# HORTICULTURAL CROPS PLANT NUTRITION SERIES

**Volume VIII**
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**Department of Horticultural Science**
**Texas A&M University**
**College Station, TX 77843-2133**

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**Editor: J. Benton Storey**

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**Preface**

The review papers in this volume represent many hours of work on the part of each student and their editor. They are presented as a permanent record of the dedication of this class to the science of mineral nutrition. The topics represent an important aspect of mineral nutrition being studied, and in some cases practiced by the author.

Chris Freeman has raised the level of this course to heights it has never known by first writing a Home Page for it during the summer and second by solving the mysteries of TTVN. He has been the production manager during the semester by bringing us on line each class meeting, setting up the computer, and recording some of the sessions.

I want each one of you at College Station, Commerce, Tarleton, and Texarkana to know how much I have appreciated you this semester. You have been very attentive and have worked hard in this very dynamic and interesting field of plant nutrition. Volume VIII of the *Horticultural Plant Nutrition Series* published by this Department includes a chapter written by each of you which will be a tangible accomplishment that you can keep in your library and on your resume.

I wish everyone of you success in your graduate study and in the productive life that you have ahead of you. I hope you will take the nutrition facts that you have learned and build on them. Some of you may have opportunity to expand our knowledge of these facts through research and others will teach your students the principles of plant nutrition. All of you will have the opportunity to use the information you have learned throughout your life time, so continue to study plant nutrition and enrich the knowledge you already have in this exciting field.

I owe a great deal to Dr. Don Cawthon, Dr. Connie Fox, and Mr. Mark Storey (who recorded the sessions) for their long hours of facilitating this course at Commerce, Tarleton, and Texarkana respectively. The many e-mail, fax, and phone messages have paid off as we have joined forces to fulfill our Land Grant Mission of meeting the needs of students across the state. I hope there will be many more TTVN courses offered between our campuses. It was my privilege to work with Don and Connie, both of whom I have known for a long time, but have not often had the honor of working with. And it was a special privilege of working with my son who is well on his way in the field of Science Education. I wish all of you the very best as we have proven to the world that Distance Education has great potential in the field of Horticulture.

J. Benton Storey, Ph.D., CPH
Editor

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# Retranslocation as a Mechanism in the Nitrogen Budgeting of Plants

**Douglas R. Smith**
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*Additional index words.  nitrogen recycling, translocation, leaf senescence, leaf abscission*

**Abstract.  Throughout the growing season, N availability is often compromised by a number of conditions.  Many plants utilize a process known as retranslocation to increase their Nitrogen Use Efficiency.  In many cases, the amount of recycled N can account for 60 to 75% of the total N taken up annually by the plant.  Many experiments have studied the rates as well as the mechanism of retranslocation.**

Higher plants have processes available to them that allow minerals and other nutrients to be moved from one location in the plant to another.  This transport occurs in a source to sink relationship, which means the nutrients are taken from one area, generally of higher concentration, to another where it is needed.  This transport occurs in both xylem and phloem tissues.  Most mineral nutrients are transported from the roots to shoots by the xylem tissue.  Mineral nutrients as well as photosynthates can be transported from leaves, or other portions of the shoots, to other leaves, fruits, roots, or other sink sites via the phloem tissue.

Minerals are moved from the site of original deposition to new locations through processes referred to as retranslocation or remobilization.  These processes occur with most of the mineral nutrients, and are a very important part of the mineral budgeting of higher plants.  The most common destinations for retranslocation are new leaves or the root system.  In fact many plants cycle their nutrients in a series of retranslocations (Marschner, 1995).

**Retranslocation as a part of the N recycling process**

Nitrogen is the most limiting mineral nutrient in plants, and is the most commonly used fertilizer nutrient (Heckathorn and Delucia, 1996). Many plants have evolved mechanisms to save as much of the N as possible during harsh conditions such as drought and during the senescence of leaves. As the soil moisture drops, so does the availability of N to the plant (Li and Redmann, 1992).

Nitrogen is recycled through a series of translocations. Both $NO_3$ and $NH_4$ are taken up by the roots. Nitrate, a readily xylem mobile form of N, is transported to the shoots. At the cellular level in the leaves, $NO_3$ is responsible for a host of different activities especially in the vacuole. Nitrate must be reduced to $NH_4$, prior to entering metabolism.

The process of reduction of $NO_3$ to $NH_4$ is normally coupled to the production of amino acids, which helps avoid $NH_4$ toxicity. The C chains used in the production of amino acids are derived from the tricarboxilic acid cycle (TCA cycle), often in the form of pyruvate and $\alpha$-ketogluterate(Voet and Voet, 1995). The most common amino acid in plants is glutamine, which is also a precursor to several other amino acids (Jeschke and Pate, 1991; Voet and Voet, 1995). N-reduction occurs only in cells that are carrying on respiration and, depending on species, can occur in both roots and shoots. Some amino acids may only be synthesized in the shoot, however (Larsson et al., 1991).

New *Agropyron dasystachyum* leaves contain much higher N concentrations than the older leaves located two nodes down. Higher concentrations of N in new leaves may be due to increased amounts of carbohydrates in the older leaves, and the retranslocation of N from the older to the newer leaves (Li and Redmann, 1992). The main cause of the retranslocation to the newer leaves is the increased demand for N, and possibly a low availability of N in the soil.

**The process**

Retranslocation occurs in a series of steps, mediated by an assortment of biochemical reactions. Initial reactions must result in the nutrient becoming available. Availability occurs either through breakdown of proteins or by the addition of a chelate. Either way, the nutrient must become mobile in the phloem sap. Several biochemical processes can increase availability including enzymatic action and plant hormones. Some nutrients such as Ca are not as mobile in the phloem and have much lower rates of retranslocation (Andrews and Siccama, 1995).

Retranslocation starts in the individual leaf cell with mobilization. The minerals are then taken to the phloem through short term transport, and loaded into the phloem, where it is transported to the required site (Marschner, 1995).

**Why is retranslocation necessary?**

There are many different reasons for plants to retranslocate nutrients, especially N. In many tallgrass prairie species, N retranslocation occurs as a response to drought. This is a method for these plants to preserve N by removing it from shoots for retranslocation to and storage in the roots and rhizomes. Once placed in these storage organs, the N is not susceptible to losses through fire or herbivory. Retranslocation prevents losses due to senescence, and increases root growth thereby increasing water uptake (Heckathorn and DeLucia, 1994).

Some plants fulfill the majority of their N reduction in the shoots. In these plants, it is necessary to retranslocate N in the reduced form to the roots (Marschner, 1995). This process may also provide important feedback to the roots on what is available as well as what is needed in the shoots.

**Retranslocation in Grains**

Nitrogen can be retranslocated to other sites of high demand as well. For instance, grains have a high demand for N. One of the selection criteria for grains as a feed component is the Nitrogen Harvest Index (NHI) which is the ratio of grain N to total aboveground plant N. The NHI is "often regarded as a measure of retranslocation efficiency of N from vegetative plant parts to the grain" (Bulman and Smith, 1994). Reports of as high as 90 to 100% of total N present at maturity has been accumulated by the time of anthesis in wheat (*Triticum aestivum* L.). Studies also suggest that N uptake and N retranslocation are negatively correlated (Bulman and Smith, 1994). Therefore, it can be assumed that the bulk of N for grain fill is a result of retranslocation.

When $^{15}N$ was used to label root uptake of wheat, it was found that 80 to 95% of that fraction absorbed was moved to the shoot within 24h (Larsson et al., 1991). Between 10 an 15% of this fraction was then remobilized and transported to the roots. It is thought that this relatively quick return to the roots by that fraction incorporated into the shoot may provide a relatively efficient system allowing shoots to provide feedback to the roots and influence uptake (Cooper and Clarkson, 1989). The same authors also proposed that a common pool of cycling N provides the shoots as well as the roots with a readily available source of N that can be drawn upon as demanded by the tissues.

It has been proposed that a majority of the N cycles through a wheat plant at least once before being incorporated in to the shoot. In an experiment by Simpson et al. (1982) the entire fraction of N taken in a 24 h period appeared to be transported through the phloem before 80 %

of that fraction was incorporated in to the shoot tissue. In experiments with rice, it was found that N was cycled through older leaves before being retranslocated to the meristematic tissues of the roots and shoots (Simpson et al., 1982).

**Retranslocation in Woody Species**

Extensive research has been undertaken in the field of retranslocation as it relates to trees. It has been shown that fertilization has positive effects on Corsican pine for up to 12 years after only one application (Crane and Banks, 1992). Estimates as high as two thirds of the N required for production of new foliage is supplied through retranslocation from senescing or abscising leaves. A prolonged abscission period has been explained as an adaptation to nutrient shortages (Escudero et al., 1992). This is possible if one considers leaves or needles as a storage organ, where nutrients can be remobilized when needed, before the organ is abscised.

Throughout the life of a leaf, the N concentration decreases. Decreasing concentration occurs primarily due to dilution as carbohydrates build up in the leaf. As senescence occurs however, N concentration continues to decline as N is retranslocated to “sinks” (Negi and Singh, 1993).

The primary factor associated with the efficiency of N retranslocation in trees is the abscission period. A longer abscission period decreases the efficiency of retranslocation (del Arco et al., 1991), and may be associated with the difficulty in determining exactly when an individual leaf will shed (Escudero et al., 1992). This phenomenon is found in both evergreens as well as deciduous species. Deciduous and evergreen species differ considerably in N retranslocation. *F. micrantha*, a deciduous species, showed 75.3 % retranslocation for N, while only 53.6% of needle N was retranslocated for the evergreen *R. arboreum* (Negi and Singh, 1993).

Contrary to popular thought, woody species native to low fertility soils are not more efficient in their retranslocation abilities. In fact the opposite is true. The species native to more fertile soils have higher concentrations of organic N that can be hydrolyzed, releasing the highly mobile amino-N (Negi and Singh, 1993).

**The costs of retranslocation**

Although retranslocation has many benefits certain problems are also associated. In tallgrass prairie species, a rate of retranslocation of approximately 30% of foliar N has been found to retranslocate under drought stress. This comes at a cost of lowered C accumulation in the immediate post stress interval, due to the placement of N in the roots and rhizomes as opposed to the photosynthetically active shoots (Heckathorn and Jeschke, 1996).

Cycling of N also costs the plant energy. Although this energy is important to overall plant production, it is considered negligible when compared to the benefit of providing a readily available N supply throughout the plant (Simpson et al., 1982).

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# Are Slow Release Fertilizers a Viable Alternative to Water Soluble Fertilizers?

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*Additional index words. controlled release fertilizers, ornamental crops, top-dressing, nutrition*

***Abstract.*** **Increasing awareness of the waste and pollution of natural resources has placed pressure on greenhouse growers to lower the amount of fertilizer runoff and to use water and fertilizers more efficiently. Many potentially useful ways to address this problem have been researched, one of which is the use of various slow or controlled-release fertilizers. With a few modifications, these fertilizers have been shown to reduce fertilizer runoff and at the same time increase plant nutrient uptake.**

Growers must supply their crops with the proper amount of essential nutrients in order to produce the highest possible quality crop in the shortest possible amount of time. This requires a constant nutrient supply and precise applications (Maynard and Lorenz, 1979). With concerns increasing over the supply and quality of our water, greenhouse growers are under more and more pressure to use fertilizers more efficiently. Among the many suggested solutions to the problems of groundwater contamination and fertilizer use efficiency is the use of slow release fertilizers, also known as controlled release fertilizers (Barron, 1974).

**Controlled Release Fertilizers are Available in Various Forms**

Two categories of controlled release fertilizers, differing in method of release control, are available. One group achieves control of release via the slow solubility of the chemicals used. These include isobutylidene diurea and urea-formaldehyde, both of which are slowly soluble. The other group achieves control of release by coating soluble fertilizers with either slowly soluble sulfur (sulfur-coated products) or with insoluble plastics (resin or polymer

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coated products). Degradation of some slowly soluble fertilizers (sulfur-coated products and urea-formaldehyde) is accomplished by soil microbes. Plastic coated fertilizers (Osmocote®, Nutricote® and various other name-brands) allow water to diffuse into the prill, which dissolves the fertilizer inside, creating a nutrient solution which diffuses out of the prill and into the media. This diffusion is dependent on media temperature, with higher temperatures leading to faster rates of diffusion and thus faster release of nutrients (Oertli and Lunt, 1962; Barron, 1974).

**Fertilizer Efficiency**

Fertilizer efficiency is the proportion of applied plant nutrients which is actually taken up by plants and can be considered as kilograms of nutrient taken up compared to kilograms of fertilizer applied. Much of the fertilizer applied is lost by various means, such as leaching, fixation into unavailable chemical forms and N volatilization into the atmosphere (Barron, 1974). Experiments have been conducted to compare the efficiency of water soluble fertilizers to controlled release fertilizers. Water soluble fertilizers are generally believed to be inefficient, although they are still the most common method of fertilization used (Barron, 1974; Hershey and Paul, 1982). The efficiency (defined as the percentage of applied N absorbed by the plant) of liquid feed fertilization has been estimated as 46% and that of Osmocote® (a controlled release fertilizer) as 89% (Holcomb, 1980).

**Nutrient Leaching and Pollution of Groundwater**

Much of the fertilizer applied to plants with fertigation is lost due to leaching. This represents a problem for the environment as well as for greenhouse crops. As pressure increases for more conscientious use of our natural resources, ways to eliminate fertilizer runoff and contamination of groundwater are being sought (Hicklenton, 1990; Cox, 1993). One way to control loss of nutrients via leaching is to use controlled release fertilizers (Oertli and Lunt, 1962). It has been found that total nitrogen lost from containers of pot chrysanthemums over the course of four weeks was lower for controlled release than for water soluble fertilizers. However, it was also found that there was just as much or more leaching from controlled release fertilizer treated pots than from water soluble fertilizer treated pots in the first two and a half weeks (Hershey and Paul, 1982).

**Plant Nutrient Uptake Varies With Plant Development**

Plants require differing amounts of nutrients at differing phases of their growth cycles. Ideally, the concentration of nutrients available to plants will parallel the needs of those plants (Barron, 1977). An application of various controlled release fertilizers at the recommended label rate exceeded the needs of the plant in the first few weeks of the growing cycle (measured by the amount of nitrogen in leachate samples) (Hershey and Paul, 1982; Cox, 1993). More nutrients being released at the beginning of growth, when roots are not extensive and therefore unable to take up a large supply of nutrients, is therefore wasteful. As a solution to this problem, a lower amount of controlled release fertilizer, perhaps one-half rate, could be used at planting and a second application, also one-half rate, made two to three weeks later (Cox, 1993).

**Fertilizer Analysis and Release Rate are Important**

As with all fertilizers, controlled release fertilizers have varying analyses and the analysis chosen should coincide with the needs of the plant. Also, the nutrient needs of the plant should be considered when deciding how much controlled release fertilizer to apply. Labels generally give one recommended rate and are not specific for specific crops. It is therefore important for the grower to be aware of the nutrient requirements for each particular crop. In addition, controlled release fertilizers have various methods and rates of nutrient release which should be considered when using them. This information is generally available from the manufacturer (Barron, 1974).

**Placement of the Controlled Release Fertilizer Should be Considered**

The primary method of applying controlled release fertilizers has been incorporation into the media prior to planting. As mixing methods are not always efficient and storage of media with incorporated controlled release fertilizer is not recommended (nutrients are released even though no plants are present), an alternative placement would be beneficial to most growers (Meadows and Fuller, 1983). Several different placement locations have been tried with varying success. Meadows and Fuller (1983; 1984) found that controlled release fertilizer placed directly into the dibble hole when transplanting cuttings or seedlings (referred to as "dibbling") produced superior plants (based on quality ratings) and also that dibbling reduced the amount of nutrients found in leachate samples than incorporation. In a separate study (1984) they also found that placement of controlled release fertilizer in the bottom of the pot (on top of 1 cm of media) produced plants of lower quality. Another common method is to apply the controlled release fertilizer to the top of the media after transplanting (called top-dressing). Payne and Adam (1980) found no significant differences between top-dressing and incorporation of controlled release fertilizers.

**Conclusions**

It has been shown in many studies that, with a few modifications, controlled release fertilizers can be more efficient and less polluting than water soluble fertilizers. Several factors should be considered when choosing the type, rate, and placement of these fertilizers. The type of controlled release fertilizer chosen will be dependent upon the needs of the plant, the type of media used and by personal experience and preference. The rate of controlled release fertilizer will also be specific to the specific crop involved, but will also be influenced by the growing cycle of the crop. Newly transplanted seedlings and cuttings would require less controlled release fertilizer with a second application later in the growing season. The choice of placement of controlled release fertilizers would depend on personal use. If a grower plans to use all of a batch of media within a short amount of time, he or she may choose to incorporate the fertilizer before planting. However, if the media will be stored for a significant amount of time, perhaps top-dressing would be beneficial.

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# Iron Deficiency on Bentgrass Golf Greens


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*Additional index words.* chlorophyll synthesis, respiratory enzymes, *Agrostis stolonifera, Agrostis palustris*



***Abstract.*** **Most iron deficiencies in bentgrass are a result of high soil pH levels or alkaline soils. Iron is a necessary micronutrient for chlorophyll synthesis thus playing a vital role in turfgrass color. Iron is immobile within the plant and is removed quickly from frequent mowing that bentgrass requires for putting green surfaces. This requires frequent low application rates of iron to replenish the plants need for iron. Acceptable levels of iron within the plant enhanced visual shoot quality by causing a darker green color of the leaf blades. Response to iron applications varies with environmental conditions. Favorable turfgrass conditions favor an increased uptake of iron into the plant. When maintained at acceptable levels in the plant, iron can help bentgrass maintain high visual shoot quality under high traffic and low mowing heights that occur on golf course greens.**


Creeping bentgrass (Agrostis palustris) provides an excellent putting surface for golf greens and is the choice of most golfers in the world. Extremely low mowing heights, heavy traffic from golfers, and frequent irrigation subject bentgrass greens to severe summer stress. Management of bentgrass, a cool-season species, in hot-humid climates in the southern United States is a difficult task.

Iron has been applied to turfgrasses for color enhancement and improved growth under Fe deficient conditions (Deal and Engel, 1965; Minner and Butler, 1984). A dark green color is a major component of visual shoot quality on bentgrass greens. To promote this aesthetic beauty, Fe has been applied to promote a darker green color for cool-season turfgrasses grown on Fe sufficient soils (Carrow, 1983; Schmidt and Snyder, 1984; Snyder and Schmidt, 1974; Wehner and Haley, 1990).

## Physiological effects of Fe

The physiological functions of Fe within the grass plant are primarily twofold. First, although Fe is not part of the chlorophyll molecule, it is one of the nutrients essential for chlorophyll synthesis (Beard, 1973; Duble, 1996). Secondly, Fe is a constituent of certain enzymes in the respiratory system. Thus, since Fe is required for chlorophyll synthesis, levels of Fe available to the plant influence turfgrass color.

Iron is also a constituent of certain respiratory enzymes such as catalase, peroxidase, and cytochrome oxidase (Machold and Scholz, 1968). The most well known heme proteins are the cytochromes. Cytochromes are constituents of redox systems in chloroplasts in addition to being a component in the redox chain in nitrate reductase (Marshner, 1995). Catalase and peroxidase activity declines under Fe deficient conditions. The decreased activity of catalase reveals Fe deficiencies in the leaves of plants. In Fe deficient roots, peroxidase activity is depressed. This does not benefit the plant due to the requirement of peroxidase for biosynthesis of lignin and suberin (Marshner, 1995).

## Iron deficiency causes and symptoms

Iron is the micronutrient most commonly deficient in turfgrass. An Fe deficiency is usually a result of insolubility rather than an absence of the element in the soil (Beard, 1973). Deficiencies of Fe are most common in alkaline soils, soils high in organic matter, poorly draining soils, and in areas where excessive thatch is present. Iron deficiency symptoms usually show when leaf tissue is below 50 ppm Fe (Duble, 1996).

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When an Fe deficiency becomes evident, the condition first appears as an interveinal yellowing of the youngest actively growing leaves.  This condition can give the leaf blade a striped appearance.  Iron deficiency symptoms are quite similar to the symptoms for N deficiency except that it first appears on the younger leaves (Oertli, 1963).  Continued frequent Fe applications are necessary to maintain a dark green color on bentgrass golf greens.  When deficiencies occur, even a browning appearance may occur along with the interveinal yellowing.

