Development and Test of Potassium Management Algorithms for Corn

Ron Potok (Solum), Kyle Freeman (Mosaic), and Scott Murrell (IPNI)

Project Summary:

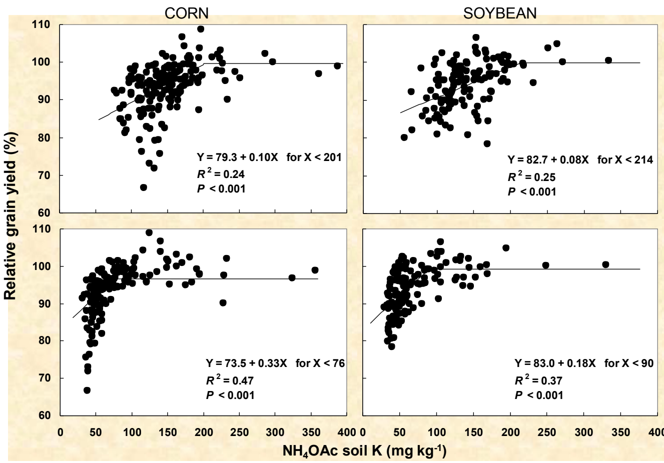
In our 1 year project spanning April 2013 – Feb 2014, we began exploring algorithms for potassium management for corn using a variety measurement-based parameters. Since potassium availability and transport to the plant is impacted by many variables, including both intrinsic soil properties and environmental factors, we focused on measuring as many of these known factors as possible. Our team, consisting of Ron Potok (Solum), Scott Murrell (IPNI), and Kyle Freeman (Mosaic) immediately partnered with Winfield solutions for professionally run, ground ready research rate-trial studies in 2013. Using four Winfield Solutions sites with replicated trials, we present a variety of soil measurements and yield analysis. While we make no conclusions on one year of data, our results did show one site with potential potassium response, and we detail the characteristics of that site. In addition, in 2013 we sampled 7 farmer fields and identified candidates for K response for strip trials in 2014. Unfortunately, with our 2014 work discontinued due to AFREC budget constraints, we did start farmer-field trials. In this report, we deliver measured of soil parameters, crop response, and analysis for potassium management for corn.

Introduction

Current potassium (K) management practices suffer from many limitations due to the large variability in plant available potassium within the growing season, within the farmer field, and growing season to season. The Potassium cycle has many familiar components – nutrient addition through application or organic decomposition, and removal through plant uptake or leaching. Compared with other nutrients, however, plant-available potassium is particularly variable due to exchangeable and non-exchangeable K available in the soil due to intrinsic soil properties. Both clay component and clay mineralogy have been found to be important factors determining to what extent the clay is source and sink for exchangeable K. Some environmental factors for determining exchangeable K include the soil temperature and freeze/thaw processes. To make matters more complicated, K is transported to roots through diffusion, which depends heavily on soil moisture, compaction, and K concentration.

In this report, we show laboratory measurements for the 2013 growing season, which include nutrient availability and soil characteristics. We then look at the four Winfield trial plots yield in depth. We sampled all fields between one and three times during the season, so also show some results on how nutrient availability changes during the season.

For laboratory nutrient analysis, Solum's Field Moist process was developed as an alternative to the standard laboratory dried ground process. It is well known that drying and grinding soil samples changes the exchangeable K, particularly in soils with a significant clay component. In fact, laboratory (artificially) applied heat during the drying process can either increase or decrease exchangeable K in a soil sample, according to the particular clay fixation / release balance. Solum's Field Moist process removes the unintended conversion between exchangeable and non-exchangeable K by processing the soil in its native field-moist state. Decades of research in Iowa have shown significantly better correlation between yield and field moist K measurements than the standard lab dried ground process, shown below.



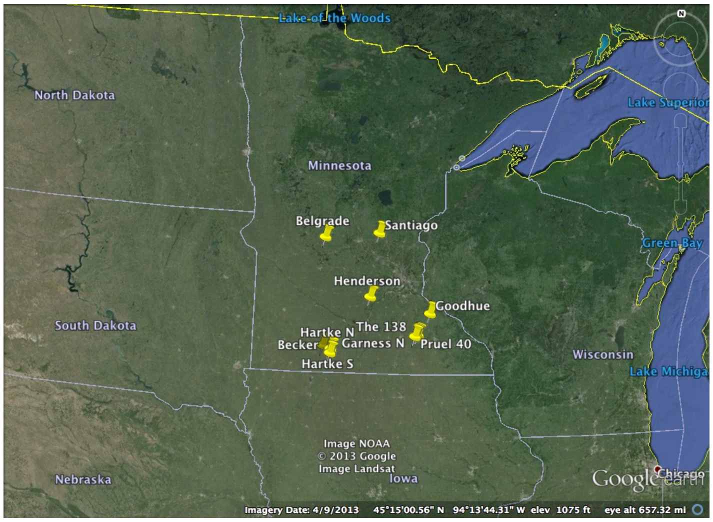
Mallarino, et al, 2002.

The goal of this research was to improve upon these correlation-calibration plots on farms in Minnesota by including many variables, including intrinsic soil properties. In order to characterize the intrinsic soil properties that drive the fixation / release process, we measured soil texture and attempted to measure mineralogy properties. Soil texture will be determined by Solum's high throughput texture tool, where clay content will be determined. Since clay mineralogy also determines the diffusion rate through and fixation/release balance of the clay particles, we will also have some samples mineralogy characterized. Both of these physical properties of the soil will complement the K measurement for prediction of K availability throughout the season.

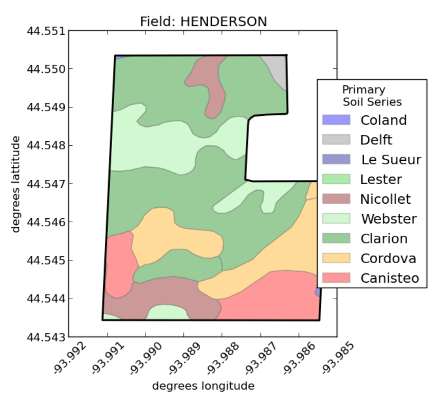
Our project consisted of 2 types of trials: farmer field and Winfield Answer Plot research plot trials. Because K application for 2013 has likely already occurred, in 2013 we characterized and select farmer fields for K trials in 2014. There were no Farmer-Field fertilizer trials in 2013, consistent with our proposal. However Winfield Solutions was ready to perform fertilizer trials in 2013. The 2013 Winfield Answer Plots consisted of a 3 applications of K, including a zero (base), on small test plots.

