg* (n.s.) **1** (12) : 10.

GUPTA, Y.P. AND DAS, N.B. 1954. *J. Indian Soc. Soil Sci.* **2** : 121-5

GUTZEIT, E. 19C6. *Zbl. Bakt.* **11** : 16, 358.

HARPER, H.J. 1932. *Bull. Okla. agric. Exp. Sta.* pp 205.

HARTWELL, B L. AND DAMON. 1947. *Bull. Rhode Island agric. Exp. Sta.* pp. 209.

HARVEY, E.S. 1952. *Amer. Fertil.* **63** : 13.

HENDRICKS, S.B. AND HILL, W.L. 1942. *Vide Commercial Fertilizers Book* published by The Blakiston Company, Philladelphia, by C.H. Collings, 4th Edn. 1947, pp. 172-76.

HIGNETT, T.P. AND NUBBUCH, T.N. 1946. *Industr. Engng Chem.* **38** : 1208.

HILL, A.V.L. 1945. Report on Scientific Research India, Roy. Soc London.

———1947. *Res. Rep. No. 100, Div. Fert. agric. Bur. Plant Industry. U.S. Dep. agric, Belttsville.*

IDNANI, M.A. 1949. *Indian Fmg* **10** : 13-5.

———1952. *ibid.* (n.s.) **2** : 30-1.

———1952 *Food & Fmg* (n s.) **4** : 347-8.

———, ACHARYA, C.N. AND RAYCHAUDHURI, S.P. 1956. *Indian Fmg* (n.s.) **6** : 95-7.

IMPERIAL CHEMICAL INDUSTRIES. 1952. *Chem. Ind.* 265.

IGNATIEFE, V. AND PAGE, H.J. 1958. Efficient Use of Fertiliser. F.A.O. Agricultural Studies No. 3 (Book). 1-355. Rome.

I.C.A.R. 1956. Research Report Series No. 4. First report of model agronomic experiments, *kharif* 1956 pp 1-67.

———1961. Research Report Series No. 7 Second report of model agronomic experiments, *rabi* 1956-57. pp 1-69.

———1962. Research Report Series No. 8. Co-ordinated agronomic experiments. Third report of model experiments, *kharif* 1957-58. pp 1-109.

———1962. Research Report Series No. 9. Fourth report of model agronomic experiments, *rabi* 1957-58 pp. 1-127.

———1963. Research Report Series No. 12. Fifth report of model agronomic experiments, *kharif.* 1958. pp 1-65.

I.C.A.R 1963. *Research Report Series No. 14.* Sixth report of model agronomic experiments, *rabi* 1958-59. pp 1-90.

———1964. *Research Report Series No. 16* Seventh report of model agronomic experiments, *kharif* and *rabi*, 1959-60.

———1964. *Research Report Series No. 17*, Eighth report of model agronomic Experiments, *kharif* and *rabi*, 1959-60. pp 1-99.

———1965. *Research Report Series No. 23.* Twelfth report of model agronomic Experiments, 1961-62, pp 1-163.

———1963. *Research Report Series No. 13.* Coordinated Simple Fertiliser Trials on cultivators' fields, *kharif* and *rabi* 1958-59.

INDIAN STANDARDS INSTITUTION, 1963. *Glossary of Terms used in Fertiliser Trade and Industry* (Rev) **4** : 631-8.

INDIAN TEA ASSOCIATION. 1949. *Rep. Indian Tea Ass.*

JAYARAMAN, N. 1963. *A new phosphate fertiliser.* Indian chemical manufacture, 1 (3).

JOHN, JOHN K, 1963. Speech : Chairman, The Fertiliser Association of India on the occasion of the Seventh Annual Meeting of the Association of the 14th December, 1962, *Fertil. News* **8** (1) : 7-16.

JOSHI, N.V. AND SINGH, H.D. 1938. *Proc. 25th Indian Sci. Congr. Ass.* III. (Abstr.) pp. 225.

KADAM, B.S. 1952. *Annu. Rev. biochem. Res. India*, p 23.

KALAMKAR, R.J. 1942a. *Curr. Sci.* **11** ; 190.

———1942b. *Nagpur agric. Coll. Mag.* **16** : 149-154.

——— AND SRIPAL SINGH 1935. *Indian J. agric. Sci.* **5** : 346-54.

KARUNAKAR, P.D. 1948. Proc. 7th Meeting Crops and Soils Wing, Board of Agriculture and Animal Husbandry, I C A.R.

KEEN, B.A. 1946. Note by Imperial Bureau of Sciences, London, on addition of organic matter to tropical soils.

KHAN, M.A. 1946. *Punjab Fmg.* **11** : 9-10.

KHANNA, K.L. AND ROY, P.K. 1957. *J. Indian Soc. Soil Sci.* **4** : 189-92.

