DO CRITICAL SOIL PHOSPHORUS CONCENTRATIONS VARY IN SPACE AND IF SO WHY?

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JUSTIFICATION

The soil phosphorus (P) quantity-intensity relationship describes both the availability and reserve supply of soil P to plants. When we plot intensity versus quantity the shape of the curve is largely influenced by the soil's chemistry and mineralogy. Traditionally, we view plant available P as a function of the initial soil P concentration, soil pH, Fe oxide content, and extractable Al (Daly et al., 2015; Wang et al., 2015; Fink et al., 2016). The goal of agronomic soil testing is to provide some information on the quantity-intensity relationship for a given soil to inform fertilizer recommendations (McGrath et al., 2014). This is done by determining a critical soil P concentration above which yield increase from P fertilizer would not be expected. Ideally, critical values are determined empirically using rate-response studies at many sites across many years. This approach results in a highly accurate, yet imprecise value due to the large sample size and large variation. In addition to varying across crops and soils, critical values are influenced by political boundaries, since they were often determined by local land grant universities using different extracting solutions, empirical data sets, and fertilization philosophies.

Plants can utilize several methods to access soil P including changes in root architecture, mycorrhizal associations, and release of root exudates and other root deposits (i.e. rhizodeposits) that alter the rhizosphere in order to increase P solubility (Shen et al., 2011). Microbes, primed by rhizodeposits, play a critical role within the rhizosphere in mediating P cycling (Rodríguez and Fraga, 1999). Conventional breeding of crops in soils with high nutrient inputs (i.e. more homogeneously distributed nutrients) has likely led to plants with reduced root plasticity making them less efficient at accessing P when heterogeneously distributed in soils, as commonly seen under no-till production (Grossman and Rice, 2012). Further confounding this situation, many states currently recommend shallow sampling in no-till (e.g. 10 cm) compared to deeper samples for tilled fields (depths up to 15 – 20 cm). However, there has been recent research indicating that this approach misrepresents P fertilizer requirement in no-till and that in fact removing the top 5 – 10 cm of the soil sample may more accurately predict P requirement (Douglas Smith, Personal communication, 2015).

Standard P fertilizer recommendations provide a single prescription per field based on one representative soil sample. However, soil P concentrations within a field can vary both across the field and with depth (Cambardella et al., 1994; Mallarino, 1996; Díaz-Zorita and Grove, 2002; Grandt et al., 2010). Producers and their advisors typically base variable rate P prescriptions on either variable soil P maps, created using zone, grid, or grid point sampling and some sort of interpolation, or yield maps and assumed nutrient removal by that crop (Rehm et al., 2001; Heege, 2015). While nutrient removal may be an attractive option due to yield map availability, the nutrient removal by a crop varies with the yield potential, which does not accurately reflect P supply (Heckman et al., 2003; Setiyono et al., 2010). However, applying standard soil test recommendations to variable soil maps might not provide a much better solution. Current soil test P recommendations may be accurate across many years and fields, however, they lack the precision necessary to leverage the advantages provided by modern variable-rate technology, particularly if critical concentrations are varying as well as the amount of P present. The spatial and temporal variations in distribution of P quantity and intensity, due to variability in soil chemistry, soil microbial communities, and plant uptake, highlight the need for research to increase the precision of soil P testing and associated recommendation systems.

OBJECTIVES

Our overarching objective is to determine if variable rate P applications can be used to efficiently manage P in grain crop production. Our specific research objectives will evaluate the spatial and temporal variability of the soil P critical concentrations in these systems. We will investigate variability in P supply as it relates to soil chemistry, soil P forms, and soil biology as well as rhizosphere interactions that influence crop P requirements. Furthermore, we hope to use this fellowship as a vehicle to initiate a regional, open source research group that shares samples and associated data for broader soil P research.

Research Questions

1. Do soil P critical concentrations vary in space and time?
2. Can traditional soil testing be used to estimate variable soil P critical concentrations and prescribe spatially variable P fertilizer rates?
3. What soil chemical and biological factors as well as rhizosphere processes control crop P requirement?

