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Nutrient Disorders in Turfgrass

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I. Nitrogen, Phosphorus and Potassium

The performance of a turf grass species will be unsatisfactory when either the supply of essential nutrients is insufficient or when some salts are present in excessive amounts. There are 16 nutrient elements which are today recognized to be essential for plant growth, namely hydrogen, carbon, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, boron, manganese, zinc, copper, molybdenum and chlorine. The amounts of each of these nutrients required for optimum plant growth vary greatly but if any one of them is not available, the plant will cease growth and reproduction. It is, therefore, imperative that optimum supplies of each nutrient are given to plants. We may know the best fertilizer rates from long experience, but there are numerous soils and crops where such an experience has not been established. Also it is not likely that soil conditions will remain constant so fertilizer requirements will change. There is thus a need for criteria by which we can recognize nutritional difficulties. Growth will in most cases be reduced but this is a rather non-specific symptom which may also have been caused by many other factors besides nutrient disorders.

Some of the symptoms developed with nutrient disorders are more or less specific and point in the direction of a certain element. They could thus be used to diagnose the problem. Other criteria are obtained from foliar analyses, which have the additional advantage that they indicate approaching difficulties before symptoms of injury appear. Foliar analyses, however, are only useful when we know how to interpret them, i.e. when we know approximately whether a certain level of nutrients indicates healthy, deficient or toxic conditions.

We have conducted a number of experiments in order to establish symptoms of certain nutrient disorders and nutrient levels in plants grown under various conditions. Both symptoms and nutrient levels should serve as a guide line to the man in the field. To a certain extent the work is still preliminary in nature and it is hoped that experiments which are currently in progress by 0. R. Lunt, V. B. Youngner and the author will furnish better detailed information.

Method and Material

Nutrient disorders were investigated with Kentucky bluegrass and bermudagrass *, i.e. with a species from the temperate and a species from the subtropical regions. Two experiments were conducted; in experiment one the plants were propagated from tillers and stolons and in experiment two from seed. The plants were grown in nutrient culture solutions. Hoagland solution I with 5 ppm Iron as Chel 138 and the usual micronutrient concentration was used as a control. As treatments the concentration of one of the following elements was lowered: Nitrogen, phosphorus, sulfur, potassium calcium, magnesium, iron, boron. In experiment 1 the concentration of the element under investigation was 0, 1/20 or 1/10 of a regular Hoagland solution. In experiment 2 the respective concentrations of the investigated elements were 0, 1/20, 1/10 l/5 and 2/5 of the concentrations of the nutrients in a Hoagland solution. While the concentrations of nutrients compared with that of a Hoagland solution, it was necessary to alter the form of the salts in which the nutrients were given. For example, in the minus nitrogen series the calcium and potassium were given in the form of chlorides, in the potassium or calcium series the nitrogen had to be given partly as sodium nitrate.

Excessive amounts of some salts were added to solutions for a diagnosis of certain toxicity symptoms.

After the symptoms of the nutrient disorders were clearly visible the plants were cut, colored pictures were taken and the tissues analysed for the variable element-Standard methods were used for the analyses. Entire tops of the plants were analysed, but once only leaf samples were taken. All nutrient contents were reported on a dry weight basis.

Nitrogen deficiency appeared first in older leaves which turned gradually chlorotic, i.e. pale green and then more and more yellow. Subsequently, leaf blades died starting from the tip.Leaf blades of nitrogen deficient plants were

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**The author wishes to thank Dr. V. B. Youngner for supplying the plant material.*

short and thin. Necrosis on leaf blades of bermudagrass was often preceded by a slightly purplish discoloration. Also, stolon internodes seem to be more intensely purple.

The total nitrogen contents of healthy control plants were 3 to 4% N. Plants suffering from severe nitrogen deficiency on the other hand, contained around 1% N. Nitrogen contents below 3% may indicate an approaching nitrogen deficiency. Between 1 and 3% nitrogen, paler leaves are to be expected. In deficient as well as in healthy plants it appeared that bermudagrass contained less nitrogen than bluegrass. Similar relations were found with other nutrients as e.g. boron, potassium and phosphorus. Growth of plants with insufficient nitrogen supplies is reduced.

Phosphorus deficiency resulted in an increased appearance of purple pigments. Living leaf blades were therefore often dark green. Thereafter they turned purple-brownish and eventually died. A more intense purple discoloration was noticed with the sheaths of bluegrass where the purple color extended higher up and with stolons of bermudagrass. Necrosis starts first with old leaf stumps (truncated blades). Necrosis of older leaves starting from tips of the blades precedes the death of the entire plant. Leaf blades of deficient plants are thin and internodes are short. Growth of severely P deficient plants ceases.

