The Fluid Fertilizer Foundation was established by the fluid fertilizer industry 32 years ago! A few of the achievements of the Fluid Fertilizer Foundation since its inception in 1982 include:

- Supported millions of dollars of applied crop production research
- Provided technical and agronomic education to thousands of agricultural professionals
- Published hundreds of scientific articles in our flagship publication, the *Fluid Journal*

This year’s Fluid Forum will be at the Talking Stick Resort, 9800 East Indian Bend Rd. on February 17-19, 2014 in Scottsdale AZ 85256.

For additional information about the 2014 Forum, please see our website at http://www.fluidfertilizer.com/

Not a Fluid Fertilizer Foundation member yet? Please contact us at 785-776-0273 or by e-mail at fluidfertilizer@fff.kscoxmail.com.
Can Soil Chemical Changes Influence Plant Growth?
Dr. Joy Pierzynski, Dr. Ganga Hettiarachchi, and Mr. Raju Khatiwada
What about mobility and lability of various P fertilizers on high P-fixing soils?

Applying Liquid Nitrogen in Spring Wheat
Drs. Olga S. Walsh, Robin J. Christaens, and Arjun Pandey
Results show high NRG-N has an advantage in terms of protein yield and NUE.

N Use Efficiency Improved on Dryland Corn
Dr. Pawel Wiatrak
Clemson algorithm successfully used in Southeastern Coastal Plains.

THE FLUID JOURNAL - MISSION
The Fluid Journal is published by the Fluid Fertilizer Foundation. The FFF is a non-profit organization committed to researching and providing information about fluid fertilizer technology. Since its formation, the FFF has funded over $3 million in fluid fertilizer research. We have accumulated thousands of pages of research data. The main goal of the Fluid Journal is to transfer this technical information into easy to read form to farmers and dealers so they may be better informed as to the technological advancements that the fluid fertilizer industry has achieved.

FOCUS
The Fluid Journal is focused on disseminating fluid fertilizer technology to universities, dealers, equipment manufacturers and fertilizer producers. Our editorial matter focuses on several areas:
- Evaluate the agronomics of fluid fertilizers in the production of maximum economic crop yields
- Evaluate application techniques for fluid fertilizers.
- Investigate and inform our readers of innovative uses of fluid fertilizers under varied cultural, pest control and water management practices.
- Evaluate the efficiencies and conveniences of fluid fertilizer systems.
- Evaluate methods of controlling environmental problems with fluids.
The world is acknowledging the limitations of productive land, clean water, and available fertilizers, acutely aware of the challenges to balance food production, environmental stewardship, and economic sustainability. The Fluid Fertilizer Foundation (FFF), in partnership with its supportive members and their customers, has an important role to play. Part of that challenge is:

- Awareness of abundance and scarcity. Most of us live in parts of the world where we’re blessed with ample amounts of food and the economic ability to purchase it.
- Implications of an adequate food supply. Via logistics, governmental policies, and humanitarian efforts, many areas of the world are blessed with adequate food stuffs.
- Ability to influence future production of nutritious crops. The FFF is in a unique position to influence and affect some of the most productive land in the world--right here in North America.

The future of crop management and growth will be in efficient use of crop nutrition to maximize plant nutrient uptake. This general concept is quickly becoming a policy statement of many organizations both governmental, as well as AID Agencies and other Non-Governmental Agencies (NGO) under the heading of Nutrient Use Efficiency (NUE).

The FFF is in a unique position to influence this future through both our offering of fluid fertilizers and educating potential users of fluid fertilizers on their intrinsic value, plus how to use them effectively. Greater nutrient efficiency through the use of fluid fertilizers has been the key core element of our business and our educational focus of product development since the FFF’s beginning 32 years ago. The successful promotion of fluid fertilizer use allows our member companies to benefit on two distinct fronts.

**Business opportunity**

FFF customers include:

- Some of the largest fertilizer manufacturers in the world
- Some of the industry’s premier blending, logistics, and storage specialists.

These experts continually provide input to better position these products in addressing customer needs as they relate to all aspects of fluid fertilizer use. This unique position affords FFF members the ability to offer premium technology that an individual company cannot provide by itself. When combined with agronomic knowledge this makes for a powerful leverage of know-how that is exceptional in the industry and all for our members and their valued customers.

The FFF has a unique position in that it capitalizes on the power of current knowledge. This strong position also allows members to capture more margins with each sale. Fluid fertilizer products routinely earn more than dry fertilizer materials, given their agronomic benefits and in some areas limited availability.

The FFF continually looks for opportunities to leverage fluid fertilizer knowledge to position our members and those we work with to further balance the value of products being developed and used with environmental constraints that the world is facing. There is a recognized need for further understanding fluid fertilizer products. Through our Roundup and Fluid Forum we are providing this understanding for our customers and organization.

**Agronomic opportunity**

Fluids are more flexible than dry formulations, can be mixed with soluble micronutrients, can be placed in a band, injected through sprinkler systems, or incorporated through drip or micro-emitters, or applied as foliar in-season applications with ease. Selecting the appropriate rate of these fluids and their application requires knowledge of nutrient availability and plant demand. Thus:

- Applying nutrients at the right time avoids wasting nutrient where plant demands are not there or balances nutrient needs to meet high demands of a very productive cropping system where high yields are demanded.
- The FFF promotes the 4-R Nutrient Stewardship standards of embracing the right rate, right form, right placement, and right timing of all fertilizers. In many agronomic settings fluid fertilizers meet these demands with value-added benefits being recognized through social, economic, and environmental considerations.

