PHOSPHORUS FERTILIZERS FOR PLANTATION CROPS

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THE use of bones, fish and the dung of birds as fertilizers is an ancient agricultural practice, dating back at least two thousand years. Not until the end of the eighteenth century, however, was it realised that the manurial value of these materials lay in the phosphorus they contained—phosphorus, the " light-bearer," discovered and named by Hennig Brandt in 1669 after the way it glowed in the dark, and later identified as an element by Antoine Lavoisier.

In 1842, a memorable date in agricultural history, John Bennett Lawes, the founder of Rothamsted Experimental Station, and Sir James Murray, of Dublin, were granted patents for " chemically decomposing, for purposes of manure, by means of sulphuric acid, bones, bone-ash or bone dust or apatite or phosphorite or any other substance containing phosphoric acid." Lawes later bought out Murray and amended his patent to cover only mineral phosphates as he could not claim novelty for the treatment of bones. Thus began the world's inorganic fertilizer industry.

Commercial Phosphorus Fertilizers

The principal phosphorus fertilizers used today are superphosphate, basic slag, rock phosphate and ammonium phosphate. Bone products and guano are still widely used. Before the 1939-45 war, world output of phosphate rock was estimated at 13 million tons, of which 35 per cent. was produced in North Africa, 30 per cent. in the United States, 18 per cent. in the U.S.S.R. and 10 per cent. in the Commonwealth territories of Nauru and Ocean Island, in the Pacific, and Christmas Island, off Singapore. Since the war, output has risen to 21½ million tons (excluding the U.S.S.R., for which no reliable figures are available) and, of this, the U.S.A. contributes no less than 11 million tons. Two main types of deposit are distinguished: firstly, the crystalline apatites which occur chiefly as veins or intrusions in igneous rocks, notably in the Kola Peninsular in the U.S.S.R.; and secondly, the amorphous sedimentary deposits known as phosphorite, usually of marine origin and formed from the decomposition either of phosphatic limestones or of animal remains, examples of which occur in Florida, Tennessee and the western United States and in French Morocco, Algeria, Tunisia, Egypt and the Pacific Islands.

Table I

Composition of Phosphate Rock: Typical Analyses (from Gray, A. N., "Phosphates and superphosphate," 2nd ed., 1944, and Waggaman, W. H., "Phosphoric acid, phosphates and phosphatic fertilizer'," 2n ed., 1952).

	P_2O_5 (per cent.)
Kola apatite	30·1
Morocco (Khouribga)	35·1
„ Safi (Louis Gentil)	31·9
Algeria, Constantine	30·6
Tunisia, Gafsa	27·6 to 30·6
Egypt, Safaga	31·0
„ Kosseir	30·6
Idaho, Utah, etc. (high grade)	27·0 to 36·5
Florida, land pebble	30·0 to 34·0
„ hard rock	36·4
„ soft	25·0 to 27·0
Tennesse, brown	30·0 to 38·0
„ blue	27·0 to 32·0
Nauru	38·9
Ocean Island	40·3
Christmas Island	39·5
Curaçao	35·7 to 40·7

Apart from the nature of the deposit and the amount of phosphorus it contains, the quality of phosphate rock depends also upon its content of iron and aluminium oxides and of fluorine, all of which tend to reduce its availability to plants and may require special processes for their removal during the preparation of manufactured fertilizers. The seller usually guarantees that the iron and aluminium oxides do not exceed a certain figure, which may vary from 0·5 to 3 per cent. or more. The fluorine content, too, usually lies between these limits.

It is estimated that some 80 per cent. of all phosphate rock output goes into superphosphate. This fertiliser is still made, as in Lawes' day, by treating ground phosphate rock with sulphuric acid, but modern methods and accurate mechanical mixing ensure a uniform product in far better physical condition than was obtainable a hundred years ago. The present product usually contains about 18 per cent. water-soluble P_2O_5. A higher grade, termed triple superphosphate (sometimes known as "double" or "concentrated" superphosphate), is made by treating phosphate rock with phosphoric, instead of sulphuric acid, and may contain nearly 50 per cent. P_2O_5. Another variant, recently developed in the United Kingdom though not at present commercially produced there is obtained by substituting nitric acid for sulphuric acid; the resulting product, after removal of calcium nitrate by treatment with ammonia and ammonium sulphate, being known as nitrophosphate. A typical analysis is 13·8 per cent. N and 13·8 per cent. total P_2O_5 (13·0 per cent. soluble in 2 per cent .citric acid and 4·5 per cent. soluble in water). Alternative processes have been developed in France, the Netherlands and the United States. Yet another variant, dicalcium phosphate, containing about 40 per cent. P_2O_5 soluble in neutral ammonium citrate solution, is manufactured in certain parts of the world by treating phosphate rock with hydrochloric acid, obtained as a by-product in the preparation of sulphate of potash, and then precipitating the dissolved phosphate.