———, BHATTACHARYYA, P.B., AND SINGH, K P. 1957. *J. Indian Soc. Soil Sci.* **4** : 11-21.

KIBE, M.M., PERUR, N.G. AND NARAYANAN, N. 1953. *Agric. Coll. Mag. Poona* **44** : 49-52.

KOCH, A. 1910. *Zbl. Bakt.* **11** : 26, 335.

KORADDI, V.R. AND SETH, JAGADISH. 1964. *J. Indian Soc. Soil Sci.* **12** : 387-392.

KRISHNAN, M. S. 1949. *Rec. geol. Surv. India* (professional paper) **77** (9) 22-3.

LAGATU, H. AND MAUME, L. 1935. *C. R. Acad Sci.* **200** : 502.

LEATHER, J. W. 1907. *Mem. Dep. Agric. (Indian Chem. Ser.*) **1** : 45-57.

LEWIN, P.J. 1931. *Bull. 3, Nigeria agric. Dep. Sta.*

MADHOK, M.R. 1942. *Proc. 4th. Meet. Crops Soils Wing.* Indian Coun . agric. Res., New Delhi.

MAHAPATRA, I.C. AND SAHU, B.N. 1963 *Rice News Teller* **11** (2) :

MANDAL, S.C., DAS, S.K. AND MUKHERJI, H.N. 1955. *J. Indian Soc. Soil Sci.* **3** : 71-5

MANN, H H. AND BARNES, T. W. 1940. *J. agric. Sci.* **30** : 345.

MEHTA, P.E. 1945. *Sci & Cult.* **11** 76.

MERZ, A.R. AND BROWN, B.E. 1943. *Circ. No. 679. U. S. Dep. Agric.*

MEYER. 1930. *Z. Pflernahr. Dung.* 15 (A) 101.

MITSCHERLICH, F. 1909. *Landw. Jb.* **38** : 537.

MITSUI. S. 1950. *Inorganic Nutrition, Fertilisation and Soil Amelioration for Lowland Rice.* (Book) Yokendo Ltd., Tokyo.

MUKHERJEE, H. N. *et al.* 1955. *Proc. Bihar Acad. agric Sci.* **4** : 140.

MUKHERJEE, H.N. AND SINHA, P. 1953-54. *Proc. Bihar Acad. agric. Sci.* (2 & 3) : 146-52.

MUKHERJEE, J.N. 1949. *Sci. & Cult.* 15 ; 235-7.

——— J. N , RAYCHAUDHURI, S. P. AND SUNDARA RAO, W. V. B. 1953. *Proc. 8th Meet. Crops Soils Wing. B. Agric.* Indian Coun. agric. Res., New Delhi

NAIR, C. K. N. 1952. *Rep. Proc. Symp. on Chemicals for Agriculture, N. C. L. Poona.*

NANDY, N. K. 1946. *Indian agric. Sci.* 16 : 435-44.

NARSING RAO, M. B. V. 1954. *Madras agric. J.* 41 : 165.

OLSEN, S. R. *et al.* 1954. *Circ. No.* 939, *U. S. Dep. Agric.*

PARKAR, F. W. 1921. *Soil Sci.* 12 : 209-132.

——— *et al.* 1951. *Agric. J.* 43 : 105-112.

——— AND TROUG, E. 1923. *Soil Sci.* 10 : 49-60.

PARR, C. H. AND BOSE, R. D. 1944. *Indian Fmg* 5 : 156-62.

PARTHASARATHY, S. V. 1952. *Madras agric. J.* (Sp. Conf) 39 : 104.

PATEL, D. K. AND VISWANATH, B, 1946. *Indian J. agric. Sci.* 16 : 428-34.

PATEL, S. P.. GHOSH. A. B. AND SEN, S. 1963. *J. Indian Soc. Soil Sci.* 11 : 225-238.

PATHAK, A. N. 1954. *Madras agric. J.* 41 : 127- 33.

———, MUKHERJEE, S. K. AND SRIKHANDE, J. G. 1950 *Curr. Sci.* 18 : 290-1.

PHUKAN, L. N. 1950. *Rep. agric. Chem. Assam.*

PLUSTE, M. H. R. J. 1951. *Proc. fert. Soc.* No. 13.

PRASAD, B. L. 1963. *Relative Efficiency of Soil and Foilar Application of Nitrogen on Barley under Rainfed Conditions.* M. Sc. Thesis, I. A. R. I., New Delhi.

RAHEJA, P.C. AND MISRA, M. D. 1955. *Indian J. agric. Sci.* 25 : 87.

——— AND YAWALKAR. K.S. 1960. Urea as a fertiliser. *Rev. Ser. No. 20. Indian Coun. agric. Res.*

———, DAJI, J. A. AND MUKHEJEE, S. K. 1961. Relative performance of nitrogenoul fertilisers. *Rev. No. 33, Indian Coun. agric. Res.*

——— *et al.* 1956. *Proc. Crops Soils Wing. Agric.* Indian Coun. agric. Res. Simla.