## Factors effecting Fe uptake by bentgrass

Plants can absorb Fe as either the $Fe^{2+}$ or $Fe^{3+}$ ions.  However, Fe is physiologically active only in the $Fe^{2+}$ state (Beard, 1973).  Iron is a micronutrient and the amount of Fe found in plant tissues is minimal.  Iron is also immobile in the plant.

Several plant attributes, environmental conditions, and management practices can effect uptake of Fe.  On sand-based bentgrass greens, excessive fertilization can often occur to meet high standards of club members.  This can create high P levels resulting in a decrease in Fe uptake.  Poorly drained soils in addition to excessive irrigation can also reduce uptake.  Environmental factors such as low soil temperatures, excessively dry soils, and areas receiving low light will also exhibit less Fe uptake.  Plant genetics can be a dominant factor determining the amount of Fe uptake.  Different cultivars of the same species can exhibit quite different amounts of Fe uptake (Duble, 1996).  All of these factors can influence the quantity of Fe uptake by bentgrass.

In Virginia, Snyder and Schmidt (1974) reported the greatest Fe color enhancement on bentgrass during cool, dry periods.  In Georgia, where Fe applications on creeping bentgrass in stressful summer months is common, research was conducted indicating that color and quality responses to Fe applications were minimal during this stressful period (Glinski, Carrow, and Karnok, 1990). Ideally, Fe application should be applied when bentgrass is at peak growth and under minimal stress. This does not occur on many golf courses during hot summer months when many people are playing golf. Careful analysis should be given to determine if frequent Fe applications are cost effective or simply a waste of time and money.

## Correcting Fe deficiency in bentgrass

Since Fe deficiencies of turfgrasses grown on alkaline soils is common, one approach to correcting Fe chlorosis has been to reduce soil alkalinity to allow more Fe uptake by the plant ( Minner and Butler, 1984). This can be accomplished by applying acidifying materials such as sulfur or sulfuric acid. This type of application is not practiced as a management tool for bentgrass golf greens. Instead, products such as $FeSO_4$ are more commonly used and applied as a foliar spray (Sturkie and Rouse, 1967). This product is usually applied at a rate of 60 ml to 150 ml per 93 $m^2$. There are many other products that work well as foliar applications. These products such as Ferromec® and MaxiGreen® are more commonly used. Ferromec® consists of 15% N, 3% S, and 6% Fe. Iron chelates are quite effective on common turfgrass mowed infrequently. However, due to high maintenance qualities of maintaining bentgrass at extremely low mowing heights (0.3 cm), foliar applications are more advantageous. These foliar applications are usually not chelated. Chelates are more difficult for the plant to absorb than other smaller ions.

Applications of Fe to bentgrass do improve color and visual shoot quality of the plant. However, the duration or residual of Fe applications does not last for an extended period of time. Typically, Fe applications improve color of bentgrass for only 1 to 3 weeks. Maximum color response can occur within days of a foliar application if environmental conditions are favorable. In bentgrass, Fe is immobile in the plant and is removed with clippings. Since most bentgrass is mowed daily, the response is short lived. This calls for repeated Fe applications on a biweekly or monthly basis to maintain high visual shoot quality for golf course greens.

## Conclusions

Creeping bentgrass greens are extremely difficult to manage in stressful summer months. It is proven that Fe applications can enhance color shoot quality in all months ( Glinski, Carrow, and Karnok, 1990). Response rates vary during seasons with favorable bentgrass growing conditions increasing uptake of Fe by the plant.

Perhaps the best indicator of Fe deficiencies will be soil pH. A good turf manager monitors soil pH constantly and management techniques need to be exercised to keep pH between 6 and 7 if possible. Applying products with sulfur in the analysis can help lower pH slightly to increase Fe uptake by the plant. The pH level between 6 and 7 promotes maximum turf growth, which will reduce the chances of experiencing Fe deficiency symptoms.

Iron deficiencies are not usually so severe to become fatal to the plant, but can severely decrease visual quality of bentgrass. Repeated low rate applications will help keep Fe levels from being deficient in the plant and will promote healthier, high quality bentgrass. Iron is only one micronutrient and acceptable levels of other nutrients needs to be carefully examined and maintained.

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# Nitrogen Fertilization and its Effect on Chinch Bug Populations in Sorghum and St. Augustine grass

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*Additional index words. Stenotaphrum secundatum, Blissus leucopterus* complex.
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***Abstract.*** **Overwintered chinch bug females reared on susceptible varieties of sorghum developed faster, lived longer, laid more eggs, and had a lower mortality than those reared on resistant varieties. Chinch bug resistance was decreased by the addition of sodium nitrate and increased with the addition of superphosphate in pot and field experiments. Experiments conducted on chinch bug populations in St. Augustinegrass showed that an organic source of nitrogen resulted in lower chinch bug populations and lower levels of damage to the turf when compared to an inorganic source of nitrogen. Chinch bug responses to highly available nitrogen may be due to a preference for lush turf, or biological regulation effects such as mortality and oviposition rates.**

**Introduction**

Nitrogen is important to insects as well as plants. There is a marked difference in the N content of insects (7%) and plants (2%). Because of this difference insects must consume the parts of the plant that will yield enough N for the insect to grow and reproduce (Dale, 1988). Fertilization will effect host selection, growth rates, survival and reproduction of insect populations. Generally N fertilization increases insect populations and their subsequent damage (Mattson, 1980). However in some cases the opposite maybe true. According to Scriber (1984), a minimum of 115 studies show that

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an increase in N fertility increased insect growth, fecundity, and populations. Conversely, a minimum of 44 studies indicate a decrease in insect populations or resulting damage to plants with increase N fertilization.

It is the purpose of this paper to review the findings of several experiments investigating the effects of N fertility on chinch bug populations in sorghum and St. Augustinegrass.

**Varietial differences in sorghum to chinch bugs**

A series of experiments were conducted by R. G. Dahms at the Oklahoma Agricultural Experiment Station in 1936 to investigate the effect of several varieties of sorghum and other host plants on biology of the chinch bug. The first experiment investigated the relationship of plant variety in the seedling stage on oviposition and longevity of adults. Dahms found that overwintered females reared on chinch bug susceptible varieties lived longer, laid more eggs, and had a higher daily oviposition rate than those reared on resistant varieties.

Another series of experiments were conducted to determine the effect of a resistant cultivar (Atlas sorgo) and a susceptible cultivar (Dwarf Yellow milo) on rate of development, mortality, and body length of nymphs. The average duration of each stadium, which is the time interval between instars, was higher in the chinch bug resistant variety (Fig. 1). First generation varietial difference was small for the first three instars, but became more pronounced in instar four and five . Differences in development of instars became more pronounced in the second and third generations. The lack of differences in development time for the initial three stadia of the first generation may be attributed to the fact that adults were collected from barley, an excellent host for chinch bugs. As the chinch bugs feed and developed varietial differences in became more pronounced.

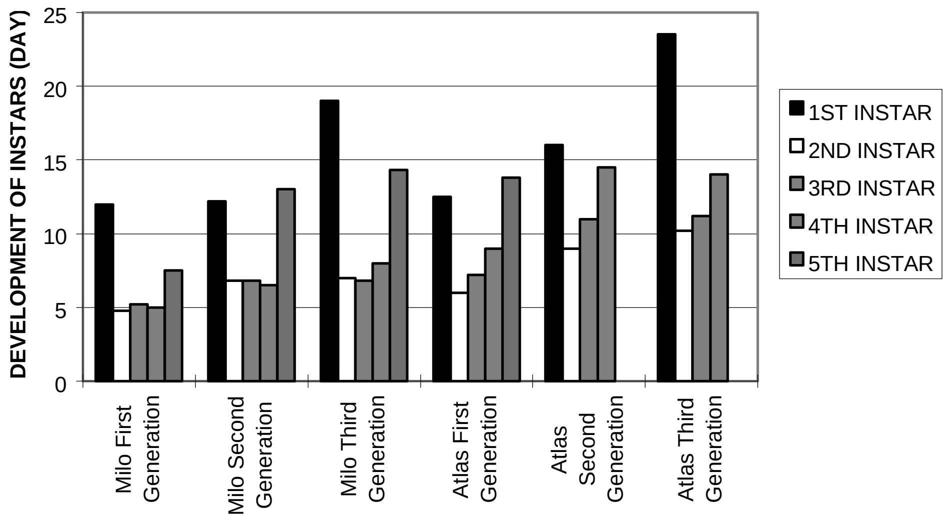


**Fig. 1.** Rate of development of first, second and third generations of chinch bug nymphs reared on seedling plants of Dwarf Yellow milo and Atlas sorgo, Lawton Okla., 1935. (Based on Dahms et al. 1936.)

Mortality was high for the first-generation nymphs on both varieties during the first stadium (Fig. 2). Only four of the 25 nymphs that reached the second instar became adults on Atlas sorgo where 23 reached adulthood on Dwarf Yellow milo. The four adults reared on Atlas sorgo survived for only 3 days. The 23 adults reared on Dwarf Yellow milo were active, copulated and all of the females laid eggs. The average length of 5$^{th}$ instar nymphs and adults reared on the susceptible cultivar was 0.5 mm longer than those reared on Atlas sorgo (Dahms et al., 1936).

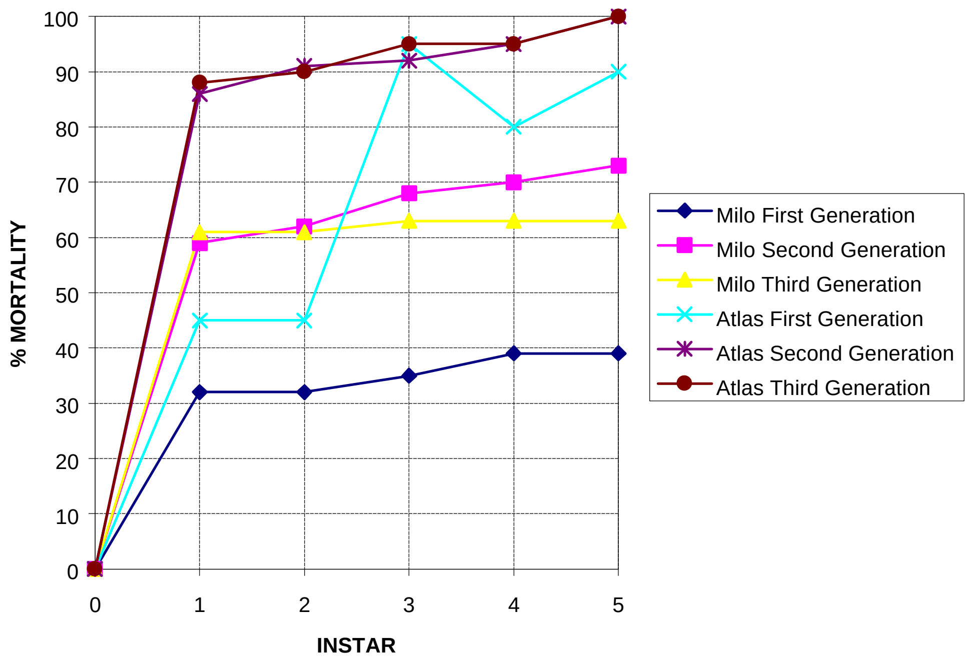


**Fig. 2.** Mortality of the first, second and third generation of chinch bug nymphs reared on seedling plants of Dwarf Yellow milo and Atlas sorgo, Lawton, Okla., 1935. (Based on Dahms et al. 1936.)

**Effects of N on chinch bugs in sorghum**

The findings of Dahms et al. (1936) initiated a second series of experiments by Webster and Mitchell to determine the N fractions in Atlas sorgo and Dwarf Yellow milo sorghum plants. Amino N combined with the basic fraction (diamino acids) account for higher percentages of soluble N found in the susceptible cultivar (Fig. 3). They concluded that resistant cultivars generally have a lower N content than susceptible varieties grown under like conditions (Webster and Mitchell, 1940).

The effect of fertilizers on chinch bug resistance in sorghums was the next area to be investigated. Dahms and Fenton (1940) found that in pot and field experiments with Atlas sorgo, Dwarf Yellow milo, and Finney milo the resistance to chinch bugs was decreased by the addition of sodium nitrate ($NaNO_3$) and increased with the addition of superphosphate to soils.

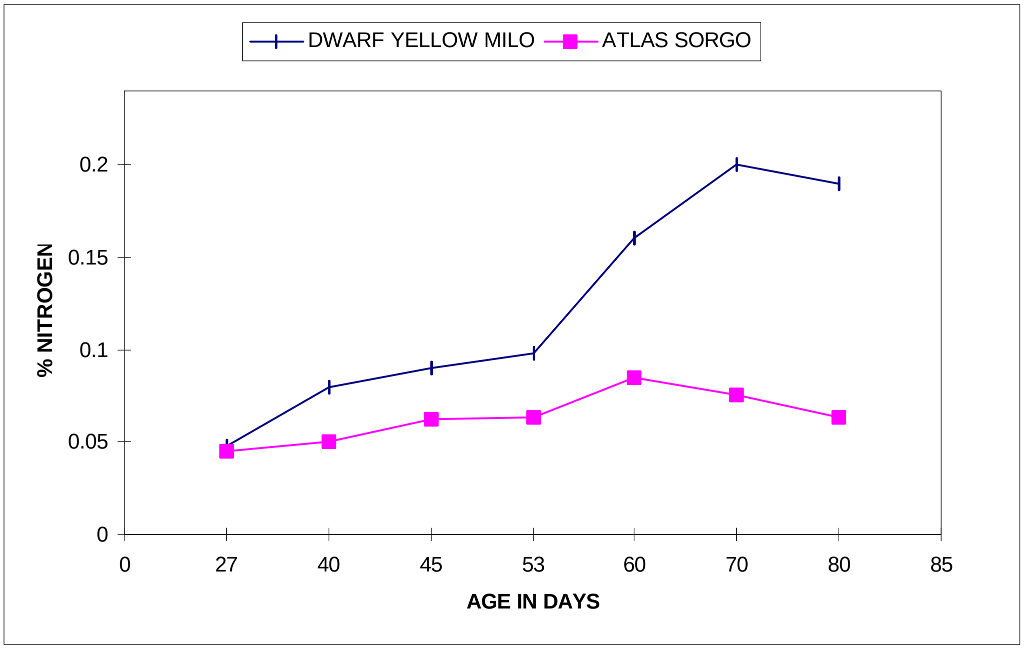


**Fig. 3.** Combined percentages of amino and basic nitrogen for a resistant cultivar (Atlas sorgo) and a susceptible cultivar (Dwarf Yellow milo). (From Dahms and Fenton, 1940.)

With the previous experiments as a basis another series of experiments were initiated to investigate the effect of P, N, and other nutrients on the oviposition and longevity of chinch bugs on seedlings grown in various nutrient solutions. According to Dahms (1947), more eggs were laid on plants growing in high N solutions versus plants growing in low N solutions. Chinch bugs feeding on plants in low N solutions or high P solutions had lower oviposition rates compared to bugs reared on plants grown in high N or low P solutions for Atlas sorgo and Finney milo. Dahms (1947) concluded that the addition of N to soils deficient in N would benefit chinch bugs, while P amendments to P deficient soils would be detrimental to chinch bug populations.

**Effects of N on chinch bugs in St. Augustinegrass**

Several experiments were carried out by Horn and Pritchett using 'Floratine' St. Augustinegrass, 'Emerald' zoysiagrass, 'Tiflawn' bermudagrass, and centipedegrasses to investigate the response of chinch bug populations to different sources and rates of N, P, and K (Table 1). The results show that source and rate have an effect on the susceptibility of 'Floratine' St. Augustinegrass to chinch bug injury (Horn and Pritchett, 1963). Agrinite®, the organic source of N, resulted in lower chinch bug populations and lower levels of damage to the turf. When fertilization rates were increased using the inorganic source of N ($NH_4NO_3$) the damage due to infestation increased. Plots fertilized at the highest rate with an inorganic source of N were 63% killed by chinch bugs. Damage was much less on plots fertilized at the same rate of N with the organic N source (Horn and Pritchett, 1963).

Table 1. Effects of Three Rates of Nitrogen, Phosphorus, and Potash on Chinch Bug Damage[x] to 'Floratine' St. Augustinegrass and chinch bug populations[y].

| Sources of Nitrogen | Rates of Fertilization | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Nitrogen (N) | | | Phosphorus ($P_2O_5$) | | | Potash ($K_2O$) | | |
| | Pounds per 1000 ft$^2$ year$^{-1}$ | | | | | | | | |
| | 4 | 8 | 16 | 0 | 2 | 4 | 2 | 4 | 8 |
| Inorganic | 8.3[z] | 6.6 | 3.7 | 6.5 | 6.4 | 5.7 | 5.8 | 6.7 | 6.1 |
| Organic | 8.7 | 8.6 | 7.8 | 8.6 | 8.5 | 7.9 | 8.5 | 8.4 | 8.1 |
| Check | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 |
| | Five Minute Chinch Bug Count | | | | | | | | |
| | All N Rates | | Check | | | | | | |
| Inorganic | 60 | | 28 | 41 | 64 | 74 | 59 | 52 | 68 |
| Organic | 40 | | 28 | 41 | 52 | 52 | 48 | 48 | 45 |

[x]Rating Scale 9.0 = no damage 1.0 = plot mostly dead
[y]Reproduced form Horn and Pritchett (1963).
[z]Each entry is average of 3 replications

The most recent findings relating fertility and its effect on chinch bug populations were reported by Busey and Snyder. A chinch bug susceptible cultivar of St. Augustine was subjected to a factorial array of fertilization treatments in a randomized block design. The fertility factors were rate (0, 2.5, 5.0, 10.0 g N $m^{-2}$ $mo^{-1}$) and source ($NH_4NO_3$, IBDU, and Milorganite®). Stages of chinch bug outbreaks were grouped into stages for date x block combinations:

Stage I < 150 adults $m^{-2}$ (no visible damage)

Stage II < 450 adults $m^{-2}$ (no visible damage)

Stage III > 800 adults $m^{-2}$ (damage visible)

Stage IV chinch bugs declining from number > 800 adults $m^{-2}$ (most grass dead)

Relative chinch bug density was calculated by dividing by the average absolute chinch bug density for the control in the respective block x date combination. Ammonium nitrate enhanced chinch bug absolute density in Stages I & II when compared to the unfertilized control (Table 2). No significant differences in absolute density were found for N source for Stages I & II. Relative density for Stages I & II were significantly influenced by N source. Ammonium nitrate increased relative density by 65% when compared to unfertilized plots. Rates above 2.5 g N $m^{-2}$ $mo^{-1}$ increased Stage I & II relative density compared to unfertilized plots. Ammonium nitrate enhanced absolute and relative chinch bug densities contrasted with the controls. There were some inconsistencies in the data, presumably due to migration of the chinch bugs, since all of the plots were destroyed by chinch bug damage during the study (Busey and Snyder, 1993).

Table 2. Southern chinch bug absolute population density (adults $m^{-2}$) and relative density (ratio of fertilized to nonfertilized control plots) for different outbreak stages and different nitrogen sources and rates[z].

| Treatment | Stage I & II | | Stage III | | Stage IV | |
|---|---|---|---|---|---|---|
| | Absolute | Relative | Absolute | Relative | Absolute | Relative |
| Nitrogen sources | | | | | | |
| Ammonium nitrate | 197* | | | | 559 | 7.83 |
| | | 1.65** | 1299* | 1.86** | | |
| IBDU | 164 | 1.28 | 1197 | 1.53 | 860 | 13.70 |
| Milorganite® | 124 | 1.00 | 1125 | 1.46 | 738 | 10.90 |
| Nitrogen rates ($g N m^{-2} mo^{-1}$) | | | | | | |
| 2.5 | 128 | 0.99 | | | 947* | 16.63* |
| | | | 1293* | 1.75** | | |
| 5.0 | 186* | | 1150 | 1.55 | 530 | 6.43 |
| | | 1.45* | | | | |
| 10.0 | 170 | | 1179 | 1.56 | 681 | 9.37 |
| | | 1.49* | | | | |
| Fertilized mean | 162 | 1.31 | 1207* | 1.62* | 719 | 10.81 |
| Nonfertilized mean | 130 | 1.00 | 852 | 1.00 | 207 | 1.00 |
| C.V. (%) | 42 | 43 | 39 | 50 | 90 | 130 |
| Analysis of F-test probabilities, ignoring nonfertilized controls | | | | | | |
| Nitrogen sources | NS | * | NS | NS | NS | NS |
| Nitrogen rates | NS | NS | NS | NS | NS | NS |
| Sources X rates | NS | NS | NS | NS | NS | NS |

[z]From Busey and Snyder (1993).
Means for combined Stages I + II are of four replications pooled over three dates of observation. Means for Stage III are of four replications at one date of observation: means for Stage IV represent only two replications pooled at one and two dates of observation.
*, ** Differs from nonfertilized controls at P = 0.05 or 0.01, respectively

The second experiment involved fertilizing 20 St. Augustinegrass cultivars at high (14.7 g $N m^{-2} y^{-1}$) and low (4.8 g $N m^{-2} y^{-1}$) fertilization treatments. Plots were evaluated once per month for percent dead canopy which was assumed to be caused by chinch bug activity. Results of the second experiment showed chinch bug damage was more severe in the high fertilization plots (Table 3) (Busey and Snyder, 1993).