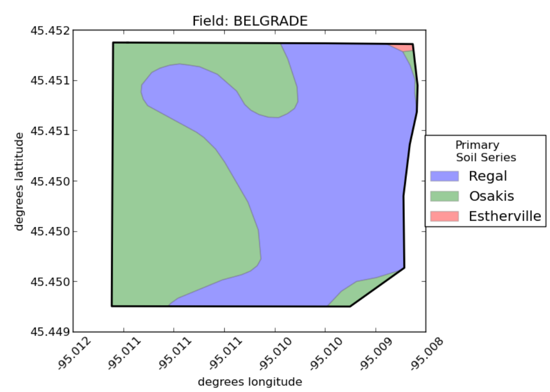
I. Field Experiment Design Details

We had two different field protocols for our experiments. In the first, we used Winfield research plots to conduct K rate studies. Winfield research plots are small plot



research design, with randomized replicated studies. We used 3 treatments – base (0lbs), treatment rate 1 (100lbs of KCl), and treatment rate 2 (150 lbs of KCl). Each plot was replicated 2-3 times. All plots used the same hybrid, a 96-day RM CropPlan Genetics corn and received fertilizer and insecticide. There were 4 Winfield sites with





the replicated trial plots: Belgrade (West-Central MN), Goodhue (SE MN), Henderson (West-Central MN), and Santiago (N MN). Both Santiago and Belgrade have coarse soil, and are irrigated. Goodhue and Henderson are dryland plots. All plots contain a variety of common soils, a few examples shown here for Henderson and Belgrade (above).

We also sampled a number of farmer fields which growers thought may show a response to potassium. Our goal with these fields was to sample at least 6 fields twice during the season and measure. Using intuition developed from the Winfield rate trial plots in 2013, we would then select the farmer fields for strip trials in 2014. Our research protocol for grower fields in 2013 is included below.

We had 7 fields participate in the farmer-field trials in 2013, above our target of 6 fields. Four fields were near Central Valley Cooperative in Owatonna, MN, and three were near NuWay Coop in SW Minnesota.

Solum Field Moist Potassium Management for Corn Production

Objective:

The objective of the proposed 2-year trial is to 1) In year 1 determine fields that should respond to Potassium and 2) in year 2 determine crop response to Potassium added based on Solum Field Moist K measurement. This year (2013) we will answering the questions: Do fields with 'optimal' dried-ground Potassium measurements have 'below optimal' field moist K?, Does 'build and maintain' practice for K correlate with the soil Field-Moist K measurement, and How does field-moist potassium change within the season? Specifically, in 2013 we will find fields that should respond to Potassium application for Field-Moist K but would not respond according to the standard dried ground measurement. In Fall 2013, we will apply potassium in strip trials and measure yield response in the 2014 growing season.

Brief Summary:

Since Potassium has already been applied for the 2013 growing season, we will be conducting a survey of fields to identify candidates for yield response in 2014. Growers will identify fields which are 2-3 years away from soil sampling, but were sampled 1-2 years ago and the grower has the soil nutrient data from that sampling event. The initial field criteria are that the fields contain representative soil series for the region and that the fields do not contain obvious yield-limiting factors such as compaction, poor drainage, or weed infestations. A field with straight rows with varying soil type (but includes clay) and topography is preferred. Fields with a history of manure applications, i.e. applications within the past 3 years, should not be selected this year.

Protocol Guidelines:

Select a field which has not been sampled recently, but may be a candidate for K limiting the crop yield. All management practices in the field should be the same (same variety or hybrid, seed treatment, planting date). Solum will sample the soil at a 2.5 acre grid three (3) times during the season – preplant, near V4 and post-harvest. After harvest and post-harvest sampling in 2013, Solum will select fields for K response and setup strip trials for the 2014 growing season.

Grower requirements:

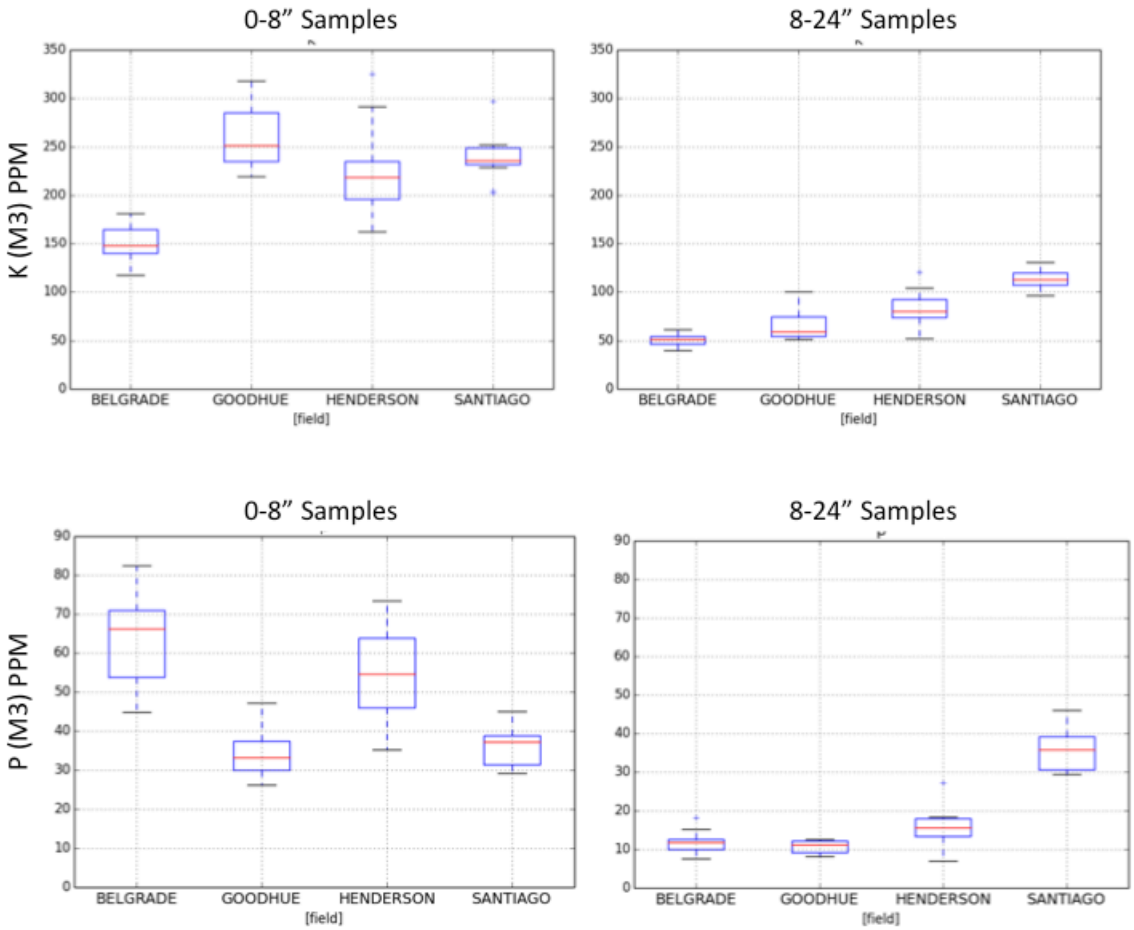
1. Yield monitor is properly calibrated, only one combine is used to harvest the field, the field is harvested all in the same day and harvested with the rows and not at an angle.
2. All factors in the field must be the same (planting date, hybrid, etc)
3. Provide management information relevant for this trial.
4. Trial must be harvested using a calibrated yield monitor with GPS.

