1. Title: Importance of micronutrients in maximizing corn yield

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3. Objectives and Relevance to the Missouri Fertilizer and Lime Industry:

The main objective of this research is to determine the impact of various micronutrient packages offered by the fertilizer industry on corn yield. The specific objectives are to:

1) quantify the impact of pre-formulated micronutrient packages on corn yield.
2) determine plant tissue concentration of applied micro- and macronutrients.
3) compare nutrient uptake and yield between glyphosate- and non-glyphosate treated corn.

The use of micronutrients is increasing as the costs of fungicides and pesticides have many growers and producers focused on balanced plant nutrition to optimize plant health (Brown, 2008). Pre-formulated micronutrient packages are advertised to improve yields and nutritional content of Missouri's crops. Increased yields would translate into greater returns for Missouri producers and increased fertilizer sales. Statistics on micronutrient use and yield improvement in Missouri are scant. However, ever-higher crop yields and, with the advent of cellulosic biofuel production, increases in whole plant removal will result in more micronutrients leaving farmers' fields. This increase in micronutrients leaving the field and a potential reduction in soil supply power (associated with reductions in soil organic matter caused by the removal of not only grain yield but also crop residues) emphasize the importance to critically examine the role of micronutrient fertilization in Missouri.

Observations such as glyphosate-induced Mn deficiency (GIMD) have drawn considerable attention to micronutrient fertilization in soybean. The reasons for GIMD are largely attributed to in-plant interactions of glyphosate and micronutrients, and thus may also occur in other glyphosate resistant crops. Yet, interactions of glyphosate and micronutrients in corn have received little attention. It is important to remember that, even when no obvious deficiency symptoms are observed, tie-up of micronutrients in plants may occur and may limit crop yields.

Dozens of micronutrient formulations are available for the Ag market in general and corn producers in particular (Bio-Max Corn Mix, AgXplore CornScience, Agrium Pro-Corn Mix among others). However, evaluation of product performance by independent researchers is largely lacking, complicating the decision making process for farmers. Because of their critical roles in major physiological processes, suboptimal availability of micronutrients can lead to inefficient utilization of other inputs and limit corn yields. Although micronutrients are only required in low amounts and soil-test based micronutrient fertilization recommendations are available, these recommendations generally were developed many years ago for hybrids with significantly lower yield potentials. Thus, to achieve the unprecedented yield potential of modern hybrids, it is likely that greater amounts of micronutrient are required for growers to reap the benefits of the genetic yield potential of these hybrids. Furthermore, testing of soil samples for micronutrient availability is often omitted which precludes soil-test based micronutrient fertilization. In addition, many relatively new formulations of micronutrient products are available to Missouri growers, but their effects on yields of modern hybrids are uncertain.

The primary differences among most nutrient packages are the chemical forms in which the elements are delivered (Table 1), the presence of secondary macronutrients, micronutrient composition, the amount of each nutrient applied (recommended rates) and timing of application. Since these factors influence the accessibility by plants, differences in the effectiveness of these products can also be expected.

Table 1. Types of micronutrient delivery chemicals and associated attributes.

Chemical	**Type**	**Stability**	**Comments**
EDTA, DTPA,EDDHA	Chelated	Strong	Stable at high pH and phosphates, crop safe
Amino Acids, Citrates, Glucoheptonates	Complexed	Weak	Poor stability, but cheaper
Sulfates, Carbonates, Nitrates	Inorganics	Highly water soluble	Soil application ineffective; higher rates needed.

Differences also affect price, with the cheapest materials most often being the least stable and most at risk for loss. In Missouri, few experiments on the effects of these different products on corn growth and yield have been conducted by independent researchers. Thus, this project will evaluate the different classes of products to better understand their efficacy and suitability for use on corn in Missouri.