Table 3. Southern chinch bug damage (% of canopy dead) of St. Augustinegrass turf plots split into high (14.7 g $N m^{-2} y^{-1}$) compared with low (4.8 g $N m^{-2} y^{-1}$) fertilization rates, as a function of month of damage[z].

| | Month of damage |
|---|---|

| Treatment | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| High fertilization | 0 | 20*** | 33*** | 44*** | 56** |
| Low fertilization | 0 | 14 | 24 | 34 | 47 |

[z]From Busey and Snyder (1993).
Number of observations was 37, 37, 34, 24, and 13 , respectively, for months 0, 1, 2, 3, and 4.
**, *** Fertilization treatments differ at $P = 0.01$ and $P = 0.0001$, respectively.

**Summary**

The growth and survival of insect herbivores is often dependent on the N concentration of plant tissue (Mattson, 1980). High levels of N may enhance a host plants nutritional value. However this can be countered by N acting as a feeding deterrent or enhancing toxic allelochemicals (Mattson, 1980). In a recent review of the literature, Scriber (1984) found a minimum of 115 studies showing that an increase in N fertility increased insect growth, fecundity, and populations. Conversely, a minimum of 44 studies indicate a decrease in insect populations or resulting damage to plants with increased N fertilization. Insect responses to N fertility are species and host dependent making inferences from unrelated studies difficult.

The first experiments conducted on chinch bugs found that overwintered females reared on chinch bug susceptible varieties of sorghum developed faster, lived longer, laid more eggs, had a higher daily oviposition rate, lower mortality, and longer body length than those reared on resistant varieties (Dahms, 1936). A later study attributed the varietial differences in sorghum to higher levels of amino N combined with the diamino acids found in the susceptible cultivar (Webster and Mitchell, 1940). Dahms and Fenton (1940) found in both pot and field experiments chinch bug resistance was decreased by the addition of $NaNO_3$ and increased with the addition of superphosphate to soils. An additional study concluded that the addition of N to soils deficient in

N would benefit chinch bugs, while P amendments to P deficient soils would be detrimental to chinch bug populations (Dahms, 1947). Experiments conducted on chinch bug populations in St. Augustinegrass showed that an organic source of N resulted in lower chinch bug populations and lower levels of damage to the turf when compared to an inorganic source of N (Horn and Pritchett, 1963; Busey and Snyder, 1993). Chinch bug responses to highly available N may be due to a preference for lush turf, or biological regulation effects such as mortality and oviposition rates (Busey and Snyder, 1993). However, due to the difficulty in conducting research on such a mobile pest many questions proposed by researchers have yet to be answered.

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# Does Nitrogen Affect Thatch Production in Turfgrass?

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***Abstract.*** **There are many essential nutrients required for proper turfgrass management. Nitrogen is typically the nutrient applied in the largest amounts. Nitrogen requirements vary with the intended use of the turfgrass, soil medium, and the desired turf aesthetics. Thatch is a tightly intermingled organic layer of dead and living shoots, stems, and roots that develops between the zone of green vegetation and the soil surface. Thatch can be detrimental to the turf's aesthetics and can increase the turf's susceptibility to pest and disease damage. The type and rate of nitrogen fertilizer applied to the turf determines the thatch thickness.**

Thatch has been a problem to turfgrass managers for many years. High amounts of fertilizer are necessary to provide the turf with adequate nutrients to promote a rapidly growing dense sod with dark green color. The excessive use of fertilizer does produce a dense turf but it also produces excess organic material. If organic matter production is greater than decomposition, thatch accumulation will result.

## What is thatch?

Thatch is a tightly intermingled organic layer of dead and living plant material that develops between the zone of green vegetation and the soil surface (Beard, 1982). There is also a layer adjacent to the thatch called mat. The mat layer is directly below the thatch layer. The mat layer is developed from secondary cultural practices such as topdressing and cultivation. Mat is defined as the partially decomposed thatch intermixed with the mineral soil from cultural practices and from soil flora and fauna activity (White, 1984).

The evaluation of thatch development in studies has raised a common question of how to measure the thatch. Some researchers have proposed devices that measure the compressibility of the turf. The "thatchmeter" was developed to measure the distance the turf compressed when a designated weight is applied to the turf. A study was initiated with the thatchmeter on bermudagrass (*Cynodon dactylon* var. Tifdwarf) greens to measure the compressibility of the turf as an indicator of thatch development. The areas with more thatch compressed deeper (Volk, 1972) (Fig. 1).

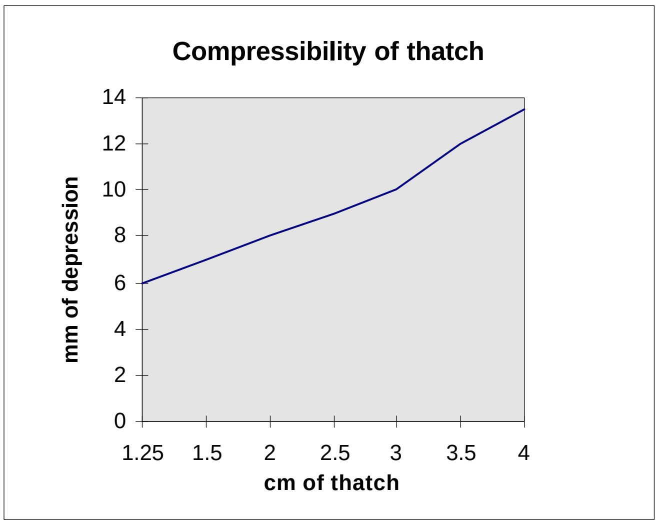


Fig.1 Compressibility of thatch on cm depth of thatch to the top of the mineral soil (Volk, 1972).

A simpler method of measuring thatch is to remove a plug and measure the distance from the top of the thatch layer to the bottom of the thatch. One other method used to measure thatch is called ashing. Ashing invovles removing a plug of grass, cutting off the roots and shoots of the plug, and subjecting the plug to 500°C - 600°C for 1-3 hours. The intense heat releases the hydrogen and oxygen ions leaving the carbon. The remaining ash is weighed to give an organic material content (Sartain, 1985).

## Rates of Nitrogen

Depending on the use of the turf determines the amount of N needed in a growing season. Golf greens require approximately 3.62 - 6.34 kgs N per 1000 $ft^2$ per year whereas an athletic field requires approximately 2.72 - 5.44 kgs N per 1000 $ft^2$ per year. Soil characteristics and desired aesthetics determine many turf manager's fertility programs.

The influence on thatch development from N rates has shown that increasing N levels will increase thatch accumulation. A study on St.Augustinegrass (*Stenotaphrum secundatum* var. Tx. common) showed that with increasing rates from .125 to 0.25 to 0.5 kg/are/month had increased thatch development from 13.2 to 18.8 mm at a 3.8 mm cutting height and from 16.5 to 22.8 mm at a 7.6 mm cutting height (Beard, 1978), (Table 1).

Table 1 The influence of three nitrogen nutritional levels and two cutting heights on the thatching tendency of Common St. Augustinegrass (Beard, 1978).

| **Cutting Height (mm)** | **Nitrogen Rate (kg/are**/month)** .125 | **.25** | **.5** |
|---|---|---|---|
| **3.8** | 13.2* | 17.7 | 18.8 |
| **7.6** | 16.5 | 21.8 | 22.8 |

*Thatch thickness expressed in millimeters
** 1 are = 100 $meters^2$

A more recent study by K.S. Kim (1985) demonstrated the same principle idea. With increasing N levels the thatch thickness increased. Tifgreen and Tifway [*Cynodon dactylon* (L.) Pers. x C. *trasnsvaalensis* Davy] were used in this study. Both bermudagrass varieties demonstrated the effects of increasing N levels having an effect on thatch development (Table 2). Thatch accumulation increased with high rates of plant growth. In this study the shoot density increased, leaf density increased, and thatch production increased due to the greater plant growth at the higher N levels compared to lower N levels. One study on bermudagrass by Smith (1979) resulted in 30% more thatch when treated with 75 kg soluble N $ha^{-1}$ than when treated with 25 kg soluble N $ha^{-1}$ due to the increased plant growth.

Table 2 Effects of Nitrogen on thatch accumulation in Tifway and Tifgreen Bermuda (Kim, 1985).

| **Bermuda Variety** | **Parameter** | **Nitrogen Level (kg/are* /month)** .25 | .5 | 1.0 | 1.5 |
|---|---|---|---|---|---|
| **Tifway** | **thatch thickness (mm)** | 11.5 | 12.2 | 12.4 | 13.8 |
| | **shoot density (per 100 $cm^2$)** | 151 | 154 | 161 | 164 |
| | **# of leaves (per shoot)** | 16.2 | 16.3 | 18.5 | 15.4 |
| **Tifgreen** | **thatch thickness (mm)** | 11.1 | 12.0 | 13.4 | 15.7 |
| | **shoot density (per 100 $cm^2$)** | 153 | 157 | 172 | 175 |
| | **# of leaves (per shoot)** | 14.0 | 16.8 | 17.1 | 17.8 |

*1 are = 100 $meters^2$

All of these examples support the theory that high rates of N do increase thatch accumulation. It should be pointed out that although thatch increased with the higher rates used in this study, the higher rates are beyond what is normally used in practice. There was no significant increase in thatch production in relation to N fertility rates, but applying N to a N-deficient turf could cause some increase in thatch, and at very high N levels, thatch may be enhanced (Carrow, 1987). Normal rates of N do promote thatch development but are also controllable with secondary cultivation practices such as verticutting, topdressing and aerifying.

## Nitrogen Sources

The source of N also plays an important role in thatch development. Many past studies indicate different levels of thatch occur depending on the N source. Ammonium sulfate, ammonium nitrate, sewage sludge, calcium nitrate, and Isobutylidene diurea (IBDU) are all common fertilizers used on turf as N sources.

Sewage sludge produced a high quality turf but it produced more thatch than $NH_4NO_3$ (White, 1984). The sewage sludge treatments produced a darker green, more dense turf than $NH_4NO_3$. This observation of having a higher quality turf and more thatch is consistent with the findings of Meinhold et al. (1973), who found that stimulating leaf and shoot growth by N fertility contributed to an increase in thatch development in Tifgreen bermudagrass.

Sartain (1985) found that sewage sludge produced significantly greater amounts of thatch than did IBDU. IBDU consistently promoted the lowest level of thatch accumulation when compared to both $(NH_4)_2SO_4$ and sewage sludge. This consistent lower amount of thatch can be attributed to the more even release of N from the IBDU over a period of time depending upon fertilizer particle size and quantity of water present. Ammonium sulfate produced the greatest amount of thatch compared to sewage sludge and IBDU. The rate of growth and total N uptake was greatest in the $(NH_4)_2SO_4$ plots (Table 3).

Table 3 Effect of Nitrogen source and rate on thatch (Sartain, 1985).

| **Nitrogen** | | | | |
|---|---|---|---|---|
| **Source** | **Rate ($g\ m^{-2}$)** | **Growth (kg $ha^{-1}\ day^{-1}$)** | **N Uptake ($g\ ha^{-1}\ day^{-1}$)** | **Thatch Accumulation ($dag\ kg^{-1}$)** |
| **AS*** | **5** | 29.5 | 1300 | 54.1 |
| | **10** | 27.1 | 1201 | 45.2 |
| **IBDU*** | **5** | 25.4 | 1174 | 23.6 |
| | **10** | 24.8 | 1161 | 23.4 |
| **SS*** | **5** | 20.9 | 911 | 26.0 |
| | **10** | 20.4 | 1024 | 31.3 |

*AS = ammonium sulfate, IBDU = Isobutylidene diurea, SS = sewage sludge

Different fertility sources produced different thatch depths (Smith, 1979). Calcium nitrate and $(NH_4)_2NO_3$ were found to produce different amounts of thatch, but the results of this study were less direct. Along with N sources, aerification was the main focus of the study. Smith found consistently more thatch in the $(NH_4)_2SO_4$ plots versus the $Ca(NO_3)_2$ plots. Maximum thatch production occurred in plots receiving lowest aerification for both $Ca(NO_3)_2$ and $(NH_4)_2SO_4$. Therefore frequent aerification can reduce the amount of thatch that develops as a result of N fertility (Table 4).

Table 4. Thatch thickness after one growing season of aerification and fertility treatments (Smith, 979).[e]

| Treatment | Nitrogen | Thickness (mm) |
|---|---|---|
| Aerification semiyearly | AS[♣] biwkly | 12.4 bc* |
| | CN biwkly | 12.4 bc |
| | AS + L biwk1ly | 13.1 b |
| | AS + L + TPD biwkly | 17.3 a |
| | | Avg. 12.6 |
| Aerification monthly | CN biwkly | 8.8 d |
| | AS + L biwkly | 10.3 bcd |
| | CN wkly | 10.3 bcd |
| | AS + L wkly | 10.6 bcd |
| | | Avg. 10.0 |
| Aerification biweekly | CN biwkly | 9.5 d |
| | AS + L biwkly | 11.0 bcd |
| | CN wkly | 9.6 cd |
| | AS + L wkly | 11.0 bcd |
| | | Avg. 10.3 |

*common letters means no significant differences as tested by Duncan's multiple range test at 5% level.
♣AS = ammonium sulfate, CN = calcium nitrate, L= lime, TPD = topdressing,

## Conclusion

There are several factors that relate to turfgrass thatch accumulation. The liberal use of fertilizers to produce a dark green dense turf can be detrimental to the turf. High rates of N promotes excessive organic material production. The microbes are unable to break down the organic material at a rate that will deter thatch and mat accumulation. The type of fertilizer will also affect thatch accumulation. Ammonium sulfate produces higher amounts of thatch than $Ca(NO_3)_2$, and IBDU has been proven to produce the least amount of thatch when compared to $(NH_4)_2SO_4$ and sewage sludge. Most researchers will agree that although N plays an important role in thatch development, cultivation practices do also affect the amount of thatch and mat that accumulates.

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# Foliar fertilization of orchids

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*Additional index words.* orchid cultivation

***Abstract.*** **Foliar fertilization is an efficient and economic way of supplementing nutrients to plants. Foliar feeding of orchids depends on the types of orchids grown, the media used, and in what climatic conditions they are cultivated. Foliar application of nutrients is a common practice in many orchid farms. Even though there are limited studies of nutrient uptake by foliar sprays in orchids, those which exist demonstrate its effectiveness. Despite some disadvantages of foliar fertilization in general, this technique has many practical uses in a commercial operation.**

Over the years there has been a lot of controversy about foliar fertilization of orchids (Poole and Sheehnan,1980). The major concern being the nature of the cuticle (Morrison, 1988). Sheehnan et al. (1967) treated mature Cattleya 'Trimos' plants with both foliar sprays and root drench applications of radioactive P derived from phosphoric acid. Samples were taken after 0.5, 2, 12, 24, and 120 hours and analyzed. Almost 35% of the amount supplied was found 24 hours later in the pseudobulb below the leaf that had been sprayed, thus determining its efficient absorption through leaves. This suggests that other nutrients with similar movements as P can also enter orchid leaves in the same manner.

## Orchid Leaves

In general, the outer wall of the leaf is covered by the cuticle which is composed of

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cutin and epicuticular wax (Marschner, 1995). The wax is the main barrier to nutrient passage. The main functions of these structures is to protect the leaf from excessive water loss by transpiration and against excessive leaching by rain (Marschner, 1995; Sinclair, 1986). The cuticle thickness varies with habitat and exposure, and may sometimes be thicker on the upper surface (Sinclair, 1986).

There are two distinct categories of orchid leaves (Sinclair, 1986). The first is ribbed or plicated which are thin, membranous and sometimes deciduous with little water storage capacity and seldom have trichomes. Examples include *Coelogyne barbata, Calanthe furcata,* and most *Cataseum* species. The second is the leathery group which is subdivided into soft, hard, and fleshy types with more rigid, thicker leaves and lacking prominent veins. Also, the cuticle is thicker and waxier. These include *Paphiopedilum* and *Phalaenopsis* orchids.

Trichomes or leaf hairs facilitate foliar uptake due to the increased surface area (Marschner,1995). Trichomes are not a dominant feature in orchids. But some thin leaf groups have hair on the lower surface of the leaf while thicker, leathery leaves are often devoid of hairs (Sinclair, 1986). But there has been evidence of glandular trichomes on both leaf surfaces in the Pleurothallidinae, which contains 3000 species in 30 genera , including *Masdevilla* (Pridgeon,1981). Assumption of mineral uptake by these trichomes can be made, but have not been proven.

In addition, closed stomatas, sites of gas exchange on leaves, occurring during the night favor foliar application (Hew, 1991). Since nocturnal applications of foliar sprays result in higher labor and less efficiency, farmers spray all leaves, mainly the bottom surfaces until slight runoff and also direct sprays to the root zone (Khaw, 1982).

A surface tension reducing agent is added to the foliar spray to maximize penetration into the leaf. This allows the solution to cover more surface area primarily the cuticle pores (Morrison, 1988). In addition, silicon-based surfactants seem to decrease leaf damage and increase efficiency of sprays, mainly for leaves with thick cuticles (Horesch et al, 1981).

## When to Feed

Factors affecting orchid nutrition include the species, the stage of growth, potting media, and growing conditions (Poole and Sheehnan,1980; Soon,1980). Feeding starts in spring in temperate climates when orchids start actively growing due to longer days and higher temperatures (Brian and Wilma Ritterhausen,1985). A weak solution is given on a fortnightly basis. Maximum growth occurs during the summer increasing feeding to once a week or 10 days, depending on how often the orchids are watered (Brian and Wilama Ritterhausen,1989). Feeding may be reduced or discontinued when growth slows down or ceases in winter (Soon,1980). In comparison, orchids in the tropics have growth year-round due to the high temperatures and abundance of sunlight while the productivity is limited only by the supply of moisture and nutrients (Soon,1980).

## Advantages and Uses

In general, foliar fertilization is a rapid method of correcting micronutrient deficiencies (Marschner,1995). These trace minerals are required in small amounts by orchids making its application more economical (Baker and Baker,1996). The application of macronutrients has encountered some drawbacks mainly that of foliage burn at higher rates (Alexander and Schroeder,1987). However, urea, which has high N, can be applied at high concentrations without being phytotoxic (Alexander and Schroeder,1987) and is absorbed and translocated very rapidly after application (Klein and Weinbaum,1984). Also combining foliar fertilizers with pesticides has proven to increase pesticide efficiency and keep application costs to a minimum (Et Attal et al.,1984).

Feeding a uniform group of orchids is best accomplished by spraying the foliage with a fine nozzle. Khaw (1982) recommends using a high pressure pump in order to give a 'misty' spray droplet and prevent excessive run-off and thus save on the quantity of fertilizer used. Also, a solid cone is preferable for effective coverage of plant parts. Foliage is kept a good healthy green and growth will speed up, particularly in young plants (Brian and Wilma Ritterhausen,1985). Spraying with foliar fertilizer benefits leaves which have turned yellow due to the need of repotting or loss of roots (Brian and Wilma Ritterhausen, 1989). Also, newly repotted plants are sprayed until they produce new roots to take up feed. In addition, there is no danger of salts building up in the media since the fertilizer enters through the leaves (McKenzie,1980). Moreover, one can save time combining fertilizer, insecticide, and fungicide in one application (Ibara,1980; Hew and Lim,1989). Lastly, viral infections can be repressed for many years by an aggressive fertilizer program (Soon,1980) which can include foliar applications.