Solum will provide:

1. Soil sampling and measurement at a 2.5 acre grid preplant, near V4, and post-harvest.
2. Analysis of the results after harvest to see if there is a yield response expected by Solum's Field Moist K measurement.
3. A strip trial K application plan for Fall 2013 for fields expected to show a crop response to application of K.

II. Soil fertility measurements

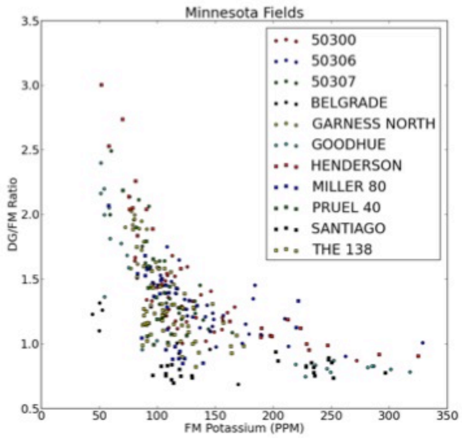
We present soil fertility measurements sampled several times during the year. For the Winfield plots, we tested K preseason (pre-plant and pre-application) at two depths (0-8" and 8-24"). The soil values for the various plots are show below. Only field moist values are shown here. We also show P for comparison. All fields are in the sufficient range for P (and all other nutrients, data not shown).

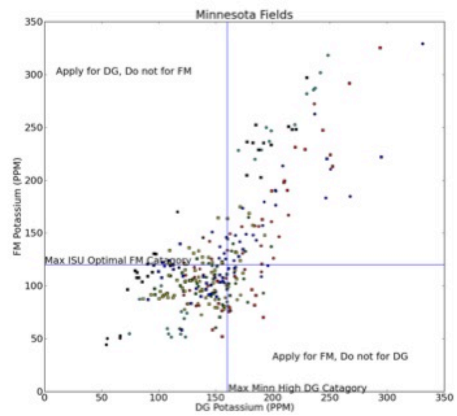


For comparison, we performed the standard Dried Ground analysis on all samples as well. Drying and grinding the soil samples tends to move K from the ‘plant-unavailable’ (known as ‘fixed’) state to the ‘plant-available’ state when K levels are low. Basically, upon heating K can move from being trapped in the clay lattice towards the surface, where it becomes available for extraction (by either chemicals or the plant). When K levels are high, the opposite tends to happen – K that was plant available moves into the clay lattice, where it gets ‘fixed’.

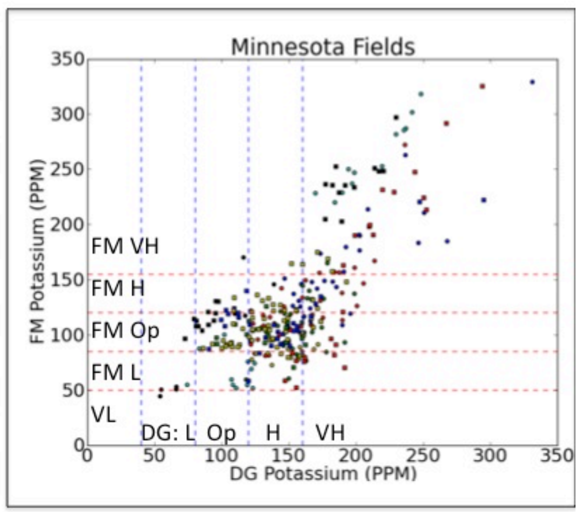
The amount of K fixation by clay obviously depends on many parameters, most specifically about the soil texture, mineralogy, and concentration of plant available and fixed K. Looking at the dried/ground to field moist K ratio allows one way to visualize how much the plant available potassium will change with the application of heat. The ratio value of 1 corresponds to no change in K with the application of heat to that sample. At low concentrations (around 50-100PPM of FM K), there seems is about a factor of 1.5-2x increase in the amount of K available. Meaning if there was 100PPM measured in the FM case, a value of 200PPM would be read by the DG method. This obviously would change the fertilizer strategy significantly.

For fertilizer recommendation reference, Iowa State University Field Moist Potassium recommendations are shown on the left axis. In addition, Minnesota Dried Ground Potassium recommendations are shown on the x-axis. One can see that the majority of the data is in the optimal, high, or very high potassium categories, meaning there is a limited chance for response to potassium application according to University recommendations. However, there are more fields below the ‘high’ category for the field moist measurement than the dried ground measurement. However, since we were aware that there are many factors that impact K availability, we use the next sections of this report to explore other soil parameters that can impact K availability.



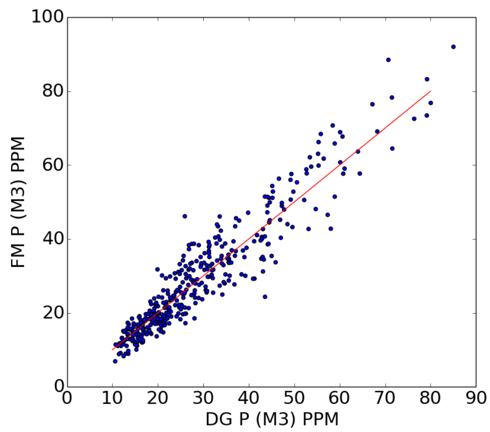


Field	K FM	K DG	Clay %
50300	124	159	25
50306	158	188	21
50307	107	158	22
BELGRADE	94	91	11
GARNESS N	90	153	15
GOODHUE	164	161	17
HENDERSON	154	200	18
MILLER 80	113	142	19
PRUEL 40	100	133	15
SANTIAGO	176	142	7
THE 138	113	135	16

