1. Title **Managing phosphorus, manganese and glyphosate interactions to increase soybean yields**

2. Investigators Felix B. Fritschi and James H. Houx III, Univ. of Missouri

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

The overall objective of this project is to examine the two- and three-way interactions of P, Mn, and glyphosate in response to fertilizer treatments and herbicide regimes.

Specific objectives:

1) To determine if pop-up P applications will improve early season growth, soybean yield, and seed quality.
2) To determine if Mn fertilization will increase soybean yield and seed quality.
3) To examine if P and Mn fertilization individually or in concert increase yields of glyphosate and glufosinate tolerant soybeans.

A large number of soils in Missouri are low in plant available P (Bray I P). It is well established that yields of P-deficient soybeans are reduced and that these soybeans have reduced N fixation rates. Low P can reduce the growth of the soybean plant *per se*, the growth and function of the nodules, and the growth of both the plant and the nodule (Israel, 1987; Israel, 1993; Sa and Israel, 1991; Almeida et al., 2000). Because P deficiency can strongly reduce yields, soil-test guided P fertilization recommendations have been developed and are commonly used by US farmers. However, because of its low mobility, P deficiencies can occur early in the season, even in soils with adequate soil-test P levels particularly when soil temperatures are cool and root growth is slow. Therefore, starter or pop-up fertilizers often contain P in an attempt to stimulate early growth.

Recently, Univ. of Missouri researchers found an interaction between P fertilization of low P soils and Mn uptake by plants (McClain, Ph.D. dissertation 2007). Such an interaction of P and Mn is of particular interest for soybean production since soybean has a specific requirement for Mn for the metabolism of N-fixation products delivered to leaves and pods. Because glyphosate interacts with Mn in both tank mixtures and in the plant (Bernards et al., 2005), awareness relative to Mn fertilization has increased in recent years. In fact, observations of deficiency symptoms in soybean are frequently reported following post-emergence glyphosate applications, and the occurrence of glyphosate-induced Mn deficiency symptoms ("yellow flash") has garnered attention from the fertilizer industry. In response, a number of companies have developed and/or are working on providing farmers with novel products to overcome Mn deficiency. Importantly, because of the critical role of Mn for physiological processes, particularly in soybean, chelation of Mn by glyphosate may limit yield even if deficiency symptoms are not manifested. Since approximately 90% of all soybeans grown in Missouri are herbicide resistant and most soybeans grown in the US are glyphosate tolerant (91% in 2009; NASS, 2009) the interaction of Mn with glyphosate can have a tremendous impact on the soybean industry. For instance, research results indicate that glyphosate tolerant soybeans respond to Mn fertilization with yield increases of 8 bu/acre reported in Kansas (Gordon, 2007), and up to 18 bu/acre in Indiana (Huber, 2007). This information has not been widely published or discussed, and experiments to test these observations under Missouri conditions have not been conducted to date. A yield increase of 8 bu/acre or more could easily pay for the addition of Mn fertilizer (8 bu x $11/bu = $88/acre).

Glyphosate tolerant soybeans are an amazingly important contribution to our soybean industry. However, when concerned about production of glyphosate tolerant soybeans, the question is whether or not P fertilization can stimulate Mn uptake to overcome the Mn interaction with glyphosate. We suggest that, for maximum soybean yields, a combination of Mn treatments and P fertilization may be required. This project will provide information on the impact of pop-up P, supplemental Mn, and their interactions on soybean yield responses and seed composition.

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.

The Experiment will include the following treatments:

Phosphorus: 1) Pop-up Phosphorus application (to achieve a Bray I soil test level to be >50lbs/acre P)
2) Control (no P manipulations)

Manganese: 1) 0 lb Mn $acre^{-1}$
2) 4 lb Mn $acre^{-1}$
3) 8 lb Mn $acre^{-1}$

Weed control: 1) Glyphosate or Glufosinate
2) Conventional herbicides

Varieties: 1) Roundup Ready
2) Glufosinate resistant

Number of plots = 3 Mn trts x 2 P trts x 2 Weed control trts/genotype x 2 genotypes x 4 replications = 96

Design: Each treatment will be replicated four times in a randomized complete block design using multiple splits to accommodate the treatments outlined above. The minimum plot size will be 10 x 25 ft.