Healthy bluegrass plants contained 0.12 to 0.24% total phosphorus. Contents in bermudagrass were lower between 0.1 to 0.2%. Phosphorus deficient shoots only contained between 0.05 to 0.08% P. We would, therefore, suspect the critical level around 0.1 to 0.2% P.

Potassium deficiency: Initially, bluegrass leaf blades became dark green, then, usually, older leaves turned chlorotic from the tip, sometimes with irregular patches. Older leaves gradually changed to brown and died. The chlorosis resulting from potassium deficiency was rather uniform, i.e. it was usually not restricted to interveinal areas but appeared similar across the entire leaf blade. Pale leaves and tip necrosis were also observed with bermudagrass. The chlorosis also affected stolons which were pale green or yellow. Plants were stunted and yields were reduced.

Healthy control plants of bluegrass contained between 3 and 6% potassium, dark green leaves slightly more than 1%, chlorotic leaves around 1% or less, and necrotic tissues had as little as 0.3% potassium. In bermudagrass potassium levels were generally lower; in dead tissues they were as low as 0.2%.

II. Calcium, Magnesium and Sulfur Deficiencies

In the previous section we discussed nitrogen, phosphorus and potassium deficiencies. These three nutrients are the most important ones as far as the fertilizer market is concerned. In this report we shall describe symptoms of calcium, magnesium and sulfur deficiencies. All 6 nutrients are called macronutrients because they are required in relatively large quantities in nutrients which need to be supplied only in very small quantities. Additions of calcium (and magnesium) to soils are often beneficial for other reasons than supplying an essential nutrient because of effects on the soil structure. Such effects, however, shall not be considered at this place.

Calcium deficiency: Top and root growth are stopped completely and youngest leaves show symptoms of calcium deficiency. In bluegrass a chlorosis appeared at the tip and also near the sheath, irregular streaks were seen along the margin, the blade turned brownish-purple and finally died. Some advanced symptoms resembled later stages of phosphorus deficiency except that calcium deficiency was observed with youngest leaves. Leaves of bermuda plants were small and pale green, young leaves again being affected. Stolon growth was much reduced giving the plant a stunted appearance. The purple color of stolon intermodes was darker in calcium deficient plants.

Calcium contents in healthy bluegrass plants were around 1%; in most severely deficient plants they dropped to approximately 0.10%. It is interesting that calcium contents of healthy bermudagrass grown under the same conditions as bluegrass were two to three times higher. Whether this is a matter of uptake rates or growth rates is not known, in any event, calcium does not follow the pattern observed with other nutrients.

Magnesium deficiency: Old bluegrass leaves turned purple-brown and often died. Younger leaves were chlorotic with veins appearing somewhat greener. The symptoms of magnesium deficiency in bermudagrass consisted of chlorosis of older leaves proceeding to completely yellow leaves and finally to necrosis. Stolons were short and yellow.

Below 0.4% magnesium, deficiency symptoms are to be expected, in extreme cases magnesium contents below 0.1% were found. Healthy leaves contained 0.5% and more magnesium.

Sulfur deficiency resulted in a sharp interveinal chlorosis, usually of the young growth. This was especially the case with bermudagrass. Contrary to other deficiencies where chlorotic tissues were generally pale, the yellow color of sulfur deficient leaves was, at least at the beginning, very intense. In some cases stolons of sulfur deficient bermuda plants may have been more intensely purple.

No sulfur analyses were performed but if experience from some other plants could be applied to turf grasses the critical sulfur content should be around 0.1 to 0.2%.

III. Some problems with micronutrients

Iron deficiency resulted in an intense chlorosis of growing tissues while leaves that had already been formed remained green. Since the dividing tissue is at

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the base of a grass leaf the first symptoms appeared at the base while the tip of a bluegrass leaf remained green. Younger leaves were entirely yellow and growth then ceased completely. The localization of iron deficiency symptoms to youngest leaves was also noticed with Bermuda grass.

iron contents: At below 50 to 70 ppm chlorotic leaves can be expected. There is a good correlation between the iron content of chlorotic leaves and the intensity of the green color.

Boron deficiency: Several experiments were conducted in order to produce symptoms of boron deficiency. None of these were fully successful. In some cases the leaf color changed to a pale gray-green possibly with a bronze tint. Boron contents of such tissues were around 20 ppm.