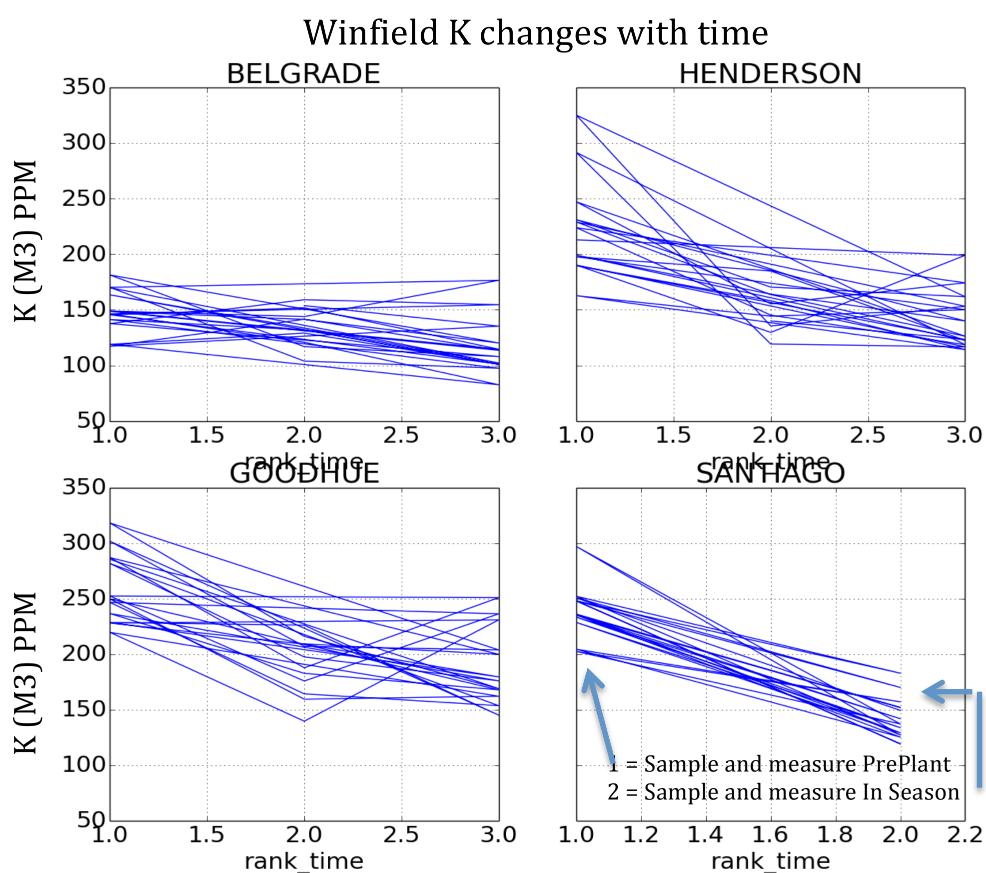


Some chance of FM response
Some chance of DG response
* Below High range

We have an additional quality control in our process – we can also measure the DG/FM ratio for phosphorus (P), which does not interact with clay, so does not change plant availability upon the drying and grinding process. Below we show the FM vs DG results for P, which match very well (as expected).

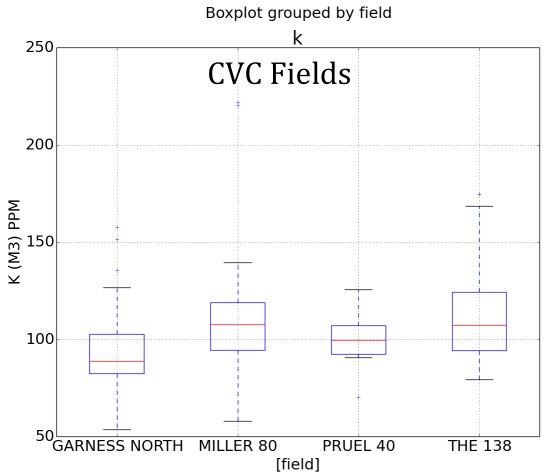


In addition to performing pre-season analysis, we also preformed a 0-8” sampling preseason (rank =1 in the plot below, around early June), a 0-8” sampling post application and plant (rank = 2, around mid July), and, in some cases, a mid August sampling (rank =3, around mid August). In several cases (Henderson, Goodhue, and Santiago), the K seems to reduce substantially during the growing season. In Belgrade’s case, it it is relatively constant. It is worth noting that Belgrade also has the

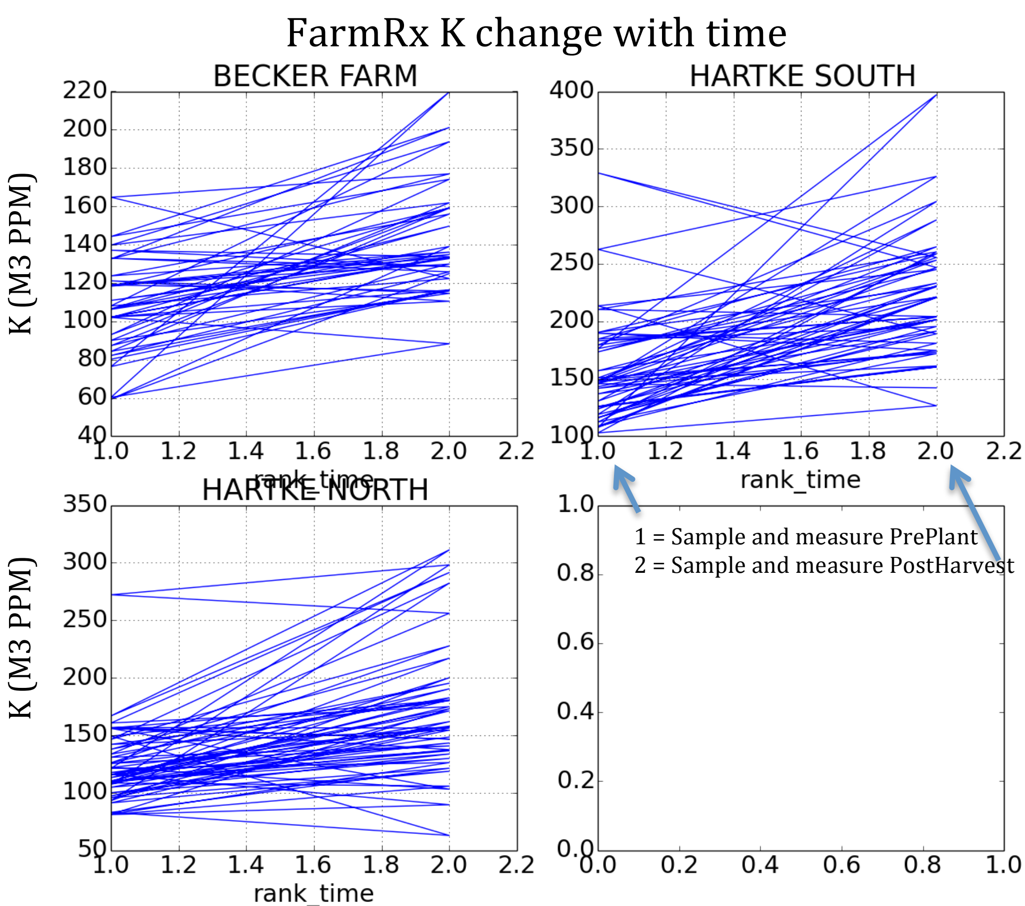


lowest K.