Cultural Practices: The experiment will be initiated in spring 2012. The site will be selected based on soil samples collected and analyzed prior to establishment. P and Mn treatments will be applied as outlined above. Manganese treatments will be established as a single pre-plant soil application at the above-specified rates. Phosphorus fertilizer will be applied as a pop-up (on the seed at planting). Fertilizer for other elements will be applied according to the MU soil test recommendations. Weed control will be conducted using either glyphosate or glufosinate to match the appropriate variety and will be applied according to recommended rates and procedures. Conventional pre- and post-emergence herbicides will be applied according to manufacturer recommendations.

Measurements: Treatment effects on crop growth and development will be assessed over the course of each growing season by frequent measurements of plant height, canopy development, and determination of growth stage. Particular attention will be given to the effect of the pop-up P application for early soybean development, and maximum biomass (mid R5 developmental stage) will be determined. The biomass samples will be assayed for ureide concentration and for concentration of macro- and micro-nutrients by ICP. Yield will be determined by harvesting with a research combine and subsamples of seed will be saved to determine treatment effects on seed composition.

5. Current Status and Importance of Research Area

Plant uptake of P can be problematic early in the growing season, particularly when germination and root growth is slowed by cool wet soils. Thus, starter P applications that place P close the developing seedling should improve its acquisition. Researchers recognize that the best responses to starter P applications mostly occur on low P soils. And, although Missouri has improved P levels steadily over the past few decades, many soils are still low in plant available P. As such, many soybean plantings may benefit from starter fertilizer applications containing P. On a low P site, pop-up (in-furrow with seed) and/or starter P placement consistently result in greater early season plant biomass, height, and tissue P levels and often improve soybean yield (Ham et al., 1973; Hoeft et al., 1975; Randall and Vetsch 2008). On high P sites, early season growth is greater with starter and pop-up P, however; final grain yields are often not different. Irrespective of this, some growers apply starter fertilizers simply to improve early seedling growth and health regardless of soil test recommendations (Roberson, 2006), and numerous producers extol the benefits of pop-up and starter applications on agriculture weblogs.

McClain (2007) has shown that P applications on low plant available P (Bray I P) soils increased leaf Mn concentrations. However, there still is a lack of understanding about P and Mn interactions and, to date, it is unclear how the three-way interaction of P, Mn, and glyphosate will play out. For instance, P may attach to the soil sorption sites that would normally interact with glyphosate molecules and may thus limit the inactivation of glyphosate (Simonsen et al., 2008).

Manganese is an essential micronutrient element for plant growth and development. It is involved in a number of critical physiological processes including photosynthesis and detoxification of oxygen radicals. A major role of Mn is the activation of a broad range of enzymes that are involved in processes such as photosynthesis, respiration, transcription, and amino acid synthesis. There are certain types of plants that seem to have especially high Mn requirements (Kering et al., 2009). We are predicting that soybean is a "high" Mn requiring plant, since it's root nodule bacteroids use Mn-activated NAD-malic enzyme as the first step in acquiring energy from the plant. Plus, 90% of the fixed nitrogen transported from root nodules to leaves and developing pods is in the form of allantoate, which requires a Mn-dependent enzyme to release the N from this molecule so it can be used for amino acid synthesis (Winkler et al., 1985). Therefore, soybean may have an especially high Mn requirement: 1) Glyphosate applied to glyphosate tolerant soybeans may tie up Mn, 2) Mn is required for energy utilization in the root bacteroids to support N fixation, and 3) Mn is required for metabolism of the N in allantoate which is supplied from the nodules to leaves and pods.

Currently most of the soybeans grown in MO and the US are glyphosate tolerant varieties. However, recently, glufosinate tolerant soybean varieties have been developed and are available to farmers. We propose to compare glufosinate and glyphosate tolerant soybean genotypes because 1) glufosinate tolerant varieties are a new alternative for soybean farmers, and 2) it is unclear whether Mn-glufosinate interactions similar to those of Mn-glyphosate interactions may occur.