## Examples of Foliar Feeding

Feeding should be given in accordance to the stage of orchid growth. Hew and Lim (1989) showed the efficient uptake of young plantlets in culture flasks where leaching was prevented. McKenzie (1980) gives some examples: 30N:4.4P:8.3K for small plants and seedlings, 18N:7.9P:14.9K for adult plants and 10N:13.1P:16.2K to induce better flowering in a plant in the bud stage. Also, organic fertilizers can be beneficial because they contain natural trace minerals (Baker and Baker,1996) but may have objectionable odor. An example listed is fish fertilizer at 1/10 of the recommended strength when used as a foliar spray.

## Conclusion

Many factors have to be considered in orchid nutrition. These include water quality and frequency of irrigation; light intensity, quality, duration; and temperature (Poole and Sheehnan,1980). Growers should work out a feeding schedule considering media, age of plant, and nutrient sources. Foliar fertilization should be efficiently used as a supplement to media fertilization. Besides the nutritional and economical potential of this technique, it can also contribute to decreasing soil and water contamination since less media fertilizer would be utilized (Alexander and Schroeder,1987).

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# Phosphorus and Potassium Effects on Soybeans

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*Additional index words.* *deficiencies, essential nutrients*

***Abstract.*** **N, P, and K are the three most important nutrients essential for plant growth. If any of these elements are eliminated, deficient, or tied up in the soil, plant growth will be reduced. Phosphorus and K have an impact on growth and yield potential in soybeans. Soil test is the cheapest and smartest investment a farmer can make. Low testing soils use various amounts of P and K fertilizer. High testing soils cost a producer large amounts of money if P and K are being added at any amount. Banding fertilizer close to the roots of the plant will enhance yield potential.**

**P Deficiency**

Phosphorus deficiency may be more limiting to the world crop production than any other deficiencies, toxicities, or diseases (PPI, 1979). Phosphorus deficiency is very hard to determine in many field crops. Phosphorus deficiency may cause the soybean plants to look much greener, thus giving them a healthy appearance. At the onset of P deficiency, the stems, leaves, or fruit are stunted. The dark green, bluish, or sometimes purple color, is caused by the restricted size of the leaf area. The darker color in the leaves is more apparent when various amounts of N have been added for plant growth (PPI, 1979).

The most damaging effect of P deficiency in soybeans occurs during pod-fill. If the plant is deficient in P at this juncture, the yield potential decreases dramatically. If the plant is deficient in P during pod-fill, the size of the seed , leaves, and stems

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are much smaller. The only way to truly know if the soybean plant has a nutrient deficiency is to take plant tissue for analysis. Low levels of P can slow plant growth by slowing movement of nutrients from the roots to the upper plant parts and inhibit the utilization of carbohydrates for cell growth (Usherwood, 1997).

Soybeans take up about half of their needed P during the last 40 days of the growing season (PPI, 1979), thus representing the time during pod-fill (Table 1).

Table 1. Percent of total P taken up by soybeans (PPI, 1979).

| After Planting | | | | |
|---|---|---|---|---|
| 40 Days | 80 Days | 100 Days | 120 Days | 140 Days |
| 2 | 44 | 51 | 76 | 100 |

**K Deficiency**

Potassium is absorbed from the soil by the plant in the ionic form (K ). The primary function of K is photosynthesis, protein synthesis, water use efficiency, and the development of a healthy root system. The maximum need for K uptake in soybeans occurs during the periods of rapid vegetative growth. Plants deficient in K tend to have weak stems and are more susceptible to some plant diseases (Sinclair and Backman, 1993). Potassium reduces mold and mildew in soybeans (PPI, 1979).

Potassium deficient plants in early stages of plant growth have irregular yellow molting around the leaf margins. This will often lead to an irregular chlorotic order that can lead to necrosis and the downward cupping of leaf margins (Sinclair and Backman, 1993). During this time, the basal portions remain green. Severe deficiency tends to produce wrinkled and mis-shapened seeds. The seeds may also have a purple appearance at the point where they were attached to the pod.

The deficiency can be corrected by applying fertilizers that contain K which increases the number of pods and the size, weight, and number of seeds (Bharati, Whigham, and Voss, 1986). Potassium fertilization also increases nodulation by Brady *rhizobium* (Sinclair and Backman, 1993). The increase in nodulation will increase the symbiotic N fixation capability in legumes such as soybeans.

**Movement of P and K**

Phosphorus moves more freely in sandy soils than it does in clay soils, but is bound to soil more than most other ions. Run off and crop removal are the only significant ways soils lose P (PPI, 1979).

Phosphorus and K both are primarily moved in the soil by diffusion. This is a slow, short range, process that depends on soil moisture. Dry conditions restrict diffusion (PPI, 1979). Potassium is more soluble than P, thus giving K the ability to move greater distances. When comparing P, K, and Ca there is a correlation on how solubility can effect the extent they are able to travel in the soil solution.

Nitrogen (as NO ) which has a negative charge, moves very freely in the soil, whereas P and K are tied up in the soil and cannot move freely (Table 2).

Table 2. The relative movement of N, P, K, and Ca in soil (PPI, 1979).

<-------------N-------------> <---P---> <---------K---------> <-----Ca----->

Crop roots, such as soybeans, usually contact less than 1 to 3% of the soil surface in which they grow (PPI, 1979). Therefore, if P and K are not available in the 1 to 3 % range, then the crop can be deficient of these two nutrients.

Research shows that if the P in a loamy soil is more than one centimeter from a root, it will never move close enough to be taken up by the root (PPI, 1979). Thus, if P and K are below the plow layer or hard pan the roots will not have access to these nutrients. However, nutrients accumulate in the upper layer of the soil after repeated fertilizer application of little or no tillage (Bharat, Whigham, and Voss, 1986).

The producer must apply a commercial fertilizer with an adequate supply of essential nutrients in order to enhance optimal growth. The best way to apply the P and K commercial fertilizers is by banding it directly beside the plant roots. Fertilizer that is placed close to roots are taken up quicker to the roots.

**Soybean Fertilization Using P and K**

Fertilizer recommendations for soybean and other crops should be based on the nutrient needs of the crop and the quantity of those nutrients available in the soil as measured by a soil test. Soil analysis results should be compared to the critical level maintenance nutrient requirement (Vitosh and Johnson, 1995). Soil test results below the critical level indicates a soil that has nutrients insufficient for crop growth (Vitosh and Johnson, 1995). If the nutritional analysis is above the critical soil test level, the soil is capable of supplying the nutrients required by the crop and no response to additional nutrients in fertilizer would be expected. Critical levels for each nutrient are provided when the soil analysis report is returned to clientele.

The necessity for high fertilizer dosage, when relatively small quantities of P are being removed, indicates that much of the added P is being tied up and is unavailable to growing plants (Brady, 1978).

Phosphorus add-in fertilizers exceed the amount that is removed by crops by more than 24% in the United States (Table 3).

Table 3. A comparison of N,P, and K removal by crops and resupply by fertilizers in the United States (Blaine and Crouse, 1997).

| | (N) | (P) | (K) |
|---|---|---|---|
| Removed in crops (thousands of tons) | 8838 | 1207 | 4152 |
| Added in fertilizers (thousands of tons) | 4580 | 1499 | 2313 |
| Addition as percent of removal | 52 | 124 | 56 |

A 2688 kg per Ha yield in Mississippi removed about 10.8 kg P and 18.9 kg K from soil in the seed alone.  Some soils, already high in fertility, can supply everything the soybean plant needs but most soils cannot match fertilizer, grade, and rate with the soil and plant needs (Blaine and Crouse,1997).

An 11 year study on Kenyon loam in Northeastern Iowa was conducted to determine the effects of P and K fertillization on high testing soils (Mallarino, Webb, and Blackmar,1991).

Analyses of variance showed that 11 year means for yields of corn and soybean were not significantly affected by either P or K fertilization. Occasional positive yield responses to fertilization were observed in individual years, but these responses often did not pay fertilizer costs. The results at this site suggest that corn and soybean producers could increase profits by not applying P or K fertilizers to high-testing soils (Mallarino, Webb, and Blackmar,1991). Phosphorous and K applications increase soil and leaf P and K content over time and with application levels (Bharati, Whigham, and Voss,1986).

Table 4. The expected response of soybeans and potash at various soil testing levels (Blaine and Crouse, 1997).

| | Yield Expected without Fertilizer | | Required Fertilizer | |
|---|---|---|---|---|
| Soil Testing Levels | Phosphate | Potash | Phosphate | Potash |
| | % | | Kg/Ha | |
| V. Low | 35-80 | 50-80 | 120 | 120 |
| Low | 75-96 | 76-96 | 60 | 60 |
| Medium | 92-100 | 92-100 | 30 | 60 |
| High | 100 | 100 | 0 | 0 |
| Very High | 100 | 100 | 0 | 0 |

The values in Table 4 indicate the percentage of maximum yield that can be obtained without fertilizer. For example, if the soil test is very low in K, the yield might be 20 to 50 %

below what it could produce with adequate levels. One hundred thirty-three kg of K per Ha are recommended to prevent this yield loss on low testing soils (Blaine and Crouse, 1997). High crop yields will lower soil fertility levels much more rapidly.

**Conclusion**

A producer must have a quality soil fertility management program in order to optimize yield. The pH must be maintained at 6.5 to 7.0 in order to enhance the uptake of P and K. Soybeans grow best on soils of medium to high fertility with favorable pH (Blaine and Crouse, 1997). The crops must be able to effectively use all essential nutrients, micro and macro nutrients that are available in the soil. The best investment that a row crop farmer can make is to take a soil sample every three years on all crop land.

Soil analyses are most often used prior to planting to evaluate the fertility level of the soil; whereas, plant analyses are used during the growing season to monitor the seasonal nutrient levels of plants, evaluate the effectiveness of fertilizer treatments and aid in the diagnosis of abnormal plant growth. Both soil tests and plant analyses are used to determine if nutrient deficiencies, toxicities, or imbalances are the causative factor of growth disorders during the growing season (Mengel and Segars, 1987).

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# The Effects of Anoxia and Soil Compaction in *Quercus stellata* due to Construction Injury

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*Additional index words. oxygen deprivation, gas exchange, drought resistance*

**Abstract. Among the many different types of oak tree species in the central Texas area, the post oak, *Quercus stellata*, seems to be one of the most sensitive to soil compaction. With the boom in building of new homes and businesses, construction damage or 'dozer blight', is prevalent. The damage is primarily in the form of soil compaction, which combined with flooding, inhibits oxidative respiration, forms toxic compounds, and obstructs root growth. Taking measures to prevent construction damage rather than attempting to ameliorate damage is the best way to avoid loss of these important trees.**

The Post Oak, *Quercus stellata*, is one of our most important landscape trees, existing in a range that extends from southern Massachusetts south to Florida and west to Texas (Wasowski and Wasowski, 1988; Dirr, 1975). The Post Oak is most prevalent in Texas in the Blackland prairie, the Post Oak Savannah, the Western Cross Timbers, and the Eastern Cross Timbers stretching from east of Wichita Falls to Texarkana in the eastern corner of the state. Its range then travels diagonally southwest past Bryan-College Station and Austin to the edge of the Hill Country (Wasowski and Wasowski, 1988).

**Characteristics**

*Quercus stellata* is a large deciduous oak with roundly lobed leaves. Typically found on dry, gravelly or sandy soils and rocky ridges, a very large Post Oak may reach a height of 25 m and width of 13 m, but the average mature tree is13 by 8 m (Dirr 1975; Odenwald and Turner, 1987). Post Oaks allowed to grow openly have a dense, round-topped crown with gnarled stout spreading branches, and are hardy from zone five to nine (Dirr, 1975).

Their value as a shade tree can be anywhere from 10-23% of the property value of a new home (Miller, 1995).

**Drought Tolerance**

Recommended as a landscape tree for Xeriscape-type landscapes, *Q. stellata* is one of the most drought tolerant large trees (Ellefson et al., 1992; Pallardy and Rhoads, 1993). *Quercus stellata* develops an extensive root system and is not prone to leaf abscission due to water stress (Pallardy and Rhoads, 1993). Post Oaks are able to avoid dehydration during times of normal drought because they develop a greater root length per unit of supported leaf area and their roots penetrate rapidly to lower soil depths (Pallardy and Rhoads, 1993). Not only are Post Oaks drought tolerant but also, along with other oak species such as *Q. alba*, they have shown superior recovery to predrought capacity. This appears to be due to increased stomatal limitation of photosynthesis, specifically by *Q. stellata*, implying that the mesophyll constituents of photosynthesis were relatively resistant to dehydration damage (Ni and Pallardy, 1992). It also appears that *Q. stellata* seedlings may not experience a change in osmotic potential during exposure to long (45 days) periods of drought (Kwon, 1989). Perhaps cavitation, which occurs in most plants at -1 to -2 MPa, is not as severe of a problem in *Q. stellata* as in other species (Taiz and Zeiger, 1991).

Evidence brought forth in an experiment on gas exchange indicated that *Q. stellata* is able to sustain photosynthesis and leaf conductance to water vapor at leaf moisture values near -3MPa. The same study revealed that *Q. stellata* seedlings had the highest photosynthetic rates and highest leaf conductance when exposed to abundant soil water. These responses imply that xeric species have a higher capacity for gaining carbon from dry soil and that this may be dependent on water stressed responses and superior ability to photosynthesize at high soil water rates (Ni, 1991).

**Soil Compaction and Flooding**

While *Q. stellata* is resilient in droughty conditions, other environmental stresses such as soil compaction, flooding, or the combination of the two results in decline and may often result in death.

The major problems that occur with soil compaction are lack of available oxygen, anoxia (completely lacking oxygen), hypoxia (partially lacking oxygen), reduction of gas exchange and density of the soil which prevents penetration by tender roots (Day and Bassuk, 1994; Janne and Welsh, 1997).

**Oxygen Deprivation**

In well-structured soils, gas-filled pores allow diffusion of $O_2$ several meters deep. In general, when the volume of the soil occupied by air is decreased below 10-12%, most plants are likely to be injured. When oxygen concentrations are below the critical oxygen pressure for a certain species aerobic respiration is slowed or halted and anaerobic respiration, fermentation, is the only way plants can produce ATP to drive basic metabolic processes. Because only 2 moles of ATP per mole of six-carbon sugar are respired as the net yield of fermentation as compared to 36 moles of ATP netted during aerobic respiration, injury to roots is caused by lack of ATP. Not only are roots that are anoxic or hypoxic unable to grow and metabolize they are also unable to support the physiological processes which shoots are dependent upon (Taiz and Zeiger, 1991;

Brady, 1990). Canopy cover is reduced as evidenced in observations from logging practices in areas where the soil has been compacted (Whitman et al., 1997). The trees cannot produce enough energy to survive.

**Flood Damage**

Flooding, whether due to natural causes or excessive irrigation practices, is a major problem especially when combined with soil compaction. Because the rate of $O_2$ diffusion is approximately 10,000 times slower through water than air, when the pores are filled with water, $O_2$ may be limiting. The detrimental effect of excessive water on $O_2$ levels is intensified in compacted soils (Day and Bassuk, 1994). Along with $O_2$ deprivation, reduction of gas exchange between the roots and the air in the pore space of the soil is detrimental (Janne and Welsh, 1997). In an experiment on the effects of flooding and containerized fruit trees, gas exchange to the roots and stomatal conductance were affected in conjunction with decreased $CO_2$ assimilation. In less than 12 hours net $CO_2$ assimilation was reduced compared to controls and in five days the net $CO_2$ assimilation was only 32% of the net assimilation of controls (Beckman et al., 1992).

The formation of toxic organic compounds is favored during flooded conditions as a result of $O_2$ deprivation (Brady, 1990; Janne and Welsh, 1997). Acetic acid, butyric acid, and bacterial metabolites are released into the soil water as anaerobic microorganisms in the soil metabolize organic substrates. These acids along with reduced sulfur compounds, such as $H_2S$ a respiratory poison, are toxic to plants when present at high concentrations (Taiz and Zeiger, 1991).

**Density**

The negative effects of soil compaction are not completely due to poor aeration. Soil layers may become so impenetrable as to obstruct the growth of roots even if enough $O_2$ is available (Brady, 1990). Compaction levels may be determined by soil bulk density defined as oven dry mass/volume or by penetration resistance measured by a penetrometer. Plant performance has been more strongly linked to resistance to the penetrometer than the level of bulk density. A MPa of 2.3 seems to be the highest approximate limit of soil strength that would allow root growth of woody species (Day and Bassuk, 1994).

**Construction Damage**

Many new homeowners in the central Texas area buy wooded lots with the intention of building a home among the trees. Unfortunately, current construction practices are not designed to preserve the Central Texas woodlands. The most irreparable damage that occurs during construction of new homes is bulldozer damage, otherwise known as 'dozer blight'. There are at least six ways that trees suffer injuries from bulldozers:

1. Soil compaction,
2. Root wounds that include disruption of mycorrhizal activity,
3. Lower trunk wounds,
4. Exposure to leaves of heat and fumes from oil and gasoline,
5. Wounds to the trunk, and
6. Wounds to the branches (Keslick, 1997).

The remainder of this paper will concern itself with the first two types of injuries.

**Roots**

The majority of a tree's root system is within the top meter of the soil. In fact, 99% is in the top meter, with most of the absorption being conducted by roots in the top 15 cm. The spread of the root system often extends more than 10 m beyond the dripline of the branches and can easily extend outward in a circle with a diameter more than twice the height of the tree. A particular root is directly connected to a given set of branches in oaks, most commonly on the corresponding side of the tree. If the roots are damaged or die, then death of the corresponding set of branches is the usual result (Relf, 1997; Tree Page, 1997).

**Compaction and Roots**

Soil compaction affects the small feeding roots less than 0.2 to 1 mm in diameter and less than 1 to 2 mm in length. These non-woody roots are the major portion of the absorbing surface of the root system. They are concentrated within the top 15 cm of the soil and a significant portion of them are located within the top few millimeters of soil, growing into the leaf litter of the forest floor, into lawns and cracks and crevices of hard pavements (Relf, 1997; Tree Page, 1997). In a study on tillage intensity and fertility level effects on N and carbon cycling in a vertisol it was found that any changes to the soil environment in a positive fashion, i.e. adding nutrients, including increased biomass inputs, were restricted to the top 10 cm of the soil (Torbert et al., 1997). Root suffocation caused by compaction combined with flooding, and impedance of root growth due to poor penetrability of the soil are the main causes of root death in compacted soils (Day and Bassuk, 1994; Janne and Welsh, 1997).

Feeder roots form relationships with mycorrhizal fungi, in particular ectomycorrhizae for oaks, which facilitate the absorption of nutrients, especially P, Zn, Mn, Cu, and water. Ectomycorrhizae flourish in leaf litter and so are especially prone to damage from soil compaction (Keslick, 1997).

**Reducing Construction Damage**

Establishing landscape trees or preserving existing trees is particularly troublesome on construction sites. The most limiting factor is $O_2$ deprivation due to compaction and drainage (Lichter and Lindsey, 1993). Protection and prevention seem to be the most effective ways to reduce construction damage. By establishing a root protection zone the chances of saving an existing Post Oak may be increased. Solid fencing should be erected at least one and one-half times the circumference of the dripline to restrict any access under the tree. The fence should be installed prior to clearing of the site, not during construction. Neither storage of materials nor pedestrian or vehicular traffic should be allowed within the root protection zone. The soil, shrubs and ground covers should be retained within the fence to prevent any disturbance (Arnold, 1997; Gilbert, 1996; Wasowski and Wasowski, 1988). Using soil amendments such as sintered fly-ash and expanded slate amendments in high proportions (20-33%) and incorporating them into the soil reduced bulk density for as long as 4 years after incorporation (Day and Bassuk, 1994). Use of such materials may be beneficial for highly trafficked areas unprotected by a fence.

## Conclusion

More effective measures will be taken to reduce construction damage as the economic importance of landscape trees becomes more obvious. This is particularly true in Central Texas, where Native Post Oaks are the predominant species. Typically developers have been ambivalent toward tree retention considering them to be obstacles in the early stages of building, yet regarding them as selling points toward the end of contracts often times after extensive damage has already occurred (Gilbert, 1996).