**4 R Stewardship**

Using the right fertilizer source at the right rate, at the right time, and in the right place has become a mantra within the fertilizer industry (4R Nutrient Stewardship TM) and certainly the FFF supports this initiative in advising its membership and customer base. Fluid fertilizers can be just the right source and when placed correctly can provide critical nutrient needs to limit environmental concerns. Low-salt fluid fertilizers offer many advantages in getting nutrients applied in the right place--in the soil or on the foliage.

The FFF financially supports fluid-fertilizer-based agronomic research that reinforces the value-added fluid based fertilizers. When combined with our tremendous educational programs being delivered by cutting edge well-respected researchers this becomes a powerful organization that is looked to as a world leader in understanding all aspects of fluid fertilizers.

This is an exciting time to be involved in the fertilizer industry. There has never been a greater need for plant nutrients to meet crop production needs. Fluid fertilizers can provide the agronomic benefits for the plant as well as the economic benefits for FFF members and their valued customers.

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**Dr. Tindall is Senior Agronomist for the J.R. Simplot Company in Boise, Idaho, and also member of the Fluid Fertilizer Foundation Board of Directors and its Editorial Committee. Dr. Galen Mooso is Manager of Agronomy for the J.R. Simplot Company in Boise, Idaho, and serves on the FFF R and E Committee.**
Wheat is the principal food grain produced in the United States. Nitrogen (N) is the nutrient that most commonly limits wheat yield and quality. Nitrogen use efficiency is currently only about 40 percent. A considerable increase from the previously estimated 33 percent NUE in the late 1990s is primarily due to advance in nutrient management strategies and cutting edge technologies. Development of efficient N management and improving N recommendations are fundamental issues that must be addressed to maintain or increase the sustainability of wheat production in the future.

While spring wheat’s primary value is its quality, represented by high grain protein content, N is vital to both yield and protein production. When evaluating NUE in spring wheat, combining yield and protein into protein yield parameter (calculated as a product of grain yield and percent grain protein) makes sense. Protein yield enables us to calculate the efficacy of a particular treatment (such as fertilizer product or application method) from the perspective of producing a better return on the investment via optimizing grain yield and quality simultaneously.

Foliar application of fluid fertilizer to wheat is not a new concept. The renewed interest of wheat producers in foliar fertilization is partially due to active promotion of fluid products as more efficient when compared to the more traditionally dry granular fertilizers.

**Foliar mechanisms**

Plants are known to take up water and various nutrients through foliage. Previous studies show that leaf stomata facilitate mineral nutrient uptake. Foliar fertilization can assist in correcting deficiencies or preventing nutrient shortages during critical growth stages due to rapid nutrient absorption and utilization. However, unlike roots, plant leaves are not adapted to attain substantial volumes of nutrients to meet the bulk of nutrient requirements. Research has shown that foliar nutrition has four distinctive consecutive steps:

- Absorption (cellular compartmentalization)
- Translocation and utilization by the plant.

Studies on Bermuda grass, winter wheat, and spring wheat have shown that between 25 and 55 percent of foliar-applied N is taken up through the leaves. The average reported N uptake efficiency is about 30 percent.

It is common practice to blend nutrients into one complex foliar mix. In some cases, one nutrient may enhance or inhibit the uptake of another nutrient; thus, interaction among the nutrients must be taken into account.

Finally, studies demonstrate that foliar fertilizers are likely to be cost effective if the price of foliar products is no more than 15 percent higher than traditional granular fertilizer sources such as urea.

**Potential/challenges**

Some of the appeal of foliar fertilization, according to market media, includes:

- Immediate benefits
- Prolonged flowering
- Increased yields
• Enhanced growth during dry spells
• Increased cold and heat tolerance
• Increased pest and disease resistance
• Maximized plant health and quality
• Improved internal circulation of the plant.

Foliar application also helps to minimize N mineralization, denitrification, runoff, and leaching- the pathway of loss association with soil-applied fertilizer. It has been suggested that foliar-applied N is readily taken up, translocated, and utilized. Lower risk of N loss and effective N uptake imply that smaller quantities of fertilizer could be sufficient to satisfy crop N requirements and to effectively correct N deficiency mid-season.

Some research results suggest that foliar fertilization could be up to 20 times more efficient than soil application. From the point of view of practicality, the majority of foliar N fertilizers is easy to transport, store, and calibrate. Furthermore, they are compatible with many other fertilizers and chemicals such as herbicides. Combined application of premixed chemicals saves time, labor, and money.

Many studies indicate that foliar fertilization is most useful when soil conditions limit nutrient availability. For example, alkaline soils do not readily release most metallic nutrients such as iron (Fe), manganese (Mn), and zinc (Zn). Foliar application has been successfully used to effectively alleviate these micronutrient deficiencies. Nitrogen is a macronutrient needed in much larger quantities compared to micronutrients. Nitrogen is a highly mobile element, both in the soil and within the plant. Some scientists point out that application of N to the soil targeting root uptake makes much more sense, because leaves may not be able to take up N in amounts adequate to satisfy the entire plant’s needs. Furthermore, foliar application of nutrients such as N often results in leaf burn as water evaporates and the fertilizer salts remain behind. Some research suggests that significant ammonia loss may occur following foliar applied N fertilizers, which in fact decreases NUE. Using stream-jet or flood nozzles, mixing the liquid N with additional water, applying less than 65kg N ha-1 per application, and avoiding applications on very warm or very cold windy days were shown to minimize concerns associated with leaf burn.