METHODS

Our proposed methodology relies on having a large number of sample points covering not only the variation within fields, but also between fields and across time. Our primary objective is to evaluate critical soil test concentration variability within fields, which will require high sample densities in each field. However, in order to determine what factors control critical concentration variability we will also need a diverse sample set across multiple fields. Ultimately, we hope to collect a large, diverse data set that will allow us to evaluate parameters that influence yield response variation within a narrow range of soil P concentrations. To date variable rate P management relies on the relationship between covariance and distance, where it is assumed that the farther apart two points are the less similar their behavior or the lower their covariance (Figure 1). This is the basis for interpolation of grid sampled soil data. However, what we are proposing is to evaluate the covariance of yield response within a very narrow range of soil P concentrations within fields and also across regions.

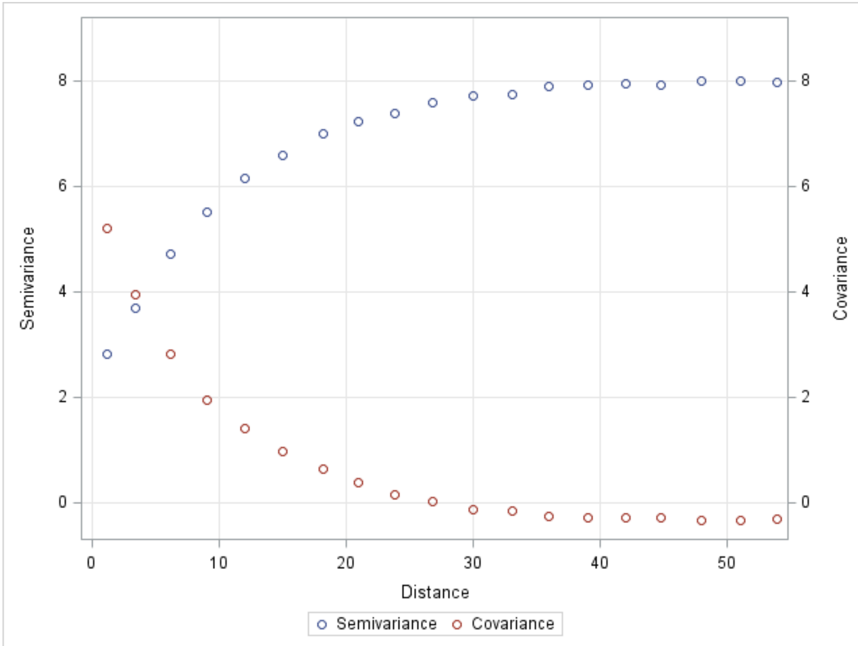

Figure 1. Example of the relationship between semivariance and covariance over distance. The farther apart two points are in space the lower their covariance.

We will select two fields in the first year and then add one additional fields in each subsequent year of the study (four years total), so that by the end of the study there will be five project fields and 14 site-years in Kentucky. Sites will be sought out that would be expected to respond to P fertilizer application based on land grant soil test guidelines. Partners in additional states have agreed to participate if additional funding to support their work can be secured. Their