After superphosphate, the second most important phosphorus fertilizer is basic slag, a by-product in the manufacture of steel from pig iron by the Bessemer (Gilchrist-Thomas) process or by the open hearth process. In both cases phosphorus, which occurs as phosphide impurity in pig iron, is removed by oxidation at a high temperature in the presence of lime or other basic materials having a strong affinity for the resultant P_2O_5. In the former process, which in many countries has been superseded, a current of air is blown through the molten mass and the high temperature required is obtained from the combustion of silicon, carbon and phosphorus contained in the metal; an ore rich in phosphorus is therefore desirable. In the latter process, the heat required is largely derived from an outside source and the presence of phosphorus is not only unnecessary but undesirable; moreover, the employment of fluorspar as a flux may convert whatever phosphorus is present into an insoluble form. Thus we may differentiate: (1) high soluble, high-grade Bessemer slags containing perhaps 18 per cent. total P_2O_5 and 15-16 per cent. P_2O_5 soluble in 2 per cent. citric acid (*i.e.*, nearly nine-tenths of the total P_2O_5 is citric-soluble): (2) high-soluble, low- or medium-grade open hearth slags containing, say, 8 to 10 per cent. total P_2O_5, of which over four-fifths may be citric-soluble, and (3) low-soluble, low- or medium-grade open hearth slags containing the same total amount of P_2O_5, but of which, owing to treatment with fluorspar, less than two-fifths is citric-soluble. As well as phosphorus, basic slags contain 40-50 per cent. CaO in various forms of combination and it is usually reckoned as a rough guide that their liming value is equal to about two-thirds of their weight in chalk or limestone.

Of the total world production of phosphate rock, it is estimated that some 10 per cent. is finely ground for direct application to the soil as a fertilizer. Its effectiveness varies greatly with the source of the material, fineness of grinding, crop, soil, climate, etc. Care should be taken in purchasing as some kinds appear to be completely valueless for direct use.

Mono-ammonium phosphate, containing in its pure state 61·7 per cent. water-soluble P_2O_5 and 12·2 per cent. N, and commercially about 50-54 per cent. P_2O_5 and 12 per cent. N, is an important ingredient of concentrated compound fertilizers. It is made either by treating phosphate rock with sulphuric acid and ammonium sulphate or by reacting phosphoric acid with ammonia. Di-ammonium phosphate, containing in its pure state 53·4 per cent. P_2O_5 and 21·1 per cent. N, is also used as an ingredient of concentrated fertilizers. Ammoniated superphosphate is prepared by treating ordinary superphosphate with aqueous or anhydrous ammonia or with ammoniacal solutions containing ammonium nitrate or urea; up to 3 per cent. of ammonia on the weight of superphosphate may be added without appreciably reducing phosphorus " availability," as determined by solubility in 2 per cent. citric acid or neutral ammonium citrate solution; triple superphosphate and ordinary compound fertilizers may be treated in the same way. Other phosphorus fertilizers are obtained by calcining or fusing phosphate rock with materials such as lime, silica and soda ash. Examples are Rhenania phosphate (25-30 per cent. P_2O_5), silico phosphate (20-35 per cent. P_2O_5), calcium magnesium phosphate (about 22 per cent. P_2O_5), fused tricalcium phosphate (26-30 per cent. P_2O_5) and defluorinated phosphate rock (about 20 per cent. P_2O_5). About nine-tenths of the phosphorus in these fertilizers is soluble in 2 per cent. citric acid. Fused calcium metaphosphate (about 64 per cent. P_2O_5) is produced at a somewhat lower temperature (1,000-1,200°C) by reacting phosphate rock with phosphorus pentoxide. Nearly all the phosphorus in this fertilizer is soluble in neutral ammonium citrate solution, but less than one-quarter in 2 per cent. citric acid.