Ironically, the very characteristics that make *Q. stellata* desirable for the landscape are what inevitably kills them under adverse conditions. Soil compaction combined with flooding, a typical situation found in landscapes of newly constructed homes, may be lethal to Post Oaks. It is impossible to assume that a tree that has the physiological characteristics designed to overcome drought, and has never been disturbed or irrigated, can overcome this type of stress. Further study targeting *Q. stellata* in regards to the effects of drought, abundant soil moisture, and flooding should be carried out.

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# Reclamation of Sodic and Saline Soils

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*Additional Index Words: salt, sodium, sodic, saline, gypsum, calcium*

**Abstract: Salt is the savor of food, but the scourge of agriculture: in excess salt kills growing plants. Sodic, saline, and sodic-saline soils affect agricultural field production in many regions across the United States as well as in numerous other countries. These soils can be productive once again with proper reclamation and management techniques available to producers the world over.**

Salted soils are unproductive unless harmful salts are lessened or removed. About 2100 years ago, the Romans plowed the semiarid fields of Carthage and applied salt to ensure that the Carthaginians could not re-establish their powerful metropolis. Efforts to recolonize the area 24 years later failed because the salted fields were still unproductive (Donahue, 1983). Soluble salt contamination of soil has caused problems for all of recorded history. Primarily this contamination occurs in arid regions of the world where inadequate rainfall results in lack of leaching resulting in accumulation of excess salts. The effects of salt devastation are apparent in many areas and are becoming more common and serious as land use intensifies and water supplies become more limited and polluted with soluble salts. The accumulation of soluble salts in the soil results in one of the most serious agricultural problems that producers face in arid regions. Harmful effects of salt include poor seed germination and plant growth, these problems result from one or both of the following conditions: (1) a limited availability of water due to a high osmotic concentration of the soil solution, and/or (2) an unsuitable physical or nutritional state caused by a high level of exchangeable sodium (Na) (Hausenbuiller, 1978).

Salts accumulation in the soils of arid regions occurs in many ways. The most common way salts are deposited in the soil is by the introduction of water that is then lost by evaporation and transpiration. The net result of this phenomenon is salt accumulation. Some soils develop in arid regions under conditions of poor drainage where there is more evaporation than precipitation (Foth, 1978). Under these conditions soluble salts and exchangeable Na may collect in amounts sufficient to impair plant growth and possibly alter soil structure and properties. Water may also move upward through the soil strata by means of artesian wells and shallow water tables (Tisdale, 1985). Evaporation of this water results in the deposition of soluble salts into the soil which strengthens the concept introduced. These soils are widespread in arid and semiarid regions where a lack of precipitation (less than 38.1 cm./yr.) hinders the leaching process (Tisdale, 1985). These types of soils are particularly prevalent in irrigated areas where improper drainage methods are used. This is the case of salt marshes, mangrove groves, and salt marshes found adjacent to salt lakes and other bodies of salty water (Black, 1968). Another source of salt introduction into the soil is by means of the ocean through tidal actions and sea spray being carried inland by wind (Hausenbuiller, 1978). Soils that form from marine parent material also contribute to the amount of soluble salts present (Tisdale, 1985). Salt accumulation can be avoided by selecting deep, well-drained soil.

Soils affected by salts have been given many descriptive and imaginative names such as white alkali, black alkali, slick spots, and summer snow. These names have been given to describe the topical appearance of the soil itself. The most common descriptors used to describe salt affected soils are saline, sodic, and saline/sodic. Saline soil can be defined as soil that contains excess salts made up of Cl and $SO_4$ salts of Na, Ca, and Mg (Tisdale, 1985). Saline soils possess a saturated extract conductivity ($EC_{SE}$) of >4ds·m$^{-1}$, pH<8.5, and have <15% exchangeable Na% (ESP) (Black, 1968). Sodic soils occur when ESP>15%, $EC_{SE}$<4ds·m$^{-1}$, and pH>8.5. In sodic soils, excess Na disperses the soil colloids and creates nutritional disorders in most plants (Tisdale, 1985). Excess Na hinders water penetration in soils yielding drought stress symptoms to be expressed by plants. Sodic/saline soils possess both the salt concentration (4ds·m$^{-1}$) to qualify it as saline and high exchangeable Na (>15% ESP) to justify it as sodic as well; however pH is <8.5 (Hausenbuiller, 1978) (Table 1).

Table 1. Summary of salt-affected soil classifications.

| *Classification* | *Conductivity (ds·m$^{-1}$)* | *Soil pH* | *Exchangeable Sodium Percent* | *Soil Physical Condition* |
|---|---|---|---|---|
| Saline | >4.0 | <8.5 | <15 | Normal |
| Sodic | <4.0 | >8.5 | >15 | Poor |
| Saline/Sodic | >4.0 | <8.5 | >15 | Normal |

Source: Tisdale et al., 1985.

Tests are performed and calculations made to determine if a soil is saline, sodic or saline/sodic. ESP is calculated to determine the percentage of exchangeable Na ions to the total exchangeable cations in the soil sample. This calculation is facilitated by the formula:

$$ESP = \frac{\text{exchangeable sodium ions}}{\text{cation exchange capacity}} *(100)$$

Soils through which salty water flows often adsorb too much Na on the soil exchange sites, the higher the value of Na adsorbed to the soil colloid the higher the ESP value will be (Donahue, 1983). Another way ESP values are derived is by a similar calculation known as the Sodium

Adsorption Ratio (SAR). This ratio is used to estimate the amount of exchangeable Na percentage of a soil, or what it is likely to become. SAR values correlate well to the ESP of a soil and are easier to calculate and estimate. The conductivity of a soil sample is easy to determine. All ions conduct electricity and because of this principle salt content can be determined by measuring electrical conductivity of the soil solution (Donahue, 1983). Soil pH is the final criteria to measure in order to classify soils as saline, sodic, or a combination of both.

Producers must consider reclamation and management when presented with the problem of producing a crop on salt-affected soils. Soil reclamation is more difficult in actual practice than in theory. Good drainage is a necessity for the reclamation of saline soils. It is essential to remove the excess salts from the root zone, and this can only be done by the application of sufficient water to leach the salts into the lower soil depths (Foth, 1978). Unless drainage is adequate, the addition of too much water will raise the water table and lead to increased accumulations of salt in the surface soil. Instead of leaching the salts from the soil they will in actuality be adding more salts (Foth, 1978). Sufficient drainage should be provided to reduce the ground water level well below the zone of root penetration. Preferably the ground water should never be less than 2.4-3.1 m below the surface, and every effort should be made to prevent it from rising nearer than 1.5-1.8 m from the soil surface if even for a brief period of time (Black, 1968). Once ample drainage has been accomplished the reclamation process can continue. In fine-textured soils the leaching process will be slow, especially if there is a clay hardpan present in the soil subsurface. Percolation of surface water into the soil with a hardpan can result in a perched water table. The water is trapped on top of the hardpan and is unable to leach through the dense clay. The presence of a dense, clay hardpan makes the reclamation process difficult even under medium and coarse-textured soils. It is questionable if reclamation of soils with very deep clay subsoils is feasible under an economic standpoint (Foth, 1978). Experiments have shown that leaching is all that is needed to reclaim saline soils that have adequate internal drainage (Loomis, 1992). The addition of chemicals, plowing under of manure, or green-manuring crops are unnecessary. In terms of irrigation, no specific direction can be given regarding the frequency of irrigation or the quantity of water to apply at each irrigation. The main points to observe are: (1) that the soil be kept moist so that the soil solution will not become sufficiently concentrated with salts to damage the growing crop, (2) that sufficient water be applied at each irrigation to result in some leaching of salts into the drainage water, and (3) that the soil of each irrigation pan be carefully leveled so that the water will enter the soil uniformly (Foth, 1978).

All that has been said concerning the need for drainage and the application of sufficient irrigation water to cause leaching is as important, if not more important in the reclamation of sodic and saline/sodic soils. It has been demonstrated that application of sufficient irrigation water coupled with sound farming practices will result in the removal of exchangeable Na and salts. This reclamation process can be hastened by amending the soil with a supply of soluble Ca (Hausenbuiller, 1978). Gypsum is the amendment used most widely for the purpose of displacing exchangeable Na. Once in soil solution, the Ca from gypsum undergoes and exchange with the Na present. The displaced Na becomes part of the soil solution and forms a soluble salt that can be leached from the soil profile. A diagram of this reaction can be seen in Equation 1.

$$Na_2 + CaSO_4 \rightleftharpoons Ca + Na_2SO_4 \qquad \text{(Equation 1)}$$

Gypsum is not a highly soluble salt; therefore it will not readily leach from the soil profile. It is for this reason that precautions must be taken to obtain maximum soil surface contact. One method to facilitate soil contact is to mix the soil with the gypsum so that extensive contact is made with the soil exchange sites. With increasing amounts of gypsum to the soil, pH of a particular soil will increase. If the soil being reclaimed possesses a high pH the addition of ground sulfur will accomplish the same results as gypsum, but at a slower pace (Loomis, 1992). The sulfur must first be oxidized in the soil and then combines with water to form sulfuric acid. Equation 2.

$$2S + 3O_2 + H_2O + 2Na \longrightarrow 2NaSO_4^{-2} + 4H^{+} \quad \text{(Equation 2)}$$

The theory behind this is that the same reaction occurs as in Equation 1, but instead of releasing Ca into the soil $H^+$ ions will be released which will result in a lowering of soil pH. Other soluble sulfates such as Fe and Al have been tested and proved effective in this process (Tisdale, 1984).

The elimination of soluble salts and exchangeable Na from soils by leaching has been a satisfactory method of reclaiming salt-affected soils. The downfall to this method is that the leached Na and salt is washed into groundwater supplies and streams making these water bodies even more salt polluted. More costly water and lower salt tolerances have focused attention on precipitation of salts, which is a relatively new concept in managing salty soils. This idea suggests that instead of leaching salts into the ground water, they can be leached to a depth of 1-2 meters, where much of the salt would form slightly soluble gypsum ($CaSO_4 \bullet 2H_2O$) or carbonates ($CaCO_3$, Mg $CO_3$) during dry cycles and not react any longer as soluble salts (Donahue, 1983). In theory any water that reaches and passes through this precipitation zone will not carry as much salt or Na into groundwater sources or surface water. Many unanswered questions arise with this new hypothesis.

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# Dairy Composting: Does it Affect the Availability of Nitrogen and Phosphorus?

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Information in this paper was taken from data listed on several different studies conducted on composting and its relationship to nutrient uptake. There are 38 dairies currently operating in Johnson County. Each dairy animal produces 6.7 kilograms of waste per day on average. A herd of 500 Holstein cows can produce 772,773.54 kg solids/year. Dairy operators are looking for economical and environmentally safe methods to deal with the large amount of waste generated by animals. Composting is rapidly becoming the logical choice for these dairy operators. The availability of Nitrogen and Phosphorus in compost were examined as well as different methods to apply the compost for best results. The average percentage of N in compost is 1.5-3.5% and P is .06-1.5%. In general, Nitrogen has a lower availability and Phosphorus remains about the same as a chemically applied nutrient.

Johnson County currently has 38 dairies. In 1996 dairies were the leaders in the Johnson County Agricultural Economy. Monies raised in 1996 totaled $32,299,854. Johnson County's economy is definitely enhanced by the presence of these dairies, but there are pros and cons in dealing with the waste generated by dairy cattle. According to ASAE data each live dairy animal produces 6.7 kilograms of waste per day on average (Table 1).

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Disposing of dairy manure in a cost effective and environmentally safe method has become a major concern for dairy producers and the general public. There is concern that the groundwater supply may become contaminated due to nitrates. Nitrate is a mobile form of N that can be easily leached into groundwater. When NO3-N is present in groundwater at a rate of more than 10 mg $kg^{-1}$ it is considered to be hazardous to the health of people. Senator Tom Harkin (D-IA) announced on September 25, 1997 that he is crafting legislation that would require large livestock operators to submit animal waste management plans to USDA for approval. The objective in Johnson County is to be able to utilize dairy manure as a compost in compliance with USDA guidelines, and increase the N and P availability in the soil.

**Table 1:** Calculations on amount of solid waste produced in one year by a herd of 500 Hostein cows weighing 635.029 kilograms each.

1) Liveweight 500 hd. x 635.029kg/hd.=317,514.68kg liveweight

2) Total Manure Solids Production
   a) Based on 24 hr. confinement (all manure collected into a waste stream)

   317,514.68 kg liveweight x 6.68 kg solids/1,000 hd./day
   =2,117.188 kg solids/day
   =772,773.54 kg solids/year

   b) Based on 6 hour/day confinement period on concrete (remaining 18 hrs./day in openlots): Total solids load on concrete entering liquied manure system=

   6 hrs/day
   24 hrs./day x 4,667.466 kg solids/day=1,166.87 lbs. solid/day
   =4,259.27 kg/year

**Types of Composting**

Composting is the controlled degradation of organic matter to simpler compounds of ($CO_2$, $H_2O$) under thermophilic, aerobic conditions (Sweeten et al., 1990). The following conditions are ideal for composting:

Oxygen-3-5% volume
Moisture-40-60% wet basis
C:N:P ratio=20-25:1:0.2
pH=7.0-8.0
Ash content in manure=45% or less
Temperature=57-74EC

The major methods of composting today are In-bin mechanically mixed, In-vessel (eg. rotating cylinder), Static Pile/Windrow (unmixed), Windrow Method, and Aerated Static Pile Windrow (eg. Beltsville Aerated Static Pile Method).

Aerated-Bin composting can be accomplished through mechanical stirring. In this process composting material is fed into an aerated bin. Environmental conditions in the bin are controlled carefully so that a steady rate of decomposition is maintained by micro-organisms. Aeration within the reactor is accomplished by forcing air into the compost using draft compressors/blowers, turning the compost mechanically or a combination of both of these. Turning the compost should be performed on a daily basis to allow oxygen to reach all micro-organisms. During the first 2 weeks forced aeration will usually exceed 4.6 to 9.1 meters. During the third week 1-2 scfm per $m^{-3}$ or less. Temperature should also be monitored by using oxygen probes that will aid in determining turning frequencies and aeration schedules which may differ for each mix of compost. In the batch-operated system perforated pipes are used to provide aeration. Air can have positive or negative pressure, or a combination of both. Every few days compost will have to be transferred to another adjacent bin in this method (Kuhlman et al., 1990).

When compost is complete it will have a black-brown crumbly appearance and an earthy smell which indicates it is ready for use. Aerobic thermophilic composting kills most pathogens and weed seeds. Other benefits of composting are the reduction of materials volume and weight. Most of the odor is dissipated, physical properties improved, and mineral elements retained. While $NH_4$-N may be volatized, total N usually remains stable (Sweeten et al., 1990).

**Effects of Composting on Nutrient Availability**

The total amount of N, P, and K excreted annually by dairy cattle averages 127, 27.22 and, 88.45 kg/head/year respectively. Nitrogen begins to transform immediately once manure is excreted. A large percent of N will be lost to the atmosphere though volatization of ammonia (Sweeten et al., 1991). Percentage of loss is dependent on wind speed, humidity, temperature and pH. Moisture can also affect loss through volatization. Nitrogen will also be made more unavailable if manure compost is not fully mature. Immature compost can create its own demand for nutrients. Micro-organisms are working during composting to break down manure. Immature compost will utilize N making it unavailable for plant growth. Low availability of N occurs frequently in compost with a high C:N ratio (Dick and McCoy et al., 1993).

When comparing nutrient content of compost to manure the following results are gained:

-P and K- higher in compost
-N-similar or slightly higher in compost
-N-availability-usually lower

-Other minerals-higher in compost

Nitrogen N, P, and K are the three nutrients in highest demand by crops. The average percentage of N in compost is 1.5-3.5%, P is .06-1.5% and K is generally twice that of P (Sweeten et al., 1990). Nutrient uptake may be increased due to compost improving soils chemical, physical, and biological properties. Another advantage is that leaching or loss of nutrients can be decreased by increasing the soil organic matter content. Organic matter helps hold nutrients that are in a water soluble form that would otherwise be leached. The addition of organic matter to soil through composting helps by increasing mineralization. This in turn helps to make micro-nutrients more available by causing minerals to chelate, which makes them more soluble and more mobile to the plant roots (Dick and McCoy et al., 1993).

When applying composts to croplands N is slowly available. Nitrogen is much more available in inorganic sources. The slow availability of N in soils that have had compost applied, however, will have N over a longer period of the growing season since the possibility of leaching is decreased. The availability of P and K in composted soils remains comparative to soils treated with chemical fertilizers. Phosphorus is usually even a little higher due to loss of dry matter during composting that causes P to become more concentrated. Following composting, nutrient availability in the growing season represents approximately 25% N, 100% P, and 80% K of the total N, P, and K in the compost (Stewart, et al. 1990).

Benefits for farmers cannot always be immediately measured when using compost. In the first year or two of composting goals should be to reduce money spent on chemical fertilizers, while maintaining yields, and to begin to restore nutrients to soil. With each year's application of compost soil fertility is improved and fertilizer costs will continue to decrease. The need for chemical nutrients can sometimes be completely eliminated and crop yields will continue to increase. Yearly applications of compost to fallow fields in addition to chemical fertilizers have been shown to greatly improve soils because of the addition of organic matter to the soil and the additional nutrients from the chemicals that are readily available for the plants. Spreading of compost can not always be evenly done. With each years application the addition of organic matter to soils will build up and improve the soil conditions immensely which allows for higher nutrient availability. It was the large loss of organic matter in soils that contributed to the dustbowl of the 1930s. Composts not only aid in restoring soil to greater productivity, they also bind toxic metals to organic matter. Toxic metals are not much of a problem in dairy manure, but they are in high pH soils, industrial waste, and sewage sludge (Dick and McCoy et al., 1993).

**Summary**

The negatives of composting are cost of equipment, space, and not being able to meet crop demands at the right time. Composting provides dilute sources of N, P, and K as compared to chemical fertilizers. The benefits of long-term composting seem to outweigh these negatives. Most dairies are already equipped with heavy machinery. When viewing the overall problem of disposing of dairy waste, composting is a logical solution to the problem. Annual compost applications yield long term benefits. Crop yields will increase and chemical fertilizer costs will continue to be reduced, and weed seed population and pathogens will be decreased by higher temperatures. Toxic metals will be bound to organic matter. Improvement of soil conditions will allow for greater nutrient uptake. Nutrients are available over a longer period of time, but may not be available at the right time to meet crop demands.

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# An Argument for the Use of *Equisetum* in Constructed Wetlands Designed for Wastewater Cleanup


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*Additional index words.* horsetail, nutrient removal, nutrient uptake, water treatment



***Abstract.* Constructed wetlands have become an increasingly popular method of treating various types of wastewater. While numerous plant species are used in these wetlands, *Equisetum* (subgenus *Equisetum*) has been ignored as a possible plant material. However, studies indicate that this plant would be highly suitable for use in constructed wetlands. *Equisetum*'s extensive root system is a positive factor in its symbiotic relationship with the microbial organisms necessary to aid in cleaning wastewater. Studies have also shown that *Equisetum* is superior in nutrient uptake to most other plant species currently used in artificial wetland systems. Additional studies have shown that *Equisetum* is even capable of taking up heavy metals such as Hg.**


Numerous municipalities, mines, agricultural businesses (farming and animal husbandry), and even nurseries have turned to constructed wetlands as a viable means of cleansing runoff waters in light of state and federal legislation regulating the use of water. These wetlands have diverse uses and can be designed to treat numerous types of runoff, even including raw wastewater (Bastian et al., 1989). Most of these wetlands utilize a combination of plant material and bacterial colonies as the means to cleanse runoff. However, the quality of the wetland system will vary depending upon plant species (Auclair, 1979). Some common plants used in constructed wetlands are *Eichhornia* spp. (water hyacinth), *Typha* spp. (cattail), *Phragmites communis* (common reed), and *Scirpus* spp. (bulrush). Yet while these and other species have been utilized in constructed wetlands, those


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of the genus *Equisetum* (subgenus *Equisetum*) have remained conspicuously absent from trials in these wetlands. Most likely, these plants, commonly known as horsetail, have been neglected due to their common perception as a troublesome $C_3$ weed, but this plant does have numerous attributes that would make it an excellent choice for use in constructed wetlands designed to remove nutrients from waste water.