Finally, we also performed similar measurements on farmer fields. In Central Valley Cooperatives case, there was only one sampling event (0-6”). The results for K are shown below.



In FarmRx case, the fields were sampled twice, rank = 1 was preplant samlpling, and rank = 2 was post-harvest sampling. The trend of each sample point is shown here. Each sample was GPS located, so we can plot its K value Interestingly, in all 3 cases,

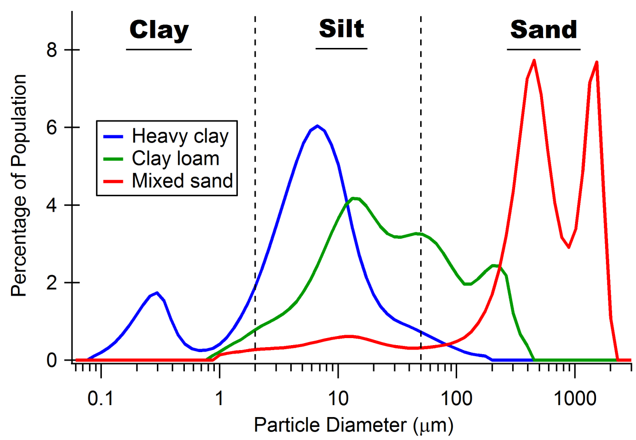


the FM K levels seem to be slightly higher post-harvest than preplant. This could be due to several factors. We will comment on that in the 'other measurements' section IV.

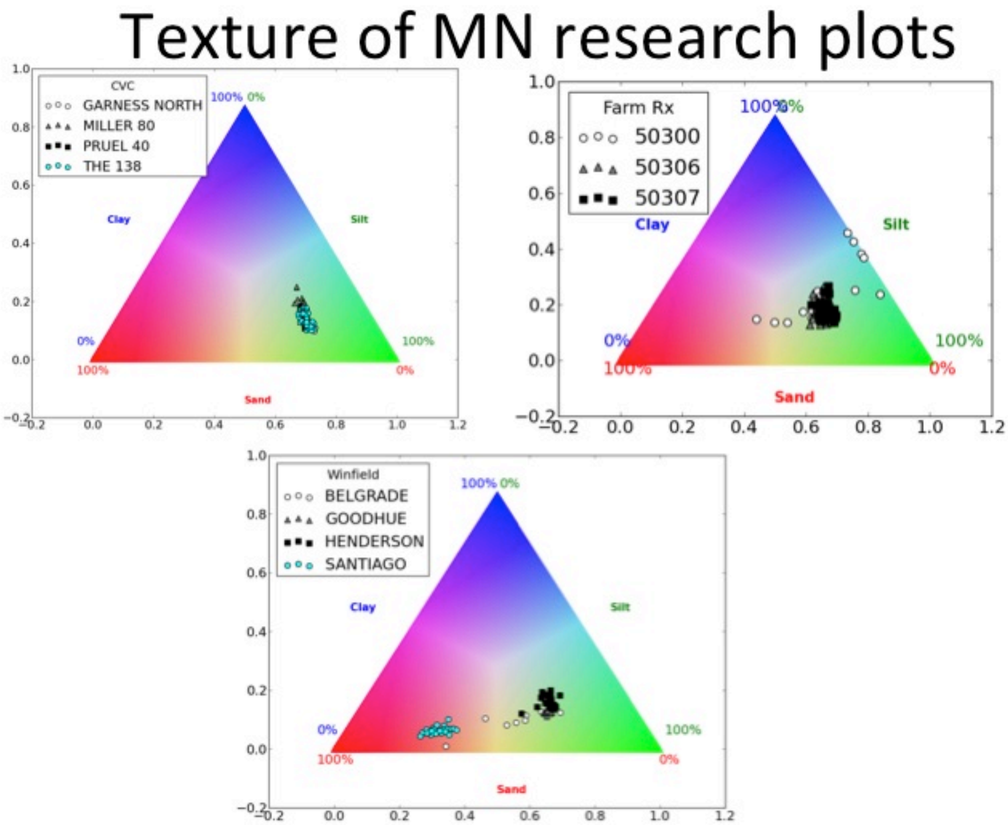
III. Intrinsic Properties: Texture, Mineralogy, K-Fixation Potential

As we motivated in the introduction, Potassium availability is impacted by intrinsic soil properties. Certain clay minerals, such as Vermiculite, can fix K, whereas other clay minerals, such as some 1:1 clay minerals do not. There are a few factors that can matter in the interaction between the clay minerals in the soil and potassium. First, clay minerals must be present. As the concentration of clay in the soil increases, known as the clay component of the texture, there is more chance for interaction with the plant-available K (the K-applied in fertilizer and the soil intrinsic plant available K). Secondly, not only the amount of clay, but the type of clay matters, which is where mineralogy comes in. Finally, if the types of clay are present which interact with K, then the direction of interaction depends on the relative K concentration between the inside the clay layer and outside the clay in the soil.

We started by measuring the texture of the soils for the clay concentration. We use a laser diffraction tool, which greatly increases throughput and decreases the cost of the texture measurement. It also gives substantially more data than the standard texture measurement, as shown below. Instead of 3 bins (sand, silt, and clay), this technique gives us ~90 bins, shown below.



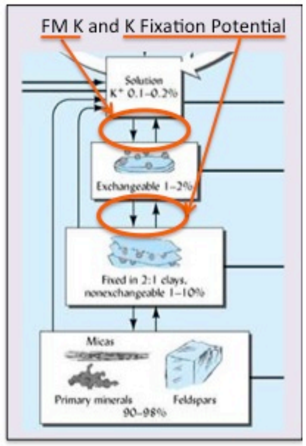
In order visualize this type of data, we present the texture results for each sample on a texture triangle, shown below. One can see, the farmer fields (CVC and FarmRx) tend to be silt loams. In contrast, in the Winfield fields, Santiago and Belgrade are both much sandier soils. (In fact, both Santiago and Belgrade are irrigated.)



