IPNI
Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 1

A MANUAL FOR 4R PLANT NUTRITION

The International Plant Nutrition Institute will release a 4R Plant Nutrition Manual in early March. Based on the conceptual framework developed with industry, government and academic partners, this manual supports a new vision for plant nutrient use in sustainable agriculture. Each of its 9 chapters relates scientific principles of 4R Nutrient Stewardship to the management of plant nutrition.

1. Goals. Society has high expectations for progress on sustainability issues associated with producing sufficient, safe, nutritious food. Nutrient applications increase crop yields, nourishing the world while sparing land for other uses, but poorly managed applications may increase nutrient losses, potentially degrading water and air quality. These issues drive increased attention to setting strong sustainability goals.

2. 4R Nutrient Stewardship. The concept is simple—apply the right source of nutrient, at the right rate, at the right time, and in the right place—but the implementation is knowledge-intensive and site-specific. Stakeholder input is essential for setting specific sustainability goals. The right practices to achieve them are best selected by the producer, with support from crop advisers and decision support tools based on sound agronomic science.

3. Right Source. There is no single right source of nutrient for all conditions, but the question of which source is right for any specific set of conditions should be continuously evaluated. This chapter provides information on the properties of the major nutrient forms supplying essential elements.

4. Right Rate. The central principle of setting the right rate is to meet the nutrient demand of the crop. This chapter provides information on crop nutrient uptake and removal, and the importance of assessing the supply of nutrients from the soil, from indigenous sources and from other materials applied to the land.

5. Right Time. Application timing that matches the timing of plant demand minimizes opportunities for losses driven by weather and soil processes. This chapter explains the dynamics of the N cycle and how nutrient uptake relates to plant growth stage.

6. Right Place. Right placement is all about positioning nutrients strategically, so plants that need them have access to them. This chapter explains the means by which plant roots take up nutrients from the soil, and how applied nutrients are retained or dispersed within the soil.

7. Adapting Practices. Best practices are dynamic and evolve as science and technology expands our understanding and opportunities, and practical experience teaches the astute observer what does or does not work under specific local conditions. A process of adaptive management is essential to determine the right practices for any enterprise involved in growing plants and producing crops.

8. Practices that Support all 4Rs. This chapter describes how to assess the soil's capacity to supply nutrients through scouting for visual symptoms, plant analysis, soil testing, and nutrient omission plots. It includes identifying the right approach to the interpretation of these sources of information.

9. Stewardship Planning and Accountability. Focusing on economic, environmental, and social priorities established by stakeholders distinguishes a 4R Nutrient Stewardship plan from other nutrient management plans. This chapter outlines steps to developing such plans, providing information on managing losses of N and P to minimize harm to the environment.

This manual is intended to help leaders—be they farmers, crop advisers, agri-retailers, extension workers, scientists, regulators or consumer advocates—to more fully acquire and disseminate this new vision for the management of plant nutrition. For details on obtaining your copy of the 4R Plant Nutrition Manual visit www.ipni.net.

– TWB –

For more information, contact Dr. Tom Bruulsema, IPNI Northeast Director, 18 Maplewood Drive, Guelph, Ontario, N1G 1L8, Canada. Phone: (519) 821-5519. E-mail: Tom.Bruulsema@ipni.net.

Abbreviations: N = nitrogen; P = phosphorus.

Note: ***Plant Nutrition TODAY*** articles are available online at the IPNI website: www.ipni.net/pnt

IPNI Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 2

MANAGING PLANT NUTRIENTS WHEN BOTH MANURE AND FERTILIZER APPLICATIONS ARE USED

There are three main sources of plant nutrients available to farmers. They are commercial fertilizers, livestock manure, and municipal sewage sludge or biosolids. There is a preconceived notion that a farmer will only use one of these sources to supplement nutrients supplied by soils. However these sources can be used in combinations very successfully.