**Foliar N products**
Several foliar N fertilizers are currently available on the market. These products vary in analysis and can include N products or mixtures of N plus other macro and micronutrients. Some of the N foliar fertilizers include:

- Urea ammonium nitrate (UAN)
- Liquid urea (LU)
- NRG

**UAN.** The most widely used foliar N fertilizer is UAN. Urea ammonium nitrate (28-0-0 or 32-0-0) is a non-pressurized solution that can be used in a variety of application practices. The liquid mix of UAN has been on the market for a long time. It provides a fast acting and long-lasting plant nutrient supply in a combination of three forms of nitrogen:

**“Highest NUE achieved with high NRG-N”**

- Nitrate-N provides quick response
- Ammonia-N provides a longer lasting response
- Organic N in urea provides sustained feeding.

However, foliar application of UAN has been recognized as the least recommended option for N application by some researchers. Early in the growing season, foliar application of UAN may cause leaf burn, but mid- and late-season applications can reduce grain yields due to burn injury caused to leaves.

**Liquid urea** is a water-based urea solution (20-0-0). LU’s proposed benefits include: slower uptake by the plant, which helps to maintain N levels within the soil plant system. LU is recommended for application during the warm growing months of the year for rapid correction of N deficiency.

Research on foliar application of LU to crops is very limited. Generally, it is noted that where dry urea functions effectively, LU should perform equally well or better due to having the advantage of higher uniformity over some dry urea sources.

**NRG** is a proprietary fluid product having an analysis of 27-0-0-15 derived from ammonium nitrate, urea, and ammonium sulfate. Additionally, it is said to include trace amounts of secondary/micronutrients as well as proprietary flavonol technology.

**Montana study**
The primary reason for foliar N fertilization in wheat is increased grain yield and improved quality-increased grain protein content. As noted earlier, protein yield represents an important parameter for evaluation of NUE in spring wheat. Previous studies in wheat showed that protein content was increased from 11 to 21 percent and from 15 to almost 17 percent. Most success in protein increase has been reported when foliar application was done just before or immediately after flowering. Many wheat growers are already using foliar products or considering including them as a part of their nutrient management plan. These producers are in need of up-to-date and unbiased information about currently marketed foliar N fertilizers.

Our study aimed to answer the following questions:

- Are LU and NRG agronomically and economically superior to UAN in improving spring wheat grain yield and protein content?
- What is the optimum dilution ratio of foliar fertilizers and the threshold at which spring wheat grain yield is reduced to leaf burn?

The field study, funded by Montana Fertilizer Tax Advisory Committee, was initiated in the spring of 2012. Three experimental sites were established:

- Two dryland, one at Western Triangle Agricultural Research Center (WTARC) near Conrad, MT, and another in a cooperating producer’s field (Jack Patton, Choteau County, MT)
- One irrigated at Western...
Figure 1. Fertilizer N source effect on spring wheat grain yield, Patton, WTARC, and WARC, 2012. The means in the same group followed by the same letter are not significantly different, $p<0.05$.

Figure 2. Fertilizer N source effect on spring wheat grain protein content, Patton, WTARC, and WARC, 2012. The means in the same group followed by the same letter are not significantly different, $p<0.05$. 
At each location, treatment structure reported in Table 1 was employed. Treatment 1 was established as an unfertilized check plot. Preplant N rate of 90 kg N ha⁻¹ was applied as side-banded urea. At growth stage Feekes 5, topdress N was foliar-applied with an ATV-mounted stream bar sprayer using three N sources: UAN, liquid urea, and NRG.

Topdress rate of 45 kg N ha⁻¹, and 3 dilution ratios of 100/0, 66/33, and 33/66 (fertilizer %/water %) were evaluated. Because NRG contains S, Fe, Mg, Mn, and Zn, soil analysis was used to ensure that any one of these nutrients is not deficient and can be corrected prior to topdress application.

Each treatment was replicated four times. Plot size was 1.5 m by 7.6 m.

Grain yield and protein content were determined at harvest.

Nitrogen use efficiency was determined using “the difference method” by deducting the total N uptake in wheat from the...
Table 1. Treatment, structure & mean spring wheat grain yield, Patton WTARC & WARC 2012

<table>
<thead>
<tr>
<th>Trt</th>
<th>Preplant N Fertilizer (urea) Rate, kg N ha⁻¹</th>
<th>Topdress N Fertilizer Source</th>
<th>Topdress N Fertilizer Rate, kg N ha⁻¹</th>
<th>Topdress N Fertilizer/ Water Ratio, %</th>
<th>Mean spring wheat grain yield, kg ha⁻¹</th>
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<td>PATTON</td>
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<td>1</td>
<td>0</td>
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<td>-</td>
<td></td>
<td>2526 (bcd)</td>
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<tr>
<td>2</td>
<td>90</td>
<td>UAN</td>
<td>45</td>
<td>100/0</td>
<td>2120 (ed)</td>
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<tr>
<td>3</td>
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<td>UAN</td>
<td>45</td>
<td>66/33</td>
<td>2234 (cde)</td>
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<tr>
<td>4</td>
<td>90</td>
<td>UAN</td>
<td>45</td>
<td>33/66</td>
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<td>100/0</td>
<td>2575 (bc)</td>
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<td>66/33</td>
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<td>7</td>
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<td>LU</td>
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<td>90</td>
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<td>10</td>
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<td>HNRGN</td>
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<td>33/66</td>
<td>3029 (a)</td>
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The means in the same column followed by the same letter are not significantly different, p<0.05.

