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The Massachusetts Turf and Lawn Grass Council Incorporated is chartered under the laws of the Commonwealth of Massachusetts as a non-profit corporation. The turf council seeks to foster "Better turf through research and education".

More detailed information on the subjects discussed here can be found in bulletins and circulars or may be had through correspondence with the editor.

The Effects Of Soil Oxygen Concentrations On Root Growth

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"The importance of soil aeration to plant development has been recognized since the beginnings of agriculture" (5), and "the possibility that oxygen may become so low in soil or other media as to limit plant growth has long been a matter of concern" (9). It is well known today that ". . . the proper supply of dissolved oxygen is necessary for good root development, and since root development is always reflected in top growth, the oxygen factor in the root environment must necessarily influence the growth of the entire plant" (7). It is my intention in this paper, using the research of others, to elaborate on these preceding statements in a manner that will give the reader a broader insight as to just how critical the oxygen factor is to root growth and development, and hence, to the complete plant.

To begin, the reader must first accept the general statement that in natural field conditions, it is the problem of insufficient oxygen that is most commonly the universal cause for concern, and not the possibility of too much oxygen, although this, too, can cause detrimental effects on plant life as is mentioned by several researchers (7) (12) (19). (Reference to this latter problem will be mentioned later in this paper.) Two possible, and obvious, causes of low oxygen content in soils are rapidly brought to mind, namely soil compaction and saturation. Suffice it to say that both can, and often do, act together, but in dealing with each individually we learn from the research of Tackett and Pearson (25) that while a point may be reached where the degree of compaction of a soil is the governing factor of root growth, and not the oxygen content, there is "a strong interaction of oxygen and bulk density", and this can usually be controlled by modern methods of soil cultivation. In dealing with constantly saturated, water-logged, or flooded soils many facts are brought to light. Although rainwater (which may contain g to 11.2 ppm of dissolved oxygen (21)) contributes to permanent, and temporary excessively wet conditions, oxygen is not always readily available to roots because of its slow diffusion rates in water (26) and hence it is insufficient to maintain root growth. This indirectly supports the findings of Letey et al (17), who found that oxygen consumption varied very little in mediums which had risen to higher moisture contents. Under these excessively wet conditions root hairs became few and irregularly distributed (26) and in standing-water hair development is totally absent and lateral roots are induced to originate, up to a restricted length of time (22). However, no root growth is possible under prolonged or permanently wet environments as no species of plant needing high oxygen concentrations could withstand this adversity (19). This would hold true, also, in areas where the water tables are unusually close to the soil surface as gas samples taken from soils under this condition consistently gave indications of as little as 1% or less oxygen as compared to the 18% plus commonly found in cultivated soils (6). Plants may survive saturated soils, though, by their apparent ability to translocate oxygen from their tops down to their roots by the means of aerenchyma in their tissues (6).

A third factor, acting indirectly however, on roots and their possible lack of sufficient oxygen, is that of the soil temperature. Rising temperatures do not reduce any given potential of oxygen concentrations in a soil as the former two do, but cause the demand of the plants to increase, thereby, in effect, creating an oxygen deficiency. This fact is derived from the work of Williamson (28). The effects of temperature, therefore, are more pronounced under conditions of low oxygen levels when the temperature rises (19). Cannon (3) says that the "growth of the root ceases because it (the oxygen level) is no longer sufficient to supply the demands for energy correlated with physiological activities at higher temperatures." These facts of course can be reversed and explained as oxygen concentrations affecting cardinal temperatures, in that low oxygen levels lower the maximal and optimal temperatures, but interestingly, they do not affect the minimal cardinal temperature (4). From a practical viewpoint commercial growers benefit by knowing that low temperatures retard oxygen diffusion rates, which in turn may retard plant growth. This could cause early seeded crops to reach harvest time at the same period as crops seeded later in the spring when growth may surpass that of the earlier plantings (14) due to the more rapid diffusion of oxygen. The findings of Himmel and Weaver (26) tie in here with what has been said. They report that better soil aeration is needed in periods or areas of higher temperatures due to increased root uptake of oxygen. The data below, taken from the labors of Cannon (3) illustrates the relationship of oxygen with temperature very nicely.

Corn roots at 3% Oxygen:	at 30°C growth is 1/16 that of normal growth
	at 20°C growth is 1/5 that of normal growth
	at 18°C growth is 1/3 that of normal growth
Corn roots at 3.5% "	: at 30°C growth is 1/3 that of normal growth
	: at 18°C growth is 2/3 that of normal growth
Corn roots at 10% "	: at 30°C growth is 9/10 that of normal growth
	at 10°C GROWTH IS NORMAL

A fourth factor, having a major effect on oxygen supply levels throughout any given soil is that of the diffusion rate of oxygen in replenishing those areas which are being depleted by plant roots. These rates are affected by the temperature, soil moisture, and bulk density of each soil along with respiration rates (24). These rates vary also with the depth of the soil (16), and with the oxygen concentrations in the air at the soil surface, with 3.8% being the lowest

The Effects of Soil Oxygen—(Continued)

level allowing root subsistence in a healthy state (24). "This would be expected on the basis of lower oxygen partial pressure gradients" (24). Conway (6) adds to the importance of adequate diffusion rates by stating that "the oxygen concentration in the soil spaces is much more effectively maintained by the process of diffusion than by factors such as temperature and pressure changes which would tend to bring about mass movement of gases." In general, the minimum rates tolerated by the vast majority of plants is commonly stated as 20×10^{-8} g. cm^2 $min.^{-1}$ (24), yet there is a variation from this figure ranging from 15×10^{-8} g. cm^2 $min.^{-1}$ for barley (16) to 30×10^{-8} g. cm^2 $min.^{-1}$ for tomatoes (24). However, sugar beets (24) and bluegrass (15), for example, fall right on the rate assumed for most plants. Here again, it should be emphasized that these rates are the minimal ones and the optimal may be far higher, as is the case with bluegrass which is 40×10^{-8} g. cm^2 $min.^{-1}$ (15).

How oxygen levels are influenced in field conditions has now been shown. Each of these casual factors, naturally, may occur quite frequently and for only short periods of time. The duration of these low oxygen supplies is of great importance (13). Short term oxygen stresses may produce detrimental effects on plants (17) in some cases, but generally plants are able to survive these periods even if they are not able to tolerate them permanently (6). This is possible due to the presence of aerenchyma in plant tissue which ". . . allows oxygen to diffuse down to the submerged organs from the atmosphere through the aerial parts of the plant" (6). Cotton is an excellent example of this ability in plants. Leonard and Pinchard (12) have shown that cotton roots will respond to additional oxygen after periods of "drastic reductions in oxygen" in the root zone, indicating that no harm is done to roots during short periods, as in this case of less than ½% of oxygen for two weeks. Apple trees, too, with roots larger than 1 mm. in diameter can subsist in oxygen .1 to 3.0% for considerable lengths of time even when the whole tree is in active growth (1). Similar instances of temporary adversity are infinite in number and apparent almost daily to most persons with any knowledge of plant life. Research by these people above, however, certainly is interesting and needed. Letey et al (14) have learned from experiments that there is a time lag in root recovery from low oxygen stresses and that the duration a plant can withstand this adversity "is dependent upon the stage of plant and root development".

It should be stated here that even under optimum conditions, Williamson (28) has found that oxygen requirement of plant roots varies with the stage of growth or development of each plant. He also has learned that "the rate at which oxygen can be supplied continually to the roots is of utmost importance to a rapidly growing plant."

With the preceding information as an introduction to root and oxygen relationships I think that this is the place to cover the morphological effects of oxygen levels on the root itself, starting with the individual cells. The first observed effect of low oxygen is the shrinking of the meristematic tissue of the root tip due to the loss of turgor by the roots' inability to absorb water (4). This is followed by a reduction in the activity of the epidermal cells resulting in a decrease or total abstenance of root hair development (22). This reduction in epidermal activity is in inverse proportion to the activity of the pericycle which results in new lateral roots. These pericycle cells, incidentally, can withstand up to 100% oxygen atmosphere with no apparent damage (12). Lemon (10) states that cell wall thickness is increased under low oxygen levels and this increase in wall thickness, in turn, retards the oxygen content inside the root itself even more. The cotical region of roots in an aerated medium have uniform, compact parenchyma with no conspicuous intercellular spaces, while roots grown in non-aerated conditions (2) have large air passages separated by narrow strands of parenchyma cells. The "first tissue to differentiate is the xylem vessels of the non-aerated roots. These vessels develop secondary thickening of their walls at a distance of 5 mm. from the root tips. The next is the xylem vessels of the aerated roots at a distance of 15 mm. from the root tipcs." The pericycle cell walls of the non-aerated roots thicken at a distance of 35 mm. from the root tip as opposed to the distance of 45 mm. in the aerated roots, at which distance the central ducts of the non-aerated roots thicken too. There was no difference in the endodermis of the two roots. It can be assumed that these differences in wall thicknesses are due to the fact that because of the greater amount of oxygen available to the aerated roots there is a more rapid respiratory rate which depletes the sugar content of the cells to the point where there is an insufficient supply for further wall development.

