FERTILIZER EVALUATION

Quantitative Evaluation of Processed And Natural Phosphates

MAURICE FRIED

Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, Beltsville, Md.

A method is proposed for the quantitative evaluation of fertilizers by means of radioactive tracers. Two classes of fertilizers are examined: processed and natural products. Processed materials can be evaluated directly by determining the *A* value of each. In one experiment superphosphate and hydroxylapatite are compared, and in another experiment monocalcium phosphate, resin phosphate, and fused iron phosphate are compared. Natural products can be evaluated by an *A* value difference method involving the relative uptake of a standard material in the presence and absence of the natural product. Examples are presented comparing monocalcium phosphate with rock phosphate, and with fused rock phosphate. The method is suggested as a means of quantitatively evaluating the effects of such factors as differences in soil and plant species on the availability of plant nutrients from fertilizers.

THE ABILITY OF A PARTICULAR MATERIAL TO SUPPLY NUTRIENT to a plant depends not only on the chemical characteristics of the material itself but also on the species grown and the conditions of plant growth. Only growing plants can determine directly the relative ability of fertilizer to supply nutrient.

Until recently the evaluation of fertilizers was based only on yield response or on increased uptake of a particular nutrient by the plant. Unfortunately, yield response and nutrient uptake often interact with both the level of other nutrients and other environmental factors that affect plant growth.

In recent years many fertilizers have been labeled with radioisotopes (*6*) for use in field and greenhouse experiments to determine uptake by the plant from the fertilizer. For fertilizer evaluation, this technique has certain advantages over yield response and total nutrient uptake. First, the ability of a particular material to supply nutrient to the plant is determined directly. Secondly, since a high level of yield response need not be obtained, normal, healthy plants can be grown. Finally, other factors that affect plant growth do not interact with the radioactive data unless they actually interact with the source of nutrient.

A method has been developed involving the use of radioisotopes that not only will compare sources of nutrients but also will evaluate quantitatively both processed and natural products.

Evaluation of Fertilizers

General Considerations

From an agronomic standpoint, the evaluation of a fertilizer requires knowledge of the ratio of the amounts of each fertilizer that will supply the same amount of plant available nutrient. When a fertilizer such as superphosphate is added to the soil, two sources of phosphorus are present in the growth medium—soil phosphorus and fertilizer phosphorus. The percentage of the total phosphorus derived from the fertilizer will depend on the plant-available amounts of both soil phosphorus and fertilizer phosphorus (*2*, *12*). If the amount of fertilizer phosphorus added is increased, the percentage of phosphorus in the plant derived from the fertilizer will increase and that from the soil will decrease.

The relationship between the amount of fertilizer added and the percentage of phosphorus derived from the fertilizer can be established empirically. For example, in a greenhouse experiment fertilizer, at each of four rates of application (10, 50, 100, and 150 pounds of phosphorus pentoxide per acre), was intimately mixed throughout a Davidson soil and millet was grown as the test crop. The results (Figure 1) indicate that the percentage of phosphorus derived from the fertilizer is not directly proportional to the amount of fertilizer added. When the rate of fertilization was increased fifteenfold from 10 pounds per acre to 150 pounds per acre, the percentage of phosphorus derived from the fertilizer increased only sixfold.

An extrapolation to a rate of application of 300 pounds per acre indicates that the percentage of phosphorus from the fertilizer was increased by a factor of 1.3 from the 150-pound rate. Thus, in comparing fertilizers labeled with the radioisotope, a knowledge of the percentage of phosphorus derived from the fertilizer from each material does not in itself give a quantitative estimate of the relative efficiency of the two materials.

A quantitative estimate of the relative efficiency of fertilizer materials can be made by an extension of the technique involving radioactive labeled fertilizers. For the purpose of describing the proposed method, fertilizers are divided into two groups: processed fertilizers—e.g., superphosphates and nitrophosphates—and natural products—e.g., rock phosphates and bone meals. As the half life of an isotope places a practical limit on the direct determination of uptake from the fertilizer, the residual value of applied phosphates is included with the natural products.

