Nutrient Balance and Fertilizer Practice

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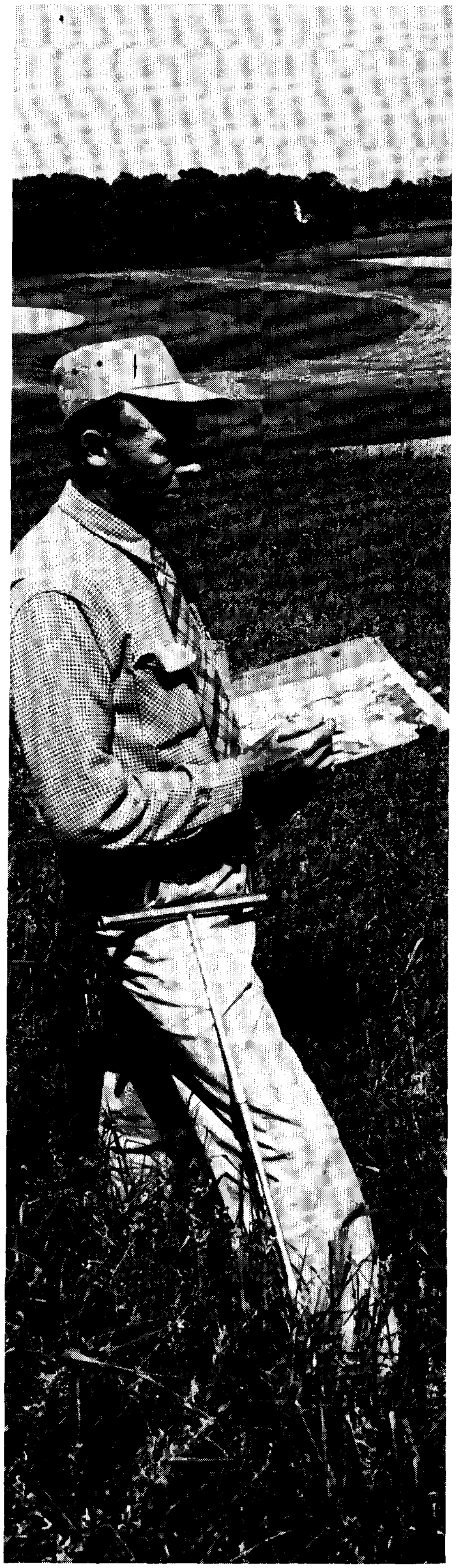
An adequate, balanced nutrient supply resulting from the soil, the fertilizer, and reactions between them is a reasonable and practical goal



◀ Modern soil survey is one of the first steps necessary to achieving adequate and balanced nutrient supplies

PERHAPS no term associated with plant nutrition and fertilizer practice has been used in more different ways than the expression "balanced fertilizer." To some this term means "non-acid forming," denoting a fertilizer that will not increase the acidity, or lime requirement, of the soil on which it is used. To others, a balanced fertilizer is one that supplies the various nutrients, and especially nitrogen, phosphorus, and potash (N, P, and K), in supposedly ideal proportions for one or more crops. Because of this confusion it is worthwhile to examine the problem of supplying crop plants with the right amounts and proportions of nutrients, looking especially at those aspects of nutrient balance that may be useful in guiding the manufacture and use of fertilizers.

One can readily find numerous examples in which proper adjustment of the ratios of nutrient elements is of practical importance in efficient fertilizer use. Dumenil and Nelson (*2*) reported that in 164 factorial experiments with N, P, and K on corn, oats, and legume hays in Iowa, there were 62 instances of significant "interactions" between nutrients. The term "interaction" is used in fertilizer experiments to denote cases in which two nutrients applied together exert an effect different from the sum of the effects of the two nutrients when used alone. Most of these interactions in the Iowa experiments were positive; i.e., yield response from the use of two nutrients used together exceeded the sum of responses obtained by using each of the nutrients alone. There were, however, occasional negative interactions, with one element tending to inhibit response to another.

Most of the interactions shown by the experiments in Iowa were between two elements, such as N-P or N-K interactions. There were, however, some instances of interactions involving all three of the added nutrients. Furthermore, in factorial experiments in which the different elements were used at different rates, interactions between elements were sometimes shown at one rate of application but not at others. Thus, in these experiments, while a proper balancing of the nutrients was an important feature of effective fertilizer use, the ratio of nutrients necessary to provide this balance differed from field to field, even with the same crop.

Obviously then, the problem of nutrient balance in fertilizer use is both important and complex. The basis for understanding the problem must be sought in plant nutrition processes.