There are striking differences in roots and root systems deficient in oxygen with those having adequate oxygen available to them. First, root hair development is dependent upon oxygen (26) and when no oxygen is available no hairs are produced (22). As Snow (22) states, "hair production depends on the ratio between the capacity of the epidermal cells to elongate and their ability to do so." As stated in the preceding discussion concerning cell effects, when no hairs are produced lateral roots are induced and this correlates with the work of Bryant (2) who found that the number of lateral roots in low oxygen mediums were three times that of the aerated roots, but the aerated roots were four times as long, indicating that epidermal cells must be elongating and root hairs developing, reducing lateral root growth, as Snow stated in a different fashion. Bryant has found that the roots of non-aerated plants were 15% greater in diameter throughout their entire length than those in higher oxygen concentrations. Gilbert and Shive (7) also find that roots low in oxygen are thicker, and shorter, and that root thickness is very important in determining the critical oxygen level as root activity increases. Lemon and Wiegand are more exact in their findings when they write: "The critical level of oxygen goes up as the square of the root radius" (11). Finally, there is a point for all plants where the oxygen level is so low that all growth of the roots will cease (12). As for the effects of high oxygen levels on roots, it is interesting to note tap root elongation of cotton plants will increase in atmospheres of up to 15% oxygen and with any higher concentrations than this optimal level, root growth will be reduced in increasing proportions up to the point where all growth of the root system is totally stopped at 90% oxygen concentration.

(Continued on Page 18)

Sulphur–Containing Fertilizers

—WHAT THEY ARE—HOW THEY ARE USED

The sulphur and primary nutrient contents of several fertilizer materials are listed in the table below. Some of these are standard fertilizer materials, ordinarily applied for their primary nutrient content. Others are primarily used for their content of sulphur, one of the other secondary nutrients, or one of the micronutrients. Several other materials, used mainly for soil improvement, also supply plant nutrient sulphur. These materials are mentioned in the next section.

The choice of which sulphur-containing fertilizer to use will depend upon local costs, availability, and the particular cultural problems to be solved. It is imperative, however, that farmers recognize the importance of sulphur to sustain profitable crop production and that they make sure that sufficient sulphur is being provided before it becomes a limiting factor in their farming operations.

Elemental Sulphur

Presently used grades of agricultural sulphur for soil application contain 85-99% sulphur and pass a 16 mesh screen.

When applied to aerated, moist soils, elemental sulphur is attacked by soil microorganisms to form sulphuric acid. This sulphuric acid in turn sup-

Sulphur and Primary Nutrient Content of Various Fertilizers
(PERCENT) [1]

MATERIAL	SULPHUR	NITROGEN	PHOSPHORUS	POTASSIUM
AMMONIA, ANHYDROUS	—	82	—	—
AMMONIA-SULPHUR SOLUTION	10	74	—	—
AMMONIUM NITRATE	—	33.5	—	—
AMMONIUM NITRATE-SULPHATE	5	30	—	—
AMMONIUM PHOSPHATE	3	11	48	—
AMMONIUM PHOSPHATE-SULPHATE	15.4	16	20	—
AMMONIUM POLYSULPHIDE	40	20	—	—
AMMONIUM SULPHATE	24	21	—	—
AMMONIUM SULPHATE-NITRATE	15	26	—	—
AMMONIUM THIOSULPHATE SOLUTION	20	12	—	—
AMMONIATED SUPERPHOSPHATE	11–13	3–7	16–19	—
COPPER SULPHATE	12.8	—	—	—
CALCIUM SULPHATE (GYPSUM)	15–18	—	—	—
DIAMMONIUM PHOSPHATE	2	18	46	—
DIAMMONIUM PHOSPHATE—SULPHUR	10–15	15–16	39–41	—
MAGNESIUM SULPHATE (KIESERITE)	23	—	—	—
MANGANESE SULPHATE	14–17	—	—	—
POTASSIUM CHLORIDE	—	—	—	60
POTASSIUM-MAGNESIUM SULPHATE	18	—	—	22
POTASSIUM SULPHATE	17–18	—	—	48–51
SODIUM NITRATE	—	16	—	—
SOIL SULPHUR (ELEMENTAL)	85–99	—	—	—
SULPHUR DIOXIDE	50	—	—	—
SUPERPHOSPHATE (NORMAL)	12	—	20	—
SUPERPHOSPHATE (CONCENTRATED)	1.5	—	30–50	—
SUPERPHOSPHATE (CONCENTRATED)—SULPHUR	20	—	40	—
UREA	—	42–46	—	—
UREA-SULPHUR	10	40	—	—
ZINC SULPHATE	13–18	—	—	—

[1] Nitrogen and sulphur expressed as percentages of elemental S and N; phosphorus and potassium expressed as percentages of P_2O_5 and K_2O equivalents.

plies the sulphate ion which is taken up by the plants.

As mentioned in the previous section, when conditions are favorable to plant growth, the speed of oxidation to sulphuric acid depends mainly on the extent of contact of the sulphur with the soil. When the sulphur is finely divided and mixed with the soil, the reaction is fairly rapid.

The acidifying effect of sulphur oxidation in the soil lowers the soil pH. On alkaline soils this is a desirable reaction leading to some of the benefits mentioned in the next section. On neutral to acid soils, however, it is necessary to compensate for this acidifying effect by suitable applications of liming materials. One hundred pounds of calcium carbonate equivalent in a liming material is needed to neutralize the acidity produced by 32 pounds of sulphur.

Ammonia-sulphur solution is a solution of elemental sulphur in anhydrous ammonia. The material can be applied to the soil with the equipment used for the straight-nitrogen fertilizer anhydrous ammonia; only slight modifications are necessary. In the soil the sulphur is precipitated in a very finely divided form. It therefore oxidizes rapidly and becomes available to the plants.

Urea-sulphur, diammonium phosphate-sulphur, triple superphosphate-sulphur and other recently developed high analysis sulphur-containing fertilizers also contain sulphur in the elemental form.

Ammonium Sulphate

In the soil, the ammonium ions from ammonium sulphate are converted to nitric acid by the action of soil bacteria. The sulphate ion by itself does not contribute to the soil acidity. However, when it is leached it is accompanied by basic cations and the loss of these does bring about an increase in soil acidity. When absorbed by plant roots the sulphate ion can indirectly decrease the acidity as a result of the compensating release of hydroxyl ions from the plant roots. However, this effect is usually negligible in contrast to the amount of sulphate that is leached, and continued use of ammonium sulphate almost always causes a decline in soil pH. On neutral to acid soils this decrease in pH may require a compensating treatment with a liming material. Approximately 112 pounds of calcium carbonate equivalent in a liming material is needed to neutralize the acidity produced by 100 pounds of ammonium sulphate.

Related materials are *ammonium nitrate-sulphate, ammonium sulphate-nitrate* and *ammonium phosphate-sulphate.*

Calcium Sulphate (Gypsum)

Gypsum has been widely used for many years as a sulphur- and calcium-bearing material for fertilization and soil reclamation. It is a neutral salt and generally has no effect on soil acidity.

Gypsum is a constituent of *normal superphosphate* and sulphur deficiencies therefore seldom occur on land adequately fertilized with this material. In the manufacture of *concentrated superphosphates,* however, the gypsum is largely removed and these materials therefore contain little or no sulphur.

Polysulphides & Thiosulphates

Ammonium polysulphide can be applied directly to the soil, metered into irrigation water, or mixed with anhydrous ammonia or ammonia solutions which in turn are applied to the soil. Ammonium polysulphide is not, however, completely compatible with some types of liquid fertilizer because of their high acidity or salt concentration. Trial mixes with small samples should be made prior to any full-scale batch operation.

Ammonium thiosulphate is another sulphur-containing material that is gaining in popularity in many areas. It can be applied in irrigation water. It is also compatible with many fertilizer solutions such as aqua ammonia, nitrogen solutions containing ammonium nitrate, urea solutions, and most nitrogen, nitrogen-phosphate, or complete fertilizer solutions. It cannot, however, be mixed with anhydrous ammonia or acid solutions such as phosphoric acid as these materials will decompose the thiosulphates.

Other Materials

Potassium sulphate, potassium magnesium sulphate and magnesium sulphate are being used to supply potassium and/or magnesium to crops. At the same time, they supply sulphur in the readily available sulphate form.

Although potassium chloride is currently the most commonly used potassium fertilizer, potassium sulphate is used to a large extent on specialty crops such as tobacco, vegetables, etc. Potassium magnesium sulphate is used to supply the three nutrients.

Sulphur dioxide has been used experimentally for direct application to the soil. It supplies readily available plant nutrient sulphur but requires special application equipment.

—Reprinted from a Publication of The Sulphur Institute

NEW PUBLICATION BY HODGKINSON & TROLL

An 11-page booklet titled "Lawn Construction and Early Maintenance" is now available to the public by writing to the Plant and Soil Sciences Department of the University of Massachusetts.

It is written by Lewis A. Hodgkinson, County Extension Agent in Agriculture of the Worcester Office, and Dr. Joseph Troll, Associate Professor, Department of Plant and Soil Sciences, University of Massachusetts.

Those requesting this booklet will find it pleasant reading and full of useful data covering everything from pre-construction preparation of new lawns to problems that may occur in initial maintenance through the first few mowings.

Hodgkinson, incidentally, is due to complete his work this winter on his Master's Degree in the Department of Plant and Soil Sciences.

