2018 Pennsylvania Soybean Board Research Project Final Report

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

Project period: 3/1/18 – 2/28/19

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Project Overview

The overall goal of this project was to develop improved soil fertility management practices for Pennsylvania soybean growers. We aimed to develop improved methods for zone-based soil sampling within fields and to verify whether previously established soil test and tissue test critical levels for phosphorus (P) and potassium (K) are still valid under modern management practices. We also investigated whether 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.

Project Methodology

This project piloted a method to identify appropriate soil fertility management zones using data from maps generated from historical yield, electrical conductivity, and planter downforce pressure (see Figure 1 below). These maps served as “layers” in a statistical analysis that resulted in soil fertility management zones each with unique historical yields, EC, and planter downforce pressure characteristics.

Yield Map

VerisEC Map

Planter Down Force Pressure Map

Management Zones

Figure 1:GIS Workflow for creating management zones for the four experimental soybean fields in 2018.

These management zone maps were created for four production-scale soybean fields at the following locations:

1) Daren Brubaker, Williamsburg, PA
2) PSU Farm Operations 37A Field, Bellefonte PA
3) PSU Farm Operations 44H Field, Bellefonte PA
4) PSU Precision Farm, State College, PA

Not surprisingly, each of these fields had a unique array of management zones. These management zones can be seen in Figure 2. At FarmOps 44H extra PKS fertilizer was put out by the farm operations team on 2/3rds of the field. Our experimental protocol and analysis accounted for this difference.