Basic Features of Plant Nutrition

First of all, plants require many different nutrients. In order for a plant to complete its life cycle it must be furnished with each one of these nutrients, some in large amounts and some in very small or trace amounts. Within relatively broad limits there are some fairly general relationships between the amounts of the different nutrients in vigorous plants. For example, as the potassium content of a plant increases, its content of magnesium and calcium decreases. But equally healthy and productive plants of the same species may show variation in their total contents and ratios of many of the essential nutrients.

Second, the absorption of nutrients by plants is a selective process. The ratios of the nutrient elements found in the plant are not necessarily the same as the ratios of these elements in the culture medium, even though the culture medium may be a true solution of the nutrient elements.

Third, plants do not grow on fertilizers; they grow on fertilized soils. Different soils present the plant with widely different ratios and amounts of the nutrient elements in soluble form, even when heavily fertilized with the same fertilizer. Within the same soil type, the supply of available nutrients may be markedly affected by moisture content or past management history.

On the basis of these three features of plant nutrition, inter-relationships and balances among nutrients may be grouped into three broad categories:

- Processes taking place within the plant whereby the functioning of one nutrient is affected by the level of another nutrient within the plant. An example of this type of process is found in the relationship between molybdenum and nitrogen. In plants deficient in molybdenum, nitrogen accumulates in the form of nitrates but these nitrates are not reduced to amino nitrogen and utilized for building protein. In this case, it has been found that molybdenum is required for the enzyme nitrate reductase.
- Effects of one nutrient upon the uptake of another nutrient when both nutrients are present in a soluble form in the soil. A frequently cited example is the reciprocal relationship between potassium and calcium, sometimes called potassium-calcium antagonism. As the level of either of these nutrients in the culture medium is increased, the concentration of the other in the plant tends to be decreased.
- Effects of one nutrient on the solubility of other nutrients in the soil. Calcium and phosphorus are frequently involved in this type of reaction. When large amounts of calcium carbonate are added to acid soils, the availability to plants of several of the trace elements is reduced. Heavy applications of phosphates may similarly reduce the availability of metallic nutrients such as copper, zinc, and iron.

In some instances interactions between two elements may operate in the same direction in more than one of these categories. For example, a high level of soluble phosphorus in the soil may depress the solubility of iron, and thus decrease iron uptake by plants, while at the same time a high level of phosphorus in the plant may deter the translocation or functioning of iron within the plants.

Nutrient Interrelationships in Plants

Critical ratios of nutrient concentrations within plants generally have not been well established. Attempts to establish these ratios must usually consider several elements simultaneously, along with the general environment within which the plant grows. For example, Leach and Taper (*4*) of McGill University have shown that the optimum ratio of iron to manganese in the leaves of dwarf kidney beans may have a relatively wide range of values when the beans are grown in solution containing 42 p.p.m. of calcium. When the calcium concentration of the nutrient solution was increased to 143 p.p.m. in their experiment, healthy plants resulted only within a narrow range of iron:manganese ratios in the leaf.

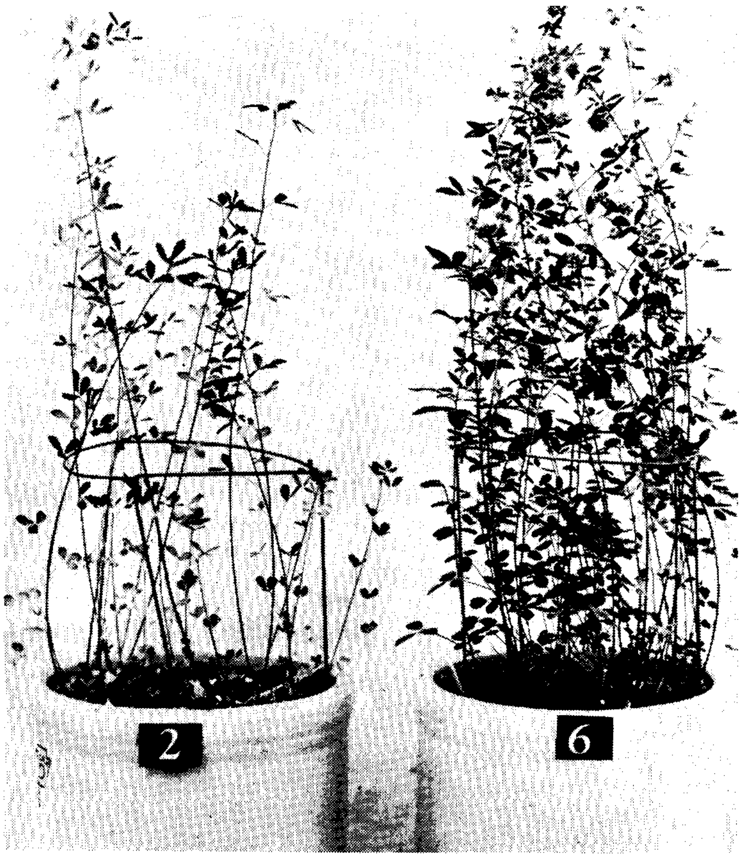
Research on interactions among nutrients within plants is currently active in many laboratories. Better understanding of these relationships will permit better interpretation of plant analyses in terms of plant nutrient requirements. This information will help in diagnosis of nutrient balance problems. Solution of these problems, however, in terms of the kind and amount of fertilizer to be used, will require some additional information.