RAI, A. K., PPASAD, C. R. AMD MANDAL, S. C. 1953. *J. Indian Soc. Soil Sci.* 11 : 137-40.

RAMAMOORTHY, B. AND DESAI, S. V. 1946. *ibid.* 16 : 103-11

RAMANUJAM, S. AND MUKHTAR SINGH 1952. *Annu. Rev. biochem. Res. India.* pp 23.

RAMASWAMY, SIVAN. 1925. *Mem. Dep. Agric. India* (Chem. Ser.) 7 : 145-200.

RAMIAH, K , GAOSA, R. L. M. AND VACHHANI, M. V. 1952. *Emp. J. Agric.* 20 : 161-74.

RAMY, T. 1902. *Zbl. Bakt.* 2 (8) : 657.

RANDHAWA, M. S. 1963. *Role of Science and Technology in Indian Agriculture, Planning Commission, New Delhi* (Booklet).

RAYCHAUDHURI, S. P. 1952 *Indian J. agric. Sci.* 22 : 223-4.

———1963. *J. Indian Soc. Soil Sci.* 11 : 83-8.

——— AND MUKHERJEE, M K. 1941. *ibid.* 11 : 205-19.

——— VYAS, N.D., DAS, S.C. AND GHOSH, A.B. 1955. *Indian J. agric. Sci.* 25 : 193-203.

——— CHANDNANI, J J. 1958. Artificial fertilisers. *Res. Bull.* pp 1-26. *Indian Coun. agric. Res. New Delhi.*

———AND SUBBIAH, B V. 1958. Soil testing kits. *Res. Bull* No. 14, *Indian Coun. agric Res. New Delhi.* pp 1-36.

———, ——— AND SINHA, M.P. 1955. *Proc. Indian Sci. Congr.* Part III pp. 362-3.

RAYDHAUDHURI, S.P. AND DATTA, N.P. 1964. Phosphorus and potassium status of Indian Soils. *Bull.* No. 36. *Indian Coun. agric. Res.* (Rev. Ser.) pp. 1-43.
REED, J.E. AND CUMMINGS, R.W. 1945. *Soil Sci.* **59** : 97-104.
REGE, R.D. 1941. Fertiliser experiments on sugarcane in India. *Misc. Bull.* No. 41. *Indian coun. agric. Res.*
RICHARDS, L.A. 1941. *Soil Sci.* **51** : 377-86.
RICHARDSON, H.L. 1952. *Proc. int. Soc. Soil. Sci.* Vol. 2.
——— 1962. Developments in the FAO fertiliser programme under the freedom from hunger campaign. *Proc.* No. 73. *Fert. Soc. London.*
RUSSELL, E J. 1919. *J. educ. Agric. Lond:* **26** : 228.
——— 1937. *Soil Conditions and Plant Growth,* 7th edn., Book) Longmans, Green and Co. London, pp 1-655.
——— AND APPLEYARD, C. 1915. *J. agric. Sci.* **7** : 1-48.
SADAPHAL, M.N. AND DAS, N.B. 1956. The effect of micro-element fertiliser on wheat. *Sci. & Cult.* **22** : 233-5.
——— AND ——— 1956. Effect of spraying urea on wheat. *ibid.* **22** : 28-40.
SAHI, B.P. AND MANDAL, S.C 1955. *Proc. Bihar Acad. agric. Sci.* **4** : 1-3.
SANYASI RAJU, M. 1952. *Madras agric. J.* **39** : 130-47.
SASTRY, V.V.K. AND VISWANATH, B. 1946. *Indian J. agric. Sci.* **16** : 426-8.
SAXENA, E.R. 1951. Proceedings on Symposium on "Chemicals for Agriculture", Poona.
SEN, A.T., DEB, B.C. AND BOSE, S.K. 1949. *Soil Sci.* **68** : 291-305.
SEN, S. 1964. Symposium on fertility of Indian soils. *Bull. nat. Inst. Sci. India* **26** : 330-5.
——— AND BAINS, S.S. 1955. *J. Indian Soc. Soil Sci.* **3** : 41-9.
——— AND SUNDARA RAO, W.V.B. 1953. *Bull.* No. 3. *Indian coun. agric. Res., New Delhi.* (Rev. Ser.).
——— BAINS, S.S. AND GUPTA, Y.C. 1952. *Indian J. agric. Sci.* **22** : 389-95.
SEN, S.C. 1953. *Proc. 22nd Meet. Sugar Tech. India.*
SETH, JAGADISH, 1963. *Indian J. Agron.* **8** : 399-402.
——— HERBERT, T.T. AND MIDDLETON, G.K. 1960. *Agron. J.* **32** : 207-9.
SETHI, R.L. 1938. *Bull.* No. 186. *Pusa agric. Res. Inst.*
———, RAMIAH, K. AND ABRAHAM, T.P. 1953. Manuring of Paddy. *Misc. Bull.* No. 38. *Indian Coun. agric. Res. New Delhi.*
SIGMOND, DE. 1933. Trans. 2nd Comm. Alkali Sub-Comm. Int. Soc. Soil Science.
SINGH, D. AND DAS, B. 1945. *Indian agric. Sci.* **15** : 201-8,
——— AND NIJHAWAN, S.D. 1943. *ibid.* **13** : 134-41.
SINGH, R.P. 1952. *Allahabad Fmr.* **26** : 81.
SINHA, M P. 1963. Short note on fertiliser trials in Bihar (Private communication).
SIRUR, S.S. AND SOALAPURKAR, V.K. 1961. *Fertil. News* : **6** (12), 16.
SKINNER, J. J. AND BUIE, T. S. 1926. *S. Car. Agric. exp. Sta. Bull.* 227.
SRIVASTAVA, S. C. 1958. *Movement and fixation of phosphorus in Indian soils.* ph. D. Thesis, I. A. R. I.
STANFORD, G. AND NELSON, L. B. 1949. *Soil Sci.* **68.** : 157.
STEWART, A. B. 1947. Report on soil fertility investigations in India. *Indian Coun. agric. Res.* pp 1-160.
STOKLASA, J. AND ERNEST, A. 1911. *Zbl. Bakt.* **2** (14) : 723.
SUBBIAH, B. V. 1946. *Studies on some biochemical aspects of soil fertility.* M. Sc. Thesis Bombay University, I. A. R. I. Library.
——— 1950. *Curr. Sci.* **20** : 161.
——— 1952. *Studies on the factors determining the chemical composition of crops with special reference to the effect of manuring and rotations on their compo-*