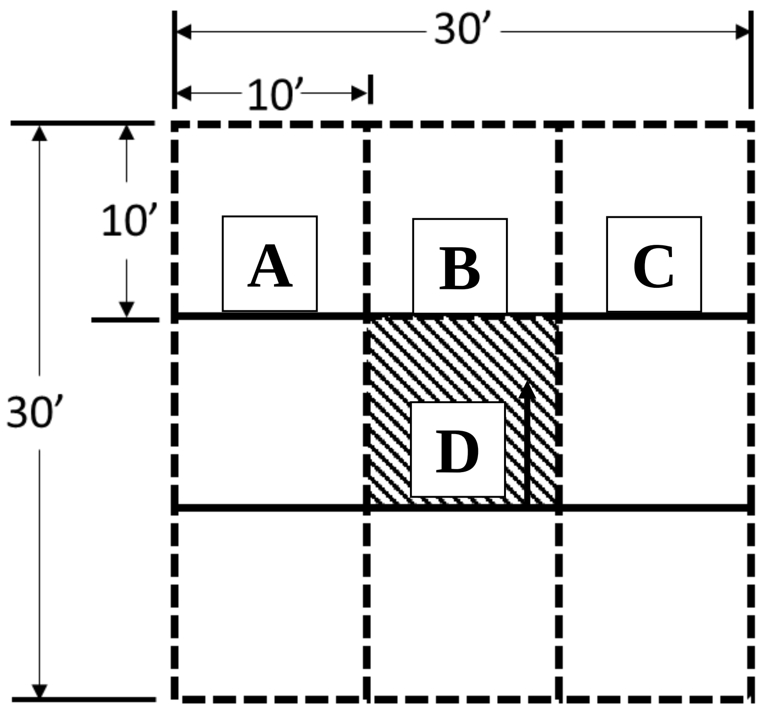

Figure 2. Plots will measure 30' x 30' and contain nine 10' subplots. Measurements will be made on the center three plots (A – C) with the center (B) subplot receiving P fertilizer.

sites would be initiated in subsequent project years, providing time to seek funding. Two sites have already been selected and sampled in Kentucky for 2016, one in Brethitt County (2.55 ha) and one in Caldwell County (4.85 ha). All project sites will be maintained in a corn-soybean, no-till rotation. As described below in more detail, P treatments will be applied in the first year at each site. Yield will then be monitored over the next four years, allowing us to assess lag in yield response over subsequent years. Plot establishment, soil and plant sampling, fertilizer application, and yield monitoring will all be mapped spatially using Real Time Kinetic corrected Global Positioning System (RTK-GPS) providing the highest level of accuracy in matching data sets across fields and over time.

Response plots will be randomly located across the entire project field. A 30’ grid following the planter path will be overlaid on each field using GIS software. Then a 10’ grid, matching the planter width (four row – 30” rows) will be overlaid on the 30’ grid. In the first year a field is used, approximately 25 - 50% percent of the 30' plots will be randomly selected and assigned plot numbers (actual number of plots will be determined based on feasibility of sample collection). Each plot will contain nine 10' x 10' subplots (Figure 2). Prior to planting, two soil samples, one to a depth of 10 cm and one to a depth of 20 cm, will be collected from each of the center three subplots (labeled A – C in Figure 2). During corn planting the center subplot (B in Figure 2) will receive starter P fertilizer (as polyphosphate) placed approximately 5 cm beside and 5 cm below the seed using the planter at a rate of 60 lb-P_2O_5/acre. The planter will be modified to inject UAN into the starter stream to balance the amount of nitrogen (N) applied to each plot. In this way the entire field, whether receiving P or not, will get 50 lb-N/acre in the starter. The randomized P treatments, and concomitant N balancing treatments, will be programmed using dual product variable rate software prior to going to the field. Initially, P applications will only be made to the corn portion of the crop rotation, but this is an aspect of the methodology we would like to further develop in collaboration with the project team. In subsequent years when corn is rotated back to the fields a subset of the 30' plots not yet used will be randomly selected and P will be applied. We hope to retain these fields beyond the scope of this proposal. If 25% of the plots are used each time corn is planted, four crop rotations (16 years) of P response data could be collected from each field. Figure 3 shows the plot layout for the Brethitt County site sampled in 2016. Since this site was only 2.55 ha we were able to sample over 50% of the field. The center subplots that will receive P fertilizer are indicated with the shaded circle.

