BEYOND THE 4-RS OF NUTRIENT MANAGEMENT IN CONJUNCTION WITH A MAJOR REDUCTION IN TILLAGE

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ABSTRACT

Agribusiness and government agencies have embraced the 4-R concept (right ***form, rate, time,*** and ***place***) to improve nutrient management and environmental quality. This concept could potentially apply to individual plants in a field, but in reality most current technologies and cultural practices limit application of the concept to management zones. Data and information to make finer-scale decisions are lacking or too expensive to acquire. The assumption is frequently made that the delivery across the width of a fertilizer applicator is uniform, which may not be the case. Further, the concept assumes that the algorithm used to make nutrient recommendations is properly calibrated to promote optimum plant performance. To be valid, the soils ability to supply nutrients must be accurately assessed so that crop needs can be properly supplemented with fertilizers. At some point, trying to spatially balance the various nutrients to meet crop needs becomes overwhelmed with uncertainties or costs. At some point, the absence of reliable soil data and recommendation algorithms makes it reasonable to supply nutrients proportional to crop needs. The Ortho ratio of 27-12-0-7 for N, P, K, and S has been proposed as the appropriate formulation to meet crop needs for reproductive growth stages. Seven N fertilizer rates using the Ortho ratio were applied using an Exactrix applicator to continuous corn in replicated field strips in 2008 and 2009 in Hugoton, Kansas, U.S.A. Yield and profitability were optimized with 158 kg N/ha and a yield of 12.51 Mg/ha. Using the Ortho fertilizer approach adds confidence when establishing the optimum N rate because the other major nutrients are supplied in approximately the correct ratio.

KEYWORDS: Ortho fertilizer ratio, Exactrix applicator, Nitrogen response

INTRODUCTION

Agribusiness and government agencies have embraced the 4-R concept (right ***form, rate, time,*** and ***place***) to improve nutrient management and environmental quality. This concept could potentially apply to individual plants in a field, but in reality most current technologies and cultural practices limit application of the concept to management zones. Data and information to make finer-scale decisions are usually lacking or too expensive to acquire. No-tillage is also a major component of nutrient efficiency. Over the past three decades, innovators and scientists have developed: 1) machinery to make variable-rate nutrient applications, 2) soil and tissue sampling strategies to better define spatial variability, 3) yield-monitoring harvesters to spatially quantify grain production, 4) remote and proximal sensors to quantify crop vigor during the growing season, 5) soil sensors and water monitoring devices to better characterize soil properties, and 6) statistical procedures to analyze spatial data.

These technologies all embrace global positioning systems (GPS) and rely heavily on geographic information systems (GIS) to display and store the temporal and spatial information. The question at hand… Does the complete adoption of the 4-R technologies, with uniformly improved stored soil moisture, represent the ultimate in terms of precision agricultural production? Are there opportunities for further advancements and innovations?

Considering the above advancements and opportunities they represent, several seed corn companies have been developing cultivars that fit within the 4-R concept and have begun to market drought tolerant hybrids. In terms of the nutrients required to achieve acceptable yields, it is appropriate to more carefully examine the 4-Rs and tillage for their level of sophistication. This is because various aspects of the 4-Rs are inter-related and therefore constitute a challenge for innovators that have the knowledge and expertise to integrate the engineering, chemical, and agronomic aspects of nutrient applications. Minimizing tillage obviously improves the uniformity of the land and the water distribution in the root zone.

Nutrient application issues that deserve further attention include: 1) the uniformity of fertilizer delivery across the width of the applicator (or segment thereof), 2) ways to utilize chemical reactions in the soil to optimize timely nutrient availability and minimize losses, and 3) strategic placement of nutrients relative to rooting patterns and changing soil pH.

Insuring uniform distribution of liquid fertilizers within an applicator is critical and yet can be highly problematic with materials like anhydrous ammonia. To complicate the issue, this primary nitrogen (N) fertilizer source converts from liquid to gas as pressure is reduced. The bubbling and frosty nature of anhydrous ammonia flow makes accurate metering virtually impossible. One combined solution is to pressurize the anhydrous ammonia system (use a pump, a high pressure manifold delivery system and a series of orifices to keep the material in a liquid form). The system maintains liquid streaming flow by forcing the liquid through a series of carefully-sized orifices so that the pressure does not drop below tank pressure until the point of injection in the soil. Pressurizing the liquid with a hydraulically-controlled positive displacement pump and orifices makes it possible to quickly alter the delivery rate to the target location and in the process address one aspect of ***Place*** (uniformity across the applicator based on the specific potential of the land) and a special aspect of ***Rate*** (desired application rate which is assured by the low CV application…or absolute uniformity).

