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A METHOD FOR DETERMINING THE NUTRIENT NEEDS OF SHADE TREES WITH SPECIAL REFERENCE TO PHOSPHORUS

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A METHOD FOR DETERMINING THE NUTRIENT NEEDS OF SHADE TREES WITH SPECIAL REFERENCE TO PHOSPHORUS

A BIOLOGICAL method for estimating the amount of available phosphorus supplied to shade trees by various soils is presented. The procedure is based upon the principle of proportional nutrient absorption whereby leaf analyses, interpreted on the basis of an established reference scale, indicate soil phosphorus supply in terms of rock phosphate fertilizer.

Shade tree feeding has recently become an extensive business. Although some professional foresters and forest schools are still inclined to view tree fertilization as nonsense, if not quackery, it is apparent that many tree owners believe that results justify the expenditure. Experiments have shown that well fed trees are not only of greater æsthetic value to their owners (luxuriant foliage of good color) but are better able to withstand insect and fungus attack or adverse weather conditions than are undernourished, and consequently less vigorous specimens. The need for supplementary feeding is considerable since many shade trees are forced to grow in the limited volume of soil between city streets and sidewalks, or on crowded suburban lawns where they must compete with thick turf. Soils of such locations are often low grade fill not particularly rich in mineral nutrients.

TREE FEEDING METHODS

A good share of the shade tree feeding today is done with so-called balanced fertilizers, containing, in various proportions, all of the essential nutrients most likely to be deficient in soils. Each concern engaged in tree feeding or the manufacture of tree fertilizers has their own particular "blend" of tree food which is supposed to—and usually will—correct any ordinary nutrient deficiency. Obviously, since all the important food elements are supplied, this method is about fool-proof; whatever the deficiency, it is corrected. The use of balanced fertilizers has, in the majority of cases, produced satisfactory results. Of this there is ample proof. But the efficiency of the method may be questioned.

It is well known that many soils are deficient in only one or two essential nutrients. Thus a soil low in only phosphorus—a rather common condition—is, according to current practice, supplied unneeded quantities of nitrogen, potash, magnesium, etc. in order to correct a phosphorus deficiency. Certainly this procedure is wasteful. It may even be dangerous if the soil fertilized is naturally rich in the unneeded elements supplied. High nutrient concentrations are often toxic to plants and trees are no exceptions. Regarding this general tendency toward "shotgun" fertilization, the following question may be asked: assuming a knowledge of the nutrient requirements of the species to be fed, is it not equally important to know how nearly the soil in question fulfills these requirements—what nutrients are deficient, and to what degree? Apparently some kind of soil analysis is essential if tree feeding is to be placed upon an economic, as well as an effective, basis.

SOIL ANALYSIS

The ordinary methods of direct chemical analysis are not completely satisfactory because no distinction is made between available (to trees in this case) and non-available nutrients. Certain of the so-called extraction methods in which "available" nutrients are leached from soils with various solvents are preferable. But it is doubtful if any solvent duplicates exactly the nutrient extractive and absorptive powers of plants growing in a natural environment.

Probably the most reliable methods for evaluating the chemical fertility of soils depend upon the reactions of "indicator" or "test" plants—nutrient extraction by plants. Many species have been found to absorb nutrients in proportion to the available supply. Thus, if the relation is sufficiently good, a measure of the former will indicate the latter. Procedures based upon this principle of proportional absorption—biological methods—have been successfully used to determine the fertilizer requirements of various field and garden crops and of coniferous seedlings (Mitchell, 1934). This experiment was conducted to test the reliability of shade tree leaf analysis as an indicator of soil nutrient conditions.

DETAILS OF EXPERIMENT

Four quarter-acre sample plots were established in an even-aged (about 40 years) stand of mixed hardwoods composed mainly of red oak (*Quercus borealis* Michx.), chestnut oak (*Quercus montana* Willd.), and red maple (*Acer rubrum* L.). The stand had been rather heavily thinned; all trees were in the dominant or co-dominant classes and spacing was relatively wide and regular. The control plot was left untreated and the others were supplied varying amounts of finely ground rock phosphate. An even distribution of the fertilizer was obtained by gridironing the plots with chalk line. Plots were fertilized May 23, 1934, all trees were numbered, and diameter measurements taken. On October 1 of the same year leaves of the various species were gathered, dried and stored in labeled envelopes for chemical analysis.[1] Leaves were taken from approximately the same location on each tree, *i.e.*, from the end of the branches near the top of the crown on the south side. Standardization of leaf sampling is important because it has been found (Mitchell, unpublished; Gast, personal communication) that the chemical composition of leaves varies with the location on the tree. Also, since most shade trees are open-grown, it is best to sample only leaves exposed to full sun light.