In the first year we are only using the center three plots because we need to determine the

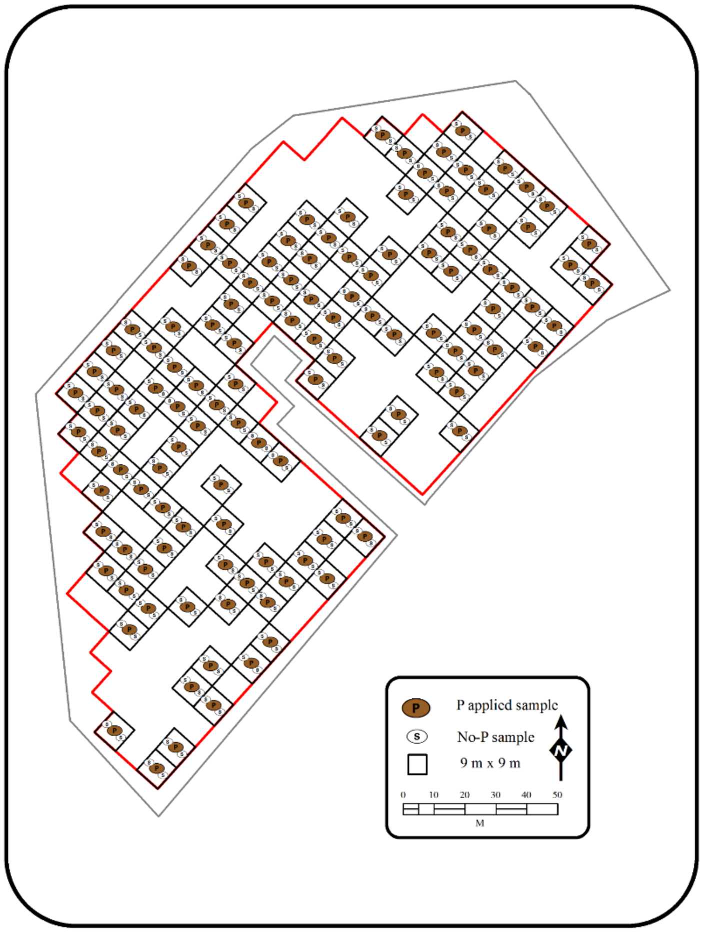

Figure 3. Brethitt County site showing the 30' plots and three subplots that were sampled.

spatial accuracy of our fertilizer application. In subsequent years we will randomly select three subplots to receive P, allowing error estimation for yield response. In the first year we will turn on the P fertilizer as we cross the boundary of the subplot D (Figure 2, arrow indicates direction of travel) and turn off the P as we cross the boundary exiting B. We will analyze flow meter data collected to determine the distance going into and out of the plot that does not receive a full rate, we anticipate this distance will be about 2.5’ going into and out of the plot. If for example that distance is 2.5’ at each side of the subplot then each subplot will be 15’ x 10’ in future years. The total plot size would be 45’ x 30’. Yield data will only be collected from the center 10’ x 10’ of each subplot in this situation ensuring that yield is matched to a full rate of P. Yield will be mapped with using a two row plot combine equipped with a customized yield monitor and RTK GPS. This harvest method should allow adequate precision and accuracy to match yield response to P treatments and soil physical, chemical, and biological measurements. This method of soil sampling and P application will provide the yield response (ΔY, Equation 1) to P fertilizer for each plot. Where $\bar{Y}_P$ is the mean yield from the subplots receiving P fertilizer and $\bar{Y}_0$ is the mean yield subplots receiving no P fertilizer. As described above, only one subplot will receive P and the two adjacent subplots will be used to determine$\bar{Y}_0$. In future years three of the six subplots not receiving P will be randomly selected and used to determine average yield without P fertilizer.

Equation 1. Yield response equation.