*Equisetum* has been categorized as a member of the order Equisetales and is the only genus in the family Equisetaceae (Agashe, 1995). According to Agashe, Equisetaceae dates back to the Upper Carboniferous and attained a high level of diversification by the Permocarboniferous period. The order flourished in the Mesozoic era but declined in the Cenezoic. Today it is composed solely by the genus *Equisetum.* This genus has been in existence since the mid-Permian period (Agashe, 1995).

The plant's life cycle is much like that of other spore-bearers. *Equisetum,* however, includes the formation of a cone-like strobilus from which the spores are released (Taylor and Taylor, 1993). Aside from the formation of the strobilus, *Equisetum*'s life cycle exactly parallels the life cycles of other plants which undergo sporophytic and gametophytic stages. *Equisetum* also reproduces asexually by rhizomes.

**Root System**

One of *Equisetum*'s chief attributes making it a suitable plant matter for constructed wetlands is its root system. *Equisetum* is remarkable for its extensive rhizome systems with the potential to cover hundreds of feet and to reach depths of six to seven feet (Hauke, 1963), and *Equisetum*'s much-acclaimed root system is also extensive. In fact, much of its reputation as a weed and its resistance to any method of eradication resulting in soil disturbance is due to this massive root system (Cloutier and Watson, 1985). This root system also has its benefits. Within gravel bed microcosm wetlands, a greater root biomass has been found to result in a greater chance for N uptake or nitrification mediated by $O_2$ transport to the rhizome (Zhu and Sikora, 1995). This study found that in a comparison of reed and *Typha*, the higher removal rate of

$NH_4$-N by reed was likely due to its greater rhizosphere development while the lower removal rate in *Typha* was due to its low root biomass weight. These results indicate that *Equisetum* use would also result in a higher removal rate of $NH_4$-N due to its extensive root system.

Additionally, *Equisetum*'s root system would also seem ideal since these extensive subsurface systems offer abundant room for microbial colonies. The basis for selection of aquatic plants for wastewater treatment rests upon the species's ability to work in cooperation with microorganisms (Wolverton, 1989). This cooperative growth between macrophytic plant species and microorganisms is the basis for wastewater treatment in wetlands since these microorganisms form symbiotic relationships with the higher plants, and this relationship normally results in an increase in degradation rates and in the removal of organic chemicals form the wastewater (Wolverton, 1989). Additionally, this study has found that the electrical charges associated with aquatic plant root hairs react with opposite charges on colloidal particles like suspended solids. This causes them to adhere to the root hair where they are removed from the wastewater and are sorbed into the plant and microorganisms. Since *Equisetum* is an aquatic plant with an extensive subsurface system, it probably fits all of these requirements exceptionally well.

**Nutrient Uptake**

In addition to the advantages *Equisetum* derives from its subsurface structures, it is remarkable for its abilities to take up nutrients. In fact, numerous studies have indicated *Equisetum*'s superior potential for removing nutrients. One study examined the storage of C, P, and N in littoral *Equisetum* stands and found that these stands are effective in the retention of nutrients and organic matter coming from the land (Sarvala et al., 1982). The study found that during August, when the *Equisetum* stands were in the height of their yearly growth, its C and nutrient stores were almost a hundredfold times those of other living components of lake Pääjärvi, an oligotrophic and mesohumic lake in southern Finland. Indeed, during its active growth cycle, *Equisetum* proved to be a dominant sink for these three nutrients, and it would doubtless behave in the same way in constructed wetlands.

*Equisetum* has also been shown effective as a sink for other elements. A study of *Equisetum arvense* near Mount St. Helens has shown that the plant is capable of taking up considerable amounts of Hg vented from the volcano during and following its May 1980 eruption (Siegel et al., 1984). While this study is concerned primarily with the use of plant materials as a means of charting Hg levels, *Equisetum* should not be overlooked as a possible means of cleansing wastewater of heavy metals.

One of the most thorough studies of *Equisetum*'s abilities to take up nutrients and organic matter shows that these plants surpass most of the other plant species currently used in constructed wetlands (Auclair, 1979). This study compared *Equisetum fluviatile* to *Typha angustifolia, Phragmites communis, Scirpus fluviatilis, Eleocharis plaustris,* and *Scirpus validus* and found that the *Equisetum* had the greatest concentrations of ash, N, P, K, Ca, Mg, Fe, and Mn and also had the highest total concentration of nutrients. Perhaps most exceptional is *Equisetum*'s ability to take up Fe, and Auclair calls for further study of *Equisetum* for this reason. In fact, Zn was the only nutrient for which *Equisetum* did not have the highest concentration.

**Conclusions**

Due to *Equisetum*'s exceptional abilities at taking up nutrients and organic matter, it would appear to be an appropriate and functional plant material to use in a constructed wetland designed to treat wastewater. Its extensive root system allows a large surface area for microbial populations and also aids the plant in the removal of $NH_4$-N. Further, *Equisetum* has been proven more effective at taking up most nutrients than other plant species commonly used in constructed wetland systems.

These attributes call for additional study of the use of *Equisetum* in nutrient removal from wastewater; however, this plant has other distinct advantages. Unlike other plants used in constructed wetlands, *Equisetum* produces limited litter which might fall back into the wetland and reintroduce nutrients into wastewater that is being cleansed (Kadlec and Knight, 1996). The plant's free-standing vertical growth is easy to manage and tends not to take up space that could be valuable in agricultural or nursery operations. *Equisetum*'s lack of sensitivity to herbicides would be a distinct benefit in agricultural or horticultural uses since the plant will remain relatively unaffected by herbicides used to control weeds invading crops.

For all of these reasons, *Equisetum* clearly merits attention as a plant choice in constructed wetlands.

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# Effects of Nitrogen Fertility on Thatch Management for Dwarf Bermudagrasses

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***Abstract.*** **Dwarf bermudagrass *(Cynodon spp.)* is the most highly adapted grass for use on golf greens in the southern United States. Tifdwarf, and Tifgreen have been the industry standard bermudagrasses for the past four decades, although some new dwarf bermudagrass varieties are now available. Thatch accumulation on these dwarf grasses is the number one problem for superintendents trying to maintain healthy greens. Thatch causes many problems that are detrimental to turf quality. Nitrogen rates and sources have been shown to significantly influence the rate of thatch accumulation in these turfs although it is recommended to also control thatch mechanically.**

## Historical Perspective of Greens Type Bermudagrasses

Grasses with a prostrate growth habit, such as bentgrass and bermudagrass, maintain a high residual leaf area at close mowing heights, and are the preferred grass types for putting greens. Bermudagrass, a $C_4$ grass, is the most highly adapted grass for use on golf greens in the hot, humid regions of the southern United States. Carbohydrate reserves and root development are not significantly reduced in bermudagrass even at putting green mowing heights (Duble, 1996). Increased mowing heights make greens type bermudagrasses stemmy, spindly, and more susceptible to scalping.

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Bermudagrass (*Cynodon* spp.) is found in over one hundred countries throughout the subtropical and tropical areas of the world, including the southern United States. Common bermudagrass *(C. dactylon)* was introduced into this country during the colonial period from Africa or India (Duble, 1996). Bermudagrass is a sod forming perennial that spreads by stolons, rhizomes, and seed. Common bermudagrass became very popular as a golf turf in the south. It grows on a variety of soils, both acid and alkaline, and is tolerant to high salinity.

Natural hybrids between *C. dactylon* and *C. transvaalensis*, and crosses resulting from grass breeding programs have been released by state universities, the Crop Research Division of the USDA, and the U.S. Golf Association Green Section. All of the hybrid bermudagrasses are sterile or have variable offspring and must be propagated by sprigs or sod. Much work has been done in developing bermudagrass as a greens type grass able to withstand the ever growing pressure of the golfing public. Past breeding and selection introduced many improved varieties able to withstand lower mowing heights and more traffic. Some of the earliest selections came from Africa in the 1930s. These varieties, Uganda, Royal Cape and Hall's selection were improved from common bermudagrass with less seed head production and slower growth habit.

In the US, a variety known as Bayshore was selected from a golf course in Miami in the 1950s (Duble, 1996). It was a very popular natural hybrid that was later replaced on golf greens in the 60s by the superior variety Tifgreen. Tifgreen, released in 1956 by Georgia AES, was a tremendous advancement for the golf industry. It was a natural hybrid that maintained high density at the 6.35mm mowing heights common to that time. This low growing, rapid spreading variety quickly became the most popular choice for southern golf greens. Nine years after Tifgreen, Tifdwarf was released from the Georgia AES. Tifdwarf is a vegetative mutant that occurred from Tifgreen, and resembles Tifgreen except that its leaves and internodes are significantly shorter, and is darker green. The dwarf growth characteristics of Tifdwarf gave it superior putting quality on greens as mowing heights were lowered to 4.76mm.

**New Dwarf Bermudagrasses**

Over the past three to four decades, the only bermudagrass varieties specifically adapted for use on golf greens in the southern US were Tifgreen and Tifdwarf. Both require daily mowing at heights of 4.76mm or less and N requirements of 1980 to 2970 kg N $ha^{-1}$ $month^{-1}$ during the growing season. These hybrid bermudagrasses require cultivation practices such as vertical mowing, aerification, and topdressing to maintain high quality putting turf and control thatch buildup. Increased demand for dwarf bermudagrasses with “bentgrass” putting characteristics, off-type occurrence in Tifdwarf, and the potential disastrous results that could arise from dependence on a single variety have accelerated interest in development of new bermudagrasses for golf greens. The industry has responded in the 90s with a wave of new bermudagrass cultivars with dwarf characteristics. Researchers are studying several of these new dwarf hybrids that spread vigorously and have little vertical leaf growth. Some of the cultivars, Champion and Floradwarf, are already commercially available and in place on many southern greens. A few others, MS Supreme, TW-72, and Mini-Verde, will be commercially available before the end of the century. Southern superintendents who struggle to maintain healthy greens at 4.76mm may find these new grasses to be the answer. Breeders and growers of these new cultivars have made claims about the superior performance of their varieties as compared to Tifdwarf, but little has been done to prove these claims. These new grasses may require distinctly different management practices and fertilizer programs than Tifdwarf.

Performance of several of these varieties is well established based on replicated trials at many locations. However, some have limited testing in replicated performance trials. Much less information exists on the management requirements of these new dwarf bermudagrasses. For example, many superintendents report greater difficulty in fall and spring overseeding transition with some of the new dwarf bermudagrass greens. Questions also exist about the best approach to manage thatch development in these grasses. Many of these grasses will likely be planted to greens in Spring 1998 as part of a cooperative program between the United States Golf Association, The National Turfgrass Evaluation Program, and the Golf Course Superintendents Association of America. However, this On-site Testing Program will most likely not be able to accommodate sufficient variation in cultural variables at one location to provide sufficient information on which to base cultural recommendations. There is an extremely strong need for information on the cultural requirements of many of the new dwarf bermudagrasses.

## Thatch Management

Thatch management has probably been the biggest concern for superintendents in the management of bermudagrass golf greens. Increased thatch levels bring about problems such as poor soil air exchange, water infiltration, and nutrient use (Ferguson, 1964; Hanson and Juska, 1969; Madison, 1971; Thompson and Ward, 1966). This leads to problems of sponginess of turf, development of shallow root systems, uneven mowing (scalping), increased disease incidence, increased insect damage, and reduced drought, cold, and wear tolerance (Duble, 1996).

Thatch is defined as "the tightly intermingled layer of living and dead stems, leaves and stolons that develops between the green vegetation and the soil surface" (Thompson and Ward, 1966). There is also a layer under the thatch that is commonly called the mat layer. It is defined as "the intermingled layer of living and dead stems, leaves, stolons, and mineral soil that develops directly below thatch" (Thompson and Ward, 1966). Thatch and mat form chiefly from the periodically sloughed off (senesced) roots, horizontal stems (stolons and rhizomes), stubble, mature leaf sheaths, and blades (Ledeboer and Skogley, 1967). The mat layer is more desirable in turf because of the increased microbial activity in the soil medium.

Several factors contribute to thatch accumulation. These include: varieties with increased vigor (more stems, roots, rhizomes), low pH in thatch layer, and high N (Ferguson, 1964; Hanson and Juska, 1969). Thatch accumulation is directly related to its decomposition rate, and thatch buildup in sod occurs only when production of plant material exceeds decomposition (Smith, 1969). Decomposition is a metabolic activity carried out by soil microbial populations. Rate of added material decay depends mainly upon soil environment, type of organisms involved, and chemical composition of added organic material (Hutchings and Martin, 1934). Proteins and carbohydrates decompose more rapidly than do hemicellulose and cellulose, and lignins are very resistant to decomposition (Ledeboer and Skogley, 1969; Ledeboer and Skogley, 1973). Duble and Menn (1972) reported that lignin/cellulose ratio is less than 0.25 in bermudagrass shoots and greater than 2.0 in the thatch. The constituents of thatch that are harder to decompose are the plant stems, roots, rhizomes and stolons as opposed to the leaf sheaths and blades (Ledeboer and Skogley, 1969). Increased N leads to a higher lignin/cellulose ratio in bermudagrass, which leads to increased tissue production and decreased levels of decomposition (Meinhold et al., 1973). The increased fertility also leads to increased rates of senescence and replacement, which adds to the thatch layer (Riley, 1975). Increased stress of plants in a golf green situation caused by close and frequent mowing also leads to an increase in the sloughing off of leaf sheaths, stems, and root parts (Madison, 1962).

On sand based soils, there is also a high need for K and P fertilization. Potassium is important because of its contribution to root growth, environmental stress tolerance (heat, cold, and drought), wear tolerance and reducing the turf's susceptibility to leaf spot diseases (Duble, 1996). Pest problems in bermudagrass are widespread and increase with increasing levels of management (Duble, 1996). High N, close mowing and frequent irrigation increases the susceptibility of bermudagrass to insects and diseases. Nitrogen rates and thatch levels are controlling factors in the severity of brown patch and dollar spot diseases.

Fertilizer type and rate affects rates of thatch accumulation. Turfgrasses grown on sandy soils in the southern United States require large quantities of N fertilizers (1980 to 2970 kg N $ha^{-1}$ $month^{-1}$) to remain a desirable dark green color. N is applied as a soluble, slow release organic, or natural organic compound. Slow or controlled release N sources are generally more expensive than soluble inorganic N sources like $(NH_4)_2SO_4$. Oxidation of the $NH_4^+$ in $(NH_4)_2SO_4$ acidifies the soil, but $NO_3^-$ is more leaching prone. According to Tisdale and Nelson (1975), increased acidity tends to slow the nitrification process. Acidifying the soil has been shown to increase thatch buildup due to slowing the microbial breakdown of the thatch. Adding $CaSO_4$ to an acid soil counteracts some detrimental effects, and reduces thatch accumulation.

Another factor that directly affects thatch accumulation is the activity of soil microorganisms. Soil microorganism activity is influenced by many soil conditions such as soil temperature, pH, moisture, and aeration. Microbial populations are most active in aerated soil environments of near neutral pH, with adequate moisture, and temperatures between 60-80$^{o}$F. Microorganisms are most active where organic matter is the highest as they depend on it for food (Starkey, 1954). Maintaining an adequate environment for soil microbial decomposition is an important tool in managing thatch accumulation. Sartain (1978), reported that increased acidity promoted thatch accumulation by decreasing microbial activity.

Sartain tested acidity and N source on thatch accumulation. He had treatments of 1) isobutylidene diurea (IBDU), a slowly soluble synthetic organic N fertilizer whose rate of N release depends on soil moisture, 2) $(NH_4)_2SO_4$, and 3) activated sewage sludge. Sartain (1978) reported that IBDU (31-0-0) consistently promoted the lowest level of thatch accumulation as compared with the N-sources Sewage Sludge (6-0.9-0) and $(NH_4)_2SO_4$ (21-0-0) applied at equal annual N totals. In general, turfgrass growth rates in response to applied sewage sludge were inferior to the synthetic organic slow-release N-sources. Application of activated sewage sludge resulted in 14% more thatch accumulation than $NH_4NO_3$ (White and Dickens, 1982).

Meinhold et al. (1973) reported that increasing N fertilization increases the lignin cellulose ratio, which leads to lower carbon evolution from microbial activity. The thatch became harder to break down with the increased lignin content. Rate and source of N have pronounced effects on bermudagrass thatch accumulation (Smith, 1970). Similar to Sartain's findings, Smith found that using $(NH_4)_2SO_4$ reduced pH, and reduced Ca and K concentrations in the soil, which led to decreased microbial breakdown of thatch as compared to other sources (Smith, 1970). Using $(NH_4)_2SO_4$ increased thatch by as much as 14% (Riley, 1975).

Although N fertility is very important in controlling thatch buildup in turf, research has shown that topdressing and mechanically removing thatch by vertical mowing and aerification is more effective in decreasing thatch and increasing the mat layer. White and Dickens (1982) reported that 4 topdressings per year reduced thatch accumulation more than 1, and increased mat depth, while not affecting turf quality. Thompson and Ward (1966) also reported that topdressing with soil was the most effective way to reduce thatch in Tifgreen bermudagrass. Vertical mowing effectively reduced thatch in Kentucky bluegrass and bermudagrass (Murray and Juska, 1977; Johnson, 1979). Carrow et al.(1987) showed that sand topdressing reduced thatch by as much as 62%.

Removing thatch mechanically from golf greens by vertical mowing and aerification retards buildup of excessive thatch or removes it after it has accumulated to a detrimental level (Duble,1996). Riley (1975) reported a linear relationship between vertical mowing and thatch depth while not affecting turf quality on Tifgreen and Tifdwarf. Core aerification helps in maintaining an adequate environment for soil microorganisms. Smith (1979) reported that increasing aerification from twice yearly to monthly slightly decreased thatch thickness. Bi-weekly light vertical mowing and core aerification could decrease thatch by up to 25% (McWhirter and Ward, 1976; Carrow et al., 1987; Weston and Dunn, 1985).

**Conclusion**

Mowing dwarf bermudagrasses at today's golf green heights increases stress on the plants, which leads to higher levels of thatch. This leads to other management problems. Thatch needs to be controlled in order to maintain healthy greens. The new bermudagrasses that grow more vigorously may have even more problems with thatch buildup. Although mechanical thatch reduction is the best way to control thatch, N fertility can also be an important tool in preventing thatch buildup.

Research has shown that use of activated sewage sludge as an N-source is detrimental to dwarf bermudagrass by causing significant thatch increase. $(NH_4)_2SO_4$ and fertilizers that decrease pH reduce microbial thatch breakdown and high rates of N from any source lead to higher replacement and senescence that increases the thatch layer. It is very important to continue to investigate the problems that thatch causes and how it can be best controlled.

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# Can Plants Be Used to Clean Up Soils Contaminated With Heavy Metals?

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*Additional index words.* phytoremediation, phytoextraction, metallophytes, accumulators, excluders.

***Abstract.* Metallophytes are plants that can accumulate unusually high levels of toxic heavy metals. Their potential use in phytoextraction, the use of green plants to remove and contain an environmental contaminant, is being investigated. Three types of metallophyte species exist on metalliferous soils. Accumulators allow the unrestricted uptake and transport of metals to their biomass. Indicators regulate both uptake and translocation maintaining plant concentrations equal to those of the soil. Excluders maintain low biomass concentrations by way of an excluding mechanism in the roots that restricts translocation. Tolerant and non-tolerant races of the same plant species exist. Phytoextraction is emerging as a more economical and ecologically sound method of soil remediation than traditional methods.**

The ability of some plant species to colonize metalliferous soils has long been recognized, and such species have been used as geobotanical indicators in surface mineral exploration (Brooks, 1972). Termed metallophytes, these plants can accumulate unusually high levels of toxic metals such as Cd, Cu, Mn, Pb and Zn. Metal-rich mine tailings, metal smelting, electroplating, ore refining, and municipal sludge dumping are some of the most important human activities that contaminate soils with large quantities of heavy metals.

Of the approximately one-thousand contaminated Superfund sites identified on the United States Environmental Protection Agency’s National Priority list of 1986, 40% of them involve heavy metal contamination associated with industrial activities and 70% of those sites involve two or more metals (Ebbs, 1997). The most commonly used methods of dealing with heavy metal pollution are either the removal and burial of the contaminated soil, an extremely expensive process, or simply isolation of the site (Kumar, 1995).