Boron toxicity has been studied because it may occasionally present a problem in Western States when irrigation water of a poor quality, i.e. with a relatively high boron content is used. Several grass species were grown in 1 strength Hoagland solutions to which excessive amounts of boron had been added. These additions were, however, not much higher than what is considered a normal supply, Boron toxicity led to tip burns and blotchy necroses in tip and marginal areas, From numerous analyses we concluded that boron was accumulated in these specific areas. For more details the reader is referred to a previous publication, (J. J. Oertli, 0. R. Lunt and V. B. Youngner, Agronomy Journal 53: 262-265, 1961).

In that paper it was pointed out that since injury and boron were both concentrated in tip areas mowing will remove the bulk of boron. Growth of turf cut at intervals, therefore, may not be reduced substantially by excessive boron supplies. Since then some critical experiments (unpublished data, U.C.L.A.) have shown that this may be the case for many weeks, but thereafter growth is reduced by excessive boron supplies. There were some indications that environmental conditions may influence the response to boron.

Other micronutrients: No experiments have been conducted to determine deficiency symptoms of manganese, zinc, copper, molybdenum and chlorine since such disorders are rare.

The effect of excessive supplies of zinc or copper was investigated. Both zinc and copper toxicity resulted in tip burns.

Summarizing the data, we can say that most nutrient deficiencies resulted in some type of chlorosis often accompanied by intensified purple colors. A careful comparison of certain details may however permit us to distinguish between various nutrients or groups of nutrients. Symptoms may appear first on new growth as in the case of iron or on the oldest leaves as is typical for nitrogen deficiency. With some deficiencies chlorosis is interveinal as with sulfur or magnesium, while with others it covers the entire leaf area. Other details as purple or chlorotic discoloration of stolons should be of further help. It is hoped that as more experiments are conducted further helpful symptoms will be observed. In combination with foliar analyses it may then be possible to diagnose any nutrient disorder with a high degree of certainty.

After a good diagnosis the cure usually consists of proper fertilization or leaching of toxic substances. Only rarely will there be special problems such as fixation of certain nutrients. In general, corrective actions will not pose great difficulties.

The Mode of Action of Dalapon

By J. K. Leasure
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Dalapon, known chemically as 2, 2-dichloropropionic acid, is a systemic grass herbicide. This means that dalapon enters into the plant and is moved around by the plant throughout its system, thus affecting parts often well removed from the sprayed portions. Of course, dalapon sodium salt, like most chemicals including common table salt, will cause a quick acute burn of plant foliage when applied at high concentrations. This quick burn kills the tissue adjacent to the droplets and may effectively stop movement of the dalapon into the living processes of the plant.

When properly used to take advantage of its systemic properties, sodium dalapon is not applied in sufficient concentration or in phytotoxic mixtures to cause acute foliage burn. Tests with radioactive dalapon have shown that considerable uptake and movement take place within a few hours after application to actively growing grass foliage and penetration into the leaves continues over a substantial period of time. Also, there is movement to areas of high metabolic activity. It seems quite likely that concentrations high enough to cause quick foliar bum might well produce much less control of established plants than lower systemic concentrations.

The study of the mode of action of dalapon is an area of many unknowns. We do not know, for example, exactly how dalapon penetrates through the surface of the leaf to the living tissues underneath. We do not know exactly how it moves from the living leaf tissue down through the stem to the buds or into the roots. We do not know how much dalapon has to accumulate in these bud areas to make the buds dormant or to kill them. We do not know how long a toxic concentration has to be maintained in any one of these tissues in order to kill it. All of these are problems which are worthy of study and are of considerable interest to research workets in the Dow Plant

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Science group, in several land grant college and Federal research groups across the country, and in laboratories in other countries.

One of the first questions to arise in any study of mode of action of any chemical is whether the plant changes the chemical in any way. In the case of dalapon, this question has been answered by work done by the Dow research laboratories in Midland, Michigan, and by others including a research group at the University of California.

Dalapon enters the plant, is moved about through the plant systems and even may be excreted from the roots into the surrounding soil as dalapon. It apparently is not metabolized by the plant to any appreciable extent whatever. On the other hand, dalapon is quickly degraded via microbiological action in soil.

The systemic process in plants has been studied using radioisotope tracers in which one of the carbon atoms of dalapon is replaced by radioactive carbon 14 and by the use of paper chromatography. The technique of paper chromatography has made the analysis of groups of chemicals considerably simpler than before this technique was developed. A drop of plant extract can be separated into the various chemical components by washing it slowly down a strip of filter paper with a suitable solvent.