$$\Delta Y = \bar{Y}_P - \bar{Y}_0$$

In the first year, Mehlich 3 P, K, Ca, Mg, and Zn concentration, soil pH, Sikora Buffer pH, and organic matter will be determined on all samples. After harvest in the fall we will map soil electrical conductivity (EC) using a Veris unit. Yield response data and soil maps will be used to select a subset of samples to determine soil texture (hydrometer method). We will evaluate how microbial community structure responds to the spatial variability present in the field using high-throughput phospholipid fatty acid (PLFA) analysis at each of the sampled grid points. PLFA provides information on total microbial and fungal biomass as well as the relative proportion and concentration of major microbial groups (G+, G-, arbuscular mycorrhizal fungi, etc.). Yield will be mapped with adequate precision to match yield response to P treatments and soil chemistry and biology. In addition, crop response to P will be measured using V4 biomass, time to canopy closure, percent of plants showing silks when high P plots have reached approximately 90% silked, and grain moisture at harvest. We will also be partnering with the Biosystems and Agricultural Engineering Department at University of Kentucky to collect high resolution imagery of project fields to see if spectral measurements can aid in predicting P response and to quantify P response across time. An unmanned aerial systems equipped with a multispectral camera will be deployed over each test site a minimum of two times per season to coincide with crop responses measurements at the V4 and silking stages. Visible and near-infrared images will be stitched into a georectified orthomosaic and reflectance indices (e.g. NDVI) will be extracted over the individual subplots. Time permitting, additional imagery will be collected throughout the growing season on a monthly basis. Additionally, logging weather stations will be used to collect daily soil moisture, precipitation, and temperature data throughout the growing season at each site.

The initial sample density would be cost and time prohibitive for more advanced laboratory methods and multiple sample depths. Therefore, results from the first year for any field will be used to select a subset of sample points that accurately represent the range of variability in soil microbial structure, yield, soil P, and pH for more detailed analysis across the rooting depth using advanced analytical methods (e.g. Next Generation Sequencing (NGS) to fully elucidate the specific organism present, P sorption isotherms, and soil P fractionation to quantify organic and inorganic P forms present). Final decisions on more advanced methods will be determined by project partners after collection of preliminary data from the first year. Multivariate analysis will then be used to correlate shifts in variables such as microbial community structure and variation in P forms present to the changes in the various environmental variables measured.

Finally, an important component of the proposed project is developing a collaborative effort across state lines to review and potentially revise soil test P recommendations, not just for variable rate P application, but also for conventional flat-rate P management. A critical first step in this effort is to create a multi-state database of historic P response data used to formulate existing recommendations. It is widely understood that a large amount of the historic soil test and crop response data used to generate current soil test P recommendations was never published and as result has been lost over time. Nonetheless, some of the P response data has been published in one form or another and some is still available in archived land grant university research reports (Peaslee, 1978; Thom, 1985; Mallarino and Blackmer, 1992; Heckman et al., 2006). We propose to use this project as a catalyst to bring together a coalition of the willing. This coalition will provide existing P response datasets from their home institution, with available metadata, which will be compiled in an open database. Going forward a framework will be developed for data from this project and other P response research to be added to the database. Ultimately, our goal will be to seek financial support for a broader coalition that will create the framework for a public database of P and K response trials. It is important to understand the basis for current recommendations in order to fully leverage data collected under this project and develop new recommendations going forward. Ultimately, data from this project and others should be presented in a transparent manner so the end user has the opportunity to judge for themselves the strengths and weaknesses of the fertility recommendations they adopt.

BUDGET

This fellowship proposal is intended to support the planned research of Mr. James Bowen a first year Ph.D. student at the University of Kentucky. Mr. Bowen's assistantship (tuition and stipend) is being covered by the Department of Plant and Soil Sciences as part of PI McGrath's startup package. Therefore, requested funds will be used to cover Mr. Bowen's research activities. The total requested budget is provided in Table 1. . In addition to the funds requested from the fellowship program, this research will be supported by funds committed by the University of Kentucky as detailed in Table 2. These matching funds include 10% of PI McGrath's time, 100% of Mr. Bowen's time.

Personnel funds (totaling $171,533) will be used to support salary and fringe for 50% of a Research Scientist 1 (Mr. Gene Hahn) and part-time undergraduate interns (details on personnel costs are provided in Table 3). Mr. Hahn is responsible for designing and executing equipment modification to facilitate project activities. He will also assist Mr. Bowen in all field activities, data collection and management, and laboratory activities. Undergraduate interns will be trained in applied field research and assist in all aspects of the project

Equipment costs are estimated at $15,000 for the entire project period. In the first two years equipment funds will be used to modify the planter and combine so that they can meet project needs. The planter requires the addition of RTK-GPS, two variable rate control modules, and electric pumps allowing precise application of liquid fertilizer. The combine that will be used for this project has seen extensive use and requires general maintenance In addition, it is outfitted with a customized yield monitor that needs to be updated to accept RTK-GPS and log at a higher frequency. We have secured a small utility vehicle (UV, John Deere gator) for free through the Federal Excess Property Program. We will purchase an automated soil probe (e.g. Wintex 1000) with an estimated total cost of $8000 using $4,000 from this project and the balance provided by other funds available to the project PI. The soil sampler will be mounted on the UV to facilitate the extensive sampling required by the project. Additional equipment funds will be used to maintain, repair, and update equipment as necessary and to support a cellular data plan for the RTK-GPS ($300/year).