We had set out to collaborate with a clay mineralogist for mineralogy results. We contacted several, including Mickey Ransom (Kansas State), Randy Southard (UC Davis), Michael Thompson (Iowa State), and Darrell Schulze (Purdue), but none were able to take on samples in order to make the collaboration work on our limited time scale.

We also contacted an outside lab, Weatherford Labs, who did say they could contract the work for $250/sample. All of the clay mineralogy experts above expressed doubt that an oil and gas lab would be able to perform the measurements needed. Soil clay mineralogy is not ‘standard mineralogy work’ that one can get completed in an outside lab. For soil clay mineralogy, many techniques are used to differentiate 2:1 vs 1:1 clays and within each of those bins. Typically, in soil mineralogy, the samples are prepped then each are split into two process flows. One set are measured immediately, while other, are soaked in an ion solution then measured. Looking at the change in height of the X-ray diffraction peaks pre- and post soak in an ion bath shows the amount of each. Since we could not find the x-ray diffraction expertise needed for the soil mineralogy, we did not continue pursuing this work.

Once it is determined how much active clay is in the soil, a further measurement is needed to determine the direction of interaction – will K tend to get fixed in the clay mineral, or will it tend to be released from the clay mineral. We began research in Q4 on clay fixation experiments. Method developed at UC Davis for measuring the potential of soil to fix potassium, natural extension to put field moist K and potassium build rates into mineralogy context. This method assesses the potential for a soil sample to fix K in nonexchangeable (slowly available) forms. The cation exchange capacity of a soil sample is determined using Ca saturation followed by exchange with Mg. The cation exchange capacity of a duplicate sample is determined using K saturation, oven-drying,



and subsequent exchange with ammonium. The K fixation capacity is calculated as the difference between the Ca exchange capacity and the K fixation capacity.

Once the Ca and K concentrations are measured, the Ca EC and K EC are calculated with the following equations:

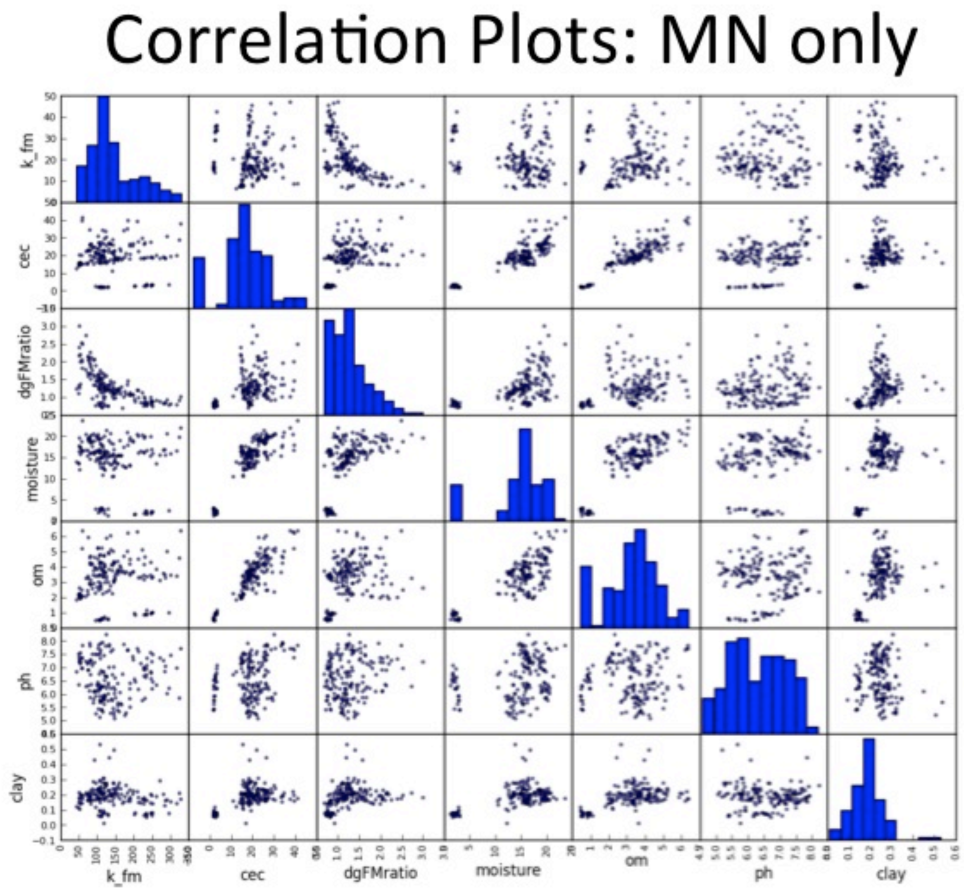
$$CaEC\ (cmol\ kg^{-1}) = \left[\frac{\left(Ca\ \frac{mg}{L}\right)(0.025\ L)}{0.00035\ kg}\right]\left(\frac{0.001\ mol\ Ca}{40\ mg\ Ca}\right)\left(\frac{200\ cmol\ (+)}{mol\ Ca}\right)$$

$$KEC\ (cmol\ kg^{-1}) = \left[\frac{\left(K\ \frac{mg}{L}\right)(0.025\ L)}{0.00035\ kg}\right]\left(\frac{0.001\ mol\ K}{39.1\ mg\ K}\right)\left(\frac{100\ cmol\ (+)}{mol\ K}\right)$$