Table 2. Mean spring wheat grain protein content & protein yield, Patton WTARC & WARC 2012

<table>
<thead>
<tr>
<th>Trt</th>
<th>Mean spring wheat grain protein content, %</th>
<th>Mean spring wheat grain protein yields, kg ha⁻¹</th>
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<tr>
<td></td>
<td>PATTON</td>
<td>WTARC</td>
</tr>
<tr>
<td>1</td>
<td>13.8 (c)</td>
<td>10.8 (c)</td>
</tr>
<tr>
<td>2</td>
<td>17.2 (a)</td>
<td>12.8 (b)</td>
</tr>
<tr>
<td>3</td>
<td>16.8 (ab)</td>
<td>13.2 (ab)</td>
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<tr>
<td>4</td>
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<td>5</td>
<td>16.7 (ab)</td>
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<td>6</td>
<td>16.8 (ab)</td>
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<td>7</td>
<td>16.5 (b)</td>
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<td>8</td>
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<td>13.1 (ab)</td>
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<tr>
<td>9</td>
<td>17.1 (a)</td>
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<td>10</td>
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The means in the same column followed by the same letter are not significantly different, p<0.05.

Table 3. Mean spring wheat N uptake & NUE, Patton WTARC & WARC 2012

<table>
<thead>
<tr>
<th>Trt</th>
<th>N Uptake, kg N ha⁻¹</th>
<th>NUE, %</th>
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<tr>
<td></td>
<td>PATTON</td>
<td>WTARC</td>
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<td>2</td>
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<tr>
<td>9</td>
<td>77 (b)</td>
<td>144 (a)</td>
</tr>
<tr>
<td>10</td>
<td>88 (a)</td>
<td>142 (a)</td>
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The means in the same column followed by the same letter are not significantly different, p<0.05.

Winter 2014
The Fluid Journal

“NRG is proprietary fluid product”

There was no apparent trend in grain protein content associated with fertilizer N source (Figure 2). At both dryland sites, high protein yields were observed with NRG, while at the irrigated site, all three fertilizer N sources performed similarly (Table 2, Figure 3). At all three sites, highest NUE was achieved with NRG (Table 3, Figure 4). The differences were significant at both dryland sites, and substantial, while not statistically significant, at the irrigated site.

Summing up

Overall, the results indicated that from the agronomic point of view, NRG has an advantage in terms of protein yield and NUE in spring wheat production in Montana. This project will be conducted for one more growing season at three experimental locations to verify these preliminary findings.

Dr. Olga S. Walsh is Assistant Professor, Robin Christiaens is a research associate, and Arjun Pandey is a graduate research assistant at the Western Triangle Ag Research Center in Conrad, Montana.
Can Soil Chemical Changes Influence Plant Growth?
What about mobility and lability of various P fertilizers on high P-fixing soils?

Ms. Joy Pierzynski, Dr. Ganga Hettiarachchi, & Mr. Raju Khatiwada

The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Winter 2014 • Vol. 22, No. 1, Issue #83

Summary: There was evidence of fertilizer P diffusion to the second section with Brazil soil and up to the third section with Idaho soil. We found no differences in P diffusion away from the point of application between the three P sources (MAP, DAP, and APP) for either soil. Percent resin P results for Brazil soil indicated there was no statistical difference between the three P sources. Results for Idaho soil were different from Brazil soil. There was significantly greater percent resin P in the center section with the APP as compared with either MAP or DAP. Speciation results indicated that the addition of P induced the formation of P solid phases, including adsorbed as well as secondary P minerals. In calcareous soil, low pH and formation of less Ca-P species in the APP-treated soils may have been the reason for observed high-resin extractable P concentrations.

It has long been recognized that interactions between phosphorus (P) and soils result in a reduction in the availability of P for crop growth over time. This necessitates additional or excessive applications of P to maintain crop productivity, which can be costly and can result in environmental problems.

In many areas of the world, extensive weathering or a unique mineralogy have produced agricultural soils that are deficient in plant-available P. As a result, when P fertilizer is added it rapidly undergoes chemical transformations that make P unavailable for plant uptake.

Direct information from literature on high P-fixing soils and the associated mechanisms reducing P availability to plants is limited. A deeper understanding of these processes may help in developing improved management strategies and/or efficient fertilizer formulations leading to higher productivity on these soils.

The objectives of this research were to:
- Investigate the mobility and ability of various P fertilizers on two high-P fixing soils
- Identify the P reaction products formed within and around the point of fertilizer application.

Methodology

Site. The five-week laboratory incubation-based experiment consisted of two different soils:
- An Oxisol collected from Rondonopolis, Brazil
- A calcareous Inceptisol soil collected from southwest Idaho.