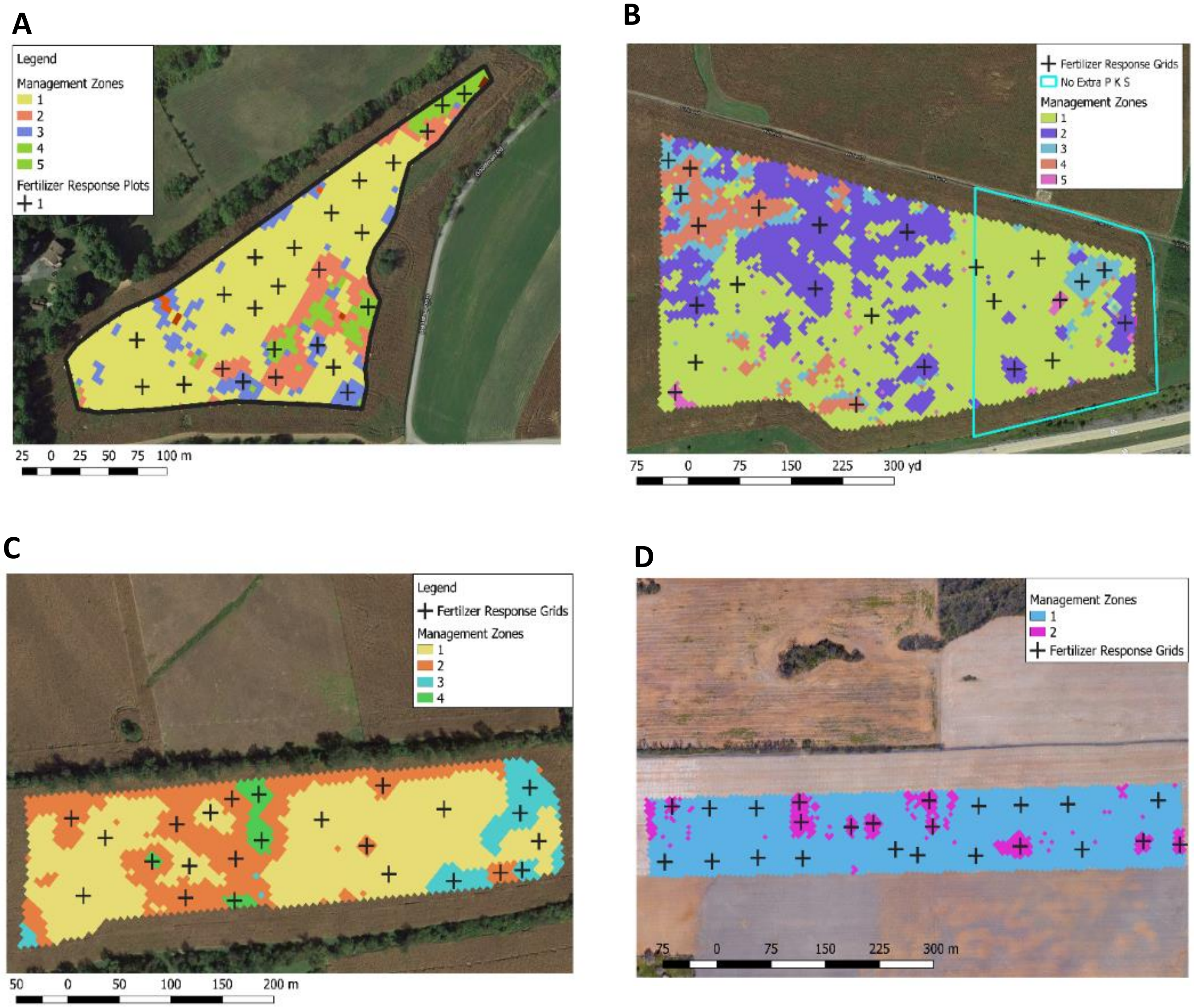


Figure 2: Management zones and fertilizer response plots for 2018 experiments. A) Daren Brubaker, B) FarmOps 44H, C) FarmOps 37A, D) PSU Precision Farm. At FarmOps 44H extra PKS fertilizer was put out by the farm operations team. The zone that received no extra fertilizer is in turquoise.

Soybeans were planted at Daren Brubaker's farm in mid-May while the remaining fields were planted at the end of May or early June. Soon after planting, basic soil fertility tests were conducted on 24 locations throughout the field. These locations were strategically chosen so that each management zone would be well represented through multiple soil cores. After soil sampling, a 2x2 grid was created at the soil sampling site (See Figures 3-4 below). As Figure 4 illustrates, each 2x2 response grid consisted of four randomly chosen soybean treatments designed to provide non-limiting levels of P, K, or S. In three of the fields, the grids were arranged with the soybean planter rows, so that each individual plot within the grid would have eight rows. At the FO37A location, soybeans were planted with a drill, which resulted in more soybean rows within each plot than at the other locations.

Figure 3: Example layout of how fertilizer response plots were arranged within a soybean field. For each field, 24 2x2 grids were strategically placed based to adequately represent differing management zones. Further information about the individual response grids are below in Figure 3.

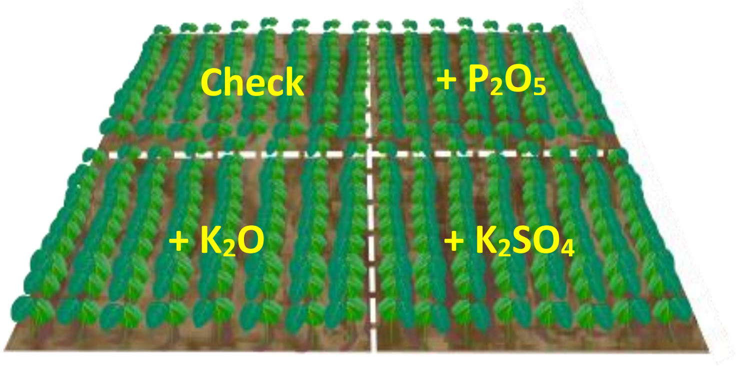


Figure 4: 2x2 fertilizer response grid. Each grid contained four randomized treatments of fertilizer designed to supply a non-limiting amount of P, K, or S.

In mid-July 25 trifoliate leaf samples were taken from the "Check" plot for each response grid at each field. These samples were dried, ground and then sampled for percentage P, K, and S using a CHNS elemental analyzer, which works by incinerating a tiny sample and measuring the element content.

At the end of October, for each location two 5' rows were hand-harvested in each plot of each response grid. These samples were then fed through a stationary combine, which recorded grain weight.

After harvest we used the same statistical analysis that we used to create the management zones to create unique zones based solely on the early season soil samples. We then took soil samples from six locations within each field to gauge the post-harvest soil fertility.