The principal bone-products available as fertilizers are bone meal and steamed bone flour. They are both slow-acting. The former contains 3-4 per cent. N and 20-24 per cent. P_2O_5, and is obtained by grinding bones from which the fat has been extracted for sale as tallow or for use in soap-making. The latter contains about 27 per cent. P_2O_5 but only 1 per cent. N, and is obtained as a by-product of gelatine and glue manufacture after steaming bones at high pressure; owing to the removal of the cartilage, it can be ground to a much finer powder than bone meal. Raw bones contain some 7-10 per cent. P_2O_5 and bone ash 30-40 per cent. P_2O_5.

The term " guano " strictly relates to the sun-dried excreta of sea birds but it has been extended to include the excreta of bats and also, under the names " fish guano " and " meat guano," dried and ground fish and slaughter house wastes. The true guano may contain anything from 9 to as much as 30 per cent. P_2O_5, and fish and meat guano from 1 to 14 per cent. P_2O_5, as well as nitrogen.

Evaluation of Phosphorus Fertilizers

In the foregoing paragraphs the phosphorus content of fertilizers has been expressed variously in terms of total, water-soluble, citric-soluble and citrate-soluble P_2O_5. Elsewhere the phosphorus content may be expressed in terms of the element P or tricalcium phosphate $Ca_3(PO_4)_2$ (tri-basic phosphate of lime). The appropriate conversion factors are:

To convert P to P_2O_5, multiply by 2·289
To convert P_2O_5 to P, multiply by 0·437
To convert $Ca_3(PO_4)_2$ to P_2O_5, multiply by 0·458
To convert P_2O_5 to $Ca_3(PO_4)_2$, multiply by 2·185.

The solubility is given as a rough indication of the " availability " of the phosphorus to plants and, when officially declared by the manufacturer, provides the purchaser with a guarantee of quality. In general, water-solubility indicates phosphorus that is readily available to plants; solubility in 2 per cent. citric acid or in neutral ammonium citrate solution indicates phosphorus that is moderately available to plants, or, perhaps, under certain conditions, just as readily available as phosphorus in the water-soluble form; and insolubility in any of these solvents, phosphorus that may be difficulty or only very slowly available to plants. These are necessarily generalizations as phosphorus in one form may be available to one plant species and not to another; while mixture with the soil may rapidly change a soluble into an insoluble form. Nevertheless they do give a quick method of estimating the relative merits of different fertilizers and provide a ready means of making cost comparisons; the water-soluble phosphorus in superphosphate fetching perhaps double the price of insoluble phosphorus in phosphate rock, with citric-soluble phosphorus in basic slag occupying an intermediate position.

Uptake of Phosphorus by Plants

Phosphorus is of major importance to plants throughout their growth. It is a constituent of nucleic acid, which occurs in all living cells. Compounds of phosphorus are concerned with the processes of respiration and with the efficient functioning and utilization of nitrogen. It is also of special significance in root development and the ripening of seeds and fruits. Characteristic symptoms of phosphorus deficiency include stunted growth, delayed ripening, poor fruiting, poor root growth and dull bluish-green leaf colour with purple tinting. Fruit from phosphorus deficient plants is usually rather soft and acid in flavour and its keeping quality poor. The amount of phosphorus taken up by (healthy) annual crop plants is indicated in Table II. The gross uptake and net annual removal in the harvested portion of certain plantation crops is indicated in Table III. In general, the uptake of P_2O_5 is appreciably smaller than that of N or K_2O, lying between one-fifth and one-half of those amounts.

Table II

Phosphorus uptake by certain annual crops (assuming average yields)

Crop	P_5O_5 uptake (lb./acre)	Crop	P_2O_5 uptake (lb./acre)
Wheat	20	Beans	40
Barley	23	Sugar beet	50
Oats	25	Carrots	40
Maize	35	Potatoes	50
Rice	20	Tomatoes	25
Peas	35	Cabbages	65

Table III

Phosphorus taken up and removed annually in produce from certain Plantation crops

Crop	Gross P_2O_5 uptake (lb./acre)	P_2O_5 removed (lb./acre)	Portion taken into account
Bananas	55	30	Fruit, one-third of stalk and leaves.
Coconuts	—	30	Nuts, leaves and inflorescences.
Coffee	40	10	Leaves and cherries.
Sugar cane	65	50	Millable cane and green tops.
Tea	—	12	Plucked shoots.

