2019 Pennsylvania Soybean Board Research Project Final Report

Using Precision Agriculture Data to Define and Refine Soil Fertility Management in Soybean Production

Project period: 3/1/19 – 2/28/20

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Project Overview

The overall goal of this project is to develop improved soil fertility management practices for Pennsylvania soybean growers. Our approach is to develop improved methods for zone-based soil sampling within fields and to verify that previously established soil test and tissue test critical levels for phosphorus (P) and potassium (K) are still valid under modern management practices. We are also seeking to determine if sulfur (S) is a limiting factor in soybean yields and whether soil test and tissue test critical levels can be identified to detect sites that will be responsive to S additions.

To develop and test new zone-based soil sampling practices, we are compiling multiple spatial data layers within fields, focusing on yield maps and soil electrical conductivity (EC) maps, to determine how those data layers differentiate zones within a field and how those zones relate to soil fertility levels. To verify soil test critical levels, fertilizer response test plots (20' x 20' plots with added P, K, and S) are embedded throughout two production fields. Soil test and tissue test nutrient levels will be analyzed in relation to yield increases from fertilizer additions to determine critical levels of the nutrients that separate responsive from non-responsive sites. Data collected from this year will be compiled with data collected from a 2018 Pennsylvania Soybean Board project with a similar structure carried out on four fields.

Methods

Prior to the 2019 growing season, two production scale soybean fields were identified to be used as test sites. One field is at the Rock Springs research station and the other field is managed commercially by a farmer collaborator, Ron Connolly. For each field, spatial data layers were compiled as available to determine variability in soil EC and yield maps. At Rock Springs, yield maps and EC maps were both available, whereas at the Connolly farm, only EC maps were available prior to the 2019 soybean crop. All EC soil maps were created using a Veris 3100 sensor cart driven across the fields in 60' wide swaths in March and April 2018. Growmark conducted the EC mapping at the Connolly farm while Helena mapped the Rock Springs field.

Within the Rock Springs field, 18 blocks of fertility response plots were established in locations of the field that strategically spanned variation observed in yield maps and soil EC. At the Connolly farm, 24 blocks of fertility response plots were established strategically spanning variation in soil EC. Each block was composed of four 20' x 20' plots arranged in a 2 x 2 grid. The fertilizer plots were established in June shortly after soybeans germinated and included treatments of (1) P and K added, (2) P and S added, (3) K and S added and (4) P, K and S added.

Just prior to applying the fertilizer treatments, a soil sample was collected from each block (12 cores, 0-6" depth) for a standard soil fertility analysis as well as percent organic matter and soil texture. Soybean trifoliate leaves were sampled at the R1 growth stage in July at both field sites and were analyzed for tissue nutrient concentration. Soybean yields from each fertilizer plots were measured at the end of the growing season, by hand-harvesting 20 linear feet of row and threshing out grain samples with a stationary small plot combine. Yields were used to determine fertilizer responsiveness of each plot and relate fertilizer responsiveness to soil test and tissue test nutrient levels to determine critical levels.

Results

The eighteen fertilizer response blocks at Rock Springs were each soil sampled to 6" depth prior to applying fertilizers. Soil fertility parameters from each block were analyzed to determine clusters of blocks that had similar fertility levels within the cluster and different fertility levels between clusters. We constrained the clustering analysis to determine three clusters because the predominant practice among commercial soil fertility consultants is to use soil EC maps to divide production fields into three zones. We wanted to see if soil EC maps were truly able to distinguish three distinct zones within fields.

Cluster analysis at the Rock Springs site indicated that clusters with differing levels of P, S, magnesium (Mg), pH and exchangeable acidity could be created from the 18 fertilizer response blocks (Table 1). For P, cluster 1 was in the optimum range (30-50 mg/kg P) and clusters 2 and 3 were below optimum. The P2O5 recommendation for each cluster, based on soil test levels and a 50 bu/ac soybean yield would be 40 lbs/ac, 80 lbs/ac, and 60 lbs/ac for clusters 1, 2, and 3, respectively. For S, cluster 1 had greater sulfur (S) than clusters 2 and 3, and all clusters are below the critical soil test level of S that has been provisionally identified through research in corn production (15 mg/kg S). Magnesium, soil pH, and exchangeable acidity were all different between clusters and followed the same patterns, with Mg and soil pH increasing and Exchangeable acidity declining from clusters 1 to 3. Cluster 1 has a below optimal soil pH level and the exchangeable acidity levels recommend that a 1T/ac limestone application be made, whereas clusters 2 and 3 have no need for a lime application. The results of the clustering indicate that cluster 1 should be managed differently that clusters 2 and 3. Cluster 1 should receive a lime application and a lower P2O5 fertilizer rate, while clusters 2 and 3 require no lime applied and higher rates of P2O5 fertilizer.