Much of the research with culture solutions has dealt with some aspect of how one nutrient affects the rate of uptake of others. This work generally establishes that plants' accumulation of required nutrients from culture solutions is not simply a process of sweeping the nutrients in through the transpiration stream.

One of the important lines of research with culture solutions has featured experiments of very short duration using whole plants or excised plant roots, and designed to provide a better understanding of the mechanism of the initial steps of nutrient uptake by roots. In this type of research, radioactive isotopes of the nutrient elements have proved very useful, in that they permit accurate measurement of very small transfers of nutrients from solution to root. Experiments have shown that the uptake of nutrients is a vital process, in which energy derived from the respiratory oxidation of organic compounds in the root cells supplies the driving force. Thus nutrient uptake is controlled by the metabolic processes of the plant, and any disturbance of these metabolic processes will be reflected in a changed rate of nutrient uptake. It is therefore to be expected that a deficiency of any one essential nutrient, perchance only a micronutrient, may be reflected in reduced uptake of several others.

A further important contribution of the short-term culture solution experiments has been the demonstration of the high degree of selectivity in certain steps in the uptake process. Hagen and his associates (3) at USDA in Beltsville, Md., have demonstrated that $H_2PO_4^-$ and $HPO_4^=$ ions are taken up by the root through the functioning of a specific "carrier" for each of the two ions.

In light of these findings, it should be no surprise that different plants may have markedly different nutri-



An example of inter-relationships between nutrients is that of molybdenum and nitrogen. Plant at left was grown on molybdenum-deficient soil, while plant at right had sufficient molybdenum to reduce nitrates in plant to amino nitrogen for building protein tional requirements. An outstanding example of such differences is provided from the work of Brown and Hendricks (*1*) on the copper and iron requirements of plants. Thatcher wheat, in which copper enzymes are the dominant terminal oxidase enzymes, grew well on an alkaline soil low in available iron, but grew poorly on an acid organic soil low in available copper. On the other hand, soybeans, in which an iron enzyme is the dominant terminal oxidase, grew well on the copper deficient organic soil and poorly on the iron deficient alkaline soil.

Instances in which changes in the level of one nutrient in the culture solution may hinder or accelerate the uptake of some one or more other nutrients have been frequent. Relationships between the composition of the nutrient solution and the nutrient content of the plants are complex; yet such relationships do exist. Through appropriate adjustment of the culture solution most plants can be provided with essential nutrient elements in the amounts and ratios required for optimum or near optimum growth. This leaves the strong inference that it would be possible, even if very difficult, to compound for a given plant a fertilizer which would dissolve to form in soil a nutrient environment very similar to that provided by a successful nutrient solution. This possibility has been attractive to many agricultural scientists, and yet it has not proved to be very helpful in actual fertilizer practice. The reason for the failure of this concept rests in the role of the soil itself in plant nutrition and in the reaction between soils and applied fertilizers.

Reactions between Fertilizers and Soil

Fertilizers are generally compounded from salts which dissolve in water to form ionic solutions. When a soil is wetted with an ionic solution, the concentration of the ions in the solution is changed. The amount of change is not the same for all the ions; the concentration of certain ions in the solution may be increased simultaneously with decreases in other ions. Different soils will show changes of differing magnitude and direction when wetted by the same salt solution. Study of the mechanisms of these changes constitutes the central theme of the science of soil chemistry. Because of these reactions between fertilizer components and the soil, the nutrient supply offered to the crop is controlled by both the fertilizer and the soil, each reacting with the other. When the same fertilizer is added to different soils, different nutrient supplies will be offered to the crop.

The nitrogen contained in fertilizers may be leached out of the soil by downward moving water. This leaching generally goes on faster in sandy soils than in fine textured soils. When fertilizers containing soluble phosphorus are added to soils, a part of the soluble phosphorus changes to forms that are nearly insoluble, and only slightly available to plants. The insoluble forms of phosphorus formed in acid soils are different in chemical nature and plant availability from those formed in calcareous soils. Similarly, soluble potassium added in fertilizer may in some soils be converted to forms having a rather low availability to plants.