When considering the weight of material applied to soil, manures are the greatest, followed by fertilizers, and lastly biosolids (See Table). However, the actual amount of nutrients supplied with fertilizer is still highest because of their greater concentrations compared to organic sources. Typical liquid dairy manure has a fertilizer analysis of 0.4% N, 0.2% P_2O_5, and 0.5% K_2O. A typical fertilizer NPK fertilizer blend, used for a small grain crop, would have a blend analysis of 22-9-18—or about 50 times greater concentrations of plant nutrients compared to liquid dairy manure. Fertilizers are much less expensive to transport compared to manure in order to supply the equal amounts of nutrients to a field. For this reason, the amount of nutrients supplied annually in the US through fertilizer is 20 times greater compared to that applied as biosolids and manure combined. Plus, only a small percentage of cropland receives manure. In Canada, only about 4% of cropland receives manure applications compared to 96% that only receives fertilizer. This excludes some organic crop production land that receives neither manure nor fertilizer.

Relative Use of Biosolids, Manures, and Fertilizers (Approximate US Totals).

Amount	Biosolids	Manures	Fertilizers
Produced (M tonne[1])	6.3	121	45
Applied to Land (M tonne[1])	2.5	109	45
Utilization	40%	90%	100%
Nutrients applied (M tonne)	0.03	1.09	22

[1]Millions of tonnes; tonnes = 1,000 kg = a metric tonne = 2,204.5 lb = 1.1 ton

Table adapted from “Fertilizers, Manure, or Biosolids”, http://www.hvmsd.org/docs/FERTILIZERS.pdf

One disadvantage of only using manure compared to a combination of manure along with additional fertilizer is that the balance of nutrients can be less than ideal. For example, a barley crop yielding 100 bu/A (5,300 kg/ha) will take (per acre) 100 lb N, 42 lb P_2O_5, and 33 lb K_2O from the soil. This equates to a N: P_2O_5: K_2O use ratio of 2.7: 1: 0.8, which translates into a higher N requirement than can be supplied from typical manures. To better supply N, P, and K to a barley crop, a farmer could apply additional N fertilizer along with manure to more closely approach the actual nutrient use ratio of the crop.

What can work well for farmers is to apply manure once every 3 years. In the year of application, manure is applied at a rate to supply the N requirements of the crop and excess P and K is supplied. For the next 2 years, only N fertilizer is required as residual P and K from the manure usually satisfies crop demand. Additional low rates of P and K might be used as seed-row starter fertilizer to get crops off to a good start under cool spring soil conditions. This approach works well to grow adequate yields while avoiding excess build up of soil P and K.

It is recommended that soil nutrient content be monitored annually or at least every 3 years, by having representative soil samples analyzed, and the results interpreted by a qualified consulting agronomist, or certified crop adviser. How often manure can be applied and what rates of fertilizer nutrients are required each year will need to be adjusted depending on the crop to be grown, crop yields, nutrient removal in harvested grain or forage, the manure type and its nutrient content, and weather conditions. By using a combination of manure and fertilizer applications, crop nutritional needs can be met while avoiding excess levels of nutrients in your soil.

– TLJ –

For more information, contact Dr. Thomas L. Jensen, Northern Great Plains Director, IPNI, 102-411 Downey Road, Saskatoon, SK S7N 4L8. Phone: (306) 652-3535. E-mail: tjensen@ipni.net.

Abbreviation: N = nitrogen; P = phosphorus.

Note: ***Plant Nutrition TODAY*** articles are available online at the IPNI website: www.ipni.net/pnt

IPNI
Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 3

WHAT IS GOING ON UNDERGROUND?

We spend a lot of time and money to get crops the nutrition they need for maximizing growth and yield. When planning for the next season, don't forget about the part of the plant hidden beneath the soil surface. There are two obvious functions for roots that come to mind; anchoring the plant to keep it upright and getting the water and nutrients needed to support growth, but there are many other things too.

Roots release a large number of organic compounds that aid the plant in its growth. As much as one-third of the carbon fixed through photosynthesis can be pumped out of the roots into the soil, assisting the plant in numerous ways. The organic compounds released from roots are grouped into high molecular weight compounds such as carbohydrates and enzymes, and low-molecular weight compounds such as sugars and organic acids.