Neither of the soils had a history of being fertilized, though the soil from Brazil had been under cultivation.

Sources. There were three P fertilizer sources used in the study:
- Monoammonium phosphate (MAP)
- Diammonium phosphate (DAP)
- Ammonium polyphosphate (APP).

MAP and DAP were added as granules and APP was added as a fluid.

Application. MAP, DAP, and APP were each applied to the center of a petri dish filled with soil at a moisture content equivalent to 60 percent of its maximum water-holding capacity. Each P source added approximately 9.8 mg P/plate for a total of four treatments, including a control treatment not receiving P. The nitrogen (N) was balanced using urea. Five replicates of each treatment on both soils were covered and incubated in petri dishes for five weeks at 25°C.

Sampling. At the end of the incubation period, concentric rings of soil surrounding the fertilizer application point were removed corresponding to 0-7.5 mm, 7.5-13.75 mm, 13.75-25 mm and 25-43.5 mm from the point of P application.

Soil samples were analyzed for soil pH, total P, and resin extractable P.
Percent P added was calculated by dividing the net increase in total P mass in each ring by the total P mass added to each petri dish, multiplied by 100.

The net increase in total P mass is the total P concentration in a ring minus the native or control total P concentration, multiplied by the soil mass in that ring.

Percent Resin P was calculated as resin extractable P concentration divided by the total P concentration, multiplied by 100.

In addition, scanning electron microscopy-energy dispersive x-ray analysis was performed on residual granules of DAP and MAP after the incubation, and P K-edge x-ray absorption near-edge structure spectroscopy (XANES) analysis of bulk soil of the 0.75 mm section for each treatment was performed to determine fertilizer reaction products.

**Statistical analyses.** All data were analyzed using the Proc GLM procedure using SAS software (SAS 9.2, 2008). The Bonferroni Pairwise Method was used for comparison of all treatments at a 0.05 level of significance. Synchrotron-based bulk x-ray adsorption near-edge structure (XANES) spectroscopy analysis was performed at sector 9 BM-B, Advanced Photon Source, Argonne, IL to determine the chemical form of P reaction products. Spectra for the various standard compounds and soil samples were edge-energy calibrated, background corrected and normalized. The reduced XANES spectra for the samples were analyzed by linear combination fitting (LCF) using IFEFFIT software (Newville, 2001).

**Study overview**

**pH.** For the Brazil soil, all treatments that received P had significantly higher pH as compared to the control treatment in the first three sections of the petri dish, with no difference at 35-43.5 mm from the point of P application (Figure 1). In general, the pH was highest at the point of P application and decreased to background levels by the fourth section. The pH increases were due to the dissolution of P fertilizer followed by chemisorption of dissolved P onto iron/aluminum oxides followed by release of hydroxyl ion and/or from the hydrolysis of urea added with MAP and APP treatments (for DAP urea was not added). Given the acidic nature of the native soil, further acidification due to the ammonium-N may not have occurred due to inhibition of the nitrification process.

For the Idaho soil, all treatments were significantly lower in pH as compared to the control treatment in all four sections of the petri dish (Figure 2). The pH, more acidic at the point of P application, increased out to the fourth section and most likely was the effect of acidification due to nitrification. The APP treatment had the lowest pH although it was not statistically significant from the MAP treatment in some sections.
**Percent P added.** For the Brazil soil (Figure 3), much of the P remained in the first two sections of the petri plate for all treatments. Most P remained close to the point of application and there were no significant differences between treatments in the 0-7.5 section. Phosphorus did diffuse into the second section (7.5-13.75 mm) for all 3 treatments. However, there were no significant differences between treatments in that section, either. High P fixation with aluminum and iron oxides and hydroxides, or forming solid phases with iron and/or aluminum, most likely prevented P movement into the outer two sections of the dish.

For the Idaho soil (Figure 4), the majority of the P remained in the center section of the petri dishes for all three treatments with no significant difference between them. MAP appeared to have greater diffusion into the second section than other treatments, though it was not significantly different from any other treatment.

**Percent Resin P.** Resin extractable P analysis is used as an estimate of plant available P in soils. Anion exchange membranes mimic P uptake by roots and is considered to be an acceptable method to assess labile P in the soil. Total soil P analysis is a measure of the many P forms that exist in soil samples. Calculation of percent resin P allows for normalization of the data when comparing treatments because of slight variations in the amount of P added to each dish and the possibility that the treatments can influence the diffusion distance for added P. High percent resin P means a greater proportion of the P in the soil is potentially available for plant uptake.

For Brazil soil (Figure 5), the center petri dish section for all three treatments had the highest extractable P though there were no significant differences between treatments. The second, third, and fourth dish sections contained significantly less resin extractable P for all treatments, with a small increase in the third and fourth sections of the dish.

Percent resin P results on the Idaho soil were more complex (Figure 6). The APP treatment had the greatest percent resin P in the center section when compared to either granular fertilizer treatment. It was clear that when P was applied as APP to Idaho calcareous soil, although it did not appear to enhance P movement further into other sections, APP helped to remain in potentially plant-available forms. DAP had significantly less labile P in calcareous soil than the MAP treatment. Moreover, there was a significant enhancement of resin extractable P levels in the 7.5-13.75 mm section for all treatments compared to the control treatment. The third and fourth sections had percent resin P values equivalent to the control treatment.