Since most chemicals found in plants are not readily visible on the paper strip, other methods for finding the chemical on the paper strip must be used. One of the easier ways of doing this is by the use of radioactive tracers. A chemical can be labelled with a radioisotope such as carbon 14 or chlorine 36 and the spots of chemical on the paper chromatogram can then be located by the use of appropriate counting equipment.

Tests with carbon 14-labelled dalapon have shown that extracts of treated plant tissue show only a single radioactive spot on the strip chromatogram and that this spot moves at the same rate as the dalapon which was applied. When this result is obtained with more than one solvent system, it indicates conclusively that the chemical identified from plant tissue is the same as the dalapon which was applied to the plant. Evidence of this type has shown that dalapon is not metabolized nor broken down by either susceptible or resistant plants but remains in the plant tissue as dalapon.

RAPIDITY OF TRANSLOCATION

Since dalapon is not metabolized, the need to follow only a single chemical has made it fairly simple to trace the pathways of dalapon through the plant. This is done by applying a known amount of radio dalapon at one spot on a single leaf, then counting various plant parts at intervals after treating. Tests of this type have shown that dalapon penetrates into and is translocated readily by both susceptible and resistant plants.

Table I showing the results of some work by Dr. C. L. Foy at the University of California indicates the percentage of applied dalapon which was moved out of a treated leaf in various lengths of time.

Tests have shown that dalapon moves readily upward in the transpiration streams either from roots or from lower leaves. It also moves readily downward in the phloem and laterally in the phloem-xylem interchange and readily retranslocates from centers of concentration to new areas of high metabolic activity which may develop later.

There is some disagreement about the influence of the age of plant leaves on the effectiveness of dalapon. It has been reported that it is important to stimulate the growth of Johnsongrass or quackgrass by fertilization and irrigation, if necessary, to get a flush of growth before treatment. Others have reported that this practice is not of prime importance but most observers report the importance of an active growth status at the time of treatment for best results.

TABLE I
Percent of Applied Dolapon-C^{14} Translocated Out of a Treated Leaf

TIME	COTTON	SORGHUM
1 hr.	0.4	0.7
8 hrs.	1.5	2.2
3 days	23.1	19.3
14 days	32.0	29.8

TRANSLOCATION RELATIVE TO LEAF AGE

An experiment by Dr. Foy with labelled dalapon indicates that for best translocation leaves should be fully expanded, green and photosynthesizing fully but should be neither immature nor senescent. A group of sorghum plants each having seven leaves was used for the experiment. A droplet of chlorine 36-labelled dalapon was placed on either the first, second, third or fourth leaf and the amount of radioactive dalapon moved out of the treated leaf was measured at the end of six days. The results are shown in Table II.

TABLE II
Percent of Dalapon-Cl^{36} Translocated in 6 Days Out of Sorghum Leaves of Different Ages

LEAF NO.	PERCENT TRANSLOCATED
1	4
2	22
3	23
4	14

The results showed that the total activity throughout the plant was markedly greater when fully-expanded active leaves were treated than when the fully-matured first leaf was treated. Treatment of the fourth leaf which was large, but young and actively growing itself, produced an intermediate response, probably because the leaf was itself a center of food utilization which naturally reduced outward transport. It would seem, then, that the leaves which should be sprayed with dalapon are those which

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are most actively photosynthesizing- that is, the young, fully-expanded green leaves which are exposed to sunlight. Those leaves which are either quite mature or shaded are probably not of too much importance in the uptake and translocation of dalapon.

SPECIES REACTION

Similar tests have been conducted on plants resistant to dalapon action as well as on plants that are susceptible. Dalapon enters and moves readily through both leaves and roots of susceptible and resistant plants. Transport in both types of plants occurs rather readily and considerable accumulation occurs in regions of high metabolic activity (vegetative buds and fruiting areas). Neither penetration nor metabolic inactivation of the chemical appears to play a major role in determining species reaction to dalapon. Since little difference is noted in either translocation or accumulation, these factors also do not appear to be important in determining species selectivity. There are undoubtedly differences in plant metabolism which account for this selectivity but we do not know what they are.

HOW DALAPON ACTS

It becomes a little more difficult to take the results of isolated experiments such as those reported, combine them with a large number of similar experiments done by many different investigators and put them together so as to tell how dalapon kills a susceptible plant such as Johnsongrass.