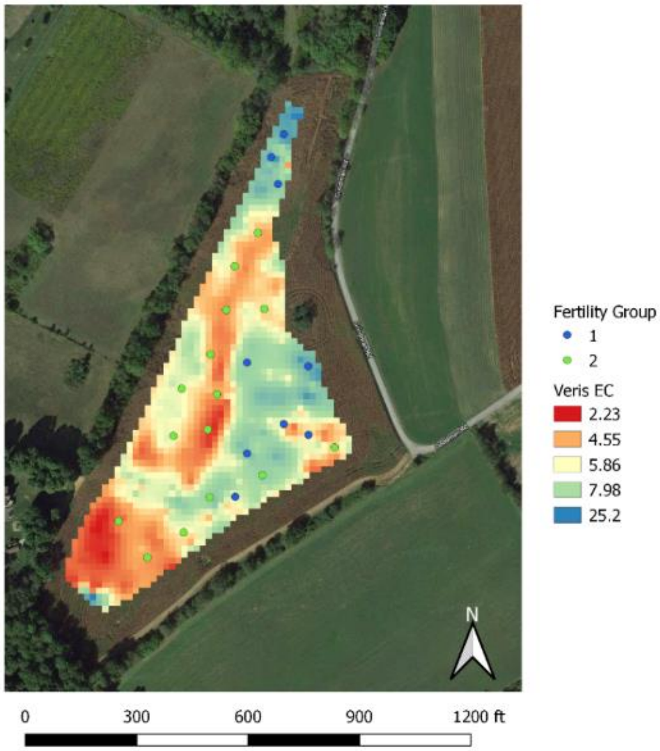
Results

Our presentation of results will focus on our key questions behind the research:

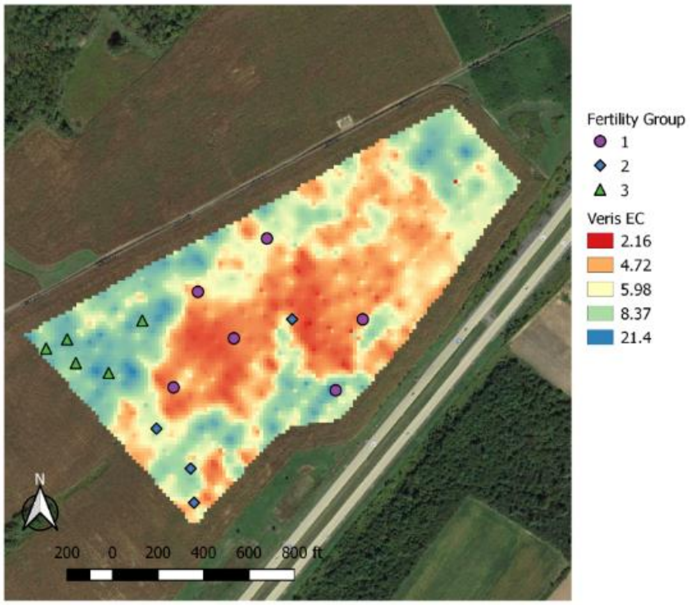
Question 1: Can we find significantly different soil fertility zones within a field?

To answer this question we performed an Analysis of Variance (ANOVA) statistical method on the basic soil test results that were collected in each location at the beginning of the growing season. Using these soil test data we determined whether factors that impact soil fertility – P, K, S, CEC, soil texture, pH – were significantly different in areas of the field where a clear difference in the VerisEC was apparent. Figure 5 below shows the results of these analyses for each field overlaid on interpolated VerisEC maps. In each of these locations we found that there were significant differences in areas where a clear difference in the EC was also manifest.

This is important because a farmer, consultant, or agronomist could delineate zones based on verisEC data and be confident that they represented unique areas of the field to soil test. Soil testing would then be more likely to reveal areas that may benefit from an increased, or even reduced, amount of P, K, and/or S fertilizer application.