Chemical reactions in soil can be both advantageous and problematic. In the case of N, nitrification is the biological process that transforms ammonium to nitrate and thus makes N loss via leaching a threat to the environment. Reducing the rate of nitrification can be accomplished with nitrification inhibitors and thereby better synchronize soil N availability and crop N need during the growing season. Using compounds like ammonium thiosulfate as a nitrification inhibitor provides sulfur (S) to the crop while reducing the pH of carbonaceous soils and therein increases the solubility of micro-nutrients. Further, injecting small amounts of an organic substance like humic and fulvic acid has the potential to protect nutrients from adsorption to soil particles. Rather, the nutrients remain in a quasi-immobile state in the soil so they can be more readily accessed by plant roots.

Placing nutrients in proximity to roots is an important aspect of crop vigor and helps beat back drought stress. Developing deeper rooting allows the plant to improve it's survivability in annual cropping. Use of starter fertilizers is common in some areas and fall application of anhydrous ammonia is popular in some situations. For the most part, the majority of N fertilizer applied to corn in the U.S. is made in a single band (under the row as with strip-tillage or between the rows). There is a perceived and real benefit to consider dual-band availability of nutrients. This increases root access to nutrients, especially on infertile soils or at times when crops are growing rapidly and nutrient uptake rate is relatively high.

The objective of this paper was to suggest that the next horizon for precision agriculture is to advance the concepts from management zones to the implements used to make applications, with due attention to the plant environment. Examples will be used to illustrate some of the points noted above and therein offer some opportunities to further refine site-specific management and possibly increase profitability. The primary example involves a field study to determine the optimum fertilizer N rate for continuous irrigated corn using in-soil blending of anhydrous ammonia, phosphorus and sulfur using an Exactrix applicator under no-till conditions.

MATERIALS AND METHODS

The field used in this study is located near Hugoton, Kansas under center-pivot irrigation. Field strips that received the fertilizer treatments were 12-rows wide with 76-cm (30 inches) spacing and replicated four times. Seven fertilizer N rates (28, 42, 63, 95, 142, 168, and 213 kg/ha) were applied using a strip-till technique whereby the nutrients are injected to a depth of ~15 cm beneath the seed row at least a week before planting. Nitrogen was injected as anhydrous ammonia while the other nutrients were co-injected in the Ortho ratio of 27-12-0-7 for N, P, K, and S, respectively. The P was applied as 10-34-0 (N, P, and K, respectively). The P value represents P_2O_5 and the K value represents K_2O. The S was applied as ammonium thiosulfate (12 -0-0-26S).

Grain was harvested with a 12-row combine that was equipped with a calibrated yield monitor. Yield monitor data were used to quantify yields.

RESULTS AND DISCUSSION

Corn yields in 2008 reached 12.51 Mg/ha (199.1 bu/acre) with 168 kg N/ha (150 lb N/acre) in spite of a hail event in June. The yield goal for this field was 13.19 Mg/ha (210 bu/acre). The fertilizer N rate that achieved the maximum statistical yield (quadratic regression) was 207 kg/ha (185 lb/acre), but the yield at 168 kg N/ha was 12.32 Mg/ha (Figure 1). Linear regression for the lowest six N rates also had a coefficient of determination of 0.9901 and predicted yield of 12.602 Mg/ha at the 168 kg/ha N rate. These data indicate that a linear-plateau model or quadratic expression would fit the data equally well. The linearity in yield response to fertilizer rate up to the maximum yield could in some way be related to the Ortho ratio of N, P, and S.