Dalapon is capable of producing an acute burn both at the point of contact of the spray droplets and on tissue located at some distance from the original application. Several chemical properties of dalapon solutions may contribute toward this acute butn. Dalapon is both a strong acid and a protein precipitant. Some destruction of cell membranes accounts for the water-soaked appearance of tissues shortly after spraying with high concentrations. The use of surfactants may also contribute to this acute toxicity.

In different kinds of broadleaf plants, acute toxicity often occurs in buds and growing tips well removed from the area of application; presumably, the mechanism is the same. That is, nontoxic amounts of dalapon ate transported but accumulate to toxic levels in these areas of high activity, resulting in burn of the tissues.

Selective dalapon response is evident from lower rates and concentrations, and effects show up primarily in meristems or growing points, either as malformed tissue or as induced dormancy in vegetative buds. It is well known that these effects are especially evident, but not limited to, the grasses. Any attempt to explain the action of a chemical in causing abnormal growth of plant tissues must be in terms of the effect of the chemical on the normal processes of growth and development, and these processes themselves are not completely understood. The specific point of attack of a chemical might be on the production of an enzyme substrate (the source of energy for the enzyme), on the enzyme which attacks the substrate to release energy, or on the enzymes which use the energy thus liberated to produce a different material. The final result probably is a complex series of actions and this very complexity accounts for the fact that the exact mechanisms of action of very few herbicides are known with any degree of certainty whatever.

A seemingly reasonable explanation of the action of dalapon as a growth regulator for grasses revolves around the metabolism of pyruvic acid. Both competitive and noncompetitive inhibition of enzyme reactions have been attributed to dalapon, and Redemann and Meikle at the Dow research laboratory, Seal Beach, California, have concluded that they may occur at the same time. The competitive action was thought to result from the competition between pyruvic acid and dalapon for attachment to pyruvate-attacking enzymes, whereas the noncompetitive action is probably due to the effect of dalapon as a protein precipitant which would inactivate the enzyme complex generally.

Perhaps an even more important site of action, but still involving pyruvate indirectly, is the competitive inhibition of pantothenic acid synthesis which was reported by Hilton of the United States Department of Agriculture. Since pantothenic acid is an intermediate in the production of co-enzyme A, and co-enzyme A is a key compound in plant metabolism and growth through its control of plant energy release mechanisms, the interference with this process in any way could disturb plant growth rather markedly. For example, energy release would be reduced, thus cutting down on both the available potential for growth and the storage capabilities of a plant. This reduction in energy potential could limit the citric acid cycle and reduce the production of nitrogen-containing compounds. (The dark green color of dalapon-treated plants is characteristic of plants having a high level of available nitrogen).

It is probable that dalapon affects more than one primary site of action. It also seems likely that light and temperature can affect the dalapon reaction through their influence on photosynthesis and on the transport of the dalapon in addition to any influence on the enzymatic processes at the site.

IMPROVING FIELD RESULTS

One very important consideration, of course, is how the results of many isolated experiments and theories help us in the field control of a grass pest such as John songrass. As we develop a better understanding of the whole process, we may be led to a critical point to be considered in making the most effective field applications. Until we reach this point, however, we have only some general guides to help us.

First, the age of the plant is important. If the grass being controlled is a seedling, then the smaller the seedling, the lower the dosage required. Also, uniformity of control may be better with young than with old seedlings. If the grass is a perennial such as Johnsongrass with an extensive underground rhizome system, the best

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time to spray is probably when the leaves are well expanded and active downward transport of carbohydrates for root storage is taking place. This would ordinarily be after the first flush of growth and before the seed heads appear. The grass should be in a vigorous stage of growth.

Second, the spray would probably be most effective on the leaves which are most active in photosynthesis. Thus, complete coverage of the lower leaves on Johnsongrass, which might be either quite mature or shaded, probably is not necessary. It is the active foliage that it is most important to contact with dalapon sprays.

Third, since penetration into the leaf starts very quickly and continues over a period of several days, proper coverage of the foliage is important. Other things being equal, a spray with many small droplets should be more effective than the same volume of spray applied in large droplets. Also the use of wetting agents sometimes can be advantageous in obtaining more uniform and complete spray coverage of foliage.

Fourth, conditions favoring a high rate of photosynthesis and downward movement of photosynthates (manufactured carbohydrates) should result in better control. These conditions, of course, would require adequate soil moisture and nutrients, plenty of sunlight and warm daytime temperatures. With a southern grass like Johnsongrass, warm night temperatures also are important.