Table 1. Results of soil fertility clustering for 18 fertilizer response blocks at the Rock Springs site. Means in a column with different letters are significantly different (P<0.05, LSD).

Cluster	P mg/kg	K mg/kg	S mg/kg	Mg mg/kg	pH	Ex. Ac. meq/100g
1	36 a	143	11 a	85 c	6.4 c	2.6 a
2	18 b	168	9 b	154 b	6.7 b	1.6 b
3	24 b	161	9 b	278 a	7.1 a	0 c

Cluster analysis at the Connolly Farm site indicated that clusters with differing levels of P, K, S, magnesium (Mg), pH and exchangeable acidity could be created from the 24 fertilizer response blocks (Table 2). For P, clusters 1 and 2 were in the above optimum range (>50 mg/kg P) while cluster 3 was in the optimum range. The P2O5 recommendations for each cluster, based on soil test levels and a 50 bu/ac soybean yield would be 0 lbs/ac, 0 lbs/ac, and 30 lbs/ac for clusters 1, 2, and 3, respectively. For K, cluster 1 was in the above optimum range (>150 mg/kg K) while clusters 2 and 3 were in the optimum range (100-150 mg/kg K). The K2O recommendations for each cluster, based on soil test levels and a 50 bu/ac soybean yield would be 0 lbs/ac, 30 lbs/ac, and 40 lbs/ac for clusters 1, 2, and 3, respectively. For S, cluster 2 had greater sulfur (S) than clusters 1 and 3, and all clusters were below the critical soil test level of S that has been provisionally identified through research in corn production (15 mg/kg S). Magnesium, soil pH, and exchangeable acidity were different between clusters, with clusters 2 and 3 falling below optimal in Mg (< 60 mg/kg Mg) and cluster 2 falling below optimum in soil pH and with a higher exchangeable acidity. For cluster 2, the exchangeable acidity levels recommend that a 1T/ac limestone application be made, which if a dolomitic limestone were used, would also supply the needed Mg. The results of the clustering indicate that each cluster should be managed uniquely with different P, K, and lime applications.

Table 2. Results of soil fertility clustering for 18 fertilizer response blocks at the Connolly Farm site. Means in a column with different letters are significantly different (P<0.05, LSD).

	P	**K**	**S**	**Mg**		**Ex. Ac.**
Cluster	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**pH**	**meq/100g**
1	56 a	160 a	8.7 b	62 a	6.8 a	1.11 b
2	53 ab	134 ab	11 a	46 b	6.3 b	2.74 a
3	40 b	116 b	8.1 b	52 ab	7.0 a	0.5 b

We used a canonical discriminant analysis to test which type of spatial data, yield maps or soil EC was best at separating the fertilizer response blocks into their respective fertility clusters at each field site. Soil EC was the strongest predictor of the fertility cluster, followed by soybean yield (Figure 1). In Figure 1A, the Rock Springs site, this can be seen where cluster 1 can be separated from clusters 2 and 3 along the X-axis, which corresponds most closely to the EC vector. In the lower panel of Figure 1A, the soil EC values for cluster 1 are in a lower range than those for clusters 2 and 3. For Rock Springs, these results suggest that soil EC maps could discriminate zones of the field with different fertility application requirements, namely a zone for cluster 1 points that should receive a 1T/ac limestone application and a lower P2O5 fertilizer rate. Figure 2 shows how the EC map at this site could be used to identify zones, with soil EC values less than 10.7 dS/m (the yellow, orange, and red pixels) corresponding to cluster 1 fertility levels and the remainder of the field corresponding to clusters 2 and 3 fertility levels.

The discriminant analysis at the Connolly Farm field was less distinct in it's ability to differentiate fertility clusters based on soil EC. There was greater overlap in the ranges of EC that occurred across the three fertility clusters. However, on average, fertility cluster 3 had a greater soil EC level than clusters 1 and 2, which corresponded with lower soil test levels and greater fertilizer recommendations for the nutrients

P and K. At the Connolly farm site, the soil EC map would not have been able to distinguish cluster 2 points, which required a lime application, from clusters 1 and 3, which did not require a lime application.