DISCUSSION OF RESULTS

CORRELATION BETWEEN LEAF ANALYSIS AND PHOSPHORUS SUPPLY

Chemical analyses indicate that there is a distinct relation between phosphorus supply and the phosphorus content of red oak leaves. In Fig. 1, A the phosphorous content values (expressed as a percent of the dry weight of leaves, $P_{\%}$) are shown plotted against units of rock phosphate supply (P). Points in the figure represent the arithmetic means of all $P_{\%}$ observations corresponding to any particular value of P. The line of average relation (regression line) was calculated according to the method of least mean squares using individual observations (42) rather than the means. Two statistical measures of accomplishment were calculated: the correlation

[1] Five or six leaves from each tree were dried, the petioles removed, and the leaf material finely ground. Phosphorus determinations in duplicate were made of each sample, using a modification of the Fiske and Subbarow (1925) method.

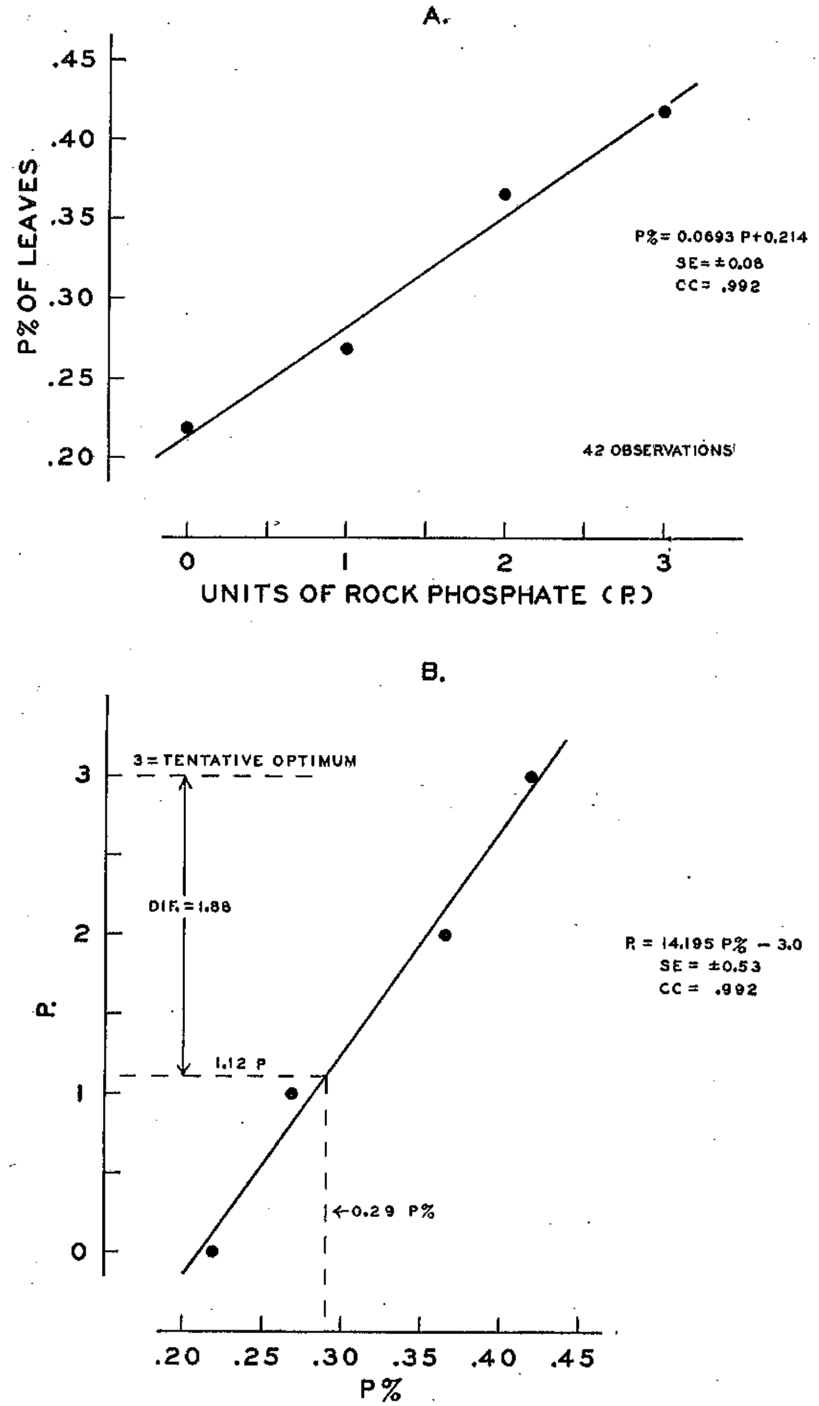

FIG. 1.—The relation between the quantity of rock phosphate fertilizer supplied to red oak trees (units of P.), and the percent phosphorus content of the leaves (P%). Both regression lines are shown: A, with P as independent variable, and B with P% as independent variable.