Fifth, in preplant treatment (particularly for quackgrass) it has been found advantageous to plow deeply following spraying. It appears that the physical action of good deep plowing complements the herbicidal effects of the dalapon. Good plowing, besides being deep, also means complete turn-over of the sod or soil.

Sixth, improved control of established perennial grasses often has followed repeat application of medium to low rates of dalapon. This has been true especially with such pests as Johnsongrass and Bermudagrass and is explained on the basis of increased total absorption of the dalapon in small doses.

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Yellowing of Turfgrass

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A green color is very desirable in turf areas and anything short of this will draw unfavorable attention. Several colors may appear in turfgrass during a season but one color -yellow -is never welcome. Yellowing of turfgrasses may be caused by many factors but some grasses are more prone to "yellowing" than others. Centipedegrass, the worst offender, is the most planted turfgrass in the lower southeast and second only to St. Augustine in popularity in Florida. Centipede is so notorious for yellowing that many people think this is a characteristic of the grass. The bahiagrasses are similar to centipedegrass in this respect. Other grasses show yellowing from time to time but the symptoms are not so common and usually are short lived.

In 1933, 0. C. Bryan reported that yellowing of centipede was caused by a deficiency of iron. He reported that yellow areas treated with ferrous sulfate recovered within 8 days. Since then, yellowing of centipede has commonly been called "iron chlorosis".

Most cases of turfgrass yellowing can be traced to a deficiency of iron but other factors may be responsible. Most important of these factors is nitrogen deficiency. When nitrogen is deficient the entire turf becomes light green or yellow-green in appearance. Manganese deficiency may also cause chlorosis but is not presently considered as a problem. Nitrogen deficiency as a possible cause can easily be ruled out by the addition of nitrogen. If the grass responds to the nitrogen application by greening-up, then nitrogen deficiency caused the yellowing. Addition of nitrogen only intensifies the yellowing when lack of iron is causing the chlorosis.

Symptoms of Iron Chlorosis

When a deficiency of iron is responsible for the chlorotic condition, turf will have irregular areas of yellowing grass. Size of these chlorotic areas may vary from a small part to the entire turf area. Chlorosis is pronounced on the younger grass blades. Repeated defoliation by frequent mowing makes the deficiency symptoms more acute. Advanced stages of iron deficiency are evidenced by a further reduction in green color which intensifies the yellowing. In advanced stages the leaves appear almost white with necrotic areas beginning to show along the margins and especially at tips of the blades. The grass may die in the most severely affected areas.

Causes of Iron Deficiency

A deficiency of iron in the leaves of grass can be caused by one or more of the following factors:

1. A deficiency of iron in the soil.
2. A high soil pH.
3. Antagonism from other essential elements.
4. Scalping or excessive removal of foliage.
5. A poor root system or weak grass.

Iron in the Soil

Florida soils vary considerably in iron content. Sandy soils along coastal areas are usually lowest in iron (400 pounds per acre) while central and northwestern Florida are highest (about 50,000 pounds per acre).

Most turfgrasses have a very low requirement for iron. Where the pH of the soil is not above 6.2, and other conditions are favorable, the supply of iron should be sufficient even in the infertile coastal soils.

Because a soil contains large amounts of iron- even 50,000 pounds per acre – is no guarantee that grass growing on it will be able to use this vast store of iron. A good indication of the availability of iron in a soil is the reaction (pH) of the soil.

The Effect of Soil pH on Iron Availability

At low soil pH levels, iron may become so soluble that it is toxic to roots, and at high pH levels it becomes so

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insoluble that it is unavailable to roots. Between these extremes is a range in which iron is relatively soluble, neither toxic nor unavailable to grass roots. For most grasses this range is between pH 5.0 and 6.5.

Some grasses, such as centipede and bahia are sensitive to low iron availability. When these grasses are planted, the proper soil pH is an even more important consideration. For these two grasses the narrow pH range between 5.5 and 6.2 is best.

High calcium levels in sandy soils produce a high pH and consequently reduce the availability of iron. Such conditions exist in most coastal soils of Florida where marland sea shells are present and soil pH is 7.0 or above.

The number of micro-organisms which carry on many important functions within the soil is affected by pH. These organisms compete at all times for the soluble iron in the soil. Iron contained in soil organic matter is converted into soluble salts and utilized by soil micro-organisms. In the spring when soluble iron reserve is low and the soil supplying power slow, an increasing microbe population (competing for the available iron) may cause a temporary deficiency of iron in centipede or bahiagrasses.