The zone surrounding the root is called the rhizosphere, typically extending a few millimeters in to the soil (about the thickness of a nickel). A jelly-like substance is excreted at the root tip that reduces friction and physically protects the delicate cells at the root tip, aggregates soil particles, maintains a pathway for water and nutrient uptake, and influences the growth and development of surrounding plants and microorganisms. These root exudates play a vital role in providing a constant nutrient supply for plants. Some of them regulate microbial growth surrounding the roots. Specific bacteria can be triggered to form nodules in legumes when signaled by the proper root exudates. Other compounds induce spores of mycorrhizal fungi to germinate and assist the plant with P and micronutrient uptake.

Many exudates can directly improve nutrient availability. For example, organic acids released from roots can solubilize P compounds in the soil. Enzymes originating in the root can speed the release of P from soil organic compounds to a form that can be used for nutrition. Specialized root compounds, called phytosiderophores, will chelate iron (Fe) in the soil and enhance plant nutrition and growth.

Roots have the ability to modify the soil pH in the rhizosphere. Plants that receive nitrate as the primary source of N nutrition generally have an elevated pH in the rhizosphere. However, plants that have an abundance of ammonium often cause their rhizosphere to become more acidic.

The physical properties of roots are also important. For example, the root length and the degree of branching are important for exploring soil resources. A root system with a large surface area has greater opportunity for nutrient uptake. The presence of abundant root hairs is beneficial for water and nutrient uptake. It is estimated that up to three-quarters of the total root surface area of many cultivated crops is provided by root hairs

Healthy root systems are often unappreciated, but essential for vigorous plant growth and high yields. Even after the crop is harvested, the decaying root system continues to provide benefits to the soil and to the following crop. Providing an environment where nutritional, chemical, physical, and biological barriers are eliminated allows the crop to reach its full potential. Don't overlook what you can't see.

– RLM –

For more information, contact Dr. Robert Mikkelsen, Western North America Director, IPNI, 4125 Sattui Court, Merced, CA 95348. Phone: (209) 725-0382. E-mail: rmikkelsen@ipni.net.

Abbreviation: N = nitrogen; P = phosphorus.

IPNI
Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 4

DO HIGH YIELDING SOYBEANS NEED TO BE FERTILIZED WITH NITROGEN?

Are higher yielding soybeans running short on N? Do they need additional N fertilizer to ensure they are properly fed? Recently, a group of scientists at University of Nebraska examined 108 published scientific studies on this topic to see if any trends could be discovered. Soybean yields in the studies ranged from 9 to 88 bu/A, and averaged 40 bu/A. Here are a few of their findings.

Soybean N requirements. The above-ground portion of a soybean plant takes up, on average, about 4.72 lb N/bu. This means that a 40 bu/A crop takes up about 189 lb N/A, while an 88 bu/A crop takes up about 415 lb N/A. The average concentration of N in the seed was found to be 6.34%. This works out to be 3.3 lb N/bu. So that same 40 bu/A crop will remove 132 lb N/A from the field at harvest, while the 88 bu/A crop will remove 290 lb N/A.

Sources of N for soybean uptake. Soybeans get their N from three sources: 1) N_2 fixation by *Bradyrhizobium*, 2) nitrate and ammonium in the soil, and 3) fertilizer N. The studies showed that on average, 50 to 60% of the N in soybeans comes from N_2 fixation. Normally, the remainder comes from the N in the soil. The maximum amount of N_2 that can be fixed was considered by the authors of the review to be 300 lb N/A. When fertilizer N is applied, it can reduce the amount of N_2 fixation. This reduction is exponential. The first 45 lb N/A can reduce maximum N fixation to about 190 lb N/A. Applying 90 lb N/A can reduce it to 125 lb N/A.