Phytoextraction, the use of green plants to remove and contain an environmental contaminant, is currently under investigation as a third alternative. This process generally requires the plant to translocate heavy metals to the easily harvestable shoots, thereby reducing the volume of contaminated material, which can then either be isolated as a hazardous waste or ashed and recycled as metal ore. Thus, plants that can hyperaccumulate particular heavy metals, while producing high biomass yields under standard agricultural practices, would be desirable for such operations (Kumar, 1995).

**Metal Uptake by Different Species**

Flora population studies on contaminated soils have shown the development of constant relationships between particular plant species and calamine (Zn) soils in western and central Europe, serpentine soils (Ni, Cr), and soils of the copperbelt (Cu) in central Africa. Some species are found only on metalliferous soils while others occur simultaneously on uncontaminated soils in the same region. This indicates the evolution of adapted metal tolerant races. The presence of a species or population on a metal contaminated soil implies that it has elevated levels of metal toxicity and that it has adapted its physiology. (Baker, 1981).

True metallophytes are plant species that can hyperaccumulate heavy metals in their biomass to a concentration > 1% on a dry matter basis. Metallophyte species vary in their abilities to accumulate metals, and for a given species these abilities may vary as well

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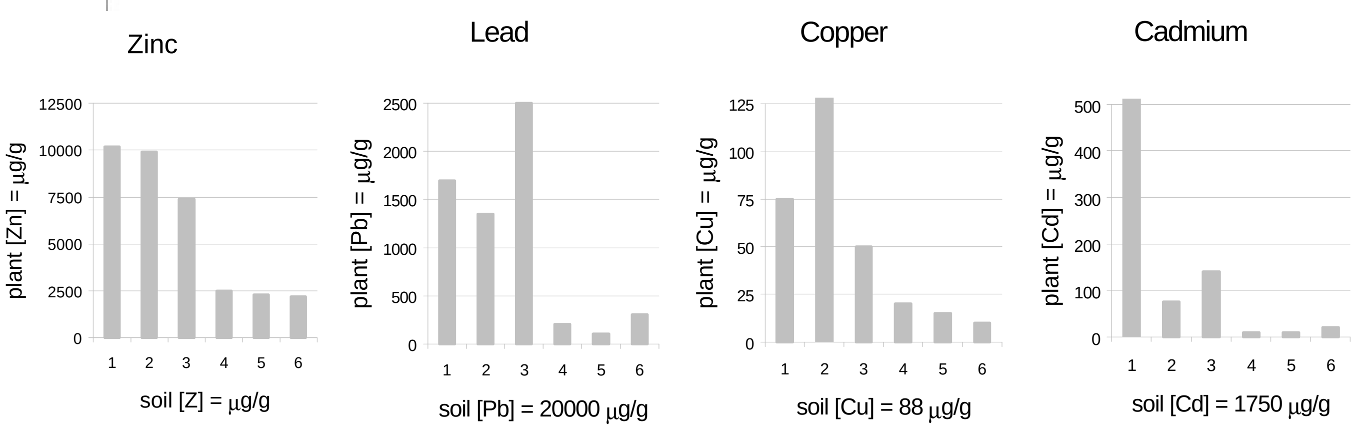
with respect to different metals (Baker and Brooks, 1989). Some plant species exhibit the capability to accumulate high levels of several different metals while others are restricted to one or two metal species (Fig. 1).




*corniculatus* 6.

**Fig. 1. Concentrations of Zn, Pb, Cu, and Cd in the leaf dry matter of six plant species growing on metalliferous soil in Germany (Ernst, 1975).**

*Thlaspi alpestre* (alpine pennycress) was found to have accumulated Zn at a concentration above 10,000 µg/g in its leaves, 25 times the toxcicity level for that of agronomic crops of 400 µg/g. *Minuartia verna* (vernal switchwort) accumulated Cu concentrations up to 120µg/g, 6 times the toxic level of 20µg/g (Ernst, 1975). The ability of any plant to take up and store Pb and Cd is astounding since these two metals are not essential mineral nutrients.

**Physiological Strategies of Plants to Metalliferous Soils**

It has been asserted that plants growing on toxic metalliferous soils cannot prevent metal uptake but only restrict it and thus accumulate metals in their tissues to varying degrees (Peterson, 1975). Adopting this approach makes their strategy for survival one of tolerance to heavy metals and not avoidance.

Based on this and other data it has been proposed (Baker, 1981) that three types of plants exist on metalliferous soils based upon their individual physiological responses: accumulators, indicators, and excluders.  Accumulator species are so named because of their ability to maintain high concentrations of heavy metals in their biomass.  Whether growing on soils of low or high metal concentration, root uptake and translocation are completely unrestricted.  Indicator species regulate both the uptake and the translocation of metals to the biomass. An increase in soil concentration would be directly reflected in an increase in biomass concentration.  Excluder species maintain biomass concentrations at a low and constant level and an excluding mechanism in the roots prevents translocation despite a high soil and root concentration.  However, this excluding mechanism is effective only up to a critical soil value, individual to each species, above which the excluding mechanism breaks down and the unrestricted transport results in toxicity (Fig. 2).

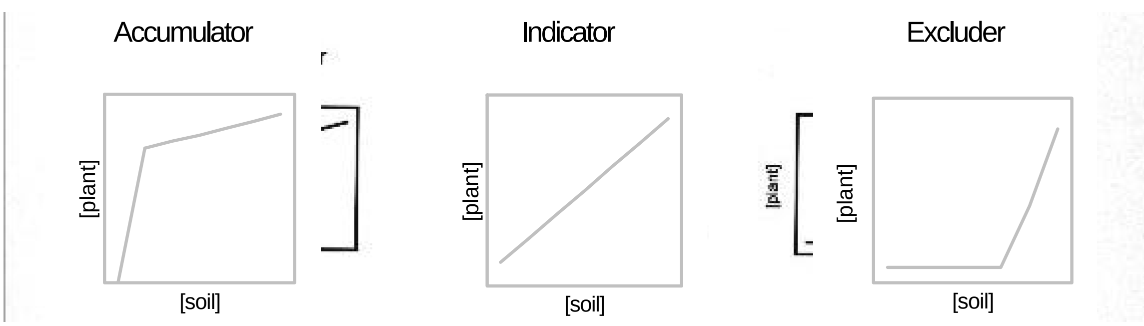



Fig. 2. Three physiological responses of plants to increasing soil metal concentrations as reflected in biomass  metal concentrations (Baker, 1981).

Tolerant and non-tolerant races of the same species are grown together in a metal-rich medium to establish the relationship between uptake and transport characteristics in excluder species. *Silene maritima*, a known Pb tolerant species and suspected excluder, was grown on a Pb rich slag. Tissue analysis of the shoots confirmed that the tolerant race was able to restrict transport of Pb from the roots to the shoots, thus avoiding toxicity, while the non-tolerant race was not, resulting in plant death. At the time of plant death the shoot of the non-tolerant race contained greater than 400 μg/g DM, while comparatively, the shoot of tolerant race contained less than 100 μg/g DM (Baker, 1978).

Metal tolerance is not simply just a genetic trait or predisposition of some plant species, but rather a condition of edaphic evolution and adaptation. Some species, or races within a species, simply lack the genetic capability to adapt their physiology. Baker (1981) asserts that this is evidenced by the knowledge that in both accumulator and excluder species internal mechanisms have been developed to actively detoxify metal ions, but in separate sites in the plant. In accumulator species the site of detoxification is in the shoots while excluders detoxify metals in the roots.

External mechanisms may also play an active role in the plants ability to avoid toxicity. Because accumulator species concentrate heavy metals in the aerial portion of the plant, over-wintering, frequent brush fires, or other natural means of defoliation may assist in detoxifying the storage sites by simply removing the sites of ever increasing toxicity (Blake, 1981). Certain excluder species have been observed to store high levels of Zn in the roots through the spring and summer, only to quickly translocate the metal to the biomass in the fall in anticipation of defoliation (Rascio, 1977).

**Conclusion**

As the United States, and other heavily industrialized countries of the world, continue in their efforts to clean up toxic heavy metal soil contamination there remains a diligent search for any new technology that would make such efforts less expensive and more ecologically sound. Removing contaminated soil from 1 ha to a depth of 7 cm creates nearly 4539 metric tons of soil that must be washed or buried. In contrast, a contaminated site populated by metallophytes, whose biomass was harvested and incinerated, would produce approximately 25 to 30 tons of ash (Kumar, 1995).

Previous research efforts toward realizing the goal of phytoremediation were concentrated simply on locating, identifying, and quantifying which plant species were capable of heavy metal hyperaccumulation, which metals they would accumulate, and how much they would accumulate. Current research has become primarily focused on genetically altering plants, of known high biomass yields and wide environmental adaptation, by introducing the gene for the protein metallothionein which is a chelator known to detoxify certain metals in some plants.

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# Compilation of Factors Influencing Flowering in *Hibiscus rosa-sinensis* Including Causes and Prevention of Bud Abscission


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*Additional Index Words: bloom, blossom, drop, illumination, nutrition.*



***Abstract*. An examination of contemporary literature reveals a variety of factors affecting the number, size and quality of flowers on *Hibiscus rosa-sinensis* L. including light intensity, fertilizer rate, fertilizer source, temperature, and watering regimen. The study reveals the causes of bud abscission: ethylene gas, dark storage, temperature, fertilizer concentration, and water stress plus prevention of bud abscission utilizing Silver Thiosulfate and auxins.**


*Hibiscus rosa-sinensis* L. is a popular patio and bedding plant (northern climates) known for large, colorful blossoms. Successful marketing of this tropical plant depends on growing techniques that assure prolific quantities of blooms. Several factors affect the quantity, size and number of blooms, including: lighting, fertilizer type and amount, temperature, and watering. Stress levels in any of these areas can have a detrimental effect on the flowering of this plant, but optimum conditions assure dramatic success.

Illumination amount and intensity has a proportional effect on flowering initiation, flower size, and quantity (Neumaier, et al., 1987). The plants perform best in full sun, although different cultivars have specific preferences (Beers and Howie, 1985). Full sun decreased the number of days to flowering (33 vs. 42); increased the average number of total buds per plant (134 vs. 111); enhanced the number of flowers per plant (92 vs. 75) but decreased flower diameter (117 mm vs. 124.4 mm) when compared with 50% shade (Neumaier, et al., 1987).

Fertilizer regimen plays a crucial role in flowering. Proper elemental concentration ratios are just as important as adequate fertilization levels. Improper elemental balance can have a detrimental effect on flowering as is the case with an overabundance of N. Nitrogen has a detrimental effect on buds when applied in excessive quantities because it produces leafy soft-stemmed growth at the expense of flowers. This is particularly noticeable in species that flower only on woody plant material (Beers and Howie, 1985). A study of controlled released fertilizer (crf) concluded that an application of ~200-300 ppm of 12 g Osmocote provided the greatest number of buds per plant (>140) while the number of buds per plant greatly diminished with Osmocote applications of 9 g and 12 g at levels greater than 300 ppm. Utilizing 3 g and 6 g Osmocote did not cause fewer buds to develop. The overall number of blooms was fewer at all concentration levels, but bud number per plant did not decrease at applications greater than 400 ppm (Neumaier, et al., 1987).

Potassium is crucial for flowering of Hibiscus. Successful growers have concluded that K, when present in amounts greater than N (1part N:3 parts K) has a beneficial effect on flower quality, quantity, color, and appearance. These growers have found that it is best to fertilize frequently and in small amounts (Beers and Howie, 1985). The trials of growers have been reinforced by scientific research. This research helps explain the reasons why proper K levels have such a beneficial effect. While increased levels of potassium in solution had a somewhat limiting effect on macroelemental concentrations in leaf tissue (N, P, and Ca), it had a beneficial effect on leaf micronutrient concentration. Iron, Mn, Zn, and Mo levels were all significantly increased with enhanced K fertilization levels (Egilla and Davies, 1995). Thus, proper macroelemental ratios can have a beneficial effect on micronutrient uptake, which can serve to enhance metabolic processes of the plant, leading to a higher quality crop.

While proper nutrition is important in promoting a strong flowering response, cultural practices are vital to assure that these flowers remain on the plant. Bud abscission is an obstacle in the production of this plant. Since the aesthetic quality correlates with market value of this crop, bud abscission prevention is crucial. There are numerous causes of bud drop, all related to stress. Any one or a combination of the following factors: water stress, improper illumination, inadequate fertilizing, and ethylene gas all can cause Hibiscus to jettison buds (Beers and Howie, 1985).

Storage conditions of this crop are responsible for the quality of plants at time of sale. Three main factors affect the loss of buds during storage and transport: darkness, temperature and ethylene buildup. To maximize crop value, it is crucial to provide proper conditions for the plant during this time of stress.

A number of studies have been conducted to determine the effect of storage condition on bud abscission in hibiscus. One study concluded that a storage temperature of 15.5° C will maximize the flower diameter and number of flowers per plant while minimizing the number of abscised buds. The same study concluded that the shortest duration of storage is best as light exclusion time is minimized (Gibbs, et al., 1989). A different study found somewhat different optimum storage temperatures, concluding that 10° C minimized bud abscission, while higher temperatures actually increased this effect (Thaxton, 1986). While light levels during storage affected bud abscission, pre-storage lighting also affected the amount of bud drop during storage. Another study determined that predark storage irradiance of 980 $\mu mol \cdot s^{-1} \cdot m^{-1}$ resulted in 58.6% abscission after subsequent storage while predark storage irradiance of 500 $\mu mol \cdot s^{-1} \cdot m^{-1}$ resulted in a 78.3% abscission, a significant increase (Force, et al., 1988).

While there is some concurrence in the literature regarding the correlation among illumination, temperature, and bud drop; there are discrepancies regarding the size of buds most likely to abscise. One such study concluded that the most mature buds abscised in significantly less time than less developed buds (Thaxton, 1986). However, another study found that dark storage abscission was greatest for buds of 10-30 mm (61.8%), followed by buds less than 10 mm (36.2%) with buds greater than 30 mm having significantly less amount of abscission during dark storage (2.7%); suggesting that the more developed buds are least likely to abscise. The authors of this study hypothesize that this is due to the fact that there is a decrease in the amount of photosynthates available to the developing flower combined with a reduction in the ability of the flower bud to compete for available assimilates (Force, et al., 1988). Another study suggests a physiological basis for this occurrence. The plant abscises less developed buds due to the fact that they have not developed structures suitable for reproductive purposes (Gilliland, et al., 1976). While the different results of some studies could be interpreted as errant research, it is more plausible that researchers did observe different results due to the influence of other variables than the ones being specifically studied. This provides an area for further study to determine environments that favor undeveloped bud abscission and environments favoring mature bud drop.

While it is important to understand the causes of bud abscission, from a practical standpoint it is valuable to determine possible methods of preventing this occurrence.

There are two areas that growers can manipulate to enhance bud retention: cultural practices and chemical enhancement.

The most cost effective prevention for bud drop are cultural practices. One study determined that the increased flower bud abscission during dark storage is due to the decreased supply of photosynthates to the developing buds. These researchers suggest that bud drop can be minimized by attempting to increase plants' assimilate reserve by high irradiance or to reduce the sink demand by partial bud removal. The main expense in these practices is labor.

Other studies have examined chemical methods of abscission prevention. Specifically the use of auxins and silver thiosulfate may be utilized in this effort.

The abscission zone creation is facilitated by an increase in membrane permeability, caused specifically by ethylene and abcscisic acid. The hypothesis is that acid phosphatase is synthesized and released in a manner similar to other hydrolytic enzymes, its activity is accelerated and enhanced by abscisic acid. Phosphatase is a membrane responsible for cell wall degradation. However, auxins maintain the integrity of cell membranes by maintaining integrity of dictyosomal vesicles and thus the integrity of the plasma membrane (Gilliland, et al., 1976). This provides another area for further study: a determination if increasing auxin concentration prevents bud abscission.

One area where significant research has been conducted on chemical control and prevention of bud drop is in application of silver Thiosulfate (SSTs). One such study determined that application of SSTs prior to ethylene or high temperature (common in Texas) exposure resulted in a decrease in bud abscission rates when compared with plants sprayed only with water. The results are quite significant. In this study both treated and untreated plants were exposed to 1 ppm ethylene for 48 hours. The untreated plants (0 mM SSTs) had 87.07 ± 15.8% bud abscission 0 days after ethylene exposure and 100.00 ± 0.0% bud abscission 10 days after exposure. In contrast, plants treated with 4 mM SSTs had only 1.16 ± 2.0% abscission 0 days after exposure to ethylene, 8.09 ± 7.5% drop at 10 days and 10.98 ± 9.6% abscission 20 days after exposure. The same study examined temperature effects at 10, 20 and 30° C. Since 30° C had the most significant effect on abscission, these results are noted here. The study found that a treatment of 0 mM had bud abscission rates of 14.29 ± 10.9%, 97.14 ± 3.2% and 97.14 ± 3.2% at days 0, 10 and 20, respectively. The treatment of 4mM SSTs resulted in bud abscission rates of 0.00 ± 0.00%, 5.26 ± 3.9% and 5.26 ± 3.9% at days 0, 20 and 20, respectively (Thaxton, 1986). This demonstrates a significant decrease in the amount of bud drop from ethylene exposure in crops treated with sodium thiosulfate. These results are confirmed by a similar study evaluating the effects of SSTs application and bud abscission induced by ethylene, and darkness. This study further concluded that SSTs is not a phytotoxicological agent (Hoyer, 1986).

**Conclusions**

Practices that growers can engage in to maximize the market value of *Hibiscus rosa-sinensis* are: proper lighting, proper fertilizer type and amount, optimum temperature, and watering. In addition, there are cultural practices and chemical applications that can minimize bud loss due to transportation and storage stress which can be utilized to preserve a good crop. There is still more research that should be conducted to really determine bud sizes that are most likely to abscise, and under which condition. This determination will assist the grower in knowing what maturity level of buds is best for transport, providing maximum aesthetic value of Hibiscus crops when they reach the point of sale.

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# The Use of VAM in Phosphorous Deficient Soils

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Additional index word: mycorrhiza, plant nutrition, *Vesicular-arbuscular mycorrhizas, Enodmycorrhiza*, fungi.

***Abstract.*** **Low Phosphorous is a growth-limiting problem associated with many agricultural soils. Discovering ways in which to increase P nutrition in plants, with minimal additions of fertilizer, is essential for crop production on such soils. Mycorrhizal associations can increase the uptake of P in areas in which available soil P is limited. Particular attention to compatibility of host plants and fungi can allow for maximum enhancement of phosphorous uptake. Factors, such as add P fertilizer, native mycorrhizal species and soil tillage practices, can influence the establishment of mycorrhizal colonization.**

Plants must obtain from their environment the mineral nutrients, which are the fundamental materials required for all of the complex biochemical reactions necessary to cell life and thus plant growth. Much of the evolution of plants has involved the development of techniques for acquisitioning these building blocks. The benefits of adding these nutrients to the soil to maximize plant growth have been known for thousands of years. Much of the scientific research concerned with plants has incorporated some aspect of plant nutrition. Agricultural and Horticultural research on crop plants has involved the determination of the quantities of nutrients required for optimal crop yields and the ability of varying soils to provide these nutrients. Certain plant species are sometimes characterized by uncommonly high or low amounts of one or more of the mineral nutrients. Scientists have categorized these nutrients by their quantities and functions in plants. Among those nutrients that are categorized as essential, Nitrogen, Phosphorous, and Potassium are the most commonly found to be limiting to plant growth. Compared with Nitrogen, Phosphorous and Potassium are required by plants in somewhat smaller quantities.

Of all of the nutrients that can be provided by natural occurrence in the earth's crust, Phosphorus (P) is most commonly the element that limits plant growth (Ravin, 1992). While the addition of P to a soil that has a limiting quantity is one obvious solution, it is not always practical. Adding P may not always be possible, especially in soils that are particularly deficient, or in countries were fertilizer costs exceed the benefits of agricultural yields. While plants have spent much of their evolution creating ways of obtaining nutrients, scientists have spent much of their time in developing ways to enhance and use these evolutionary traits to increase agricultural and horticultural production. One such evolutionary technique, developed over time, can be attributed not to plants, but to their symbiotic counterpart, the fungi.

Associations between plant roots and fungus have produced Mycorrhiza. While these associations are general not essential to most plants, they do occur naturally quite often. All gymnosperms, 83% of the dicotyledonous and 79% of the monocotyledonous plants are involved in mycorrhiza relationships (Marschner, 1995). Understanding mycorrhiza and the benefits they provided can lead to better utilizing the P in deficient soil.