UREA-SULPHUR FERTILIZER MADE BY NEW PROCESS

Urea-based fertilizers containing elemental sulphur have been marketed commercially for several years in the U.S.A. The product is obtained by melt-blending the urea and sulphur, according to U.S. Patent 3,100,698.

A new method for preparing a urea-sulphur material is described in a recent patent (U.S. Patent 3,313,613). According to this patent, prilled or granulated urea is mixed with finely divided (200 mesh) sulphur, which has been moistened with a solution of formaldehyde. The formaldehyde acts as a binder, making the sulphur particles adhere to the urea. This is probably due to the formation of methylol derivatives of urea at the points of contact of the formaldehyde-bearing sulphur particles with the urea.

The proportions of the ingredients are adjusted to give a final product containing from 75 to 95 percent urea, from 22 to 4 percent sulphur and from 3 to 0.2 percent formaldehyde. The resultant product is claimed to be free-flowing and to undergo substantially less segregation on shaking than comparable mixtures of urea and sulphur prepared without formaldehyde.

The urea-sulphur materials described in these two patents were developed in response to the increasing demand for highly concentrated fertilizers supplying plant nutrient sulphur. At the urea-content of these materials dissolves out, the sulphur is deposited in the soil in a finely divided form and the action of soil microorganisms converts it to plant available sulphate.

A possible future development in this type of fertilizer materials is indicated in the article by Dr. O. R. Lunt on controlled release fertilizers in this issue of the *Journal.* The use of sulphur-based material as a controlled availability coating on urea would serve the additional purpose of providing plant nutrient sulphur.

—Reprinted from The Sulphur Institute Journal, Summer 1967

Foliar Application Of Nutrients

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Michigan State University, East Lansing

Today is the day of chemical revolution in agriculture. Crops are sprayed or dusted with many substances. Some of these substances exert their influence by remaining on the foliage. Others, namely growth regulators and nutrients, are effective only when they are absorbed.

Foliar feeding, having originated in our generation, constitutes one of the important milestones in the progress of agricultural production. It is now an established practice with many crops. As a natural phenomenon of nutrient uptake, it exists with all forms of plant life.

Important in the attainment of our present knowledge of foliar absorption has been the use of radioisotopes.

Uptake Is Rapid

Many measurements have been made of nutrient transfer through intact leaf surfaces and subsequent transport of applied nutrients within the plant. Diffusion through leaf cuticles, the thin wax covered lm or skin on the leaf surface, may be the first rate-limiting process in nutrient absorption. Uptake is relatively rapid, however, for isolated cuticular membranes and reaches a maximum in five to 15 minutes.

Cations, such as potassium, calcium, and magnesium, penetrate cuticles more readily than the anions, phosphorus and sulphur, with the rate for urea far exceeding that of the cations. Movement into the leaf through the cuticle is greater than movement out.

Nutrient uptake by isolated leaf cells taken from under the cuticle reveals an active process. The absorption is dependent upon temperature, light, and oxygen; is subject to metabolic inhibitors (poisons); is irreversible and parallels protein synthesis.

Stomata have been considered as portals of entry for foliar applied nutrients. Many reports have shown correlations between the number or frequency of stomata and rates of absorption. Contradictory results have also been reported. Observations show, however, that the surfaces of cells bordering stomatal cavities are covered with cuticle, albeit thinner than on the leaf surface. Thus, absorption through the outer leaf surface or within stomata necessitates cuticular penetration. Wetting agents (surfactants) greatly facilitate passage of spray materials into stomatal cavities. Easy penetration into living cells is then effected by a thinner and more hydrated cuticle. Hence, wetting agents may greatly enhance absorption of nutrients applied as sprays to leaf surfaces.

Crop Responses Numerous

Phenomenal increases in plant productivity often are achieved when specific nutrients are applied as foliar sprays. Iron as ferrous sulphate is fully effective on pineapple, grain sorghum and gardenia, but on few other species. Blackheart in celery may be corrected by calcium sprays. Magnesium yellowing in certain varieties of Pascal-type celery responds to sprays of Epsom salts, whereas it is impractical to apply it to the soil. Nearly all deciduous fruit trees, citrus, grapes, vegetable crops, plantation crops, soybeans, potatoes, field beans and corn may respond to foliar sprays of specific micro and secondary nutrients, as well as to urea nitrogen, if these nutrients are in short supply. There are now numerous examples of responses to foliar sprays of iron, manganese, or zinc, and to a lesser extent, copper, boron, and molybdenum.

Foliar applications of iron, manganese, and zinc deserve special attention. For responding crops, only a few days are required for leaves to accumulate high concentrations and to store the nutrients in luxury amounts. One or two properly timed foliage sprays are sufficient. Quantities required per acre are less than if applied to the soil.

Two sprays of zinc sulphate at the rate of one pound of zinc per acre increased yields of Michigan field beans from 0 on the control to 23 bushels. In California, a three per cent spray solution of ferrous sulphate resulted in a grain sorghum yield of 4000 pounds per acre compared with only 250 for the non-sprayed. This is shown in Table 1.

The effectiveness of one or two manganese sprays for soybeans is because of rapid absorption, resulting in a luxury consumption which will then support the crop to maturity.

Spray Concentration Important

Guidlines for foliar application of nutrients are given in Tables 2, 3 and 4. Spray concentrations of urea tolerated by plant foliage depend on the species. This is also true of iron sulphate. Comparative tests with sulphate and chelated forms of iron, manganese and zinc favor the sulphate. Synthetic chelates are absorbed less readily than the sulphate salts. Translocation within the plant may, however, be enhanced by chelation. More research on foliar sprays of chelates is urgently needed.

In 1966, trials at Michigan State University, manganous sulphate (MnO) and manganous sulphate ($Mn\ SO_4$), were equally effective on soybeans. Two sprays two weeks apart at the rate of one pound per acre per spraying were sufficient for maximum productivity.

Wetting agents may greatly enhance the effectivness of nutrient sprays for most crops, especially those with waxy leaves, such as cabbage and onions. Absorption by leaves is facilitated by light, high temperatures, and a hydrated surface. Most nutrient sprays are compatible with all fungicides and insecticides, except organic mercurys, oils and arsenicals.

Risk of injury to plant foliage frequently accompanies foliar application of nutrients. Tables 2 and 3 list tolerances for various species and materials. Local conditions and stage of plant growth will modify these values, as will the volume applied per acre. Hence, a range in the amounts and concentrations is given. Leaves of most plants are not only intolerant of high concentration of liquid fertilizer, but the exposed surfaces usually fall far short of being able to absorb, in the absence of injury, sufficient nutrients to maintain growth and productivity. During early seedling growth, nutrient requirements are proportionately high as related to the available leaf absorbing surfaces.

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The effectiveness of foliar applications of nutrients, as with soil treatments, is dependent upon plant needs and other growth factors. Foliar feeding should not be used as a substitute for, but as a supplement to, sound cultural practices. Use of broad spectrum ("complete") liquid fertilizers for foliar feeding is lacking of sound experimental data with adequate control comparisons. Certain products have been the object of vigorous sales promotion and unwarranted claims for foliar feeding of small grains, corn, potatoes, sugar beets, soybeans, cucmbers, strawberries and tree fruits.

Potentials Are Great

There are stages in plant development when adequate or added growth factors may produce a phenomenal increase. These are during early seedling growth, at flowering and at early seed or fruit development. The early stage is that which responds to "starter solutions" or the so-called "pop-up" fertilizers. For the second stage, foliar applications have great potential. The leaf areas are large and often the leaf canopies are complete.

A new innovation has been suggested in timing of foliar application of nutrients for tree crops. It is a post-harvest or late autumn treatment. This timing of spray treatments is effective for preventing deficiency disorders of zinc and boron. It may be used at twice the early season concentration. Significant increases in yield and tree performance have been achieved by applying nutrient sprays shortly before leaf fall. Solutions containing four to five per cent urea may be used with very little likelihood of leaf damage.

Foliar feeding will assume greater significance with changing cultural practices. These will include narrower rows and eventually equidistant spacings, higher plant populations, widespread adoption of irrigation for the major food crops, and ultra low volume (ULV) aerial spraying with undiluted formulations.

There is also the potential of applying the major as well as the secondary and micronutrients to growing crops subject to stress conditions. Nitrogen as solid or concentrated urea or ammonium nitrate could also be applied to crops on organic or sandy soils following a heavy summer rain. The nutrient requirements for maintaining growth and productivity could thus be met immediately. The usual restrictions in the use of ground equipment and hazards of mechanically damaging the crop would not exist.

The possible benefits from the use of urea alone and in combination with other nutrients should be explored. Urea is not only absorbed very rapidly by plant foliage but it accelerates absorption of other materials.

Several reports suggest that micronutrients incorporated with 2,4-D and then applied to the foliage of beans, sugar beets and potatoes, augment the stimulatory effect of 2,4-D. The effective concentration is widened whereby it can be applied to increase yields.

Summary

Foliar applications of nutrients should be correlated with need, and an adequate supply of other growth factors. Soil tests, tissue analysis, rate and quality of growth, seed and fruit production, appearance of deficiency disorders, and general knowledge of growth requirements can serve as useful guides.