sition. Ph. D. Thesis, Bombay University, I. A. R. I. Library.

——— AND ASIJA, G. L. 1956. *Curr. Sci.* **25** : 259-60.

——— AND BAJAJ, D. C. 1961. *ibid.* **31** : 196.

——— AND DESAI. S. V. 1952 *ibid.* 21 : 100.

——— AND SURINDER MOHAN 1964. Proceedings Nuclear Radiation Chemistry Symposium, Bombay. pp. 195-98.

——— AND VENKATESWARLU, 1965. Availability and tranaformation of sulphur in rice soils, Isotopes and Radiation in Soil-Plant Studies, I. A. E. A , Vienna, pp. 563-78.

TALATI, R. P. 1941. *vide* Final Report of the All India Soil Survey Scheme, Bull No. 73. 1953. Indian Council of Agricultural Research (Report) pp. 1-233.

TAMHANE, R. V. AND GHOSH, A. B. 1962. *Fertil. News* 7 (7) 14. 30.

——— AND SUBBIAH, B.V. 1962. Soil Science and Plant Nutrition, Journal of Japan, **8**, No. 3. 97-106.

——— AND ——— 1956. Proc. 10 th Meet. Crops Soils Wing, *B. Agric., Indian Coun. agric. Res.* pp 52-62.

——— AND ———1961 Radioisotopes, Fertilisers and Cowdung Gas Plant, ICAR (Report). 123-135.

———, ——— AND OOMMEN, P. K 1957. *Proc. Board of Crops and Soils Wing of India.*

THOMAS, WALTER. 1937. *Plant Physiol.* **5** : 443-589.

TIDMORE, J. W. AND WILLIAMSON, J. T. 1932. *Bull. agric. Exp Sta.* pp 1-238.

VACHHANI, M. V. 1952. *Indian Fmg* **2** (1) : 28.

VAIDYANATHAN, M. 1933. *Analysis of Manurial Experiments In India.* Vols. I, II and III (Report). *Indian Coun. agric. Res., New Delhi.*

VAINATHEYN, K. V. 1962. *Relative Efficiency of Soil and Spray Application of urea on unirrigated wheat.* M. Sc. Thesis, I. A. R. I.

VISWANATH, B. 1925. *Annu. Rep. Madras agric. Chem.* pp. 228.

——— 1931. *Indian J. agric. Sci.* **1** : 4.

WAKSMAN. S. A. 1923. *Soil Sci.* **15** : 49-65.

——— 1932 *Principles of Soil Microbiology.* 2nd edn. William and Wilkins Co., Baltimore, U. S. A., pp 1-894.

WALTHAL, J. H. AND STRIPHIR, M.M. 1941. *J. Industr Engng Chem.* **38** : 995-1000.

WHITE, J. W. 1925 Comparative Value of Ammonia and Nitrate of Soda (Book), New York, Barrett Co.