coefficient (CC) and the standard error (SE). These are shown in Fig. 1, A. Both are highly favorable. Apparently, if the phosphorus supply (in terms of units of rock phosphate) is known, the phosphorus content of the leaves can be predicted with the aid of the regression equation,

$$P_{\%} = 0.0693\ P + 0.214,$$

with a high degree of accuracy, *i.e.*, $\pm$ 0.08 $P_{\%}$.[2]

But it is with the prediction of P supply that this investigation is primarily concerned. Therefore it is necessary to determine and test the reliability of the average relation between the two variables using $P_{\%}$ rather than P as the independent variable.

The regression line, regression equation and statistical indexes with $P_{\%}$ as the independent, and P as the dependent variable are shown in Fig. 1, B. The correlation coefficient, since it is a two-way average measuring the degree of association between two variables, is the same with either variable independent. The regression equation and standard errors are, however, quite different. But the data indicate that phosphorus supply (in terms of units of rock phosphate) can be determined with the aid of the equation,

$$P = 14.195\ P_{\%} - 3.0,$$

with a fair degree of accuracy, *i.e.*, $\pm$ 0.53 units of P.

Optimum Supply

Although it is evident from the data presented that the phosphorus content of red oak leaves is proportional to the available supply, measures other than chemical analysis are necessary to determine the optimum supply of this food element. Theoretically, this supply should produce the most satisfactory combination of height, diameter, twig and branch growth. Hardiness, luxuriance and color of foliage are other important factors that must be considered. Deuber (1930), who investigated the nutrient requirements of sugar maple seedlings, reports the following: "Twig growth of the phosphorus-starved trees was very limited, the leaves were few in number, small and of a dark reddish-green cast.[3] The margins of a number of leaves curled downward, dried and later dropped off." Taking all of these factors into consideration the optimum supply of P, for red oak on the soil used in this experiment, has been tentatively located at three units. This is, of course, subject to change on the basis of future observations.

Measuring the Phosphorus Availability of Soils

The information gained from this experiment forms the basis of a method for evaluating the available phosphorus supply of soils of unknown fertility. Assume, for example, that a red oak shade tree on an estate lawn shows signs of undernourishment. An expert is called in to remedy the condition. To do an efficient job it is not only necessary to determine what nutrient or nutrients are deficient, but to what degree. As regards phosphorus—other nutrients are discussed later—the following procedure is possible.

[2] Given an approximately normal distribution, the majority of all predictions will fall within the limits of the standard error of estimate.

[3] The reddish-green cast noted by Deuber may be a color reaction similar to that reported by Mitchell (1934); phosphorus-starved white pine seedlings developed lower needles of a "purplish tinge," believed due to the production of anthrocyanins.

A chemical analysis will show the phosphorus content of the leaves. Assume this value to be 0.29%. Interpolation, using Fig. 1, B—although solving the regression equation for P is more precise—shows that, according to the average relation between the two variables, the P value corresponding to 0.29% is 1.12 (See Fig. 1). On the basis of this relation it is evident that the soil under examination supplies—to the red oak tree in question—a quantity of *available* phosphorus equivalent, *in effect*, to 1.12 units of rock phosphate, plus the unknown amount of P supplied by the soil used in determining the reference scale. The tentative optimum supply is 3 units, of which the unknown soil is capable of supplying the equivalent of 1.12. The difference (1.88 units) should, if applied, correct the phosphorus deficiency within an error of $\pm$ 0.53 units. Thus a leaf analysis not only reveals a P deficiency, but can be accurately used to measure its magnitude.