Lowering the soil pH with sulfur or sulfur containing materials, such as ammonium sulfate, is the best approach to solving the iron solubility problem. However, in many soils the calcium carbonate level is so high that pH control with sulfur is not practical. Regular applications of sulfur, acid forming fertilizers and nitrogen sources such as ammonium sulfate have proven beneficial in increasing the iron availability to grass. It is most important to maintain a close check on soil pH when acid forming materials are used over long periods of time. An extremely acid condition in some soil types may be brought about by repeated use of acid forming fertilizers.

Antogonism From Other Elements

Copper -High concentrations of copper in soils are detrimental to grass roots and grass growing on these soils may become chlorotic from a copper induced iron deficiency. Copper induced iron chlorosis is more severe when soil pH is low. Copper also becomes insoluble at high soil pH levels; therefore, as pH increases copper toxicity decreases. Soils containing high copper concentrations should be maintained at high pH levels to reduce copper toxicity. When this condition exists, foliage sprayings of ferrous sulfate or soil applications of chelated iron have given effective control.

Sodium -In soils where the pH is 6.2 or higher, only acid-forming fertilizers should be used. Sodium nitrate should not be used on centipedegrass because, even in acid soils, the sodium in it reduces iron availability.

Nitrogen -High rates of nitrogen applied in the spring may result in an increase in iron deficiency symptoms on both centipede and bahia grasses. This detrimental effect of nitrogen appears mostly in early spring and is not usually a problem after May, The effects of 3 rates each of nitrogen, phosphorus and potassium on iron deficiency symptoms in centipedegrass are shown in Table 1.

TABLE 1
EFFECTS OF THREE RATES OF NITROGEN, PHOSPHORUS AND POTASSIUM ON IRON CHLOROSIS RATINGS OF CENTIPEDEGRASS IN MARCH 1962.

Fertilizer	Pounds 1000 sq. ft./yr.	Chlorosis Rating *
Nitrogen[a] (N)	4	5.7
	8	4.7
	16	3.3
Phosphorus[b] (P_2O_5)	0	4.7
	2	4.3
	4	4.7
Potassium[b] (K_2O)	2	5.2
	4	4.4
	8	4.1

*Rating scale: 1 (very chlorotic) to 9 (no chlorosis)
a. "F" tests indicate nitrogen rates significant.
b. No statistical difference due to these treatments.

Analysis of variance of these data gave a significant "F" test for nitrogen rates. Iron chlorosis symptoms, in the spring, increased as the rate of nitrogen was increased, but this effect was not observed after May.

Spring is the time of year when the microbe population is increasing and the grass is growing vigorously. Competition for soluble iron, in spring, is at a maximum for both grass roots and microbes. Addition of soluble nitrogen speeds up the growth of grass and further increases the use of available iron. Other fertilizer materials produce the same effect but to a lesser extent.

TABLE 2
EFFECTS OF THREE RATES OF NITROGEN, PHOSPHORUS AND POTASSIUM ON IRON CHLOROSIS RATINGS OF CENTIPEDEGRASS IN SEPTEMBER 1962.

Fertilizer	Pounds 1000 sq. ft./yr.	Chlorosis Rating *
Nitrogen[a] (N)	4	7.2
	8	6.6
	16	6.5
Phosphorus[a] (P_2O_5)	0	6.5
	2	6.9
	4	6.9
Potassium[b] (K_2O)	2	7.7
	4	7.2
	8	5.4

*Rating scale: 1 (very chlorotic) to 9 (no chlorosis)
a. "F" tests for nitrogen and phosphorus rates were not significant.
b. Potassium rate "F" test significant at 0.001% level of probability.

Potassium-Studies at the University of Florida show that spring and summer applications of potassium, when added in excess of one pound of K_2O per 1000 sq. ft., produce severe symptoms of iron chlorosis in centipede. One week following applications of potassium, iron deficiency symptoms appeared and persisted about 90 days. These data are shown in Tables 1 and 2.

Phosphorus -Phosphorus combines with iron, in acid soils, to form insoluble iron phosphate. Also, at pH's

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above 6.2 iron forms insoluble iron hydroxide which is unavailable. If soil pH is maintained between 5.5 and 6.2, iron availability is less affected by phosphorus and calcium tie-ups.