The proposed method is an extension of an earlier approach suggested by Fried and Dean (*4*) based on the thesis that when two sources of a given nutrient are present in the soil, the plant will absorb from each of these sources in proportion to the respective quantities available. By developing this concept, they arrived at the conclusion that the following relationship should exist between source of nutrient and uptake by the plant (providing both sources of nutrient are equally accessible to the plant).

$$A = \frac{B(1 - y)}{y} \qquad (1)$$

where

A = amount of nutrient available in the soil
B = amount of nutrient in the fertilizer
y = proportion of the nutrient in the plant derived from the fertilizer

Soil scientists have used this approach, referred to as the A value concept, to evaluate soils quantitatively in terms of a fertilizer standard (*4*, *8–10*). This same quantitative relationship may be expanded to evaluate different fertilizers in the same soil. Both processed and natural products may be evaluated.

Processed Phosphates

The processed materials can be labeled with a radioisotope during the manufacturing process, and the percentage of the nutrient derived from the fertilizer can be determined directly for each material. If two materials are compared on the same soil, the following equation may be written for each material.

$$A_1 = \frac{B_1(1 - y_1)}{y_1} \qquad (2)$$

$$A_2 = \frac{B_2(1 - y_2)}{y_2} \qquad (3)$$

where

A_1 = amount of nutrient available in the soil measured in terms of B_1
A_2 = amount of nutrient available in the soil measured in terms of B_2
B_1 = amount of fertilizer 1 added
B_2 = amount of fertilizer 2 added
y_1 = proportion of nutrient in the plant derived from source B_1
y_2 = proportion of nutrient in the plant derived from source B_2

Although A_1 and A_2 are not measured in the same units, they are both measures of the same constant—namely, the amount of plant-available nutrient in the soil. There exists some value of B_1 and B_2 where plants would derive the same proportion of the nutrient from either of the fertilizers—i.e., $y_1 = y_2$. Stated in another manner, at these rates of B_1 and B_2 the applied fertilizers are supplying the same amounts of plant available nutrient. Dividing Equations 2 and 3, where $y_1 = y_2$ results in the following relationship.

$$\frac{A_1}{A_2} = \frac{B_1}{B_2} \qquad (4)$$

Since the A values are not affected appreciably by rate of application, the ratio of the A values is a direct measure of the relative amounts of each material needed to supply the same amount of plant available nutrient. The relative efficiency of the two materials is the inverse of this ratio.

Many comparisons of materials have been made using radioactive labeled nutrients. They can all be recalculated in this manner, providing the requirement of equal accessibility of the soil and fertilizer nutrient were met. Equal accessibility occurs when the fertilizer is mixed throughout the greenhouse pot. When fertilizer banding takes place, the same quantitative relationships do not hold necessarily. The method is illustrated by two experiments.

Experiment I. Dean *et al.* (*7*) reported an experiment comparing superphosphate and hydroxylapatite as sources of phosphorus for four cuttings of perennial rye grass. Equations 2, 3, and 4 were applied to all cuttings. As the results were similar at each cutting, only the results of the fourth cutting (taken at 16 weeks) are presented in Table I.

The data show that for a 16-week growth of rye grass on the Evesboro soil, five times as much hydroxylapatite is needed to supply the same amount of plant-available phosphorus as superphosphate. For the Davidson soil, this ratio was 4 to 1. On the Caribou soil, already high in phosphorus, the ratio was much higher.

Table I. Super-phosphate and Hydroxylapatite as Sources of Phosphorus for Rye Grass Grown on Three Soils

	A Value, Lb. P_2O_5 per Acre		Relative Efficiency of Superphosphate-Hydroxylapatite
Soil	*Super-phosphate*	*Hydroxyl-apatite*	
Evesboro	32	166	5:1
Davidson	77	274	4:1
Caribou	922	9330	10:1