4. Procedures:

This project will be conducted for 3 years at the Bradford Research and Extension Center in Columbia, MO on a Mexico silt loam soil and will include the following treatments:

Nutrient trts
1) FHR's Bio-Max corn (foliar; glucoheptonate chelate; Zn, Mo; no Sulfur)
2) Agrisolutions' Ultra-Che Corn Mix EDTA (foliar; EDTA chelate; Cu, Mn, Zn)
3) AAT's Tetra Micronutrients' Pro-Corn Mix (foliar; citric acid and EDTA chelates; N, S, B, Fe, Mn, Zn)
4) Agrigaurdian's MOLY (foliar, non-chelated molybdate; Mo only)
5) AgXplore's MicroScience (foliar; non-chelated sulfates; B, Mn, Mo, Zn; no sulfur)
6) Inorganic Zn sulfate, Mn sulfate, Molybdate (liquid; non-chelated Zn, Mn, Mo and S)
7) untreated control

Herbicide trts
1) Conventional (No glyphosate)
2) Glyphosate

Design: Corn hybrids will be no-till planted (30" rows) in different fields each year. Each treatment (7 nutrient trts x 2 hybrids) will be replicated 4 times in a randomized complete block design. Plot sizes will be 300 sq ft.

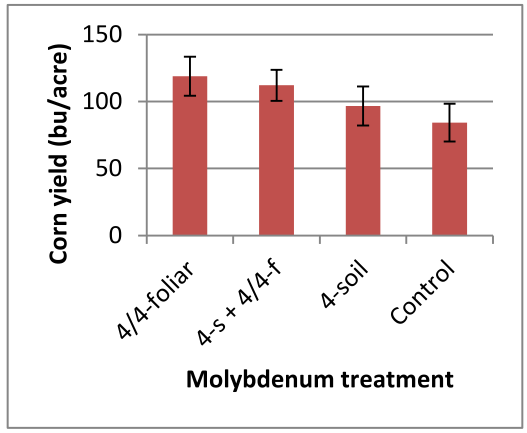
Cultural Practices: The experiment will be initiated in spring 2013. Basic P and K fertilization will be applied according to current MU soil test recommendations. Nutrient treatments will be applied at manufacturer recommended times and rates. Weed control will be conducted using conventional herbicides or Roundup at recommended rates.

Measurements: Plant growth will be monitored (plant height, chlorophyll concentration etc.) at regular intervals over the course of the season. Whole-plant tissue samples will be collected at V6 and dough stage for biomass determination and tissue composition determined by ICP-OES. Final yield will be determined with a research combine and nutrient composition analyzed on a subsample from each plot.

5. Current Status and Importance of Research Area:

Fertilizer formulators have developed numerous micronutrient packages for corn. Most of these packages contain similar micronutrients (Fe, Mn, Zn, Cu, B, Mo) and often contain primary (N, P, K) and secondary (Mg, S) macronutrients. Aside from the nutrient composition, the major difference among these products are the chemical agents used as carriers (Table 1) and this may determine the effectiveness of the product. While the effect of these different chemical agents on maintaining micronutrients in available forms are known, the various packages are designed to account for the differences with adjustments in application method and timing unique for each product. The performance of these products at recommended rates needs to be evaluated to determine if they provide micronutrients equally relative to cost.

Micronutrient requirements differ among crops. Micronutrients that are of particular importance for corn include Molybdenum and Zinc. While other micronutrients will be tested as well in this project, these two nutrients are highlighted as examples to briefly illustrate the linkage between the underlying physiology of micronutrients and yield formation in corn. Molybdenum is essential for nitrogen metabolism in corn where it is needed for the function of nitrate reductase, which is necessary for the conversion of nitrate into nitrite and the eventual incorporation of nitrate-N into proteins (Hewitt and McCready, 1956). In addition, Molybdenum is involved in the synthesis of the phytohormones abscisic acid (Xiong et al., 2001) (implicated in plant responses to drought) and auxin (growth regulation such as lateral root formation, elongation, gravity sensing etc.). Among other things, Molybdenum deficiency in corn has been shown to shorten internodes, decrease leaf area, and reduce pollen grain development (Agarwala et al., 1978 and 1979).