**XANES analysis.** Phosphorus was present as ferricydrate-adsorbed P (64.1%), vivianite-
like Fe-P (21.9%) and aluminum phosphate-like Al-P (13.9%) in the Brazil control soil (Table 1). In contrast, no Al-P was observed in P-treated soils (center sections).

All P treatments resulted in the disappearance of aluminum phosphate and an increase in the amount of aluminum adsorbed P, ferrihydrite adsorbed P, or vivianite. The changes may be due to both the increased soluble P levels and increase in pH produced by the fertilizers.

The MAP treatment shows predominantly ferrihydrite adsorbed P and vivianite-like P. DAP and APP contained alumina adsorbed P, which may be a less soluble P form; however, overall adsorbed-P concentration in DAP and APP treatments was significantly less than the MAP-treated soils.

There were no significant differences in resin extractable P between the APP and DAP-treated Brazil soils, although both had significantly higher resin extractable P than the MAP.

The XANES analysis of the control Idaho soil (Table 2) indicated the presence of hydroxyapatite-like P (48.2%), ferrihydrite-adsorbed P (31.4%) and alapatite-like P (20.4%). These P minerals would not be uncommon in a high pH calcareous soil.

MAP and DAP had a higher percentage of apatite-like P forms close to the fertilizer application point as compared to the APP treated soils. These fertilizer treatments had the highest pH at the center section of their respective plates as well.

APP had significantly less apatite-like P (Ca-P) and more Fe-P either as adsorbed or precipitated. Comparison of resin-extractable P data with XANES speciation results showed a negative correlation of Ca-P species with resin-extractable P, suggesting that Fe-P species in calcareous soils might be more available.

**Summing up**

The two soils used in this study had extreme pH, one being very acidic and the other alkaline. With the addition of granular or fluid P fertilizers, the pH values were modified to a level more favorable to higher P solubility. With increasing distance from the P application point, the soil pH either slowly increased or decreased toward its native pH.

There was evidence of fertilizer P diffusion to the second section with the Brazil soil and up to the third section with the Idaho soil. We have no evidence that there were differences in P diffusion away from the point of application between the three P sources for either soil.

The percent resin P results for Brazil soil indicated there was no statistical difference between the three sources. Results for the Idaho soil were different from the Brazil soil. There was significantly greater percent resin P in the center section with the APP (fluid fertilizer treatment) as compared with either MAP or DAP. MAP had significantly greater resin extractable P than DAP.

The speciation results indicated that the addition of P induced the formation of P solid phases, including adsorbed as well as secondary P minerals.

In calcareous soil, low pH and formation of less Ca-P species in the APP-treated soils may have been the reason for observed high resin extractable P concentrations.

Further study is needed under field conditions to see if the soil chemical changes can influence plant growth.

Ms. Joy Pierzynski is a Graduate Research Assistant working on her Ph.D, and Dr. Ganga Hettiarachchi is an Associate Professor, and Mr. Raju Khatiwada is a former graduate student in soil chemistry in the Department of Agronomy at Kansas State University.
The Fluid Journal, flagship publication of the Fluid Fertilizer Foundation (FFF), makes nearly two decades of archives available on its web site. The magazine investigates and informs its readers on innovative uses of fluid fertilizers under varied cultural, pest control, and water management practices, focusing on evaluating:

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- application techniques for fluid fertilizers
- the efficiencies and conveniences of fluid fertilizer systems
- methods of controlling environmental problems with fluids.

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For information on how to become a member of the FFF, contact the foundation’s office at 785/776-0273 or the foundation’s website: http://www.fluidfertilizer.com
Nitrogen is not uniformly utilized in the field in the Southeastern United States due to high variability in soil texture. Application of N at one rate over the entire field is not effective and may decrease environmental quality. Standard procedures for N application on corn, based on soil spatial variability, are not available for the Coastal Plain soils. Determination of the extent to which the crop will respond to additional N as side-dressing can help growers to apply only what is needed.

Numerous studies have shown high correlations between vegetation indices and crop yields. Plant normalized difference vegetation index (NDVI), N content in corn leaves, test and grain weight, and grain N content generally improved with higher N rates. Higher soil nitrate-N concentration was recorded from zones 2 and 3 than from zone 1. The predicted sidedress rate of 90 lbs/A of N, using Clemson algorithm, was 30 lbs/A N less than fixed rate and did not significantly reduce yields compared to fixed N rate. Therefore, Clemson algorithm can be successfully used in improving N use efficiency (NUE) of dryland corn in the Southeastern Coastal Plains.

The algorithm for predicting N requirements in corn grown in the Southeast has to take into account the soil spatial-variability due to high variability in soil texture. A commercially available soil electrical conductivity (EC) measurement system (Veris Technologies 3100) can help to identify variations in soil texture across the field and create soil EC zone maps using global position systems (GPS) and geographic information systems (GIS).

The main objective of this project was to evaluate application methods, rates, and Clemson N algorithm on corn under different soil electrical conductivity (EC) zones to improve NUE and yields of corn.