We are requesting $39,900 to purchase laboratory and field supplies. Supplies will include laboratory costs for routine and more advanced soil analysis, fertilizer, and field sampling materials (flags, probe tips, etc.) and are detailed in Table 3. Travel funds requested total $28,000 and will be used for vehicle rental, flights, hotels, meals, and incidental expenses related to field work and meetings.

Table 1. Total requested projected budget

Item	Year 1	Year 2	Year 3	Year 4	Total
Salary and fringe total	$ 41,232	$ 42,339	$ 43,478	$ 44,484	$ 171,533
Equipment total	$ 10,000	$ 3,000	$ 1,000	$ 1,000	$ 15,000
Supplies total	$ 9,075	$ 11,670	$ 11,175	$ 7,980	$ 39,900
Travel total	$ 4,000	$ 6,000	$ 8,000	$ 10,000	$ 28,000
Publication charges	$ -	$ -	$ -	$ -	$ -
Total Direct Costs	**$ 64,307**	**$ 63,009**	**$ 63,653**	**$ 63,464**	**$ 254,433**
Indirect Costs (10%)	$ 5,431	$ 6,001	$ 6,265	$ 6,246	$ 23,943
Total Requested Funds	**$ 69,738**	**$ 69,010**	**$ 69,919**	**$ 69,710**	**$ 278,377**

Table 2. Matching funds provided by University of Kentucky					
Item	Year 1	Year 2	Year 3	Year 4	Total
Personnel salary					
PI (10% FTE)	$ 11,628	$ 11,977	$ 12,336	$ 12,706	$ 48,647
Graduate student	$ 18,000	$ 18,540	$ 19,096	$ 19,669	$ 75,305
Personnel fringe					
PI (10% FTE)	$ 3,563	$ 3,669	$ 3,780	$ 3,859	$ 14,871
Graduate student	$ 3,793	$ 4,041	$ 4,290	$ 4,541	$ 16,665
Matching Total	$ 36,984	$ 38,227	$ 39,502	$ 40,775	$ 155,488

Table 3. Personnel and supplies budget breakdown.					
Item	Year 1	Year 2	Year 3	Year 4	Total
Personnel salary					
Research Technician (50%)	$ 25,993	$ 26,773	$ 27,576	$ 28,403	$ 108,745
Hourly undergraduate	$ 4,000	$ 4,000	$ 4,000	$ 4,000	$ 16,000
Salary subtotal	**$ 29,993**	**$ 30,773**	**$ 31,576**	**$ 32,403**	**$ 124,745**
Personnel fringe					
Research Technician (50%)	$ 10,885	$ 11,212	$ 11,548	$ 11,727	$ 45,372
Hourly undergraduate	$ 354	$ 354	$ 354	$ 354	$ 1,416
Fringe subtotal	**$ 11,239**	**$ 11,566**	**$ 11,902**	**$ 12,081**	**$ 46,788**
Supplies					
Fertilizer	$ 1,000	$ 1,500	$ 2,000	$ 2,500	$ 7,000
Routine soil analysis	$ 6,300	$ 8,295	$ 7,200	$ 3,405	$ 25,200
Other lab costs	$ 1,575	$ 1,575	$ 1,575	$ 1,575	$ 6,300
Field supplies	$ 200	$ 300	$ 400	$ 500	$ 1,400
Supplies subtotal	**$ 9,075**	**$ 11,670**	**$ 11,175**	**$ 7,980**	**$ 39,900**

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