We can expect greater frequency in micronutrient deficiencies on the major food crops (corn, potato, sugar beets, soybeans). These, undoubtedly, will respond to foliar applications of specific nutrients.

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FOLIAR APPLICATION . . .
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TABLE 1.

Response of grain sorghum to foliar sprays of ferrous (iron) sulphat (50 gal./acre)*

Spray Treatment	Yield/Acre (pounds)
Trial 1	
Control	1740
1% $Fe SO_4$	2810
3% $Fe SO_4$	2920
Trial 2	
Control	250
3% $Fe SO_4$	4000

* B. A. Krantz, *et al.* Univ. of Cal. Comparable results from soil treatments required 3200 lbs. of ferrous sulphate per acre.

TABLE 2

Tolerances of plant foliage to repeated applications of urea sprays.

Crop	Tolerances–no leaf scorch* (Lbs/100 gal. water)
VEGETABLE	
Cucumber, bean, tomato, sweet corn	4-6
Carrots, celery, onions, potatoes	15-20
FRUIT	
Apple, grape, brambles, strawberry	4-6
Cherry, peach, plum, currants	10-20**
FIELD CROPS	
Sugar beets, alfalfa, corn, wheat	5-10
Oats, barley, bromegrass, ryegrass	20-50
PLANTATION AND TROPICAL	
Tobacco, citrus, cacao	5-10
Sugarcane, banana, mango, tea, coffee	10-25
Cotton, hops, pineapple	20-50

* Higher concentrations may be used with lower volume spraying.
** Leaves are tolerant at this level as measured by scorch, but severe chlorosis may occur at these and even lower concentrations.

TABLE 3

Tolerances of plant foliage to repeated applications of mineral nutrient sprays.

Nutrition	Formulation or salt	Tolerances–no leaf scorch* (Lbs/100 gal. water)
Nitrogen	Urea	(See Table 1)
	NH_4NO_3, $(NH_4)_2HPO_4$, $NH_4H_2PO_4$, $(NH_4)_2SO_4$ and NH_4Cl	4-6
Phosphorus	H_3PO_4	3-5
	Others (see nitrogen above)	
Potassium	KNO_3, K_2SO_4 KCl	6-10
Calcium	$CaCl_2$, Ca $(NO_3)_2$	6-12
Magnesium	$MgSO_4$, Mg $(NO_3)_2$	8-24
Iron	$FeSO_4$	4-24
Manganese	$MnSO_4$	4-6
Zinc	$ZnSO_4$	3-5
Boron	Sodium borate	0.5-2
Molybdenum	Sodium molybdate	0.2-.3

* Higher concentrations may be used with lower volume spraying.

—*Reprinted from Plant Food Review Number 2, 1967*

ROOTS UNDERGROUND AGENTS

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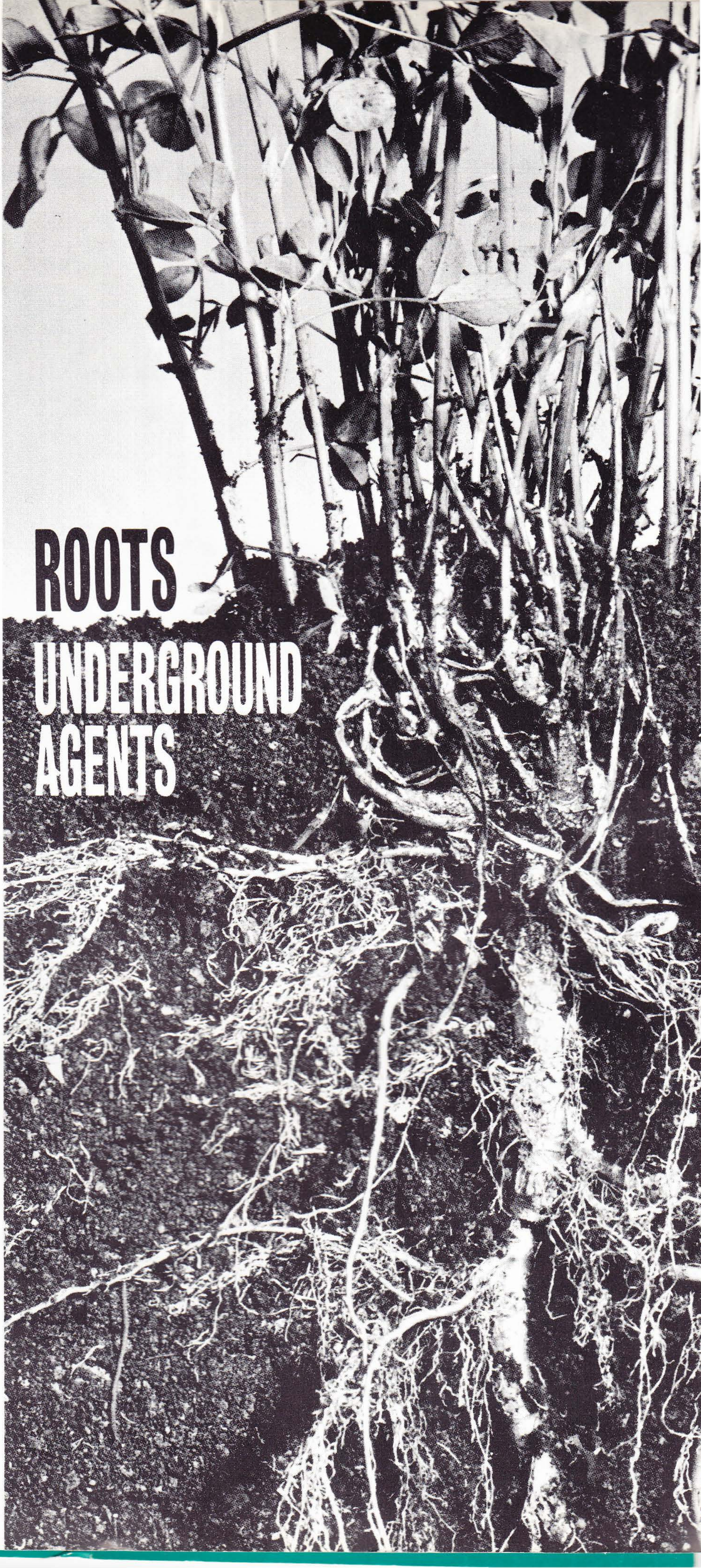


THINK HOW DESCRIPTIVE a term the word "root" has become in our language—"the root of the problem" . . . "grass roots survey" . . . "rooted to the spot" . . . "root of all evil." It's an important part of English usage, and an essential part of every plant. Yet, even though it is usually the first plant organ to emerge from the seed, it has received the least attention from research.

Of the thousands of plant studies published each year in scientific journals, only a few mention the effects of treatments on plant roots. However, few areas of research could be more fruitful.

With a few notable exceptions most of the information on roots from field experiments is simply an accumulation of observations, accompanied by little, if any, interpretive discussion. Most research on plant roots has been with pot experiments, sand culture, nutrient solution culture and excised root culture. While increasing our information in some basic areas, results of this type of research have limited application to field conditions. Many people now recognize the large gap in our knowledge of plant roots that hinders our understanding of plant nutrition.

Root Anatomy Interesting

First to emerge from a germinating seed is the primary root. It may, through branching, produce second, third, fourth order roots, etc., which may constitute all or part of the root system.

In the grass family the primary root system is augmented by the secondary root system which arises from stem nodes below or even slightly above the soil surface. These adventitious roots frequently constitute the main root system of the plant, such as in the case of corn where the primary system ceases to develop.

The root system may be of two types—tap or fibrous. It may be deep or shallow, sparse or dense, depending on the plant species, and upon environment. It may be concentrated in the surface few inches or well distributed throughout a much deeper root zone. Some tap-rooted plants may penetrate to depths of up to 30 feet, as in the case of alfalfa.

How Roots Grow

There are four distinct regions in a root's anatomy. (Figure 1) At the root tip there is a thimble-shaped group of cells called the root cap. It protects the second region or the type of tissue in the root tips known as the meristematic cells. By cell division, this meristematic tissue replenishes both the root cap cells, which slough off as roots grow through the soil, and the cells which cause root elongation.