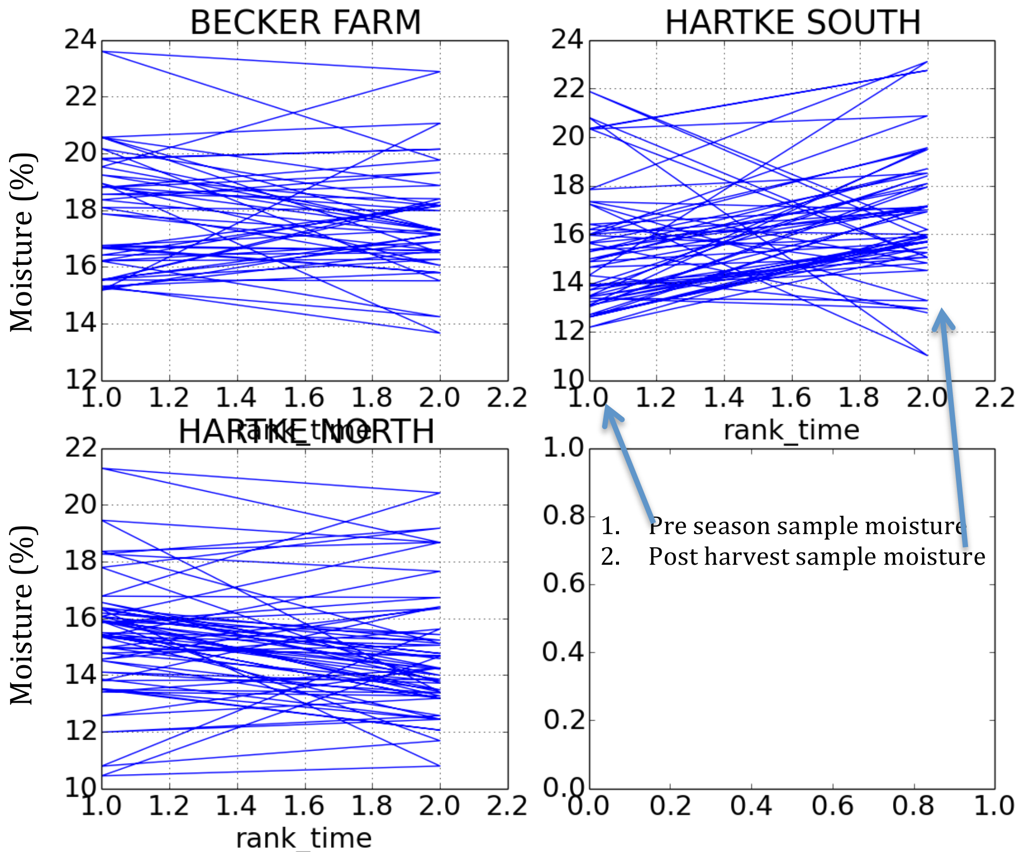
The non-exchangable K potential is then the difference between the CaEC and the KEC. We contracted Michael Thompson, a mineralogy expert at Iowa State University, in Q3 to help us with the method development in our lab in Ames, IA. We generated and SOP for the process, and we have now ordered the materials and supplies for running test samples in 2014. In Q1 2014, we were planning on running the method and comparing our lab results against samples in Michael Thompson's laboratory. Unfortunately, given the grant cutoff, we decided not to continue measurements.

IV. Pulling all the measurements together

A set of the measurements which we believe impact K plant available K during the season are shown below on a cross correlation plot. One can see a substantial amount of data has been collected for this experiment. The fields chosen for this study clearly have a substantially different soil types and nutrient availability – exactly what we were hoping for.

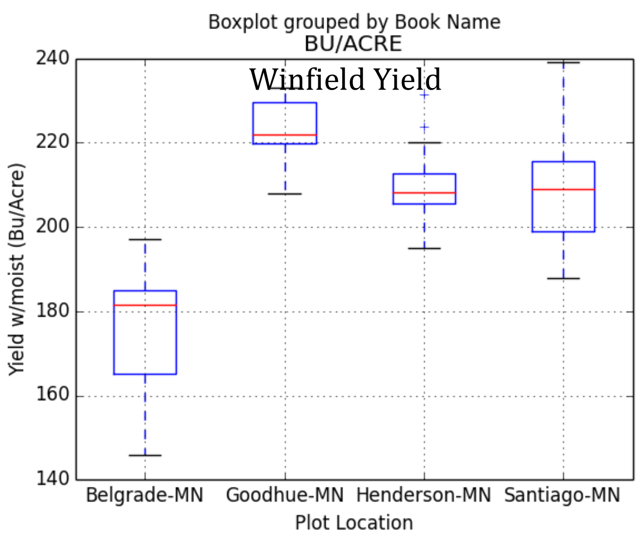


As mentioned earlier, we have measured moisture on all samples as well. There is not a large change in moisture between most of the samples. For instance, shown below is the moisture of the FarmRx samples. They collected samples pre-plant and post harvest. Clearly having the same moisture likely means they collected the harvest samples near a rain event.

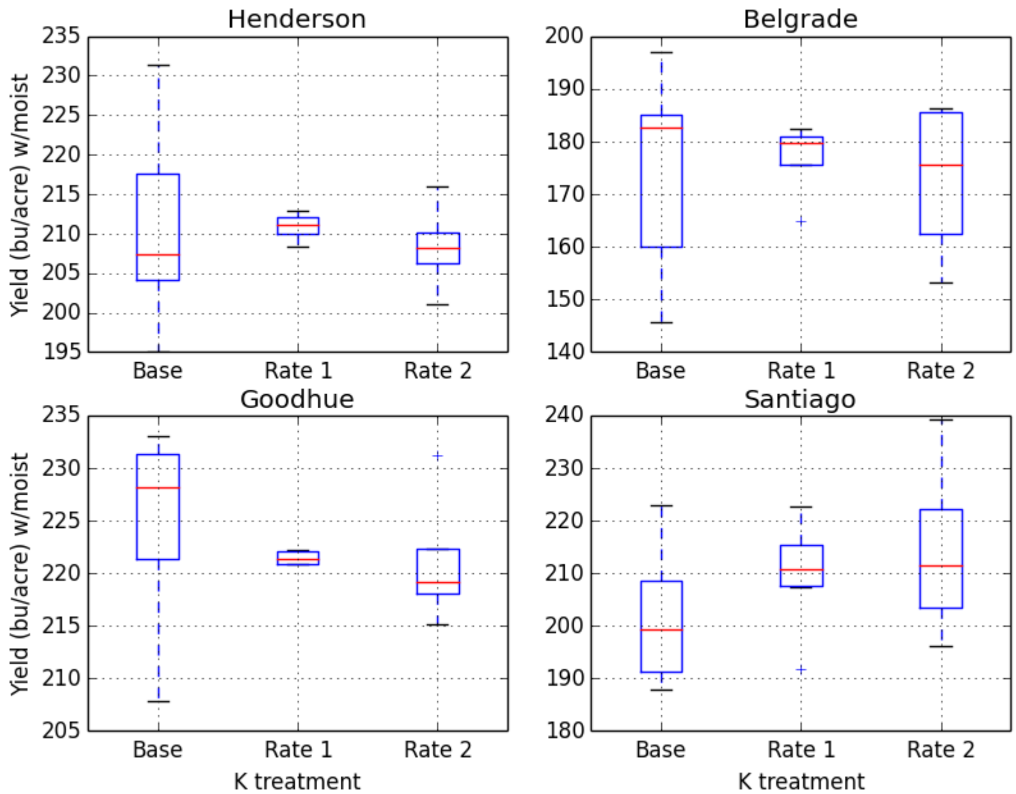


V. Yield correlations

For yield, we only have the 4 plots from 2013 Winfield trials. Below is shown the average site yield for comparison.