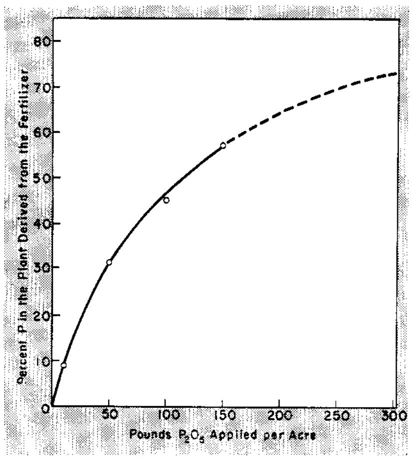

Figure 1. Evaluation of phosphate fertilizer

Experiment II. Monocalcium phosphate was compared with both fused iron phosphate and saturated phosphate resin (IRA 400) as a source of phosphorus for perennial rye grass. Four different soils were used and five cuttings of rye grass taken. The four soils were Davidson, Norfolk, Brookston, and Hagerstown. The percentage of phosphorus derived from the fertilizer was determined for the fifth cutting and the A values were calculated. The results are presented in Table II.

The results indicate that the monocalcium phosphate and resin phosphate represent approximately equivalent sources of phosphorus to perennial rye grass. Iron phosphate was not only less available to the plant, but the availability was affected to a greater degree by the soil type as compared to the other two sources. Relative to monocalcium phosphate, the phosphorus in iron phosphate was more than three times as available to the plant when applied to the Davidson soil than to the Hagerstown. Evaluation of the fertilizers on the same soil—e.g., a comparison of monocalcium phosphate and iron phosphate on the Brookston soil—indicates that six times as much phosphorus as fused iron phosphate would have to be applied to supply the same amount of plant available nutrient as that supplied by the phosphorus in monocalcium phosphate.

Table II. Relative Efficiency of Monocalcium Phosphate, Fused Iron Phosphate, and Saturated Phosphate Resin as Sources of Phosphorus to Rye Grass

	A Value, Lb. P_2O_5 per Acre			Relative Efficiency	
Soil	*Monocalcium phosphate*	*Resin phosphate*	*Iron phosphate*	*Monocalcium phosphate-resin*	*Monocalcium phosphate-$FePO_4$*
Davidson	123	102	248	0.8:1	2.4:1
Norfolk	135	139	604	1.0:1	4.5:1
Brookston	327	331	2147	1.0:1	6.6:1
Hagerstown	270	240	2333	0.9:1	8.6:1

Natural Phosphates and Residual Effects

Labeling a natural fertilizer material with the radioelement may be difficult or impossible (*5*, *7*). Nevertheless, a quantitative evaluation of both natural fertilizer materials and residual effects is feasible, using an extension of the A value concept. The evaluation is based on the thesis that A values are quantitative measures that can be added or subtracted.

The technique involves determining the A value of the soil alone, while at the same time determining the A value of the soil plus the residual material or plus the natural fertilizer. As long as the same standard is used, the two A values may be subtracted from each other. The calculations are shown below.

$$A_1 = \frac{B_1(1 - y_1)}{y_1} \qquad (5)$$

$$A_1 + A_2 = \frac{B_1(1 - y_2)}{y_2} \qquad (6)$$

where

A_1 = amount of available nutrient in the soil
A_2 = amount of available nutrient in the natural fertilizer material (or residual material)
B_1 = amount of nutrient applied as standard
y_1 and y_2 = proportion of the nutrient in the plant derived from the standard

Subtracting Equation 5 from Equation 6

$$(A_1 + A_2) - A_1 = A_2 = \frac{B_1}{y_2} - \frac{B_1}{y_1} \qquad (7)$$

gives the amount of available nutrient in the applied natural fertilizer (or residual material) in terms of the standard.

If B_2 is the total amount of nutrient in the applied natural fertilizer, then A_2/B_2 is the relative amount of each material (standard and natural product) needed to supply the same amount of plant available nutrient. The relative efficiency of the two materials is the inverse of this ratio. Thus any number of materials may be compared or residual values of applied materials determined. To illustrate this technique, two experiments are cited.