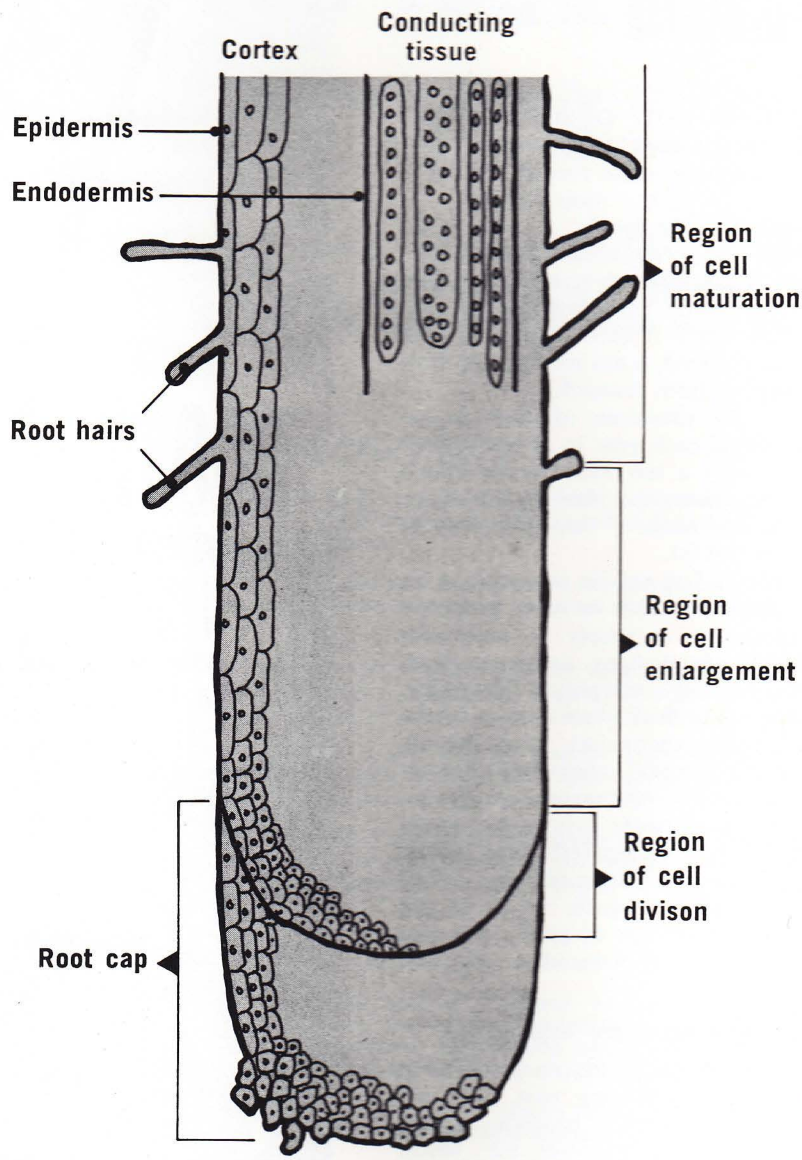
The area of cell enlargement is immediately behind the meristematic region. In this zone there is rapid cell enlargement resulting from rapid production of protoplasm and vacuoles, two principal cell components. Behind the zone of cell enlargement is the zone of maturation where the cells develop specific differences in structure and function. In this process, often called differentiation, some cells become vascular tissue (phloem and xylem), others become parenchyma (pith) and epidermal cells.

It is in the young part of the maturation zone that root hairs develop. These are slender extensions of single root epidermal cells (see Figure 2). Root hairs grow fairly rapidly and their life span is usually quite short, only a day or two for most crop plants. They grow in great profusion in the area immediately above the zone of elongation and, as the root extends, new root hairs are continually produced as older ones become non-functional.

Root hairs greatly increase the surface area of roots, and function as the main site for water and nutrient absorption. Their rapid turnover enables the root to come into contact with daily supplies of nutrients and water.

FIGURE 1

Longitudinal section of a young barley root.



Main Functions of Roots

The main functions of roots are absorption, anchorage and storage. Water and nutrient absorption have received by far the most research effort, and while there is abundant knowledge in the field there is much yet to learn. The importance of nutrient absorption to high yields has stimulated much of the research.

Storage of carbohydrates and other materials in roots is essential for the winter survival of biennial and perennial crops. Most of the commercial root crops (sugar beets, carrots) are biennials which are harvested at the end of the first growing year.

As parts of the same living organism, it is obvious that there are close relationships between growth of plant tops and roots. As a plant develops, both top and root grow, but seldom at the same relative rate.

In general, the plant part nearest the source of an essential factor will be affected least by its deficiency. For example, when, because of low light intensity or defoliation, photosynthesis is retarded, root growth will be retarded much more than top growth. What little photosynthate that is produced under these conditions will be used mainly in the tops, and very little translocated to roots. Hence, the ratio of shoot to root increases.

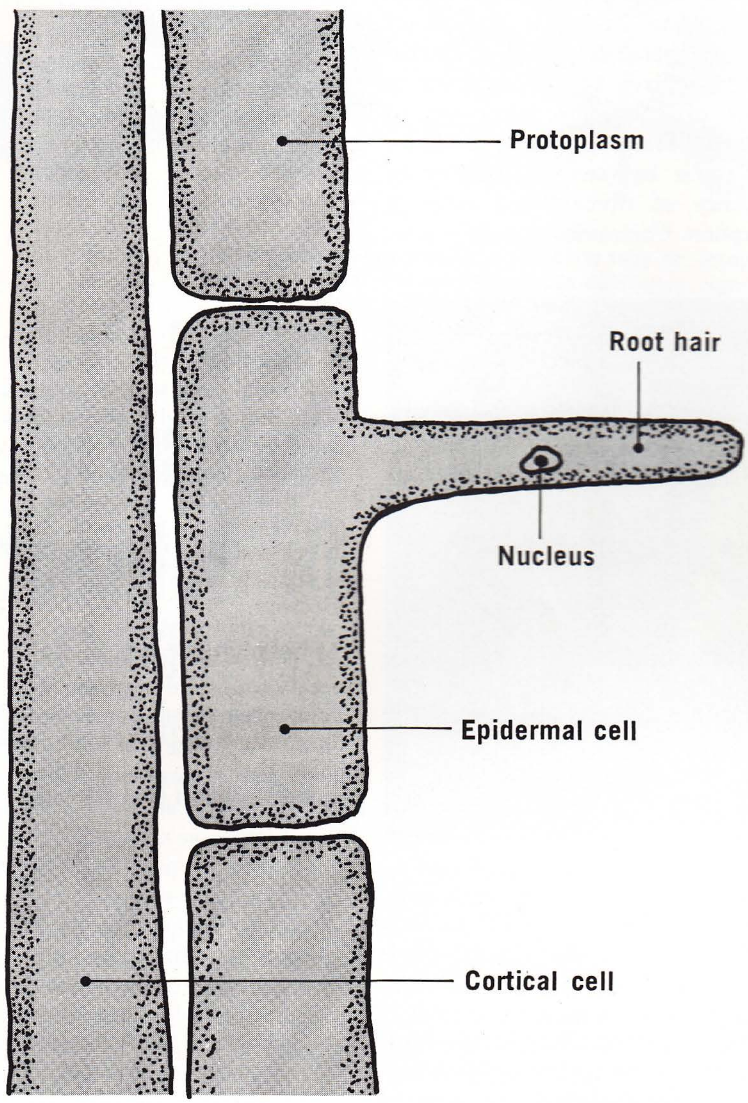
Conversely, when water or nutrients become limiting, the shoot, being further from the source, will be affected first and to the greatest extent. The equilibrium thus shifts in favor of the root, and the ratio of shoot to root decreases.

Other Functions of Roots

Metabolically, roots perform many functions essential to plant life other than absorbing nutrients and water. They are the primary site of nitrogen assimilation, and they can synthesize all their essential amino acids and proteins from inorganic nitrogen. Further, roots are the site of synthesis of many essential hormones, and of other important products. Among the latter is

FIGURE 2

Root epidermal cell showing root hair protruding.



nicotine, an alkaloid produced only in roots of tobacco plants.

Other root functions include reproduction, toxic exudation and nodulation. Even though these three functions are not prevalent in all species, they are frequently vital to the survival and/or production of some. For example, growth of adventitious shoots from sweet potato roots provides for crop propagation.

Plant roots exude a wide range of organic compounds including alkaloids, vitamins, nucleotides, flavones, sugars, enzymes, auxins, amino acids and organic acids. Some of these may stimulate certain soil microorganisms, while they may be toxic to others. Their release is important in the establishment of a rhizosphere: the highly active root-soil interface. It also has been shown that some plants produce exudates which are toxic to other plants. This ability to produce their own "herbicide" provides a very useful competitive advantage to some plants.

Nodule formation and its associated nitrogen fixation is one of the most important side-line functions of legume roots. Some of our best known crops, such as soybeans and alfalfa, could not be produced economically without symbiotic nitrogen fixation. Much of the improved pasture of the world depends upon the establishment and survival of nitrogen-fixing legumes.

In this symbiotic relationship of bacteria and plants, bacteria use energy supplied by carbohydrates of the plant to convert inert atmospheric nitrogen into a usable form.

Soil Factors Affect Growth

Soil physical conditions, soil chemical make-up, soil microorganisms, crop management, and crop breeding can greatly affect root growth.

Soil moisture and soil aeration are inversely related: as one increases the other decreases. Some crops, such as rice, have roots that develop in standing water. Others, tobacco for example, are very sensitive to poor drainage and aeration.

Soil acidity is a very significant factor influencing roots. As degree of acidity increases, so does the amount of certain toxic elements in the soil solution. Notable among these is aluminum which, in acid soils, can greatly reduce plant growth as a result of its toxic effects on roots.

Placement of fertilizer too can modify root development. When banded, root density in the area of the band is increased. Yet, the total root production is probably no greater than that obtained from the same amount of fertilizer broadcast and disked in. While band placement might result in earlier growth, broadcast fertilization usually results in a more extensive root system.

Roots are probably attacked by more disease organisms and insects than are the above-ground parts. In general, the main effect of such pests is a reduction of effective root surface for absorption. In severe cases root damage may be so severe that many roots die, new ones fail to develop, and existing ones become ineffective.