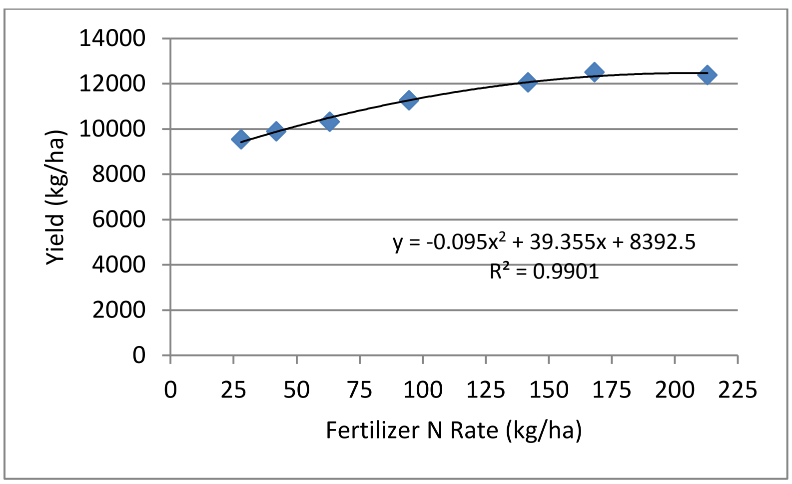

Figure 1. Corn yield response to fertilizer N rate in 2008 at Hugoton, Kansas.

The economic optimum N rate was 161 kg/ha (144 lb/acre) using the combined cost of the nutrients applied in the Ortho ratio and grain price of \$179/Mg (\$4.55/bushel) in 2008. Component fertilizer prices were N at \$0.806/kg (\$0.366/lb), P at \$1.613/kg (\$0.732/lb), and S at \$0.954/kg (\$0.433/lb).

Several measures of nitrogen use efficiency (NUE) have been proposed.

1. The "incremental" NUE at the marginally optimum N rate of 161 kg N/ha was 10.3% (calculated as the incremental N recovery in grain for each additional unit of N application).

2. The “recovery” NUE at the marginally optimum N rate was 25.8%. This approach only considers the yield that is attributed to the N fertilizer (i.e., subtracts the zero-N yield) and assumes a grain N concentration of 1.16% on a dry weight basis (0.65 lb N/bu).

3. The physiological NUE, at the optimum N rate, showed that an additional 8.6 kg of grain was produced for each additional kg of N fertilizer applied (also 8.6 lb grain for each lb. of N applied). This expression is the inverse of grain N concentration.

4. The production NUE (i.e., N applied to produce a given yield level) at the economic N rate was 76.2 kg grain for each kg of applied N fertilizer (1.22 bu/lb N fertilizer). At the point of maximum yield (derived from quadratic equation), the production NUE was only 60.2 kg grain for each kg of N fertilizer (10.7 bu/lb N fertilizer.

The above discussions address the issue of “***right rate***” on a field basis, but the study did not acknowledge spatial variability within the field strips or across the width of the applicator. Neither did the study include treatments that evaluated the most appropriate rate of individual nutrients and their placement relative to plants in a row.

Achieving uniformity in the delivery rate of anhydrous ammonia across the width of a toolbar is frequently assumed to be a trivial matter, but can be a major source of spatial variability. This is because anhydrous ammonia exists as either a liquid or a gas depending on the pressure. Pressure within the delivery system depends on the atmospheric temperature and the back-pressure that is created at the outlet port of the injection knife. These outlet ports are subject to wear and abrasion of the steel along the side of the delivery tube that is positioned behind the knife. The size of the outlet port affects the pressure within an individual delivery line. Metering a material that is transitioning between a liquid and gas is known to be problematic, which is why cooling chambers were developed in an attempt to keep the anhydrous ammonia in the liquid form through the metering device and hopefully through the manifold that distributes the material to the individual rows. Static calibration tests that collect anhydrous ammonia in water at the outlet ports of each injection knife are not very accurate because the variable back-pressure caused by soil against the outlet ports is not simulated in the above-ground static position. As with diesel engines, the feasible solution to the uniformity problem with anhydrous ammonia is to insert an orifice at the injection point in the soil.

The delivery rate of liquids through an orifice depends on the pressure in the system, which varies throughout the day because of external temperature and the amount of material in the supply tank. Mechanically pressurizing the anhydrous ammonia and forcing it through an array of orifices serves to address both the issue of uniformity across the toolbar (via orifices) and controlling the application rate (via range of pressures).