To explore the effect of Mo fertilization in mid-Missouri, we conducted a preliminary experiment at Bradford Research and Extension Center in 2012. Treatments included: 1) soil application of 4 oz at planting, 2) two foliar applications of 4 oz each (~V5 and V10), and 3) the combination of soil and foliar applied treatments (1 and 2). Although 2012 was an unusually dry year resulting in low yields, the preliminary data from this experiment indicate that supplemental application of Molybdenum may increase corn yields (difference between control and two foliar sprays: 34 bu/acre) (Fig. 1).

Zinc is also involved in multiple biochemical processes in plants. Of particular interest for corn, is zinc's role in photosynthesis where it is required for carbonic anhydrase function. This enzyme is part of the C4 photosynthetic pathway which gives plants such as corn higher photosynthetic rates than C3 plants such as soybeans (Shrotri et al., 1983). In addition, Zinc is important for protein synthesis related to pollen tube formation (Ender et al., 1983), responses of plants to stress, and carbohydrate dynamics (Shrotri et al., 1983).

Because of the roles such as those outlined above, the fertilizer industry has formulated numerous micronutrient packages for corn. Yield responses to these types of products published in refereed journals are nearly absent. However, many formulators have published research on their products online. Industry supported research at selected public institutions indicates that these products can improve yields by 5-20 bu/ac. If yield increases such as these can be achieved, micronutrient products will garner much interest from producers and retailers should be able to sell these products.

The possibility of whole-plant removals for biofuel production suggests that micronutrient deficiencies may increase in Missouri. And, ever-increasing yields will require that more micronutrients be available to crops (Tracy, 2010). This does raise concern because most micronutrients are involved in highly defined physiological processes within the plant including enzyme activation, components of enzymes, protein synthesis, carbohydrate metabolism, membrane integrity, nitrogen transport, lignification, etc. (Marschner, 1995).

This study will allow us to evaluate the influences of several different micronutrient packages representing different types (Table 1) on micronutrient uptake and corn yield.

6. Expected Economic Impact of the Project

Yield information is lacking on micronutrients in Missouri. However, if 5 bu/acre can be added to Missouri's approx. 3 million corn production acres then a net of over $111 million will be realized by Missouri producers (5 bu x $7.45 x 3 million acres).

7. Timetable for Proposed Research:

Spring 2013	Soil testing, plot establishment, planting, and general management of corn.
Summer 2013	Application of treatments, plant growth monitoring, tissue sampling and analysis, and determination of effects on crop growth and development.
Fall 2013	Harvest for yield determination and seed weight.
2014	Repeat as in 2013, with adjustment as needed based on 2013 data.
2015	Repeat as in 2013, with adjustment as needed based on 2013 and 2014 data.

8. Strategy for Application and Transfer of Knowledge:

Results of this study will be disseminated at appropriate annual field days and workshops (e.g. Missouri Crop Management Conference, Crop Injury and Diagnostics Clinic). The information gained from this project will be presented at annual meetings of professional societies (such as American Society of Agronomy, Crop Science Society, Soil Science Society of America) and will be published in a refereed journal.

9. Proposed Budget:

Category	Year 1	Year 2	Year 3	Total
Personnel Graduate Student	$18,500	$18,500	$18,500	$55,500
Field supplies (fertilizers, herbicide, bags, etc.)	$1,800	$1,800	$1,800	$5,400
Tissue and seed analyses	$2,000	$2,000	$2,000	$6,000
Travel	$1,200	$1,200	$1,200	$3,600
Total	**$23,500**	**$23,500**	**$23,500**	**$70,500**

Justification:
Personnel costs include salary (50%) and fringe benefits (health insurance) for a graduate research assistant.

Field supplies include costs associated with plot preparations, planting, weed control, harvest as well as flags, bags, tags and other consumables associated with plant sampling and harvest.

Tissue and seed analyses costs will cover ICP-MS analyses of the plant and seed samples.

Travel costs include funding for travel to the field site as well as graduate student attendance at a professional conference.

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Selected Refereed Publications:
Peng, Y., C. Li, and **F.B. Fritschi**. 2013. Apoplastic infusion of sucrose into stem internodes during female flowering does not increase grain yield in maize plants grown under nitrogen limiting conditions. Physiologia Plantarum (in press).

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PUBLICATIONS:

Proceedings and abstracts: 23

Recent Refereed Journal Articles

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