In the case of plantation crops, the total amount taken up will be considerably greater than the amount removed in the harvested portion and the actual net removal will depend upon management and how much waste is returned to the soil. The roots, trunk and branches of a rubber tree, for example, will contain very much more phosphorus than is present in the latex; of some 40 or more lb. P_2O_5 per acre taken up each year, not much more than 1 lb. will be removed in the latex and, although part of the remainder may go back to the soil when the leaves fall, the rest will not return until trees die and the trunks and branches rot (if they are sold for firewood it never will return !).

Principles of Phosphorus Manuring

The figures given above relate to phosphorus *uptake* by the plant and *removal* in produce. In estimating fertilizer *requirements* several other factors must be taken into account. Firstly, the mineral constituents of plants, including phosphorus, are not derived solely from fertilizers, which merely supplement the soil's resources. Secondly, as has already been mentioned, the interaction between fertilizer and soil (particularly acid soils and those which are rich in iron or aluminium) may reduce the availability of fertilizer phosphorus to the plant. In practice, the efficiency of phosphorus fertilizers, as measured by the proportion of fertilizer phosphorus that finds its way into the plant in the first season or two, is seldom more than 10-20 per cent. In other words, to replace every 1 lb. of P_2O_5 removed in the crop it is necessary to apply at least 5 lb. of P_2O_5 in fertilizers. If the phosphorus is needed quickly and the soil is not one that " fixes " applied phosphorus too rapidly, then fertilizers with a high degree of water-solubility, such as superphosphate or mono-ammonium phosphate, may be used. If the phosphorus requirement is spread over a long period or conditions are such that there is no particular advantage in using water-soluble fertilizers, then the less soluble materials, such as basic slag, ground rock phosphate or bone products, may be more profitable. Some economy in fertilizer usage may be achieved by placement of the fertilizer in bands, drills or manure circles exactly where it is needed, instead of spreading it broadcast; by using granular instead of powdered materials, so as to minimize " fixation " by reducing the surface area that comes into contact with the soil (this does not apply, of course, to fertilizers like bones and ground rock phosphate that are already insoluble); and by giving smaller dressings of fertilizer every one or two years instead of larger dressings every four or five years. There is some evidence that continued applications may have residual effects that last over many years.

Phosphorus Manuring of Plantation Crops

It is appropriate here to instance results produced by phosphorus fertilizers on coconuts. The main experiment of the Ceylon Coconut Research Institute, at Bandirippuwa Estate, has been carried out on an area containing adequate reserves of phosphorus and in no year has the application of one or two lb. P_2O_5 per palm given a response. The experiments at Veyangoda and Ahangama, on the other hand, are sited on soils with low reserves of plant food. Under these conditions, the application of only 0·6 lb. P_2O_5 (*i.e.*, 2 lb. rock phosphate) per palm every other year has given dramatic results. Table IV shows the increase in copra obtained each year up to 1945-46 (when the treatments were changed).

Table IV

Coconut Experiments : Yields of Copra (lbs./acre)

Year	Complete Fertilizer	Without Phosphate	Difference for Applying Phosphate
1939-40	553	490	63
1940-41	627	562	65
1941-42	998	809	189
1942-43	1,073	744	329
1943-44	1,096	774	322
1944-45	1,287	828	459
1945-46	1,115	763	352

As a result of these experiments, the following applications are recommended for bearing palms, once in every two years: on loams, sandy loams and clay soils, 0·6 lb. P_2O_5 per palm; and on laterites, lateritic gravel and white cinnamon and coarse marine sands, 0·75 lb. P_2O_5 per palm. For young palms, an annual application, rising from 0·15 lb. P_2O_5 in the second or third year after planting to 0·35 lb. P_2O_5 in the fifth year and thereafter until flowering, is advised. In every case these should be balanced by appropriate dressings of potash and nitrogen.

In the experiments of the Tea Research Institute, tea has shown a substantial response to annual dressings of up to 30 lb. P_2O_5 per acre. For ordinary conditions an annual application of 20-30 lb. P_2O_5 is recommended, together with a similar amount of potash and up to 80 lb. nitrogen per acre, depending upon economic circumstances and the cultural state of the tea bushes.

For rubber, the Rubber Research Institute recommends an annual dressing rising from 0·1 lb. P_2O_5 per tree in the first year and 0·25 lb. P_2O_5 in the second year to 0·5 lb. P_2O_5 in the seventh and subsequent years, accompanied by nitrogen and potash in the ratio $N : P_2O_5 : K_2O = 4 : 6 : 5$.