Soybean response to fertilizer N. Information about soybean response to N fertilization was reported in 67 of the 108 studies. Positive responses to N fertilization occurred in about half of them. The average yield response was 8 bu/A. A slightly higher average response of 10 bu/A occurred when low rates of N (less than 45 lb N/A) were applied after growth stage R3 (beginning pod). Typically, seasonal N demand peaks after this stage. When a subset of 12 studies with soybean yields greater than 67 bu/A was examined, 9 of the studies (75%) responded positively to N fertilization. The authors concluded that in high yielding environments, fixed N and soil N supplies may not be great enough to meet the N demands of the plant, increasing the probability that soybean may respond to N fertilization.

Conditions favoring soybean response to N. High yielding environments may have a greater chance of responding to fertilizer N, but at lower yields, there are still several situations the authors listed where responses to N were more likely. These included poor establishment of the nodule system, extremely low soil N supplies at planting, plant water stress, soil pH problems, low soil temperature, or an absence of native *Bradyrhizobium* resulting from a cropping history with infrequent or no legumes.

So do high yielding soybeans need to be fertilized with N? The answer appears to be that they might, but the yield response may only be marginally profitable. When soybean prices outpace the price of N, profitability is more likely, but such a window is usually not long-lasting. Therefore, N fertilization of soybeans still carries a financial risk even under high yielding environments. Local trials can help determine whether or not the practice makes sense in individual situations.

For more information on the details of this review, see Salvagiotti, F. et al. 2008. Field Crops Res. 108:1-13.

–TSM –

For more information, contact Dr. T. Scott Murrell, Northcentral Director, IPNI, 1851 Secretariat Dr., West Lafayette, IN 47906. Phone: (765) 413-3343. E-mail: smurrell@ipni.net.

Abbreviations: N = nitrogen.

IPNI
Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 5

SPRING NITROGEN PLANNING FOR OPTIMIZING WINTER WHEAT PRODUCTION

Wheat acreage in the Southeast has risen again in 2012. Following a significant increase in acreage from 2010 to 2011, the 2012 crop is up another 8% to 4.7 million acres. This is the highest planted area in the region in the past five years. Mississippi and North Carolina had the biggest increases adding 140,000 and 100,000 acres, respectively. The South is not known as a major wheat producing region, but yield potentials are good, averaging 63 bu/A across the region.

Wheat tiller development occurs in the fall prior to dormancy and again when the wheat begins to green up in the spring. Ideally, the plants will form 2 to 3 tillers in the fall, which are often more vigorous and yield more than spring tillers. However, if not enough tillers formed during fall growth, then spring tillering is critical for attaining optimum yields and depends heavily on N availability. Spring tillering in the Southeast typically occurs between late-January and early-March as we move north through the region. Most recommendations call for only 20 to 60 lb N/A at this time as too much N can produce excessively lush growth that can result in lodging and increased disease problems.

The demand for N is highest between jointing and flowering. This stage usually occurs a month or so after green-up and is characterized by the leaves becoming more upright. Applying the bulk of the N requirement just prior to this period of rapid uptake results in efficient fertilizer use by the crop. The key to optimizing fertilizer rate in wheat is to match nutrient supply with crop requirement. The total amount of spring N applied in the Southeast typically ranges between 80 and 120 lb N/A.

In-season diagnostic tools can help guide the final spring N application. Many universities and dealerships offer tissue testing guidelines to fine-tune spring N rates. Tissue analysis is an excellent diagnostic tool, but requires collecting samples and laboratory analysis. Optical sensors offer a non-destructive method of determining N requirements in wheat. The use of sensor technology has not been rapidly adopted in the region, but is available through some commercial fertilizer dealers. Aerial and satellite imagery are other precision approaches used to identify the optimum spring N rate for wheat.

Most of the crop grown in the Southeast is soft wheat, but there are some acres of hard wheat that will benefit from a late-season fertilizer application. In hard wheat varieties grown for bread-making, increased grain protein is a desirable characteristic. Research in the Southeast has shown that grain protein is consistently increased with a 30 to 40 lb N/A foliar application between boot stage and heading.