Experiment I. Rock phosphate was compared to monocalcium phosphate as a source of phosphorus for rye grass grown on three soils: Brookston, Davidson, and Evesboro. Because of its extremely low pH (4.8) and low magnesium content, the Evesboro soil received 800 pounds of dolomite per acre. The two treatments on each soil consisted of labeled monocalcium phosphate alone (standard), and labeled monocalcium phosphate plus 4 tons of rock phosphate (33% phosphorus pentoxide). The perennial rye grass was harvested after one month, the percentage of phosphorus derived from the monocalcium phosphate was determined, and the A values were calculated. The results are presented in Table III.

The results indicate that 4 tons of rock phosphate supplied as much phosphorus to rye grass over a 1-month period as monocalcium phosphate equivalent to 67 pounds of phosphorus pentoxide in the Evesboro, 76 in the Davidson, and 167 in the Brookston.

Table III. Relative Availability of Rock Phosphate and Monocalcium Phosphate as Sources of Phosphorus to Rye Grass for First Month of Growth

	A Value, Lb. P_2O_5 per Acre Equivalent to Monocalcium Phosphate		
Soil	Soil (A_1)	Soil plus 4 tons rock phosphate ($A_1 + A_2$)[a]	4 tons of rock phosphate, by difference (A_2)[a]
Evesboro	58	125	67
Davidson	119	195	76
Brookston	91	258	167

[a] 33% phosphorus pentoxide.

Table IV. Relative Availability of Fused Rock Phosphate (30% P_2O_5) and Monocalcium Phosphate as Sources of Phosphorus for Oats on Three Soils

	A Value, Lb. P_2O_5 per Acre Equivalent to Monocalcium Phosphate		
Soil	Soil (A_1)	Soil + 330 lb. fused rock phosphate ($A_1 + A_2$)	333 lb. fused rock phosphate, by difference (A_2)
Low Davidson	72	167	95
Med. Davidson	209	325	116
Norfolk	84	180	96

The greater relative efficiency of rock phosphate in the Brookston soil was probably related to both the lower pH and higher organic matter content of the soil. The relatively low availability of the rock phosphate in all soils is due at least partially to the short time involved and to the nature of the test crop. Plant species differ in their ability to utilize rock phosphate and rye grass is considered a poor feeder (*3, 11*).

Experiment II. Fused rock phosphate was compared to monocalcium phosphate as a source of phosphorus for oats grown on three acid soils: low Davidson (pH 5.3), medium Davidson (pH 5.8), and Norfolk (pH 5.6). The two treatments on each soil consisted of labeled monocalcium phosphate alone at the rate of 50 pounds of phosphorus pentoxide per acre and labeled monocalcium phosphate at the same rate plus 333 pounds of fused rock phosphate (100 pounds of phosphorus pentoxide). The oats were harvested after six weeks, the percentage of phosphorus was derived from the fertilizer determined, and the A values were calculated. The results are presented in Table IV.

The results indicate that on these acid soils 100 pounds of phosphorus pentoxide as fused rock phosphate mixed throughout the pot supplies approximately the same amount of phosphorus to oats as 100 pounds of phosphorus pentoxide as monocalcium phosphate when mixed throughout the pot.

Discussion

Although the techniques described will evaluate fertilizer materials quantitatively, interpretation of the results of necessity depends upon experimental conditions. Certain precautions should be observed, and certain limitations should be realized.

The first precaution is the requirement of equal accessibility to the plant of all sources of the nutrient as discussed in the text. The second precaution is that in so far as it is possible, a rate of fertilizer addition of each material should be chosen such that similar amounts of plant available phosphorus are supplied. There are several reasons for this requirement.

1. The soil phosphate level may influence the effectiveness of fertilization—e.g., rock phosphate may be available to a greater degree at low levels of soil phosphate than at high levels. The effect of soil phosphate level is under investigation at the present time. It can be minimized by choosing rates of application of each material that will supply similar amounts of available nutrient.
2. Although the A value is assumed constant at different rates of application, actual determinations by current techniques suggest a slight increase in A value with increasing rate of application of the fertilizer (on certain soils and under certain conditions). Although this is a minor effect, amounting to perhaps 10% when the rate of application is doubled, it can be minimized by choosing rates of materials that supply similar amounts of available nutrient.
3. The evaluation of natural products or residual values involves a difference between A values. The precision with which this difference can be determined depends not only upon the precision of determination of an individual A value but also on the magnitude of the difference between A values. A small difference between large values is difficult to determine precisely. However, if the difference between A values is the same magnitude as the smallest of the two values, the precision for determining the difference is not altered radically. Reasonable precision can be maintained by choosing those rates of application of the different materials that will supply similar amounts of available nutrient.