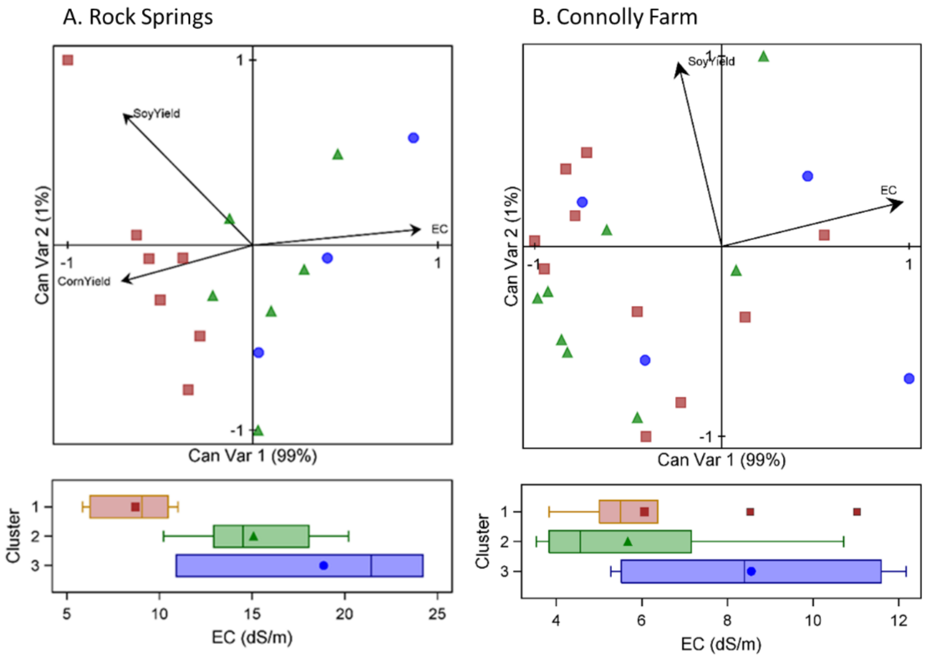

Figure 1. A canonical discriminant analysis for the fertilizer response plots in the Rock Springs field (panel A) and the Connolly Farm field (panel B). Each fertility response plot is indicated by a point, which is color coded according to the fertility cluster it was assigned to based on soil test data (Tables 1 and 2). The arrows (vectors) indicate how strongly the variables soil electrical conductivity (EC), soybean yield, and corn yield correspond to the axes which differentiate the clusters. In the lower pane of each panel, the distribution of soil EC in each cluster is visualized with a box and whiskers plot.

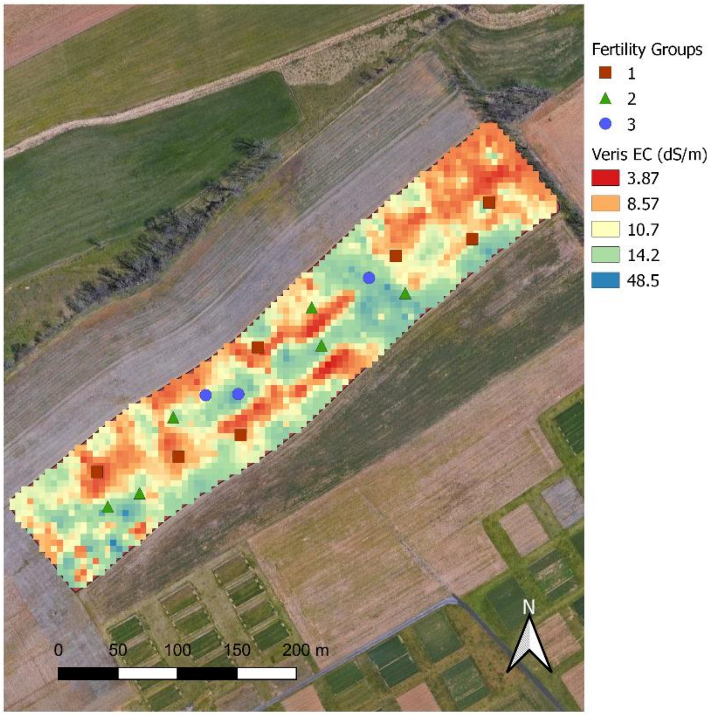

Figure 2. At the Rock Spring site, the soil EC map could be used to identify zones of the field that correspond with fertility cluster 1, which requires a 1T/ac limestone application and a lower P2O5 fertilizer recommendation. These zones would have a soil EC value less than 10.7 dS/m, and are indicated by pixels that are yellow, orange, or red.