**Methodology**

**Soil/location.** The study was conducted on Dothan loamy sand (fine loamy, kaolinitic, thermic Plinthic Kandiudult) in a production field at Clemson University, Edisto Research and Education Center (REC) near Blackville, SC in 2012. Winter wheat cover crop was killed in early spring. The experimental area was divided into four soil texture zones, based on soil electrical (EC) conductivity measurements, which were derived from Veris system measurements (Veris Technologies 3100), global positioning system (GPS), and geographic informational system (GIS). Soil zone 1 (lowest soil EC readings) was very sandy with low water and nutrient-holding capacity and soil zone 4 (highest soil EC reading) was mostly clay with high-water and nutrient-holding capacity in this experiment.

**N rates.** Each soil EC zone consisted of two N application
methods (as at-once at planting and as split applications) and five N application rates (0, 40, 80, 120, and 160 lbs/A of N) under a strip-tillage system. The methods and N rates for corn were randomized within each soil zone. To validate the Clemson algorithm for variable site-specific application, N rates were calculated using the Clemson N-prediction algorithm and compared to conventional practice for the region. The conventional practice consisted of applying about 40 lbs/A of N at planting and 120 lbs/A of N as sidedress at V6 corn stage, totaling 160 lbs/A of N. The sidedress N treatments were replicated four times in each zone of the test field. Nitrogen Rich Strips (plots with highest N rates) were established in each EC zone to determine the response index (RI) for predicting yield potential when N was applied. All test plots received 40 lbs/A of N at planting, followed by sidedress N application rates:

- Based on Clemson algorithm separately for each zone
- Averaged across soil zones
- Using a conventional rate at V6 corn growth stage.

Additionally, rates 25 percent below and above the averaged predicted rate across zones were also calculated and applied at V6 stage.

**Planting.** On 14 March, Pioneer 31G71 corn was planted in strip-till at 28,000 seeds/A using a 4-row Universal Riper-Stripper implement and John Deere 1700 MaxEmerge XP Vacuum planters.

**Plot size** was 4 rows wide by 20 feet long and 38-inch row spacing.

**Side-dressing.** Using a Reddick fluid fertilizer applicator, N (25S – fluid formulation of 25% N and 3.5% sulfur) was side-dressed applied to selected corn plants on March 21. Selected corn plots, including algorithm testing, were side-dressed with remaining N on May 9.

**Weed control** was based on the South Carolina Extension recommendations.

**Evaluation.** During corn vegetation, corn was evaluated for NDVI, total N in corn ear leaves, grain yields and yield parameters (grain moisture, test weight, kernel weight), total N in grain, and soil NO₃-N. Plant NDVI was measured in the center of two rows using a GreenSeeker.

**Harvesting.** On August 13, corn was harvested using a Kinkaid 8XP small grain combine and grain samples were analyzed for moisture, test weight, and kernel weight. Grain yield and kernel weight were adjusted to 15.5% moisture.

**Soil samples** were collected following corn harvest from a depth of 36 inches and divided into 6-inch increments for NO₃-N content and

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<tr>
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<th>22-May</th>
<th>30-May</th>
<th>7-Jun</th>
<th>15-Jun</th>
<th>20-Jun</th>
<th>29-Jun</th>
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<td>0.681</td>
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<td>NS</td>
<td>0.035</td>
<td>NS</td>
<td>NS</td>
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<td>120</td>
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<td>0.055</td>
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<th>Grain moisture</th>
<th>Test weight</th>
<th>100 kernel weight</th>
<th>Grain yield</th>
<th>Grain N</th>
</tr>
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<td></td>
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</tr>
<tr>
<td>Zone</td>
<td>%</td>
<td>%</td>
<td>lb/Bu</td>
<td>gms</td>
<td>Bu/acre</td>
<td>%</td>
</tr>
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<tr>
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<th>2.1</th>
<th>13.9</th>
<th>52.3</th>
<th>20.3</th>
<th>60.0</th>
<th>0.96</th>
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<tbody>
<tr>
<td>Split</td>
<td>2.4</td>
<td>13.8</td>
<td>53.5</td>
<td>20.9</td>
<td>79.5</td>
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<td>LSD(0.05)</td>
<td>0.058</td>
<td>NS</td>
<td>1.1</td>
<td>NS</td>
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<thead>
<tr>
<th>N rate (lb/A)</th>
<th>0</th>
<th>1.8</th>
<th>13.7</th>
<th>51.6</th>
<th>18.4</th>
<th>32.6</th>
<th>0.92</th>
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<tr>
<td>40</td>
<td>2.0</td>
<td>13.5</td>
<td>51.4</td>
<td>19.1</td>
<td>47.5</td>
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<td>80</td>
<td>2.4</td>
<td>14.1</td>
<td>52.9</td>
<td>20.5</td>
<td>66.1</td>
<td>0.97</td>
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</tr>
<tr>
<td>120</td>
<td>2.6</td>
<td>14.3</td>
<td>54.0</td>
<td>22.4</td>
<td>88.5</td>
<td>1.04</td>
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<tr>
<td>160</td>
<td>2.7</td>
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<td>54.5</td>
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<td>114.1</td>
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<td>1.6</td>
<td>1.984</td>
<td>17.9</td>
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</table>
The N content in corn ear-leaf, grain moisture at harvest, kernel weight, and grain yields was significantly higher in more productive soil zones 2 and 3 compared to less productive sandy soil zone 1 (Table 2). Also, N in corn ear leaves, test weight, grain yield, and grain was greater from split N application than from all-at-plant N application for corn. Compared to control and low N rates, N application at 160 lbs/A of N significantly increased N content in corn ear leaves, grain yield, and grain N. Application rates of 120 and 160 lbs/A of N increased grain test weight and kernel weight.