Roots Can Be Improved

Roots can be changed through plant breeding. One can cite many examples of the genetic improvement of plant roots with regard to lodging resistance, beet size and shape, degree of branching, etc. Less obvious changes have undoubtedly been made in ability to absorb nutrients. In all likelihood, increases in yield brought about through plant breeding can be attributed in part to unknown improvements in the root. Increased understanding of those root factors which affect plant yield represents a real challenge to those interested in pushing existing yield barriers aside. □

Foliar Application Of Nutrients

Part of the "Chemical Revolution In Agriculture"

TODAY IS THE DAY of chemical revolution in agriculture. Crops are sprayed or dusted with many substances. Some of these substances exert their influence by remaining on the foliage. Others, namely growth regulators and nutrients, are effective only when they are absorbed.

Foliar feeding, having originated in our generation, constitutes one of the important milestones in the progress of agricultural production. It is now an established practice with many crops. As a natural phenomenon of nutrient uptake, it exists with all forms of plant life.

Response of grain sorghum to foliar sprays of iron is striking. Plants on the left were sprayed with a 1 per cent solution of ferrous sulfate; center; no spray; right, a spray of 3 per cent solution of ferrous sulfate was used. Yields were 2810, 1740 and 2920 pounds of grain per acre, respectively. (Photo courtesy of B. A. Krantz, Univ. of California)

Important in the attainment of our present knowledge of foliar absorption has been the use of radioisotopes.

Uptake Is Rapid

Many measurements have been made of nutrient transfer through intact leaf surfaces and subsequent transport of applied nutrients within the plant. Diffusion through leaf cuticles, the thin wax covered film or skin on the leaf surface, may be the first rate-limiting process in nutrient absorption. Uptake is relatively rapid, however, for isolated cuticular membranes and reaches a maximum in five to 15 minutes.

Cations, such as potassium, calcium, and magnesium, penetrate cuticles more readily than the anions, phosphorus and sulphur, with the rate for urea far exceeding that of the cations. Movement into the leaf through the cuticle is greater than movement out.

Nutrient uptake by isolated leaf cells taken from under the cuticle reveals an active process. The absorption is dependent upon temperature, light, and oxygen; is subject to metabolic inhibitors (poisons); is irreversible, and parallels protein synthesis.

Stomata have been considered as portals of entry for foliar applied nutrients. Many reports have shown correlations between the number or frequency of stomata and rates of absorption. Contradictory results have also been reported. Observations show, however, that the surfaces of cells bordering stomatal cavities are covered with cuticle, albeit thinner than on the leaf surface. Thus, absorption through the outer leaf surface or within stomata necessitates cuticular penetration. Wetting agents (surfactants) greatly facilitate passage of spray materials into stomatal cavities. Easy penetration into living cells is then effected by a thinner and more hydrated cuticle. Hence, wetting agents may greatly enhance absorption of nutrients applied as sprays to leaf surfaces.

Crop Responses Numerous

Phenomenal increases in plant productivity often are achieved when specific nutrients are applied as foliar

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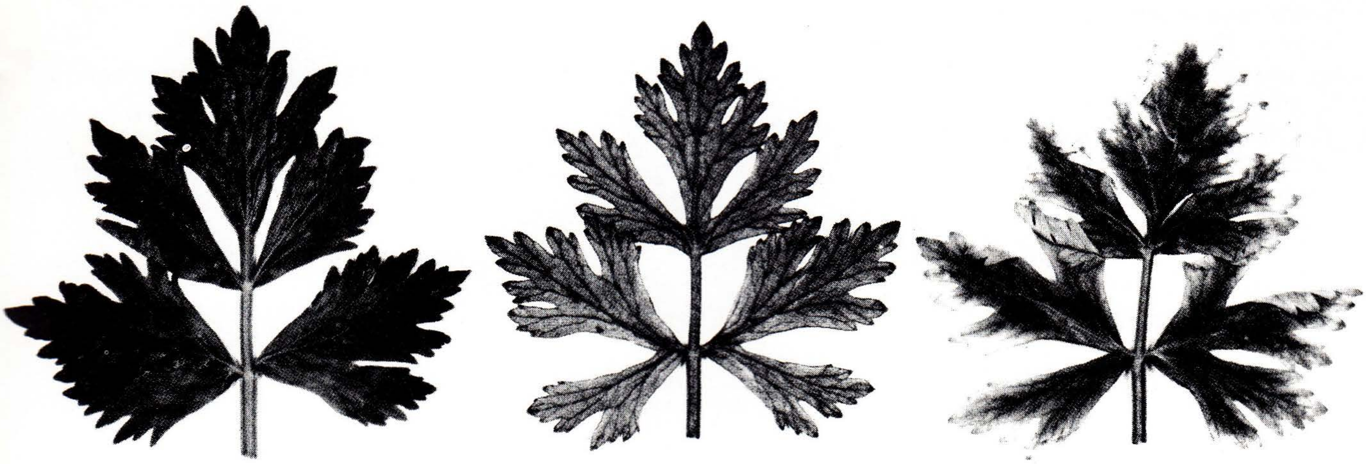


Nutrient deficiency disorders in celery may be corrected by nutrient sprays. Left, normal leaf; center, manganese deficiency; right, magnesium deficiency.

sprays. Iron as ferrous sulphate is fully effective on pineapple, grain sorghum and gardenia, but on few other species. Blackheart in celery may be corrected by calcium sprays. Magnesium yellowing in certain varieties of Pascal-type celery responds to sprays of Epsom salts, whereas it is impractical to apply it to the soil. Nearly all deciduous fruit trees, citrus, grapes, vegetable crops, plantation crops, soybeans, potatoes, field beans and corn may respond to foliar sprays of specific micro and secondary nutrients, as well as to urea nitrogen, if these nutrients are in short supply. There are now numerous examples of responses to foliar sprays of iron, manganese, or zinc, and to a lesser extent, copper, boron, and molybdenum.

Foliar applications of iron, manganese, and zinc deserve special attention. For responding crops, only a few days are required for leaves to accumulate high concentrations and to store the nutrients in luxury amounts. One or two properly timed foliage sprays are sufficient. Quantities required per acre are less than if applied to the soil.

Two sprays of zinc sulphate at the rate of one pound of zinc per acre increased yields of Michigan field beans from 0 on the control to 23 bushels. In California, a three per cent spray solution of ferrous sulphate resulted in a grain sorghum yield of 4000 pounds per acre compared with only 250 for the non-sprayed. This is shown in Table 1.

The effectiveness of one or two manganese sprays for soybeans is because of rapid absorption, resulting in a luxury consumption which will then support the crop to maturity.

Spray Concentration Important

Guidelines for foliar application of nutrients are given in Tables 2, 3 and 4. Spray concentrations of urea tolerated by plant foliage depend on the species. This is also true of iron sulphate. Comparative tests with sulphate and chelated forms of iron, manganese and zinc favor the sulphate. Synthetic chelates are absorbed less readily than the sulphate salts. Translocation within the plant may, however, be enhanced by chelation, as observed in Table 5. More research on foliar sprays of chelates is urgently needed.

In 1966, trials at Michigan State University, manganous oxide (MnO) and manganous sulphate ($Mn\ SO_4$), were equally effective on soybeans. Two sprays two weeks apart at the rate of one pound per acre per spraying were sufficient for maximum productivity.

Wetting agents may greatly enhance the effectiveness of nutrient sprays for most crops, especially those with waxy leaves, such as cabbage and onions. Absorption by leaves is facilitated by light, high temperatures, and a hydrated surface. Most nutrient sprays are compatible with all fungicides and insecticides, except organic mercurys, oils and arsenicals.

TABLE 1.

Response of grain sorghum to foliar sprays of ferrous (iron) sulphate (50 gal./acre)*

Spray Treatment	Yield/Acre (pounds)
Trial 1	
Control	1740
1% $Fe\ SO_4$	2810
3% $Fe\ SO_4$	2920
Trial 2	
Control	250
3% $Fe\ SO_4$	4000

* B. A. Krantz, *et al.* Univ. of Cal. Comparable results from soil treatments required 3200 lbs. of ferrous sulphate per acre.

Risk of injury to plant foliage frequently accompanies foliar application of nutrients. Tables 2 and 3 list tolerances for various species and materials. Local conditions and stage of plant growth will modify these values, as will the volume applied per acre. Hence, a range in the amounts and concentrations is given. Leaves of most plants are not only intolerant of high concentrations of liquid fertilizer, but the exposed surfaces usually fall far short of being able to absorb, in the absence of injury, sufficient nutrients to maintain growth and productivity. During early seedling growth, nutrient requirements are proportionally high as related to the available leaf absorbing surfaces.

The effectiveness of foliar applications of nutrients, as with soil treatments, is dependent upon plant needs and other growth factors. Foliar feeding should not be used as a substitute for, but as a supplement to, sound cultural practices. Use of broad spectrum ("complete") liquid fertilizers for foliar feeding is lacking of sound experimental data with adequate control comparisons. Certain products have been the object of vigorous sales promotion and unwarranted claims for foliar feeding of small grains, corn, potatoes, sugar beets, soybeans, cucumbers, strawberries and tree fruits.