The responsiveness of soybean yields to applied P, K, and S fertilizers in each fertilizer response block were used to determine critical soil test levels using a Cate-Nelson analysis. The Cate-Nelson analysis identifies a soil test level below which crop yields decline when the nutrient of interest is NOT applied as a fertilizer. Because of differences in yield potential at each site, the relative yield is used as a metric of fertilizer responsiveness, calculated as yield of the unfertilized plot divided by yield of the fertilized plot. Relative yield values significantly less than 1.0 indicate that yield was lost when fertilizer was not applied, presumably because of a nutrient deficiency. Because of random variation in yields that occurs during sampling plots, a relative yield value somewhat lower than 1.0 is often used as the cutoff to determine a yield reduction due to nutrient deficiency. In our analysis, because areas of plots harvested by hand were relatively small, which generates a greater level of variability in the data, we used a relative yield threshold of 0.9 to identify plots that lost yield due to a nutrient deficiency. To increase the robustness of the analysis and conclusions here, we have include fertilizer responsiveness data from the sites in both the 2018 and 2019 years of the projects funded by the Pennsylvania Soybean Board.

The Cate-Nelson analysis for soil test P indicated a critical level at 37 mg/kg Mehlich 3 P (Figure 3). Below this soil test level, soybean yields declined when P fertilizer was withheld. The current fertilizer recommendation system used at Penn State has a soil test critical level of 30 mg/kg, and fertilizers are recommended to be applied at maintenance levels when soil test P levels are between 30 and 50 mg/kg. These results suggest that the current fertilizer recommendations for P used by Penn State, if followed, would be sufficient to promote maximum crop yields at a site.

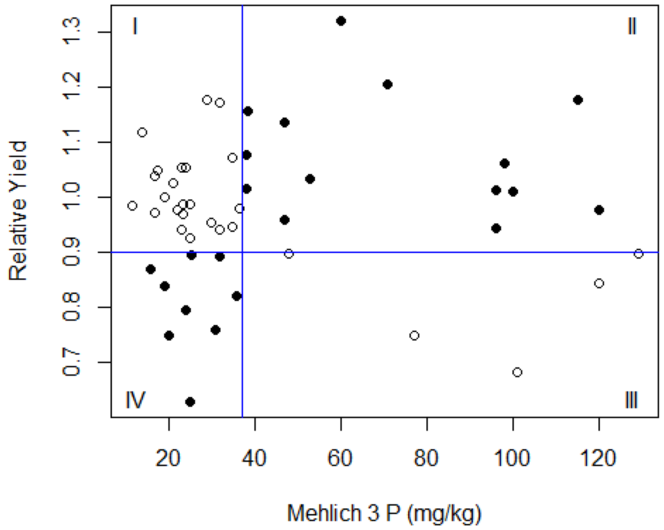

Figure 3. A Cate-Nelson analysis of the critical soil test P level below which soybean yields decline when fertilizer is withheld. The vertical blue line indicates the critical soil test level and the horizontal blue line is fixed at a relative yield level of 0.90.

The Cate-Nelson analysis for soil test K indicated a critical level at 125 mg/kg Mehlich 3 K (Figure 4). Below this soil test level, soybean yields declined when K fertilizer was withheld. The current fertilizer recommendation system used at Penn State has a soil test critical level of 100 mg/kg, and fertilizers are recommended to be applied at maintenance levels when soil test K levels are between 100 and 150 mg/kg. These results suggest that the current fertilizer recommendations for K used by Penn State, if followed, would be sufficient to promote maximum crop yields at a site.