**Phosphorous Availability and Effects on Plant Growth**

While additions of N, P, and K generally all have been shown to increase crop yields, only P absorption is continued into the later stages of growth when N and K uptake is slowing (Le Bot, 1994). Phosphorous is taken up mainly in the form of $H_2PO_4^-$ from the soil solution (Marschner, 1995). This uptake occurs by the active mechanism involving H+ cotransport or $HCO_3^-$ antiport properties (Le Bot, 1994). Phosphorus is indirectly responsible for the high cation concentration of DNA and RNA structures since it contributes to the acidic nature of the nucleic acids making up these structures (Marschner, 1995). Phosphorous is an essential component of biomembranes and energy rich compounds such as ATP, GTP, and UTP that are responsible for the synthesis of starch, cellulose, and sucrose (Marschner, 1995). Deficiencies of Phosphorus can result in decreased leaf number, leaf surface area, and leaf expansion (Marschner, 1995), due to a decline in plant hydraulic conductivity (McArthur, 1993). Frequently a shift in photoassimilates and P partitioning to favor root growth occurs when P is limiting (McArthur, 1993). Poor P nutrition can decrease the overall shoot canopy and thus photosynthetic surface area, as well as axillary bud growth (McArthur, 1993). Limited P can affect soybean growth by decreasing pod production and retention (Lauer, 1989). Low P in corn resulted in decreased respiration, low levels of soluble protein, and enzyme activity as well as accelerating the onset of senescence (Russo, 1995). As a result of the dramatic effects low P can have on many valuable agricultural crops, monitoring and maintaining adequate levels of P is essential in agricultural production. To be available to plants, P must be contained in the soil solution (Le Bot, 1994). The labile, soluble solid form of P in soil is easily converted to soil solution (Le Bot, 1994). A third P pool, an insoluble fraction, exchanges with the labile portion at a very slow rate (Le Bot, 1994). It is because of this insoluble fraction that it is necessary to add 10-15% more P than a crops' demand for it (Le Bot, 1994). While P concentration is typically between 0.3 and 3.0

kg·ha$^{-1}$, rapidly growing crops can absorb as much as 1 kg·ha$^{-1}$ day$^{-1}$ (Le Bot, 1994). Techniques that can increase the absorption in soil that are low in P would greatly benefit agricultural areas that are unable to meet P demands with added fertilizer. The mycorrhizal relationship found in many plants may be one such technique. The mycorrhizal symbioses found in P deficient soils can increase the uptake of P remarkably (McArthur, 1993).

**Mycorrhizal contributions**

While root exudes and morphological changes in roots can contribute to nutrient absorption, these methods are not easily controlled by agricultural practices apart from genetic selection for such traits. Mycorrhizal symbiosis can enhance the P nutrition of a plant beyond what could be obtained through the plant's adaptation to low P on it's own (McArthur, 1993). Microorganisms living within the rhizosphere can benefit plants by using sugars or cells and tissues sloughed off by plants as a carbon source for production of organic acids or chelators that can increase the bioavailablity of certain mineral nutrients (Marschner, 1995). These bacteria do cause nutrient absorption benefits but not to a great extent (Marschner, 1995). Since mycorrhizas do not have to compete with other microorganisms for an energy source, they can exits in greater quantities and are easier to establish in the rhizosphere (Marschner, 1995). Potato crops can benefit from mycorrhizal fungi during early to mid season growth by the resulting enhanced absorption of P (McArthur, 1993).

*Vesicular-arbuscular mycorrhizas* (VAM) are *Enodmycorrhiza*, living within the cortical cells of plant roots and extending mycelium into the surrounding soil (Marschner, 1995). VAM form bladder like storage structures both intra and intercellularly (Sullia, 1991). Branched hyphae, arbuscules, serving as absorptive structures, and sites of solute exchange with the host, are characteristic of VAM (Sullia, 1991). The combination of roots and mycorrhiza hyphae in soils increase the surface area that can absorb nutrients. (Marschner, 1995). The mycelia extend the region of P absorption beyond the root zone that is rapidly depleted in P limited soils. (Sullia, 1991). In heavily infected plants the fungal mass is typically 10% of the total root mass but can reach as much as 20% (Marschner, 1995). The total amount of P that hyphae may contribute to the plant can be as high as 70-80% of the P absorbed and the rate of uptake is 2-3 times that of nonmycorrhizal plants (Marschner, 1995).

Improved phosphorus nutrition of some VAM plants may also increase the tolerance of the plant to drought stress (Marschner, 1995). The ability of VAM fungi to make the insoluble fraction of soil available to the plant (Sullia, 1991) is of particular interest in agricultural areas in which P fertilization is limited. In calcareous soils, high rates of respiration of mycorrhizal roots can further increase the solubility of some soluble calcium phosphates and thus increase the effectiveness of P absorption by roots (Marschner, 1995). Accumulation of polyphosphates in the vacuoles can act as storage or as an alternative energy source for ATP, involved in transporting phosphate from the hyphae to the root across the plasma membrane as inorganic phosphate (Marschner, 1995). VAM roots in Potato showed higher protein concentration and enhanced microsomal ATPase and acid phosphatase activities compared with their non-mycorrhizal counterparts (McArthur, 1993). VAM may provide other benefits such as increased absorption of N, Zn, Cu, and Fe, as well as increasing chlorophyll concentration and plant growth (Runjin, 1990). Using VAM inoculum may be beneficial in reducing fertilizer inputs (Sullia, 1991).

**Practical Applications of VAM**

VAM fungi are beneficial in reclamation of mined land. The application of topsoil and irrigation to southwestern Wyoming arid regions, was successful in allowing faster inoculation with VAM, and thus assisted in the reclamation of mined lands by host plants (White, 1992). VAM cannot yet be grown in pure culture so methods of obtaining spores or fungi most be developed (Khalil, 1994). Present methods included planting already infected plant material in proximity to desired host (Camel, 1991), collecting spores from soil and incorporating them when planting host species, the addition of top soil containing spores or propagales (White, 1992). Natural inoculation can occur as wind, rain, and invertebrates, such as earthworms carrying spores over a long dispersal range (Gange, 1993).

**Problems Associated with using VAM**

While the fungi are totally dependent on the host plant for carbon sources, the plant is not necessarily dependent on the fungi (Marschner, 1995). A large proportion of the net photosynthates that are appropriated to roots is used for fungal growth and maintenance (Marschner, 1995). In soils that are high in P, or in which high levels of P fertilizer are added, VAM fungi colonization may decrease as plants adjust to higher root uptake (Marschner, 1995). Costs to plant growth by fungi use of photosynthates must be compared with the benefits that occur from enhanced absorption of P (Marschner, 1995.)

Colonization of plants is related to the compatibility of host with symbiant fungi (McArthur, 1993) and determining specific combinations for crops is essential for maximizing utilization of mycorrhizae relationships. Induced root physiology of P starved plants favor increased VAM infection (McArthur, 1993) and it may be that plants that receive appropriate P from the soil do not produce the anatomy for VAM infection (Amijee, 1990; Dhillion, 1991). In an experiment using *Syngonium*, which has somewhat thick and unbranched roots with few hairs, and *Nephrolepis*, which has a well-developed root system and root hairs, it was shown that greater colonization occurred in the *Nephrolepis* (Wang, 1993). Also, poor aeration (Wang, 1993), the composition of root exudes, toxins and other defense reactions may also decrease the colonization of VAM fungi (Marschner, 1995). Tillage and soil disturbances can delay or depress the infection of plants with mycorrhizal fungi (Marschner, 1995).

**Conclusion**

Much research has been generated that demonstrates an increased absorption of P and other essential nutrients, with the addition of symbiotic associations. Enhancing the infection of crops with VAM fungi could assist growers in utilizing soils that may have been consider to have too low a fertility for agricultural crops. This is significantly important to those countries that have soils poor in fertility and costs for fertilizer amendments are not feasible. Considerations of plant host and fungi combination, tillage practices and crop root anatomy must all be examined when determining if VAM is to be used.

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# Is There A Superior Bean Genotype That Can Use Rock Phosphate for Economical Production in Tropical Soil ?

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*Additional index words.* *Acidic, genetic, phosphorus fertilizer*

*Abstract.* **Little is known about the different genetic or phenological potential of bean cultivars to utilize rock phosphate as a phosphorus fertilizer. This is important among developing tropical countries. Comprised of acidic, highly weathered soils. Phosphorus is often the first limiting nutrient to the production of this nutritious and relatively inexpensive human food source. This less expensive form of phosphate fertilizer could be paired with an efficient use bean and liberate millions of people from dependence on imported food products.**

The common bean is an important source of protein for millions in Latin America, Africa and Asia. Beans and legumes average 19 to 28% protein content (Hernandes and Focht 1985). Beans rank second to rice as a basic food staple in many tropical and subtropical countries. (Morton ,1975)

Low phosphorus availability in these soils, however, limits bean production. There is much concern that the increasing demands of growing populations cannot be met under the current production constraints (Janssen , 1989).

Bean farming is conducted mainly by poor farmers cultivating ten hectares or less. Who are not able to purchase great quantities of fertilizer. Combined with the capacity of many tropical soils to fix applied phosphorus into forms unavailable to plants (Sanchez and Uehara 1980) the prospects for prosperity seem bleak. An alternative genetically improved P efficient bean and the available rock phosphate could make economical and profitable production of an important food source possible.

**Soil Phosphorus**

Phosphorus occurs in soil almost exclusively as orthophosphate. The total content of P in the soil ranges from .02 to .15%. In mineral soils the proportion of organic P is between 20 and 80%. Weathered mineral soils and volcanic organic soils predominate in the tropics and subtropics. The mineral soils bind the P as Fe and Al compounds. The organic compounds bind the P in the volcanic soil. Many attempts have been recorded to develop a procedure to access insoluble P from the third or non-labile fraction of the soil, but none have been successful. The first fraction (the P in soil solution) is available to the plant. Only the P held on clay surface (the second fraction or labile pool) contributes to the solute P as well as the non-labile pool.

The acidity often observed in tropical soils further complicates matters. Anions are adsorbed more strongly when the soil pH is raised and the ions are able to exchange with adsorbed phosphate and release P into the soil solution. This process is known as desorption. When these acidic soils are limed to raise pH. Low soluble precipitates, such as Ca, Fe and Al phosphates may be formed. The availability of applied P as well as liberated P is decreased if the concentration of these ions is high as is often the case in tropical soils. ( Amarasiri and Olsen, 1973). Calcium carbonates can even adsorb P slowly returning it to apitate and the third soil fraction at pH greater than 7.0.

These same scientists reported that liming and adding P increased yield of rye and millet until the soil pH reached about 6.5. They blamed the precipitated Fe and Al hydroxides for inactivation of added P . They also noted that Pigeon peas on limed and fertilized soils had better root systems concluding that greater root development accounted for the higher yields.

Another important mechanism for soil to release P into solution is decomposition of organic matter ( Hernandez and Focht 1976). Rhizobium inoculated nodules of the pigeon pea facilitate the use of organically bound P but the procedure did not increase yields or P in the soil solution. Lynch and Beebe 1995 to the same conclusions. This is in contrast to the expected plant root interaction with soluble P described by Marshner (1986). He explained the N2 fixation process of the microbes may help the roots effect pH changes in the rhizosphere and influence p uptake. Given that the most important ions containing P in the soil are H2PO4- and HPO4 2- (depending on the soil pH) and the root can be as much as one pH unit different from the soil. The end result is increased uptake of the P by the roots.

**Factors That Effect Bean Plant Phosphorus Uptake Efficiency**

Lynch and Beebe ( 1995) defined efficiency to be "the ability of a system to convert inputs to outputs". They further suggested six main physiological mechanisms that could be sources of increased P efficiency in beans:

1. Reduced tissue P requirements
2. Longer season phenology which extends the time available for physiological use of P,
3. High P seed reserves for seedling establishment. ( In fact large seeded Andean genotypes have proven outstanding at P utilization Yan et al., 1995),
4. Root exudates which can liberate inorganic P from Fe and Al compounds,
5. Mycorihizal symbiosis and

6. Root activity and architecture .

These researchers hypothesize genetic differences for P efficiency in bean germplasm are primarily caused by genetic variation for root traits. This was also postulated by Fawole et al. (1982) when they did experiments of inheritance and physiology of bean growth under P stress. Heritable variation for root dry weight existed in the beans studied. Back crosses that showed little variation . Fawole believes that only a few genes contribute to root mass and dominance variance is the most likely mode of inheritance.

**Conclusions**

Marshner (1986) reported several studies in Britain have proven rock phosphates give satisfactory crop yield responses on acid soil. This also is normally the most available and economical form of phosphate fertilizer in the tropics. The challenge now is to selectively produce palatable, high yielding, heavy rooted beans. This can be done form the strains of culturally acceptable beans already in existence.

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# The Effect of Potassium Fertility on Disease Resistance in Turfgrass Species.

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**Abstract. Plant nutrition is recognized as an important component in disease resistance for turfgrass species. Potassium is one of the most important nutrients involved in plant health, playing an essential role in both mechanical and biochemical defense mechanisms. A review of the literature indicates inconsistencies concerning the relationship between K and disease severity in turfgrass species. Some studies show a negative correlation between plant K levels and disease, while others show no correlation. Therefore, potassium's effect on disease must be considered on a species-by-species basis. A complete, balanced fertility program did consistently decreased disease severity and should be an integral part of any successful turf management program.**

The relationship between nutrition and disease has been recognized since the beginning of the 20th century (Beringer and Trolldenier, 1979). A large body of literature exists documenting the effects of plant nutrition on diseases. A plant's nutritional status can determine its level of resistance to a given pathogen (Huber and Arny, 1985). Potassium, an essential nutrient, is considered to play an important role in host plant resistance.

**The Role of Potassium in Plant Nutrition**

The role of K in plant nutrition has been extensively researched. Although K is not directly associated with the molecular structure of any plant constituent, it has been

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designated an essential element in all higher plants. Excluding C, H, and O, K is second only to N in concentrations required by plants for growth, development and reproduction (Turner and Humnel, 1992). It plays vital roles in such physiological functions as photosynthesis, carbohydrate and protein synthesis, osmoregulation, cell expansion, stomatal movement, and regulation of numerous enzymatic reactions (Turner and Humnel, 1992), (Marschner, 1995).

**The Role of Potassium in Disease Resistance**

Potassium is important in numerous plant processes. Growth, stress and wear tolerance, weed encroachment, disease incidence and overall aesthetic quality are all affected by K levels within a plant (Turner and Hummel, 1992). Of these factors, potassium's effect on disease incidence has received the most attention.

Potassium has been shown to play a significant role in disease resistance. Its role in cell wall integrity is recognized as an important component of disease prevention. For example, in K deficient plants, the outer epidermal wall tends to be thin relative to K sufficient plants, allowing pathogens to easily penetrate host cells. Also, high K levels enhance lignification of cell walls, preventing pathogen penetration (Beringer and Trolldenier, 1979).

Aside from its role in mechanical defenses to pathogen penetration, little else is known about the specific mechanisms by which K effects disease resistance. This is especially true in the area of biochemical defense mechanisms. Due to its involvement in enzymatic activity, K is thought to participate in nearly all cellular functions that influence disease severity (Huber and Arny, 1985). However, the specific mechanisms of this influence are still unknown. Huber and Arny, 1985, speculated that "potassium probably exerts its greatest effect on disease through specific metabolic functions that alter compatibility relationships of the host-pathogen environment." For example, in K deficient plants, the synthesis of high-molecular weight compounds, such as protein, starch and cellulose, is inhibited. As a result, low-molecular weight organic compounds accumulate providing an excellent food source for pathogen development (Marschner, 1995).

**Potassium Levels and Disease Incidents in Turfgrass Species**

The effects of K fertility on disease incidents are well documented for many plants, including some turfgrass species. The results however, have been inconsistent.

Goss and Gould (1967) studied the interrelationship between fertility levels and the occurrence of *Ophiobolus graminis* Sacc. var. *avenae* E.M. Turner, on *Agrostis* spp. The most severe infections were found on those plots that received the highest nitrogen fertility levels. However, K had a suppressing effect on Ophiobolus patch throughout the experiment.

Goss (1972) reviewed a study by Evans on leaf spot disease in coastal bermudagrass. Potassium deficiency was shown to significantly influence disease severity (Table 1).

**Table 1** - The effects of various combinations of N, P, K and lime on leaf-spot disease of Bermudagrass*

| Fertilizer treatments** | Spots per leaf, average |
|---|---|
| NPKL | 13.5 |
| N(.5)PKL | 19.9 |
| NP(.5)KL | 23.1 |
| NKL | 16.0 |
| NPK | 19.6 |
| NPL | 147.5 |

* Data was taken from Evans et al. 1964.
** N = 178 Kg/ha, P = 39 Kg/ha, K = 74 Kg/ha, and L = lime to bring pH to 6.5

Markland et al. (1969) studied the influence of N fertilizers on the incidence of dollar spot, *Sclerotinia homoeocarpa* F.T. Bennett, in creeping bentgrass, *Agrostis palustis* Huds, and found that K levels in the foliage showed a high negative correlation with the number of disease sites. They speculated that plant tissue low in K accumulate amino acids, amides and carbohydrates, which provide pathogens with an increased food supply.

Dollar spot (*Slerotinia* spp.) incidence in tifway bermudagrass [*Cynodon dactylon* (L.) Pers] was related to K application rate, source, and frequency (Horn, 1969). Potassium reduced dollar spot at all application rates. Similar results were reported for leaf spot (Helminthosporium spp.) in bermudagrass (Juska and Murray, 1974). Also, there was less incidence of leaf spot in plots fertilized with N and K, as opposed to those plots only fertilized with N.

The incidence of snow mold (*Typhula itoana*) and dollar spot (*Sclerontinia hemoerra*) on Penncross creeping bentgrass was not affected by K fertilization. Brown patch (*Rhizoctonia soloni* Kuhn) actually increased slightly, but not significantly, with K applications (Waddinton, 1978).

Nitrogen greatly effected the incidence of *Prechslera* spp. and *Puccinia coronata* on perennial ryegrass (*Colium perenne*), but K had no significant effect (Lam and Lewis, 1982).

Potassium only had a slight influence on dollar spot in bermudagrass, with less disease occuring at the lowest K level (Carrow et al, 1987). These findings refute those of Horn (1969).

According to the literature, the role of K in disease incidence varied depending on the plant / pathogen systems. Therefore, sweeping generalizations about potassium's effect on disease can not be made. It does become apparent however, that the effects of K on disease incidence are mainly confined to the deficiency ranges, and excess amounts of K does not appear to be beneficial.

**The Importance of Balanced Nutrition**

The balance or ratio of all nutrients may play as important a role in disease resistance as the level of any one specific nutrient (Huber and Arny, 1985). The highest disease severity was found on plots fertilized with high rates of N fertilizer (Hull et al, 1979). Those plots receiving complete N-P-K fertilizers showed significantly less disease (Table 2).

**Table 2** - Visual scores of stripe smut incidence on variously fertilized 'Merion' Kentucky bluegrass turf in June 1972

| Nutrients applied | Fertilization rate** | | | |
|---|---|---|---|---|
| | x | 2x | 4x | Avg. |
| | | ---------disease score***---------- | | |
| N:0:0 | 3.2bc* | 4.2bc | 8.8d | 5.4s |
| N:P:0 | 1.5ab | 2.2ab | 3.2ab | 2.3r |
| N:0:K | 1.5ab | 2.2ab | 4.8c | 2.8r |
| N:P:K | 1.0a | 1.2a | 2.5ab | 1.6r |
| Avg. | 1.8y | 2.5y | 4.8z | |

* Values within the ratio by rate interaction and averages followed by the same letter are not significantly different at the 5% confidence level.
** Fertilizer rate: x = 12-2-4 g/m2 N-P-K.
*** Visual disease scores; 0 = no disease, 10 = completely infected.

Regardless of the inconsistencies present in the literature concerning K's effect on disease, it is apparent that nutrient management is a vital component in disease prevention. A balanced fertility program, one that maintains all essential elements within sufficient ranges, will help reduce both disease incidence and severity.

## Conclusion

Potassium will not increase disease resistance in all instances. But, when incorporated into a complete, balanced fertility program, K will lower disease incidence in turfgrass species.

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