Potentials Are Great

There are stages in plant development when adequate or added growth factors may produce a phenomenal increase. These are during early seedling growth, at flowering and at early seed or fruit development. The early stage is that which responds to "starter solutions" or the so-called "pop-up" fertilizers. For the second stage, foliar applications have great potential. The leaf areas are large and often the leaf canopies are complete.

A new innovation has been suggested in timing of foliar application of nutrients for tree crops. It is a post-harvest or late autumn treatment. This timing of spray treatments is effective for preventing deficiency disorders of zinc and boron. It may be used at twice the early season concentration. Significant increases in yield and tree performance have been achieved by applying nutrient sprays shortly before leaf fall. Solutions containing four to five per cent urea may be used with very little likelihood of leaf damage.

Foliar feeding will assume greater significance with changing cultural practices. These will include narrower rows and eventually equidistant spacings, higher plant populations, widespread adoption of irrigation for the major food crops, and ultra low volume (ULV) aerial spraying with undiluted formulations.

There is also the potential of applying the major as well as the secondary and micronutrients to growing crops subject to stress conditions. Nitrogen as solid or concentrated urea or ammonium nitrate could also be applied to crops on organic or sandy soils following a heavy summer rain. The nutrient requirements for maintaining growth and productivity could thus be met immediately. The usual restrictions in the use of ground equipment and hazards of mechanically damaging the crop would not exist.

The possible benefits from the use of urea alone and in combination with other nutrients should be explored. Urea is not only absorbed very rapidly by plant foliage but it accelerates absorption of other materials.

TABLE 2.

Tolerances of plant foliage to repeated applications of urea sprays

CROP	Tolerances—no leaf scorch* (Lbs/100 gal. water)
VEGETABLE	
Cucumber, bean, tomato, sweet corn	4-6
Carrots, celery, onions, potatoes	15-20
FRUIT	
Apple, grape, brambles, strawberry	4-6
Cherry, peach, plum, currants	10-20**
FIELD CROPS	
Sugar beets, alfalfa, corn, wheat	5-10
Oats, barley, bromegrass, ryegrass	20-50
PLANTATION AND TROPICAL	
Tobacco, citrus, cacao	5-10
Sugarcane, banana, mango, tea, coffee	10-25
Cotton, hops, pineapple	20-50

* Higher concentrations may be used with lower volume spraying.
** Leaves are tolerant at this level as measured by scorch, but severe chlorosis may occur at these and even lower concentrations.

TABLE 3.

Tolerances of plant foliage to repeated applications of mineral nutrient sprays

Nutrient	Formulation or salt	Tolerances—no leaf scorch* (Lbs/100 gal. water)
Nitrogen	Urea	(See Table I)
	NH_4NO_3, $(NH_4)_2HPO_4$, $NH_4H_2PO_4$, $(NH_4)_2SO_4$ and NH_4Cl	4-6
Phosphorus	H_3PO_4	3-5
	Others (see nitrogen above)	
Potassium	KNO_3, K_2SO_4, KCl	6-10
Calcium	$CaCl_2$, $Ca(NO_3)_2$	6-12
Magnesium	$MgSO_4$, $Mg(NO_3)_2$	8-24
Iron	$FeSO_4$	4-24
Manganese	$MnSO_4$	4-6
Zinc	$ZnSO_4$	3-5
Boron	Sodium borate	0.5-2
Molybdenum	Sodium molybdate	0.2-0.3

* Higher concentrations may be used with lower volume spraying.

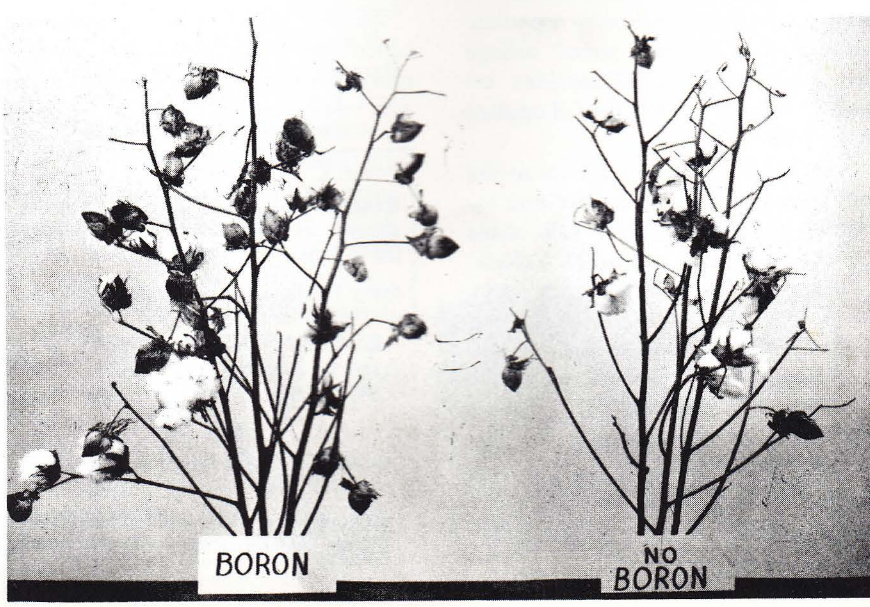
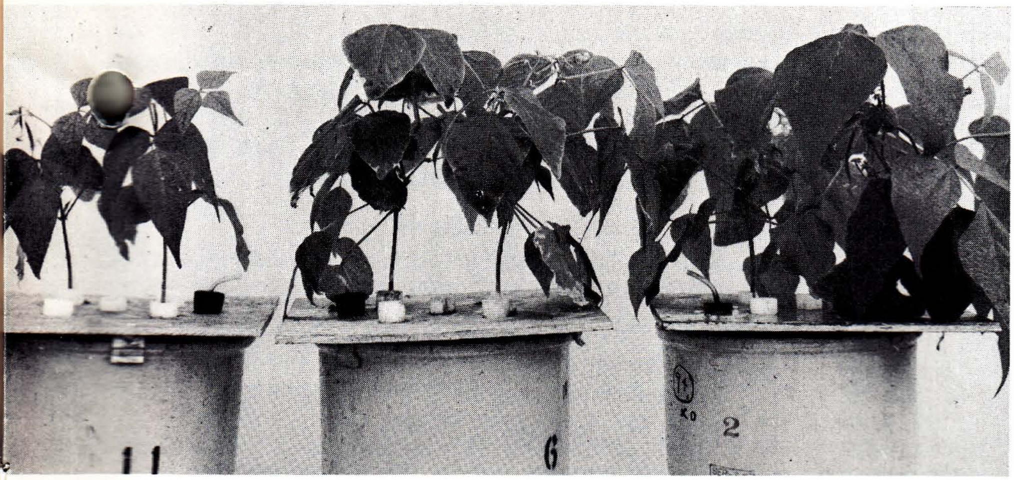


Photo shows comparative effect of boron (sodium borate) on cotton. Plant at left is from field sprayed with 0.2 pounds of actual boron per acre at early squaring stage; right, non-treated. Yields were 104 and 754 pounds of lint per acre, respectively. (Photo courtesy of '' '' Rogers, Clemson Univ.)



A comparison of foliar and root feeding shows effects on bean plant growth. Plants on left sprayed weekly with the nutrient solution; center plants daily (no nutrients provided to the roots). The plants on the right were root fed. The same nutrients were applied to both roots and foliage, with 10-fold the concentration for foliar feeding as for root feeding.

Several reports suggest that micronutrients incorporated with 2,4-D and then applied to the foliage of beans, sugar beets and potatoes, augment the stimulatory effect of 2,4-D. The effective concentration is widened whereby it can be applied to increase yields.

Summary

Foliar applications of nutrients should be correlated with need, and an adequate supply of other growth factors. Soil tests, tissue analysis, rate and quality of growth, seed and fruit production. appearance of deficiency disorders, and general knowledge of growth requirements can serve as useful guides.

We can expect greater frequency in micronutrient deficiencies on the major food crops (corn, potato, sugar beets, soybeans). These, undoubtedly, will respond to foliar applications of specific nutrients. □

TABLE 4.

Suggested pounds per acre of micronutrients to apply as sprays. (High volume: 50-150 gallons/acre)

Micronutrient	Lbs/acre*
Iron	4-12
Manganese	1-2
Zinc	0.3-0.7
Copper	0.3-0.5
Boron	0.1-0.5
Molybdenum	0.05-0.1

* Expressed as element.

TABLE 5.

Effects of chelation on absorption of iron by bean leaves*

Source of Iron	Absorption (relative)	Translocation (per cent of absorbed)
$FeSO_4$	20	0.5
Fe-EDTA	13	2.5
Fe-EDDHA	2	6.0
$FeSO_4$ + Urea	46	0.6

* Wittwer, *et al.* Qualitas Plant. 14:105-120. 1967.

Reprints of this article are available.

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The Effects of Soil Oxygen (Continued from Page 4)

The following data has been obtained in a variety of ways using different oxygen measuring devices, but it can be assumed that the figures mentioned are accurately obtained with means such as that described by Willey and Tanner in their report on a membrane-covered electrode (27).