Concurrent pressurization of otherwise incompatible compounds and simultaneously injecting them through orifices into the same soil zone can result in exothermic or endothermic chemical reactions that may form precipitates. One example is the co-injection of anhydrous ammonia and a phosphorus source such as 10-34-0. Sulfur (S) sources like ammonium-thiosulfate (12-0-0-26S) can be mixed with 10-34-0 and co-injected to provide the benefits of a nitrification inhibitor and thereby reduce the potential for nitrate leaching. The co-injection of N and P is not a new concept, but rather was conceptualized about 30 years ago. Graduate students conducting the research were unable to obtain consistent results because of problems encountered with metering of the anhydrous ammonia. Pressurizing the delivery system, as noted above, was the key to controlling the flow rate and delivery of liquid fertilizers. Fertilizer applicators like the Exactrix nutrient management system makes it possible to simultaneously co-inject three liquid streams with spatial precision within the field and across the width of the applicator (Figure 2).

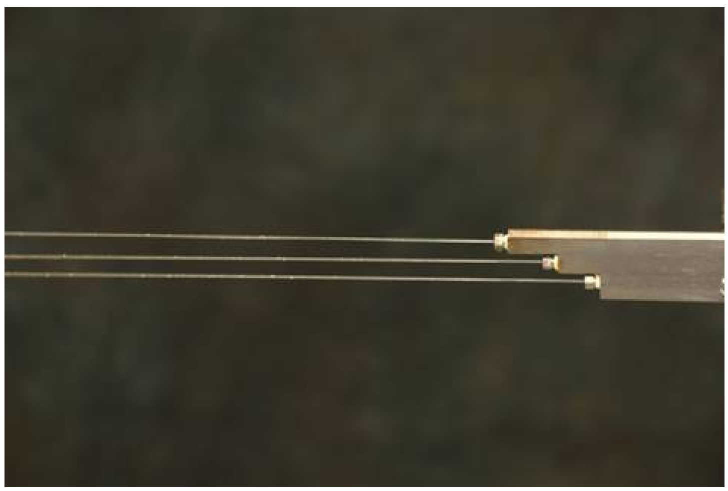

Figure 2. Triple stream of pressurized liquids as they exit orifices at the base of fertilizer injection knife.

Other possibilities for co-injection include humic materials because they have a high cation exchange capacity and thus offer the potential to act as a chelating agent to stabilize nutrients in the injection zone. Humic materials are commonly applied to horticultural crops that are grown on sandy soils that have a low pH. The point to be made is that technologies exist to spatially inject about any kind of chemical cocktail (fertilizer blend) into soil if there is a science-based reason that is economically feasible. The role of individual nutrients and compounds that influence soil fertility are quite well known, but when used in combination and when the materials are strategically placed relative to plants, the potential is unknown.

It will be difficult for university scientists to address the complexity of chemical reactions in soil considering that modern field-scale implements are beyond the scope of most faculties. This means that scientists who wish to address the problems and concerns associated with production agriculture will probably find it essential to cooperate in field-scale studies with producers. In the above example, the producer's yield goal of 13.2 Mg/ha (210 bu/acre) would have generated a fertilizer N recommendation of 298 kg N/ha (266 lb N/acre) for a soil with 2% organic matter (44 kg/ha or 40 lb/acre credit) and a default residual N credit of 33 kg N/ha (30 lb N/acre) (Kansas State University Extension bulletin, MF 2586). The maximum yield in the above study reached 12.51 Mg/ha (199.1 bu/acre) which was achieved with 168 kg N/ha (150 lb N/acre), for a savings of 130 kg N/ha (~116 lb N/acre) below the recommended rate. The extent to which this fertilizer savings can be attributed to; 1) better plant access to the nutrients, 2) the appropriate blend of N, P, and S, 3) N stabilization by ammonium-thiosulfate, 4) uniform application rate across the tool bar, or 5) a combination of the above is not known.