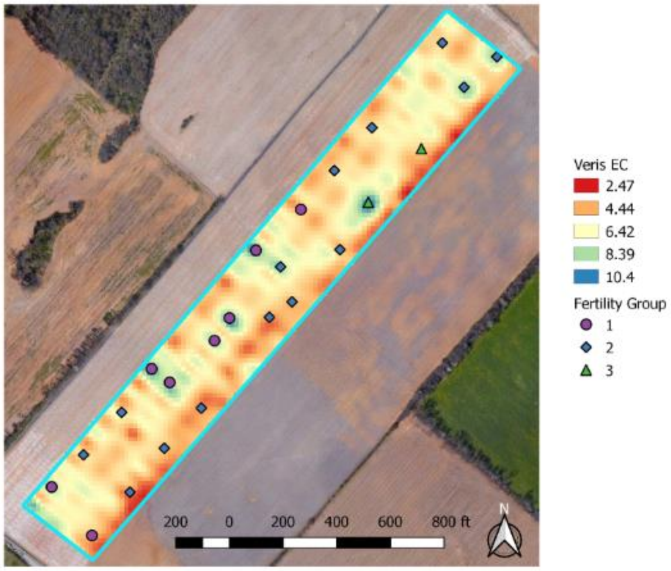


	CEC	K ppm	P ppm	S ppm	pH	Clay
Sig. Dif.	*		*	*	*	*
● 1	15	168	15	15	7.0	42
● 2	11	142	29	23	5.7	28



	CEC	K ppm	P ppm	S ppm	pH	Clay
Sig. Dif.	*	*		*	*	*
● 1	9	70	60	13	6.6	30
◆ 2	11	86	70	10	7.1	36
▲ 3	17	150	108	11	7.5	45

	CEC	K ppm	P ppm	S ppm	pH	Clay
Sig. Dif.	*	*	*		*	*
● 1	10	194	87	15	6.6	28
◆ 2	15	252	98	16	6.9	34
▲ 3	18	262	50	15	7.5	43



	CEC	K ppm	P ppm	S ppm	pH	Clay
Sig. Dif.	*	*	*			*
● 1	10	84	30	15	6.5	37
◆ 2	10	106	51	14	6.4	30
▲ 3	13	167	67	13	6.7	35

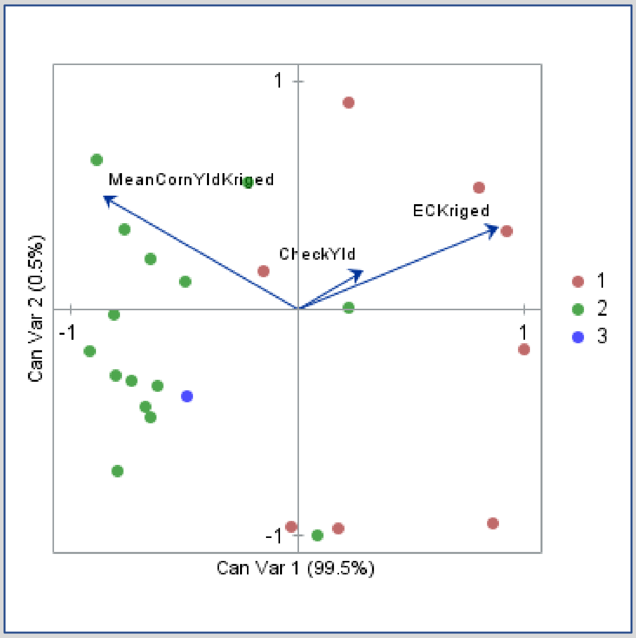
Figure 5: VerisEC maps with significantly different soil test data for the four experimental sites. Clockwise from the upper left, Daren Brubaker's farm, FarmOps 44H, Farmops 37A, PSU precision farm

Question 2: Which proximally sensed data (VersEC, past yield maps, downforce pressure maps) are most valuable to determining management zones?

We have found and shown that VerisEC data are able to delineate management zones that can often accurately represent different soil fertility characteristics within a field. However, what about using past yield or planter downforce pressure data to visually determine different management zones? Or, is VerisEC the best method for coming up with fertility management zones.

To answer this we used a statistical technique called canonical discriminant analysis. This analysis allowed us to do two things: 1) verify that zones based on soil test data were indeed unique and, 2) most importantly, determine which input variables are most valuable to determining these zones. This analysis culminates in a graph with two “canonical axes”. An explanation of this procedure can be found in Box 6. Canonical graphs for each location are in Figure 5 on the following page.