In this discussion, the soil solution is taken to represent the nutrient environment of a plant growing on the particular soil at a given time. Over the growing season, the soil solution is renewed by solution of certain fractions of the undissolved nutrients in the soil. The rates at which the different nutrients become available to plants differ in different soils. This adds further complexity to the problem of compounding a fertilizer intended to promote a specific ratio of nutrients in different soils.

In addition to the differences in nutrient supply or composition of the soil solution that may come about through reaction of the same fertilizer with different soils, differences in available nutrients occasioned by native nutrient supplies in unfertilized soils may also upset the performance of any "balanced" fertilizer. For example, the soils of subhumid and semi-arid areas are often well supplied with available potassium. A fertilizer compounded so as to provide adequate balanced nutrition to a given plant on these soils might well contain little or no potassium, but such a fertilizer would be ineffective on many soils of the humid eastern United States.

Some soils may be well supplied with all but one of the nutrients needed by a certain crop. On these soils, a fertilizer carrying only this one nutrient is a balanced one for this crop.

Differences in soils sufficient to require distinctly different fertilizers may often occur within very short distances in the same field. Examples of these differences are very frequent in fields recently leveled for irrigation. On such fields, the original subsoil may be exposed in the places where cutting was necessary in the leveling process, and the places that were originally low may be filled with topsoil scraped off the high spots. The areas from which topsoil has been removed usually have a much lower supply of available nitrogen, phosphorus, and zinc than do the areas with added topsoil. Use of the same kind and rate of fertilizer over the entire field will result in either inefficient use of nutrients on the filled areas or nutrient deficiencies on the cut areas.

General growing conditions for the crop will also alter its nutrient requirements. Crops produced under irrigation, when water is not limiting, can efficiently use more nutrients than the same crops produced on the same soil but with limited water supply, and at times they can use somewhat different nutrient ratios. Similarly, weather differences from year to year may dictate changes in the kind and amount of fertilizers. In cold wet seasons it is usually desirable to use more nitrogen and potassium than is required in warmer, drier seasons.

Thus, the compounding of a "balanced fertilizer" for general use on all soils for a given crop even in a limited agricultural region is not likely to succeed.

Balanced Nutrient Supply

An adequate and balanced nutrient supply resulting from the soil, the fertilizer, and the reactions between them is the objective of a proper fertilizer program. This is a reasonable and practical goal. In order for it to be reached fertilizer practices need to be designed on the basis of the requirements of the crop, the characteristics of soil on which it is to be grown, including its management history, and the growing conditions and cultural practices in the area.

In any given region, the first step toward this objective is an understanding of its soils. For each major soil, the properties important in nutrient-supplying power and in reactions between the soil and added fertilizer need to be determined. Physical characteristics such as water holding capacity must be evaluated in relation to the climate of the area and the needs of the crops to be grown. The relationship of the soils of the region to those of other regions should be understood, so that research results and farmer experience gained in other areas can be readily applied. A modern soil survey of the region is a necessary part of the development of the information needed for this first step.

The second step consists of research to develop and test alternative fertilizer-use programs on specific soils and crops in the region. This phase of the work must be backstopped by basic research in soil chemistry, plant nutrition, and soil-water-plant relationships. Through an understanding of the soils as described in the first step, basic research from all over the world can be brought to bear upon the fertilizer-use problem of a given region.

Carefully controlled field experiments with fertilizers, conducted on the major soils and crops of the region, are another essential part of this second step. The objective of these field experiments is to evaluate the nutrient-supplying power of the soils in relation to the needs of the crops and the timing of these needs. This information must be obtained for the growing conditions of the area. The effects of liming, crop residue management, use of barnyard manures, and other soil management practices common to the area should be studied as they relate to the nutrient-supplying power of the soil. The results of these field experiments should be correlated with plant and soil analyses in order to develop the basis for advisory services to growers.

The amount of effort necessary for this type of research will depend on the complexity of the soil and cropping patterns in the region. This type of research is generally a continuing activity, with new problems becoming important with changes in cropping and fertilizer practices. Careful study of farmer experiences with fertilizers on the different soils and crops of the region can be useful in this stage of the program.

The third step toward achieving an adequate and balanced nutrient supply for the crops in a region is the development of educational and advisory services. The farmers and fertilizer dealers of the region need to recognize the differences and relationships among the soils of the region, and to be aware of the results of field experiments with fertilizers. Advisory services, staffed by people familiar with the soils, crops, and research results of the area, and utilizing soil and plant tissue tests where necessary, should be established.

A final necessary step is for the fertilizer industry to make available to farmers the materials and mixtures suggested by the research and advisory programs.

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PLANT NUTRIENTS AND REGULATORS

PESTICIDES

PESTICIDES/FOOD PROCESSING

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