Studies that evaluate the uniformity of anhydrous ammonia distribution across the width of a toolbar under field conditions are rare because it would require harvesting row-by-row to address the confounding effects of current and past traffic patterns. Replicated and randomized field-strip studies that compare anhydrous ammonia applicator technologies are not common but exist. One study in Kansas compared a Continental Vertical Dam manifold and Exactrix nutrient management system (pressurized system with orifices) and determined the average CV values for yield were 3.0% and 1.7%, respectively, across N rates ranging from 112 to 202 kg N/ha (100 to 180 lb N/acre) with average yields (calibrated yield monitor) of 13.25 and 13.75 Mg/ha (211 and 218 bu/acre), respectively. Another study in Indiana compared a Hiniker Cooler Impellicone system with an Exactrix system and determined average CV values for yield were 6.2% and 2.6%, respectively, across N rates ranging from 134 to 202 kg N/ha (120 to 180 lb N/acre) with average yields (weight wagon) of 11.24 and 11.75 Mg/ha (179 and 187 bu/acre), respectively. Although these examples only represent individual fields, they illustrate an apparent yield advantage for using a pressurized system with outlet orifices to distribute anhydrous ammonia over non-pumped systems. These yield differences can be attributed to uniformity of application rate across the toolbar in that more definitive data are not available.

The 4-Rs that have been widely publicized are largely focused on data and information that contribute to a "proactive" management strategy. Spatial decisions are typically focused at the management-zone level. A higher level of management, and perhaps a 5th R, might be termed the "right chemistry" to include the effects on soil biological activity within the soil environment around plant roots. This proposed emphasis would be intended to complement the original 4-Rs by taking advantage of new or improved nutrient formulations that balance and better accommodate the changing nutrient needs of crops during the growing season. As time goes by and more is learned about synchronizing crop needs with nutrient availability, it is likely that producers will find it useful to start to include "reactive" management strategies. The term "adaptive management" tends to capture the intent of in-season management using remote sensing and crop canopy sensors to assess crop chlorophyll status and biomass accumulation.

Summary

The 4-R concept has been widely promoted around the globe as a way to think about improving nutrient management and thereby help protect the environment, increase nutrient use efficiency, and increase profitability. This concept has carried over to include various cultural practices like plant population, cultivar selection, pest management practices, and water related considerations. As these considerations become closer to being optimized, it will be ever-more important to consider a higher level of management that focuses on the soil environment around plants. Not only would this more-detailed approach increase the spatial resolution of the management, but it would focus on chemical reactions in the soil and interactions with roots. Technologies are available to use the soil as a reaction chamber upon the addition of various nutrient sources, but much is to be learned about how to optimize the chemistry involved. Producer observations of crop growth and yields within fields provide strong evidence that soil chemistry can be important in terms of nutrient use efficiency and profitability. Hence, the "***right chemistry***" is proposed as the **5th R** to round out management practices. Including this parameter in the management scheme naturally brings crops into focus because photosynthesis and biomass production have a direct bearing on yields and profitability. As such, tissue testing and foliar applications of nutrients provide the linkage between plant biochemistry and soil chemistry.

1. Use TIMES NEW ROMAN, 12-POINT typeface for the ENTIRE manuscript. If you
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3. Start paragraphs with a paragraph indent of five (5) spaces (i.e., first letter on space
6).
4. SINGLE spacing. Do not leave a space between paragraphs. It is IMPERATIVE that
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6. Type only to line 46 on the title page.
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V. MARGINS

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12. Three blank lines before the first heading (ABSTRACT).
13. One blank line, followed by text, flush left, left and right justified, Times New Roman
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15. The word "Keywords:" flush left, lower case, bold; follow by colon, 5 spaces, and
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16. Three blank lines.
17. Second heading (e.g., INTRODUCTION).

EXAMPLE

Line01:**SITE SPECIFIC HERBICIDE MANAGEMENT FOR**
Line02**:PRESERVING WATER QUALITY**
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Line06: Plant Science Department
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Line18**: ABSTRACT**
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Line 20: Start of abstract
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secondary headings should not have an initial capital letter.
- All headings should be flush left in their column.

For example:

Table 1. Indent second and additional lines of the caption.

Headings	
subheading (footnote 1) subheading	
-unit of measure	numbers
numbers	

1 Footnote.
3. Color is allowed where appropriate, use sparingly.

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Avoid using footnotes if possible. It is better to place the information in the text between parentheses or to list it as a reference. If it is necessary to use footnotes, use superscript numbers. The footnote should be typed the full width of the page.

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