To optimize production, the right fertilizer plan is needed this spring. 4R Nutrient Stewardship is focused on four central components: applying the right fertilizer source at the right rate, at the right time in the growing season, and in the right place. Each of the four "rights" is directly related to the other three in at least one way, interconnected into a unified, effective system. None of the 4Rs can be right if one of them is wrong. While some wheat production systems will have unique fertility needs, the scientific principles behind the specific recommendations are the same. To learn more about how the 4Rs can be applied to wheat production, visit the IPNI website **www.ipni.net/video** to view the video "The Right Way to Grow Wheat…4R Nutrient Stewardship".

– SBP –

For more information, contact Dr. Steve Phillips, Southeast Director, IPNI, 3118 Rocky Meadows Rd., Owens Cross Roads, AL 35763, Phone (256) 529-9932. E-mail: sphillips@ipni.net.

Abbreviations: N = nitrogen.

IPNI
Plant Nutrition TODAY
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 6

NITROGEN LOSS PATHWAYS – WHICH IS YOURS?

The well-known poem by Robert Frost, "The Road Not Taken", kindles our imagination about the richness of life gained by taking the less traveled paths. While it may seem a far reach, this "less traveled path" metaphor also pertains to you and the N nutrition of your plants; whether you are a professional turf or crop manager, or a hobby horticulturalist.

Greater fertilizer N costs and knowledge of the environmental impacts of N losses are driving us all toward better N stewardship. Weather, or the lack of its control, hinders us from perfect N management. But weather variability should not prevent us from striving for lower losses down the "more traveled N loss pathways".

The nitrate leaching and drainage N loss pathway is probably the "more traveled" in humid, higher rainfall environments (>25 to 30 in./yr). Nitrate losses under annual crop systems may range between 10 and 40 lbs of N/A/yr in higher rainfall environments. Nitrate losses under deep-rooted perennial crops are often lower. If rainfall, irrigation (>1/2 in. within a few days after application), or tillage do not soil incorporate surface-applied urea or urea-containing N fertilizers within a few days after application, ammonia volatilization (gaseous loss as ammonia) may range from 20 to 40% of the N applied, and rival N losses from leaching and drainage. Recent research has shown that such ammonia volatilization losses can also occur if urea is applied on snowpack or wet soil surfaces in colder environments.

Gaseous loss of N from soils as nitrous oxide (a potent greenhouse gas affecting climate change), through nitrification and denitrification processes, is often <2 to 8 lbs of N/A in humid regions and may be <1 to 2 lbs/A in less humid regions (e.g. west of the Mississippi River). While this N loss is globally important, it may have small economic significance to the majority of individual landowners and crop producers. Loss of N_2 during denitrification, especially in wet fine-textured soils with poor internal drainage, is a more prominent N loss compared to nitrous oxide.

From an economic vantage point, the focus for most of us should be on the "more traveled N loss pathway" in our own particular plant and soil system. That means taking management action to reduce the risks of loss via nitrate leaching/drainage or ammonia volatilization. To start, we need to better understand the characteristics, properties and best management practices for the N fertilizers we may choose among.

Consider visiting the Nutrient Source Specifics articles available on-line at **www.ipni.net/specifics** and talk with your nutrient supplier, crop adviser, or agricultural professional to learn more about the N fertilizers available for your use. Identify ways to prevent N loss down the "more traveled loss pathways", and get more in your plants. Your bottom-line will improve and our water and air resources will be better protected. Dare to venture beyond your past boundaries, and choose the "less traveled pathway" toward higher N use efficiency this year!

– CSS –

For more information, contact Dr. Clifford S. Snyder, Nitrogen Program Director, IPNI, P.O. Drawer 10509, Conway, AR 72034. Phone (501) 336-8110. Fax (501) 329-2318. E-mail: csnyder@ipni.net.

Abbreviations: N = nitrogen.