Box 6. Canonical Discriminant Analysis Procedure



The experiment at Daren BrubaKer’s farm will be used as an example to briefly explain the interpretation behind canonical discriminant analysis. To explain this, we’ll look at Axis 1 (Can Var 1) first. Think of Axis 1 as a plane, and then look at the arrows. Those arrows correspond the variables in question, Corn yield, EC, etc. The further out from Axis 1 that the arrow reaches (ignore the angle), the stronger the variable’s correlation with the canonical axis, and thus the stronger that variable is at predicting the management zones. At Daren’s trial both the previous yield map (Mean Corn Yield Kriged) and VerisEC were roughly equally as strong at predicting these management zones. However, in the rest of the locations VerisEC was superior to yield maps. So, if you were to leave the VerisEC out, past yield data would likely not be as effective at delineating management zones, and would likely result in more errors.

The colored dots represent zones created from soil test data. These soil test data zones were created with the same statistical procedure as the management zones created with the proximal sensing data (EC + yield maps + planter downforce. If we continue to look at Axis 1, take a paper or your hand and place it over the entire graph. Then slide it to the right, you’ll see the green dots from Soil Zone 2 appear. More and more green dots will appear as you slide your hand right until you get to a blue dot, Zone 3. Then as you keep going right you get to the red dots, Zone 1. However, after you pass the first couple of red dots there are still some stragglers from Zone 2 in the Zone 1 region. These are considered errors – the model classified the green Zone 2 points as Zone 1.

We’ve been focusing on Axis 1 so much because it explains 99.5% of the variability. Axis 2 thus isn’t that important, but to interpret it you could tilt your head sideways and imagine the same procedure that we went through with Axis 1 and apply it to Axis 2.