The amount of oxygen in the soil available to roots influences the ability of the roots to absorb vital elements from the soil, as well as water absorption, which is likely the most critical factor as all elements must be dissolved in this media in order to enter the plant roots. When roots fail to function as absorbers for the plant it is because of the lack of oxygen which hinder the respiration of the cell protoplasm. As a result the cells die (26). This reduces the total root surface which is most effective in water uptake and consequently this also lowers the total uptake of nutrients (13). Potassium, according to Peterson (19), was absorbed by soybeans in the greatest quantity when the oxygen level was at 20%, and in the lowest quatity when at 3.8% oxygen. Others (8) (13) (18) agree with his findings. Phosphorus, calcium, and magnesium also tend to be absorbed in greater quantities as the oxygen levels rise (9) (13) (16) (18). Nitrogen uptake increased with rising oxygen levels too, but only up to the maximum of 2½% oxygen concentration. Any further rise in oxygen had little or no effect on its uptake rate (12). The majority of the minor nutrients remained constant or increased, as the oxygen level went down. Sodium uptake rises very sharply as oxygen levels fall (9) (13) (16). So it can be said that oxygen plays a major role in nutrient absorption by roots even if the root system is not experiencing an oxygen deficiency in the soil.

Not only are nutrients affected by oxygen levels in plant uptake, but the absorption rates vary from specie to specie and with the period of time so much so that the only completely true, general statement that can be made concerning nutrient absorption by roots in varying oxygen concentrations is that the root system of each specie of plant has its own optional level of oxygen for nutrient uptake.

Once again, roots differ from specie to specie, in their reactions to high oxygen concentrations. For example, Gilbert and Shive (7) found no detrimental effects of high oxygen to the roots of tomato and conclude that "the oxygen tension required for optimum growth of this species may be considerably above that maintained at equilibrium with the oxygen of the air." Letey et al. (12), however, found that the elongation of cotton tap roots ceased in levels over 15% oxygen. Furthermore, they (12) found along with Peterson (19), that excessively high oxygen levels may be toxic to roots, but may recover from short periods under these conditions.

The minimum levels of oxygen that roots will tolerate has been mentioned several times previously and it should be evident that roots are able to withstand oxygen levels as low as none at all for short durations with no harm (4) (12) (19) (24) (28). It has been mentioned that the minimum oxygen levels necessary for root growth vary with the temperature and stage of growth of each species (4) (28). Other researchers have declared that for long, extended periods, as little as no oxygen whatsoever is needed for barley roots (provided the nitrate anion concentration is increased several folds) (29), to .5% for roots in general (19), 3% for apple provided roots are over 1 mm. in diameter (1), and as stated by Stolzy et al., 3.5% in the air at the soil surface. So it can be deduced that minimum levels of oxygen vary widely with many influencing variables.

SUMMARY

Cardinal concentrations of oxygen in relation to root growth varies from plant specie to plant specie.
Oxygen concentrations affect the maximal and optimal cardinal temperatures, but not the minimal.
Diffusion rates of oxygen are more influential than partial pressures and temperature changes in maintaining oxygen levels.
Low oxygen levels have an adverse effect on morphology of root cells, and their function.
Low oxygen levels retard development of root hairs, lateral growth of roots, and elongation of roots.
Low oxygen levels increase the thickness of roots.
Oxygen levels affect uptake of water and nutrients.
Oxygen levels are affected by soil bulk density, soil moisture, and diffusion rates.
Diffusion rates are retarded by water.
Oxygen may be translocated from shoots to roots for short periods.

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To live in a scientific age, an age of rapidly accumulating knowledge, imposes heavy obligations upon education and upon the resultant social and industrial controls. In the presence of modern science those who do not know can not long survive, else they must seek the primitive place of the earth where the more elemental practices may persist for a time. Even in these primitive places, science will soon catch up and there will again recur the old biological requirement to learn, to move, or to cease to exist.

Otis W. Caldwell

Perpetuation Of Rare Animals

A ten-year old boy's interest in raising animals grew with his years until today he is the owner of a game farm in Catskill, New York, doing an annual business of over a million dollars from the sale of rare animals and tourist admissions. Last year, half a million visitors ($1.50 for adults and $.75 for children) came to see the 164 species of wildlife (not counting the birds), twenty-four hundred of which are of the horned or hoofed variety. Attendance this year was up fifteen percent over last year's.

The Catskill Game Farm is one of the few self-supporting zoological parks in the country. The farm has been approved by the federal government as a zoological park, which means that it can import animals from certain parts of the world. The facilities meet the rigid standards set up by the U.S. Department of Agriculture.

The game farm opens at 9 A.M. and closes at 6 P.M. daily from April 15 to November 15 every year. In the park or exhibit area of 178 acres, the children are permitted to mix freely with some of the animals during certain hours of the day. The rest of the twelve hundred acres is breeding grounds.

There are a number of specimens which are the sole representatives of their species in the United States: Congo buffalo, Nubian and Somali wild asses, Siberian roe deer, musk ox, and many species of antelope. White rhinos, which have been re-established in sanctuaries in Africa, have recently been added to the exhibits, and while none have been born in captivity so far, the farm hopes to report the birth of this species some day.

The farm, operating as a hobby, was first known in 1933 as Lindemann's Deer Farm. Its founder and owner, Roland Lindemann, studied botany and zoology as a youth, then went to Germany to receive his formal education. This path led him into the banking business. Just as World War II broke out, he sold his controlling interest in several industrial branch banks and returned to his mountain farm. It was open free to the public until 1941.

At that time, expenses and wages were so high that the Lindemanns had to either reduce the number of animals or become commercial. They shut down for a while and reopened the farm as a zoological park in 1945, with a rare collection of 750 deer. Mr. Lindemann traded some of these for other animals and imported others. Eventually, he went to Africa himself to catch more wild animals, also to Australia, Norway, and remote parts of the United States. Today, he has a representative in Africa who traps and catches animals for him.

There are 160 well-trained personnel who work at the game farm. Dr. Heinz Heck is the director in charge; Frank Dovigh, assistant director; Doctors Jenkins and Pettit, veterinarians. They key men live on the game farm. Eighty percent of these specialists attend training courses on the premises to absorb all technical phases of the business. At least a high-school education is required to participate in the courses. Dr. Heck, a zoologist, and others supervise these men in their study of the animals, including identification of every parasite that might breed on them. The courses last nearly six months during the cold-weather season. In three years, these employes are well trained in basic zoology; they then take over every aspect of farm operation. Some are second and third generation workers.

Young zoologists fresh from college also go there to learn and to work. Zoo officials and park executives are frequent guests, coming to buy or to trade animals, to see the latest rare specimen, or simply to exchange experiences and information. Scientific groups are also welcome to study at the farm. Recently, a team of Dartmouth researchers went there to do a study on the rare Przewalski horses which may prove to be a living remnant of prehistoric horses.

Several years ago, Mr. Lindemann realized the need of a special breeding ground to perpetuate these rare animals. He was fortunate in obtaining groups of them for this purpose, so that now, besides managing a zoo and a breeding farm, he is a major supplier to other zoos. Practically all of the equines — zebra, wild asses, prehistoric horses, hartebeests, mountain sheep, and goats — are raised here and distributed to zoos. Today, about half of the game farm's rare animals go to zoological parks, about twenty percent to private individuals, and thirty percent are kept on the premises to build up the farm's own herds. In the near future, an African section with buildings and facilities on forty acres will be opened. Construction already is under way.

Recently, Mr. Lindemann received the silver Robert and Beatrice Everly Award from the Park and Recreation Foundation for excellence in conservation of endangered species. This was presented to him by Mrs. Lyndon B. Johnson at the American Institute of Park Executives' convention in Milwaukee. He has also received a Distinguished Service Award from AIPE and is a Fellow member of the American Association of Zoological Parks and Aquariums.

Mr. Lindemann says people are more zoo-minded today than ever before. He looks to a bright future for the farm and the perpetuation of rare animals.

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FROM

MASSACHUSETTS TURF AND LAWN GRASS COUNCIL INCORPORATED

RFD #2, HADLEY, MASS. 01035

SULPHATE INCREASES AVAILABILITY OF FERTILIZER PHOSPHATE

Evidence that sulphate may increase the availability to crops of fertilizer phosphate is presented in a recent paper by two Austrian scientists. Although the acidifying effect of elemental sulphur on sparingly soluble phosphates such as phosphate rock or dicalcium phosphate is known to make the phosphate content of these materials more available to plants, little work has been done on actual sulphate-phosphate interactions.

The authors of the paper have studied the effect of sulphate and phosphate on tomatoes grown on a krasnozem soil which was not sulphur deficient. Even so, responses to added sulphur were obtained when phosphate was applied. Although the plant sulphur content increased with application of sulphur, the comparatively high content in the control plants indicated that there was no deficiency. The experimental evidence indicates that sulphate improves phosphorus uptake, but only in the presence of applied phosphate.

The authors conclude that where the presence of sulphate enables better utilization of added phosphate such as on certain high phosphate fixing sesquioxide soils, the increasing use of ammonium phosphates and more concentrated superphosphates in Australian agriculture may induce problems not only with respect to sulphur deficiency, but also with respect to the residual availability of applied phosphates. (Menary, R. C. and Hughes, J. D. in *Australian J. Exp. Agri. Animal Husbandry.* **(1967) 7 (25) 168-173.)**

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