Thus, while the importance of P and Mn for plant growth is well established, there are many unresolved questions about the interactions of P and Mn uptake, glyphosate/glufosinate and Mn, and the three-way interactions of P, Mn and glyphosate/glufosinate that need to be answered. Particularly in soybean, it is important to develop fertilizer management practices that account for these interactions.

6. Expected Economic Impact of the Project

Based on harvested acres, soybean is the most important grain crop in Missouri. Approximately 5.35 million acres were planted in 2011 with the vast majority of these acres being glyphosate tolerant varieties (NASS, 2011). Thus, if a yield gain such as the reported increase of 8 bu/ acre in Kansas, could be realized in Missouri as a result of improved Mn and P management, the impact on the agricultural community, both, at the farm level as well as for the fertilizer industry would be impressive
(8 bu /acre x $11 / bu x 5.35 million acres = $471 million statewide).

7. Timetable for Proposed Research

Spring 2012	Soil sampling and analysis, treatment establishment, planting, and general management.
Summer 2012	Determination of treatment effects on crop growth and development
Fall 2012	Harvest for yield and seed composition determination
2013	Repeat treatments, management and data collection as in 2012
2014	Repeat treatments, management and data collection as in 2013

8. Strategy for Application and Transfer of Knowledge

Results of this study will be disseminated at appropriate annual field days and workshops. 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				
PhD Student	$19,000	$19,570	$20,157	$58,727
Undergraduate help	$3,200	$3,200	$3,200	$9,600
Field cost (fertilizers, herbicide, bags, etc.)	$2,500	$2,500	$2,500	$7,500
Tissue and seed analyses (ICP, NIR, ureide)	$3,200	$3,200	$3,200	$9,600
Travel	$1,500	$1,500	$1,500	$4,500
Total	**$29,400**	**$29,970**	**$30,557**	**$89,927**

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Felix B. Fritschi

Division of Plant Sciences
1-31 Agriculture Building
Columbia, MO 65211

Phone: (573) 882-3023
Email: fritschif@missouri.edu

Education:
Ph.D., Plant Biology, 2002. Univ. of California, Davis.
M.S., Agronomy, 1996. University of Florida
Ing. HTL, Crop Science, 1993. Swiss College of Agriculture

Professional Experience (Since 2002)**:**
Assistant Professor, Univ. of Missouri, 2007 – present.
Post-doctoral Research Associate, USDA-ARS. 2002 – 2006

Membership in Professional Societies:
American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
Gamma Sigma Delta Agricultural Honor Society
Alpha Zeta Honor Society.

Publications:
Refereed Journal Articles: 21; Proceedings and Abstracts: 83

Selected Refereed Publications:

Fritschi, F.B., J.D. Ray, L.C. Purcell, C.A. King, J.R. Smith, and D.V. Charlson. 2011. Diversity and implications of soybean stem nitrogen concentration. Journal of Plant Nutrition. (in press)

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James H. Houx III

Division of Plant Sciences
1-31 Agriculture Building
Columbia, MO 65211
Phone: (573) 882-3057
Email: houxj@missouri.edu

Education:
Ph.D., Plant Sciences, 2008. University. of Missouri.
M.S., Forest Resource Management, 2001. University. of Missouri
B.S., Forest Resource Management, 1992. University. of Missouri

Professional Experience (Since 2002)**:**
Post Doctoral Fellow, University of Missouri 2008 – Present
Research Specialist, University of Missouri 2002 – 2008.

Membership in Professional Societies:
American Society of Agronomy
Crop Science Society of America
Soil Science Society of America
National Cattleman's Beef Association

PUBLICATIONS:

Proceedings and abstracts: 16

Recent Refereed Journal Articles

Roberts, CA, **JH Houx III**, and FB Fritschi. 2011. Near-infrared analysis of sweet sorghum bagasse. Crop Sci. 51:2284-2288.

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