Effects of Scalping and Thatch Removal

Scalping is excessive removal of grass leaves by infrequent close mowing or heavy verticutting for thatch removal. Excessive removal of leaves by verticutting or close mowing may result in symptoms of iron deficiency. When clippings are removed, by either of these operations, the iron they contain is lost and this plus the subsequent stimulation of growth, may result in temporary iron deficiency symptoms. Centipede and the bahia grasses are most sensitive to close mowing and verticutting but other grasses may at times show this effect.

It may be desirable to remove excess thatch by scalping or verticutting. To avoid causing iron chlorosis, scalping or verticutting can be done during the winter in northern and central Florida and in the early fall in southern Florida.

Effects of a Poor Root System and a Weak Top

A grass with an extensive root system has a better chance of absorbing the soluble iron present in the soil than one with a limited root system. Any reduction in the root system of a grass reduces its total ability to absorb iron and other fertilizer elements. A weak top (leaf and stems), caused by close mowing or pest damage reduces the amount of roots. During the cool season, grass root growth is faster than top growth; during the summer the reverse is true.

Parasitic nematode populations, that reduce extent and effectiveness of roots, are highest during the warm seasons. Several species of nematodes have been shown to drastically reduce the root system of turfgrasses. Symptoms of iron deficiency are common where nematode populations are high. These symptoms commonly appear on all turf species grown in Florida. Fungus and other diseases that damage grass roots will produce the same effects. Insects that chew on grass leaves, such as armyworms and sod webworms may, indirectly, produce iron deficiency symptoms.

Control of Iron Chlorosis

The cause of iron chlorosis must first be determined before the required control measures can be used. First eliminate nitrogen as the possible cause of the chlorosis by applying a readily available nitrogen source. After it has been established that nitrogen is not responsible for the yellowing, determine pH of the soil. If the pH is above 6.2, apply dusting sulfur at the rate of 2 pounds per 1000 square feet. Sulfur can be applied as a spray or in the dry form but should be washed in immediately after application to prevent burning. Where soil pH is high, 5 lbs. of ammonium sulfate per 1000 square feet should be applied when nitrogen fertilizer is needed. Ammonium sulfate will lower the soil pH and provide the nitrogen and sulfur necessary for grass, Do not use aluminum sulfate for soil pH control.

If soil pH is between 5.5 and 6.2 and iron deficiency symptoms evident, the root system should be examined. Short, stubby and dark roots indicate a very poor root system and a possible cause for iron deficiency symptoms. Nematodes feed on (and inside) roots causing them to be partially, and in some instances, completely non-functional. Treat a small area with nematacide such as Nemagon, Fumazone or VC-13, at the recommended rate and allow 3 weeks for a visible response. If the treated area shows a decided green-up within 3 to 4 weeks, the entire area should be treated.

Alkaline forming fertilizers such as sodium nitrate should not be used. A single application of potash should not exceed 2 pounds of sulfate of potash per 1000 sq. ft.

Control of pH is not feasible in some soil types (such as marls) because the soil is extremely high in calcium carbonate, and the spraying of an iron solution on the foliage is a satisfactory control for iron deficiency symptoms. Soil applications of a chelate formulated for alkaline conditions is a satisfactory control. Periodic additions of sulfur or ammonium sulfate will be beneficial even on marls or other high pH soils. Grass growing in soils high in copper, such as old vegetable field and citrus grove sites, should be sprayed regularly with iron to control iron deficiency symptoms.

Table 3 gives materials and rates that have proven effective in controlling iron deficiency symptoms in turfgras ses.

Grasses sensitive to a low supply of iron or a high pH should not be planted on soils where these conditions exist. However, the symptoms of iron deficiency can be controlled by understanding the cause and using the proper treatment for control.

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TABLE 3
'SOURCES OF IRON AND RATES RECOMMENDED FOR CONTROL OF IRON DEFICIENCY IN TURFGRASSES

SOIL APPLICATIONS	ACID SOILS Metallic Iron Lb/1000 wq. ft.	Lbs/acre	AKLALINE SOILS Metallic Lron Lb/1000sq. ft.	Lbs/acre
Ferrous ammonium sulfate (14% metallic iron)	0.25	10	0.25	10
Ferrous sulfate (coppers) (20% metallic iron)	0.25	10	Not Recommended	
Lron chelate	Use manufacturer's recommendation		Special formulation for alkaline soils Use Manufacturer's recommendation	
FOR FOLIAGE SPRAYING	FOR BOTH ACID AND ALKALINE SOILS Pounds of metallic iron per 100 gallons of spray per acre.			
Ferrous sulfate (20% metallic iron)	10			