Significantly higher N concentration was recorded from soil zones 2 and 3 than from soil zone 1, and greater with higher N rates for 18-24, 24-30, and 30-36 inch soil depth (Table 3). Plant NDVI was also significantly greater from applications 80, 120, and 160 lbs/A of N than from the control and 40 lbs/A of N.

The N content in corn ear-leaf, grain moisture at harvest, kernel weight, and grain yields was significantly higher in more productive soil zones 2 and 3 compared to less productive sandy soil zone 1 (Table 2). Also, N in corn ear leaves, test weight, grain yield, and grain was greater from split N application than from all-at-plant N application for corn. Compared to control and low N rates, N application at 160 lbs/A of N significantly increased N content in corn ear leaves, grain yield, and grain N. Application rates of 120 and 160 lbs/A of N increased grain test weight and kernel weight.

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Predicted N rates based on Clemson algorithm were at 40 lbs/A of N for soil zone 1, 140 lbs/A of N for soil zones 2 and 3, 120 lbs/A of N for across soil zones and were comparable to a fixed rate of 120 lbs/A of N and to 25% above and below the average across zones (Table 4). Grain yields from plots with a predicted sidedress rate of 90 lbs/A of N (predicted rate across soil zones and decreased by 25%) were 30 lbs/A of N less than the fixed N rate and did not significantly lower yields compared to higher N rates for soil zones 1, 2, and 3.

**Study results**

Generally, higher than average rainfall during the vegetation season, compared to the 30-year average, contributed to greater plant growth and yields. Significantly higher plant NDVI was recorded from soil zones 2 and 3 than from zone 1, and from split than all-at-plant N application rate on June 7, 20, and 29 (Table 1). Plant NDVI was also significantly greater from applications 80, 120, and 160 lbs/A of N than from the control and 40 lbs/A of N.

The N content in corn ear-leaf, grain moisture at harvest, kernel weight, and grain yields was significantly higher in more productive soil zones 2 and 3 compared to less productive sandy soil zone 1 (Table 2). Also, N in corn ear leaves, test weight, grain yield, and grain was greater from split N application than from all-at-plant N application for corn. Compared to control and low N rates, N application at 160 lbs/A of N significantly increased N content in corn ear leaves, grain yield, and grain N. Application rates of 120 and 160 lbs/A of N increased grain test weight and kernel weight.

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**Table 3. Influence of soil zone, N method, and N rates on NO3-N content in soil samples at 6 inches increments and up to 36 inches soil depth.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil depth</th>
<th>0-6</th>
<th>12-Jun</th>
<th>18-Dec</th>
<th>24-24</th>
<th>24-30</th>
<th>30-36</th>
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<tbody>
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<td>Zone</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
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<td>2.96</td>
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<td>3</td>
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<tr>
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<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
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<tr>
<td>N method</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>At plant</td>
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<td>N rate (lb/A)</td>
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**Table 4. Testing predicted sidedress N rates based on Clemson algorithm for each zone and across zones in comparison to a fixed N rate of 120 lb N/acre.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N rate/acre</th>
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<td>Individually for each zone:</td>
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<td>40</td>
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<tr>
<td>2</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
</tr>
<tr>
<td>Across soil zones</td>
<td></td>
</tr>
<tr>
<td>Fixed N rate</td>
<td>120</td>
</tr>
<tr>
<td>Increased by 25% compared to predicted across zones</td>
<td>150</td>
</tr>
<tr>
<td>Decreased by 25% compared to predicted N rates across zones</td>
<td>90</td>
</tr>
</tbody>
</table>

**Figure 1: Influence of predicted sidedress N rates using Clemson algorithm for each zone and across zones in comparison to a fixed N rate of 120 lb N/acre on corn grain yields in soil zone 1. Letters indicate significant difference at p≤0.05.**
Dr. Wiatrak is Assistant Professor/Agronomist in the Department of Entomology, Soils, and Plant Sciences at Clemson University in Blackville, South Carolina.

Summing up
Grain yields were significantly higher for soil zones 2 and 3 than zone 1, higher from split than all-at-planting, and higher from the highest rate of 160 lbs/A of N compared to other N treatments of corn (Figures 1, 2 and 3). Higher grain yields were mostly due to:

- Greater plant NDVI
- N content in corn leaves
- Test and grain weight
- Grain N content.

The soil nitrate-N concentration was higher from zones 2 and 3 due to higher holding capacity of these zones compared to zone 1, and higher with high N rates at 18-24, 24-30, and 30-36 inch soil depths, indicating N movement into lower soil profiles with high N rates.

The predicted rate of 90 lbs/A of N using Clemson algorithm and NDVI readings did not significantly decrease grain yields compared to the fixed sidedress N rate of 120 lbs/A of N. Therefore, sidedress N rates could be decreased by 30 lbs/A of N without significant yield reduction for soil zones 1, 2, and 3, indicating that Clemson algorithm could be efficiently used in predicting sidedress N rates and improving NUE and profitability of corn production.

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