DISCUSSION OF METHOD

According to the proposed method soil phosphorus supply is evaluated in terms of units of rock phosphate. This measure may be called the *phosphorus availability equivalent* (as read from the vertical scale of Fig. 1, B). The difference between the availability equivalent and the optimum is the amount of P (as units of rock phosphate) that any given soil will need. The zero of the reference scale may prove confusing. It is not an absolute zero since the soil used in the experiment undoubtedly supplied some phosphorus. This fact, however, does not influence the accuracy of the procedure; the same type of soil formed the basis for each of the fertilization plots, and may therefor be regarded as a constant.

In order to establish a reference scale approaching as nearly as possible the minimum, the plots were laid out on a soil known to be very deficient in phosphorus (Mitchell, 1934). The scale can, however, be used to evaluate lower supplies if encountered. Thus, if $P_{\%}$ is found to be 0.20, the corresponding value of P is a negative value (—0.16). The difference between —0.16 and 3.00 is 3.16, the amount of rock phosphate to be supplied. But it is not desirable to carry calculations much beyond the basic data.

Similar standards could, of course, be determined on the basis of other phosphorus fertilizers (superphosphates, bone meal, etc.). Rock phosphate was chosen because it is cheap, easily obtained and is less subject to leaching than the more soluble phosphates. Furthermore recent unpublished experiments have shown that it is an excellent source of phosphorus for coniferous species. Judging from the speedy response noted in this experiment where the fertilizer was applied only four months before leaf samples were taken, rock phosphate is a good source for hardwoods as well.

There is some evidence to show that the mineral nutrient concentration of tree leaves varies with the season (time). McHargue and Roy (1932) found that the percentage content[4] of phosphorus, potassium and nitrogen in leaves of 23 species of deciduous trees tended to be higher at the beginning of the growing season than at the end. The opposite was true of silica, ash and calcium. Copper, manganese and zinc remained constant. From this it would seem that the reference scale established is applicable only in the fall of the year. But, even though the nutrient concentration does vary with time, it is possible to work out a three variable alignment chart (time, P, and $P_{\%}$) so that the reference scale may be applied at any time during the growing season.

[4] Since the mineral nutrients were expressed only on a percentage (of dry wt.) basis, variations in these values do not necessarily indicate either translocation or even changes in the total quantities present because leaf weight can not be considered a constant. (See discussion, Mitchell, 1934, p. 75).

Other Nutrients and Species

Analyses have shown that the phosphorus contents of red maple and chestnut oak leaves are, as with red oak, proportional to the phosphorus supply. But, in the case of maple, although the line of average relation is of approximately the same slope, the $P_{\%}$ values are nearly twice as large for identical treatments. This is in agreement with the findings of McHargue and Roy (*loc. cit.*, Table 1, p. 384).

Preliminary analyses indicate that there is a correlation between the phosphorus, nitrogen and potassium content of the leaves of various deciduous trees, and the quantities of these nutrients supplied by soils. The reliability of these relations is being tested.

SUMMARY AND CONCLUSIONS

Experimental results indicate a close association between soil phosphorus supply and the quantity of this element in red oak leaves. Statistical analysis of the data shows that either variable may be predicted with a relatively high degree of accuracy.

It is therefore possible to determine from leaf analyses, using the calculated average relation between the two variables as a reference scale—"standard of comparison"—, the phosphorus supply of soils in terms of units of rock phosphate fertilizer. Some data have been obtained to show that the availability of other mineral nutrients may be similarly evaluated.

Leaf tests in connection with the feeding of a relatively large number of trees growing on essentially the same soil type—a condition encountered on many estates —are believed to be entirely practical. Since many soils are deficient in but one or two of the essential nutrients, the savings in unnecessary fertilizer ingredients, if this waste could be prevented, would more than offset the cost of leaf analysis.

Tree fertilization based upon definite knowledge of both the nutrient requirements of the species and the chemical fertility of the soil is certainly more precise and efficient than the blanket application, without such information, of the best balanced fertilizer ever mixed. It is not possible to prepare a single fertilizer, regardless of the empirical formula upon which it is based, that will be specifically applicable to any and all soil conditions.

REFERENCES

Deuber, C. G., 1930. Fertilization of Hardwoods. National Shade Tree Conference Proceedings.

Fiske, C. H., and Subbarow, Y., 1925. The Colorimeteric Determination of Phosphorus. Jour. Biol. Chem. 66: 375-400.

McHargue, J. S., and Roy, W. R., 1932. Mineral and Nitrogen Content of the Leaves of Some Forest Trees at Different Times in the Growing Season. Botanical Gazette 94: 381-393.

Mitchell, Harold L., 1934. Pot culture Tests of Forest Soil Fertility. The Black Rock Forest Bulletin 5. Cornwall-on-the-Hudson, New York.