Conclusions

The quantitative evaluation of fertilizer materials by the method presented shows the effect of other factors known to affect the availability of fertilizers. One effect, that of soil, is indicated by the data presented in Tables I, II, and III. Although the results in Table IV do not show a soil effect, in a duplicate of the same experiment with two high pH soils, 100 pounds of phosphorus pentoxide as monocalcium phosphate supplied 17 times as much available phosphorus as an equivalent amount of fused rock phosphate. This is in contrast to the 1 to 1 ratio shown in Table IV.

Plant species may also affect the availability of the fertilizer. In a study of the feeding power of plants for rock phosphate, Fried (*3*) showed that the percentage of phosphorus derived from the fertilizer is a function of plant species when one of the sources of phosphorus is rock phosphate. The quantitative evaluation of factors affecting fertilizer evaluation such as soil, plant species, and others is a further extension of the proposed technique.

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TRACE ELEMENTS

Progress Report on Research with Particular Reference to New Jersey Soils

FIRMAN E. BEAR
New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, N. J.

For the past 14 years the New Jersey Agricultural Experiment Station's department of soils has been studying trace-element relationships in soils and plants. These studies involved laboratory, greenhouse, cylinder, and field work with boron, molybdenum, iron, manganese, zinc, copper, cobalt, iodine, fluorine, and bromine. Soils were examined for their total and available contents of these elements. Efforts were made to determine optimum levels of these elements in crop plants and to diagnose deficiency and toxicity symptoms. Finally, some conclusions were arrived at, and suggestions made concerning use of these elements in crop production, with particular reference to New Jersey.

Boron, molybdenum, iron, manganese, zinc, and copper, belong to a group called minor or trace elements, among the 15 elements that are known to be required by plants. Soil supplies of nitrogen and of the major and secondary mineral nutrients, including phosphorus, potassium, calcium, magnesium, and sulfur, are regularly renewed by use of fertilizers and liming materials. But the soil itself is usually depended on to supply the necessary amounts of trace elements. Applications of manure and compost aid in maintaining adequate quantities of these elements in usable form. Deep-rooted plants, such as sweet clover, alfalfa, and ragweed, absorb trace elements from lower soil horizons and elevate them to the surface. Additional supplies are made available by growing green manures and plowing them under (*1*).

The standard fertilizer and liming materials contribute small quantities as impurities. But there are many conditions under which it becomes necessary to supply additional amounts of one or another or of several of these elements for plant use. As crop yields are stepped up to ever higher levels, likelihood of trace-element deficiency is increased.

Trace-element requirements of animals are somewhat similar to those of plants, but there are important differences. Animals require iron, manganese, copper, and zinc but, so far as is known, they have little if any direct need for boron or molybdenum. Deficiencies of these elements in soils, however, may result in the production of low-quality crops, thus indirectly affecting the animals that consume them. Animals also require cobalt, fluorine, and iodine, trace elements that are normally contained in but have no known value to crop plants. Because most crop plants are grown primarily for food or feed, it is important to consider trace elements in soils in relation to the needs of both plants and animals.

Experimental Program

The soils department of the New Jersey Agricultural Experiment Station has studied soil-plant relationships of every one of these trace elements, and some additional ones, in considerable detail during the past 14 years. A large amount of analytical work, involving spectrographic as well as chemical procedures, has been and is being done on soils and plants. Tests of trace-element salts on plants have been carried out in the greenhouse with solution cultures and soil, in outdoor cylinders of soil, and in fields on the Station Farm and at widely separated locations about the state.

Early in these studies 20 of the most important agricultural soils of New Jersey were selected for special examination. Representative virgin areas of these soils were located, from which supplies could be obtained as required. The names of these soils and their content of nine trace elements are given in Table I.