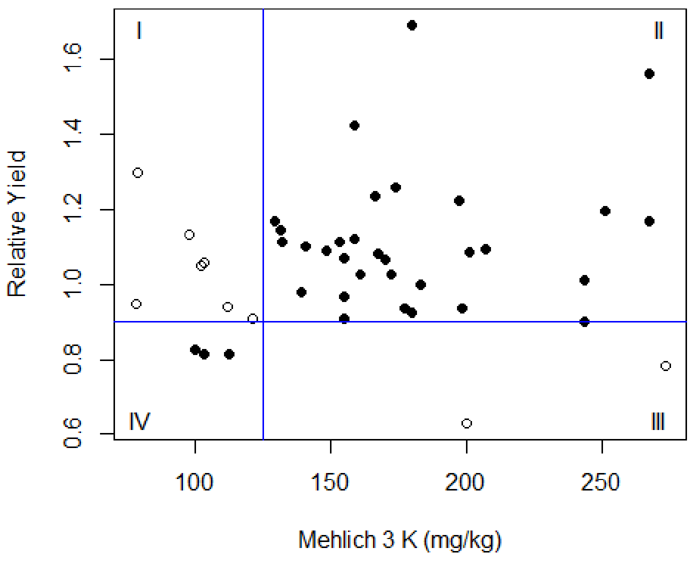

Figure 4. A Cate-Nelson analysis of the critical soil test K level below which soybean yields decline when fertilizer is withheld. The vertical blue line indicates the critical soil test level and the horizontal blue line is fixed at a relative yield level of 0.90.

The Cate-Nelson analysis for soil test S indicated a critical level at 13.5 mg/kg Mehlich 3 S (Figure 5). Below this soil test level, soybean yields declined when S fertilizer was withheld. The current fertilizer recommendation system used at Penn State has a provisional soil test critical level of 15 mg/kg, which was determined from experiments in corn production. Our provisional interpretation of the soil test S level in corn is that below 15 mg/kg, the likelihood of a yield response to applied S fertilizer increases, but is not guaranteed. The data here suggest that using a critical soil test S of 15 mg/kg in soybean production would also protect against yield losses by recommending that S be applied when soil test levels are below that.

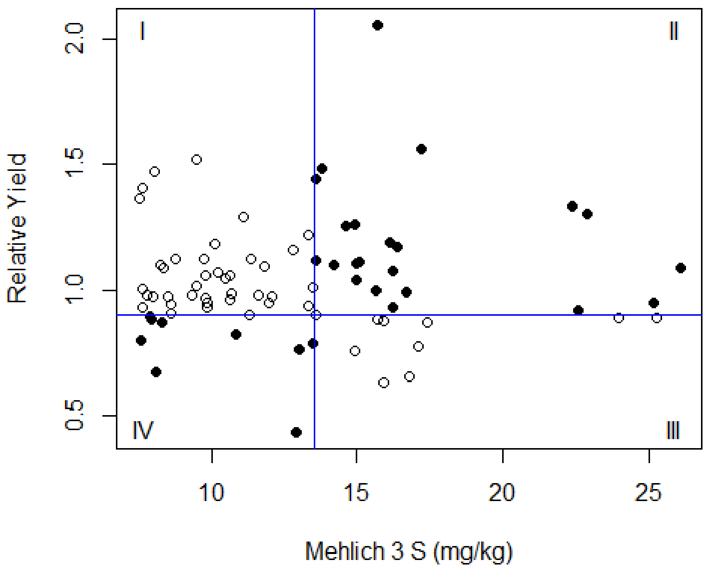

Figure 5. A Cate-Nelson analysis of the critical soil test S level below which soybean yields decline when fertilizer is withheld. The vertical blue line indicates the critical soil test level and the horizontal blue line is fixed at a relative yield level of 0.90.

Conclusions

The results of both 2018 and 2019 Pennsylvania Soybean Board projects on "*Using Precision Agriculture Data to Define and Refine Soil Fertility Management in Soybean Production*" were consistent in their findings. Soil EC maps created by Veris sensors or other technologies that measure apparent soil electrical conductivity can be used successfully to divide fields into zones that have different soil fertility requirements. We observed that EC maps at different sites could differentiate between zones of fields with different lime, P, and K fertilizer requirements. However, there were sometimes differences in fertilizer recommendations within soil EC zones that could not be differentiated by the soil EC maps. Therefore, EC maps improved the spatial resolution at which fertilizer and lime applications can be made within a field, but may not capture every level of variability that exists within a field. Nonetheless, our study suggests that soil EC mapping is a useful tool that farmers should consider for developing soil sampling and fertilizer recommendations on a zone by zone basis.

The results of our fertilizer response plots, which harnessed natural variations in soil test levels between and within fields, generally confirmed that existing soil test critical levels for P, K, and S used by Penn State and the fertilizer recommendations to maintain soil test levels in the optimum range made by Penn State are sufficient to support modern soybean genetics and production practices. This is the first study to evaluate soil test S critical levels in soybean production in Pennsylvania, and it is noteworthy that the critical S level determined in previous research for corn production is similar to that determined here for soybean production. A consistent critical S level for corn and soybean production will help farmers and agronomists gain confidence in making S recommendations for their cropping systems as atmospheric S depositions decline.

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