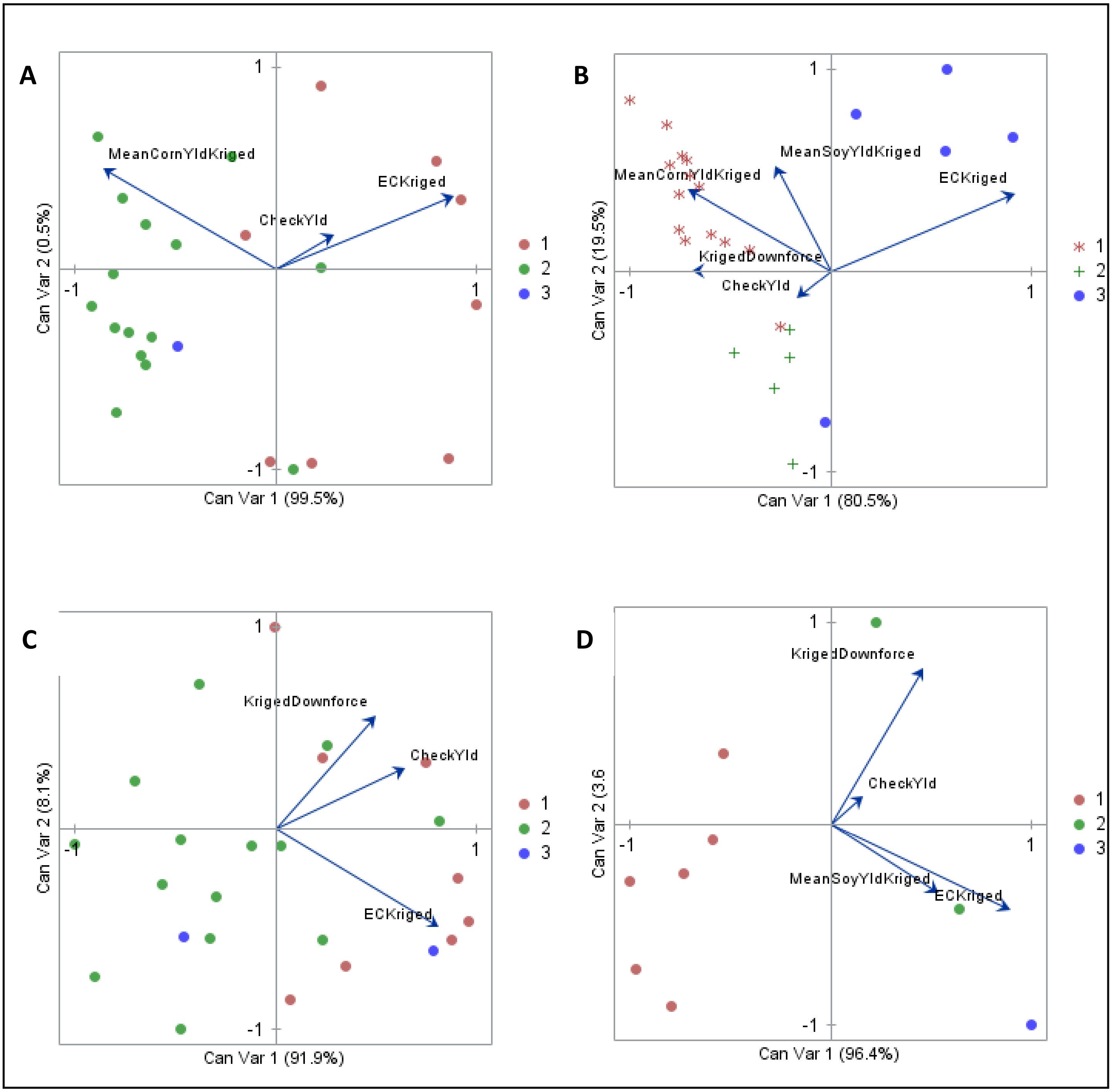


Figure 6: Canonical Discriminant Analysis Plots for 2018 soybean experimental plots: A) Daren Brubaker, B) FarmOps37A, C) PSU Precision Farm, D) FarmOps44H where no extra PKS were added.

In each of these locations the datapoints representing management zones created from the early season soil testing roughly cluster together in individual groups. This further suggests that these locations have soil fertility management zones that can be represented by this type of analysis. This is important, because it provides a background for the second purpose of this analysis – determining which data layers are most useful for soil fertility zones in the field. The results of this second point differed somewhat between fields but some there were some consistent trends across all fields. First, in each location, Veris EC was the strongest determining factor of soil fertility zones. The second most important predictor was past yield maps. Planter downforce pressure data was the least useful at determining soil fertility management zones.

These results suggest that VerisEC with yield maps (if available) are likely enough to determine soil fertility management zones. This is encouraging because it suggests that precision tools such as downforce pressure sensors will likely not be a necessary expense for producers wishing to adopt a zonal soil sampling method.

Question 3: Do the current soil test critical level recommendations for P and K need to be updated? In addition, what the soil test critical levels for S?

This was a major question of ours and the principal question behind the 2x2 response grids in each field. A key strategy of efficient soil fertility management is to build soil test nutrient concentrations to a 'critical level'. Soils with nutrient levels below the critical level do not have the capacity to supply sufficient nutrients to the crop. Without a fertilizer addition to supply the needed nutrients, soybean yields would decline. When soil test nutrient levels are above the critical level, a fertilizer addition is not likely to increase the crop yield because the soil contains sufficient nutrients already.

The current soil fertility critical levels for P and K in Pennsylvania soybean production are nearly 30 years old (Beegle and Oravec, 1990). In these last three decades soybean management has changed thanks to improved genetics and agronomic practices. We hypothesized that with these changes the current soil test fertility levels would likely need to be updated.

As we mentioned previously in our experimental procedure, we collected yield for each plot within the 2x2 fertilizer response grid. We then divided the yield from the check plot by the yield in the plot with the P, K, or S treatment (see Box 7) (the relative yield for S was calculated a little differently). Data for all sites were combined, save for the FO37A location which was left out due to yield irregularities. The relative yield values for each of these macronutrients were then plotted against the trifoliate level and the early-season soil test level of the same macronutrient in question. The soil test critical level for that macronutrient was then determined through a Cate-Nelson analysis (see Box 8 for a detailed description).