IPNI
Plant Nutrition **TODAY**
Better Crops, Better Environment...through Science

From Scientific Staff of the
International Plant Nutrition Institute (IPNI)
3500 Parkway Lane, Suite 550
Norcross, Georgia 30092-2844 USA
Phone: 770-447-0335 Fax: 770-448-0439
E-mail: info@ipni.net Website: www.ipni.net

Spring 2012, No. 7

PLACING FERTILIZER WITH SEED

Placing fertilizer in-furrow with the seed during planting is a common practice in small grain production and to some extent in row crop production. Placing fertilizer with the seed can be an effective and beneficial management practice, but over application and mismanagement can result in seedling damage, and ultimate stand and yield loss. The type of crop, fertilizer source, row spacing, and soil environment all affect how much fertilizer can be safely applied with seed.

Type of crop: Some crops are more susceptible to injury from in-furrow fertilization than others. Oil seed crops are particularly sensitive; therefore most guidelines allow no fertilizer placed with the seed of these crops. The general order of sensitively (most to least) among major Great Plains crops is soybeans > sorghum > corn > small grains.

Type of fertilizer: Fertilizers are salts, and these salts can affect the ability of the seedling to absorb water… too much fertilizer (salt) and seedling desiccation or "burn" can occur. Some fertilizer materials have a higher salt index or burn potential than others. Salt index values are usually included in basic agronomic texts, or are available from fertilizer dealers or extension resources. As a general rule, most common N and K fertilizers have higher salt indexes than P fertilizers; therefore, a common predictor for the potential for salt damage is the sum of $N+K_2O$ per acre applied with the seed. For example, most guidelines for corn in 30 inch rows will allow for no more than 10 lb/A of $N+K_2O$ in medium to fine textured soils—assuming no urea-containing products are used.

Ammonia formation potential of fertilizer: Fertilizers that have the potential to release free ammonia can cause ammonia toxicity to germinating seeds or young emerging seedlings. Thus, extra caution must be used with in-furrow placement of urea-containing fertilizers. In some cases urea-ammonium nitrate (UAN) or urea can be applied successfully in-furrow in small grain production, but this requires carefully consideration of several factors including those discussed below.

Row spacing: For a specific set of circumstances (i.e. crop, soil conditions, etc.) the safe rate of in-furrow fertilizer increases as row spacing narrows or decreases. A narrowing row space has the effect of diluting fertilizer over more linear feet of row.

Soil type and environment: Soil conditions that tend to concentrate salts, or stress the germinating seed, increase the potential for damage. So, the safe limit for in-furrow fertilization is reduced with sandier soil texture and in drier soil conditions. Also, environmental conditions that induce stress and/or slow germination (e.g. cold temperature) can prolong fertilizer-seed contact and thus increase the likelihood of damage.

Seed bed utilization: The more scatter there is between seed and fertilizer in the seed band or row, the more fertilizer can be safely applied. The type of planting equipment and seed opener influences the intimacy of seed-fertilizer contact. The concept of "seed bed utilization" has been used to address this factor. SBU is simply the seed row width divided by the row width (i.e. proportion of row width occupied by seed row). The wider the seed row for a specific row width the greater the SBU. As SBU increases so does the safe rate of in-furrow fertilization.

The information presented here is mostly general and conceptual. A detailed listing of recommendations and guidelines is beyond the scope of this brief publication. For more specific information regarding safe rates of in-furrow fertilization for specific crops and conditions, one should refer to university extension resources, and/or consult a knowledgeable and experienced crop advisor or industry professional. Also, an Excel decision support tool is available online. Visit the IPNI website **www.ipni.net/toolbox.**

– WMS –

For more information, contact Dr. W.M. (Mike) Stewart, Southern and Central Great Plains Director, IPNI, 2423 Rogers Key, San Antonio, TX 78258. Phone: (210) 764-1588. E-mail: mstewart@ipni.net.

Abbreviations: N = nitrogen; P = phosphorus; K = potassium.

Note: ***Plant Nutrition TODAY*** articles are available online at the IPNI website: www.ipni.net/pnt