Box 7. Relative Yield Calculation

$$Relative\ Yield_P = \frac{Yield_{Check}}{Yield_{P_2O_5}} \qquad Eq.1$$

$$Relative\ Yield_K = \frac{Yield_{Check}}{Yield_{P_2O_5}} \qquad Eq.2$$

$$Relative\ Yield_S = \frac{Yield_{K_2O}}{Yield_{K_2SO_4}} \qquad Eq.3$$

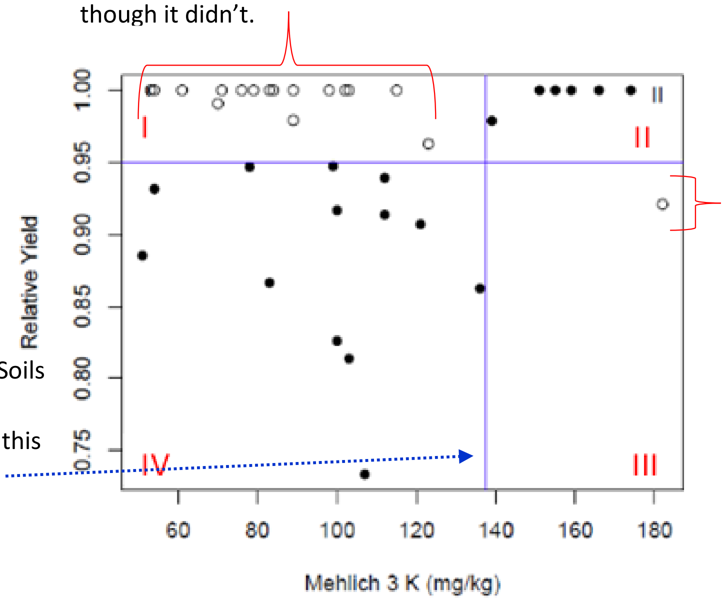
Figure 6 presents the Cate-Nelson plots for P, K, and S. Based on these analyses we found that the critical soil test levels of P and K may need to be increased from their current recommended levels. For example, we found that the recommended critical soil test level for P may need to be increased from 30 ppm to 49 ppm (See Table 1 below:

Table 1: Currently recommended Pennsylvania critical levels for soil test and plant tissue K, P, and S as compared to those identified by analysis of the 2018 soybean fertility trials.

Nutrient	Current Critical Level	Preliminary Recommendation based on 2018 data	Change from current to preliminary recommendation
Mehlich-3 P	30 ppm	49 ppm	+ 19 ppm
Mehlich-3 K	100 ppm	138 ppm	+ 38 ppm
Mehlich 3 S	15 ppm	No recommendation	No change
R1 Trifoliate K	1.71	2.6	+ 0.89%
R1 Trifoliate P	0.26	0.48	+ 0.22%
R1 Trifoliate S	0.21	0.30	+ .09%

Box 8. Cate-Nelson Analysis

Observations in quadrant I are errors because the prediction is that applying fertilizer would increase the yield, even though it didn't.



Critical soil test level: Soils with nutrient concentrations below this level cannot supply sufficient nutrients to meet the needs of the crop and a fertilizer application is required or yields will decline.

Observations in quadrant III are errors because the prediction is that existing soil nutrient levels are sufficient to achieve the maximum yield, yet these observations exhibited a yield increase with fertilizer additions.

Example Cate-Nelson analysis for relative soybean yield by Mehlich 3 K soil test. For this analysis we tallied the yield for each fertilizer treatment and calculated a relative yield based on a check treatment where no fertilizer was applied. Each experimental plot was then plotted on a graph comparing relative soybean yield versus soil or plant tissue nutrient levels. With the Cate-Nelson approach a horizontal and vertical line are then drawn, splitting the datapoints into four quadrants. The horizontal line is manually set at a relative yield of 0.95 and statistical analysis determines the best placement of the vertical line to maximize the number of points predicted by the model (black dots) and minimize errors (hollow dots). It is this vertical line that then serves as the final critical value. For this analysis plots with a relative yield above 1.0 were set to 1.0 in concordance with previous soil fertility practice (Dyson and Conyers, 2013).

Given this significant increase in the recommended fertility levels of P and K it is possible that soybean farmers could be missing out on increased yields. If our data from 2018 is correct, then farmers who do not apply fertilizer because soil test levels are at the currently defined critical level could be missing out on yield increases as high as 20%. Even with the increased cost of fertilizer, attaining higher yields of just 2 bushels would warrant the increased cost. Due to slowly decreasing ambient S levels these recommendations could provide a basis for setting a soil test critical level for S in Pennsylvania.

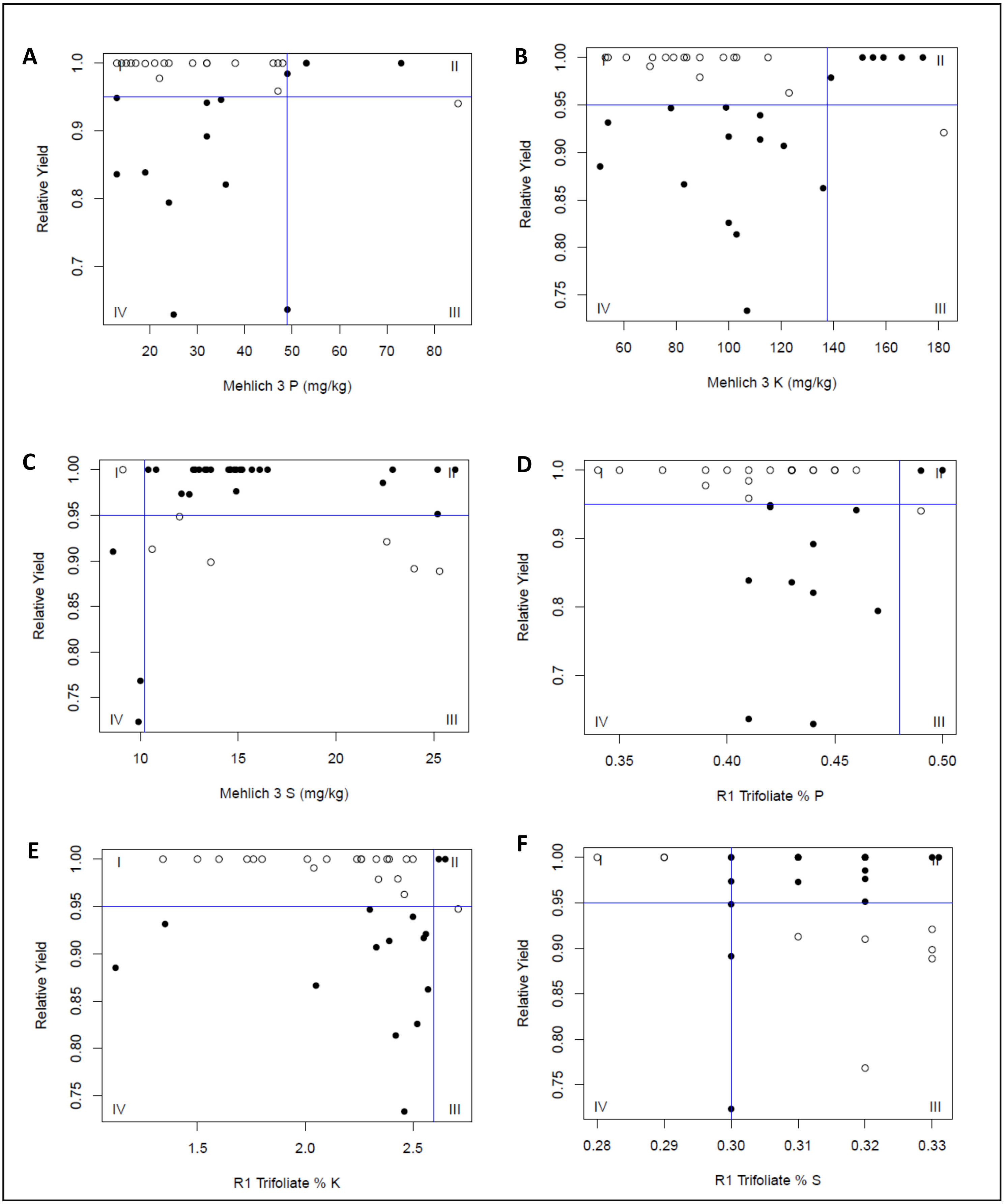


Figure 7: Cate-Nelson Analyses for three of the four locations (FarmOps37A site was left out due to concerns about the accuracy of the yield estimation because of a smaller harvested area). A,B, and C show relative yield and respective Mehlich 3 soil test results. D,E, and F show relative yield and respective in-season nutrient testing results.

Question 4: What is the buffering capacity of the soil in individual soil fertility management zones.

We are still analyzing data for this research question

Conclusion:

The funding from the Pennsylvania Soybean Board allowed us to pilot a method for soil sampling that accounts for inherent soil differences within the field that affect soil fertility. The most useful data for this method were 1) VerisEC data and 2) past yield maps. Perhaps most importantly, this research suggests that soil test critical levels for P and K may need to be updated to provide farmers with the best chance to reach an economic optimum yield.