The yield at Belgrade was significantly less than historical yields, likely due to inclement weather events such as hail. The other plots all had yields above 200 bushel/acre, making them better candidates for observing differences between K treatments. As noted in section I, the sites each got 3 treatments, 0lbs (base), 100lbs KCl (Rate 1), and 150 lbs KCl (Rate 2).



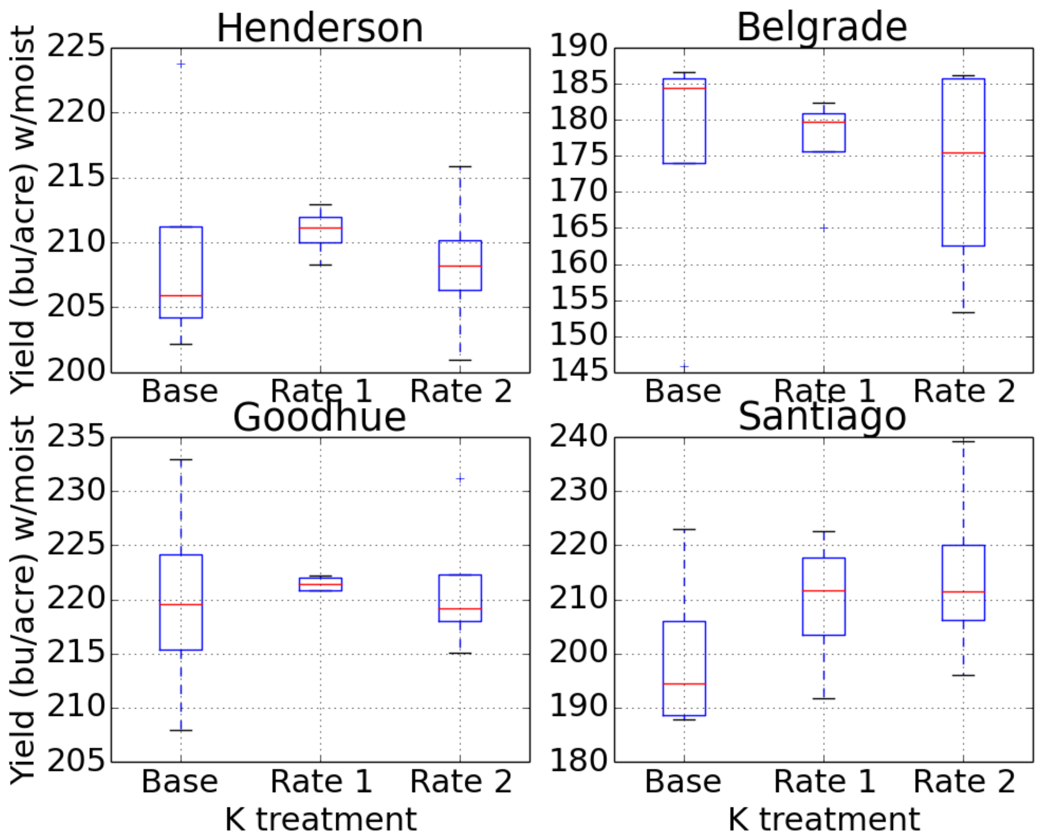
On first glance, there does not seem to be a strong correlation between the K treatments and yield. In Appendix 1, the plot designs are shown. Belgrade, Goodhue and Henderson have a replicated block design, with one block of all 'base'. Analyzing just the base blocks (for instance plot 35 and 36 for Belgrade), we can get an idea of the repeatability within the block, hence an idea of the yield signal we can observe. The Avg and Std of the plots are shown below.

Check plots	Avg (bu)	Stdev (bu)
Belgrade	174	17
Goodhue	229	4
Henderson	211	13

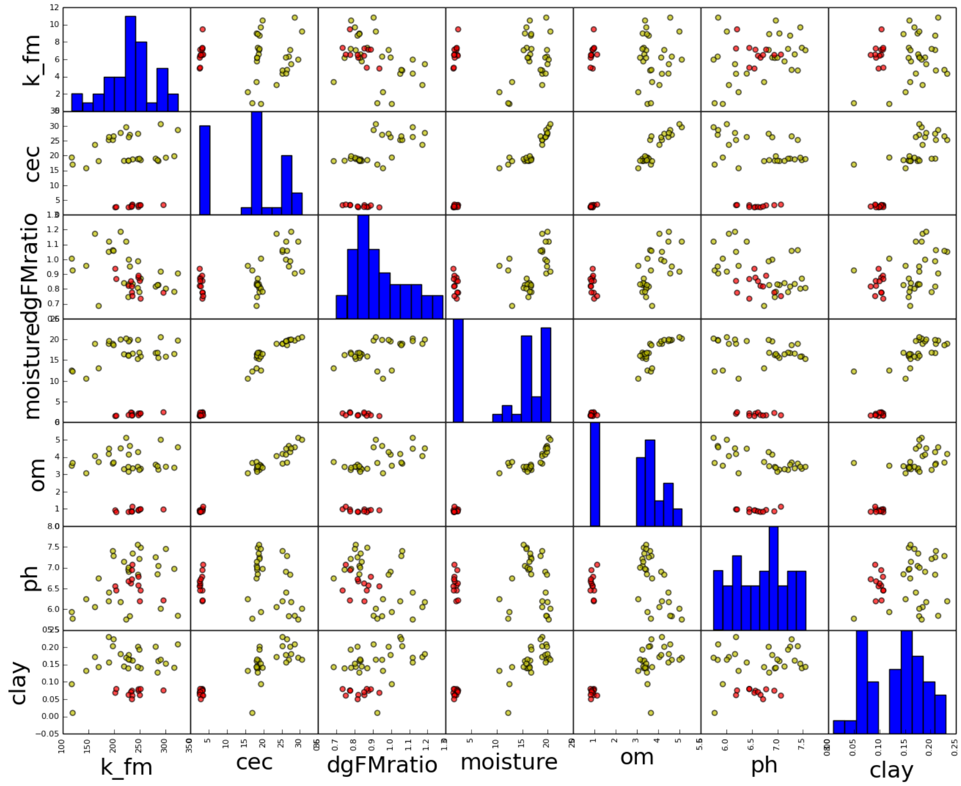
If we remove the check plots from the above data, we can see the average trends with the sites with treatments. Clearly only Santiago has a trend. Unfortunately, due to plot design of Santiago, we do not know the experimental resolution. However, running Anova on the Santiago data reveals there is not a significant difference between the treatments (p ~ 0.22).

Although none of the treatments have a statistically significant impact on the yield, it is still worthwhile looking at how the Santiago plots differ from the other plots in the measured data. More data (and years) could eventually confirm that there is indeed a difference, especially for the Santiago plots.

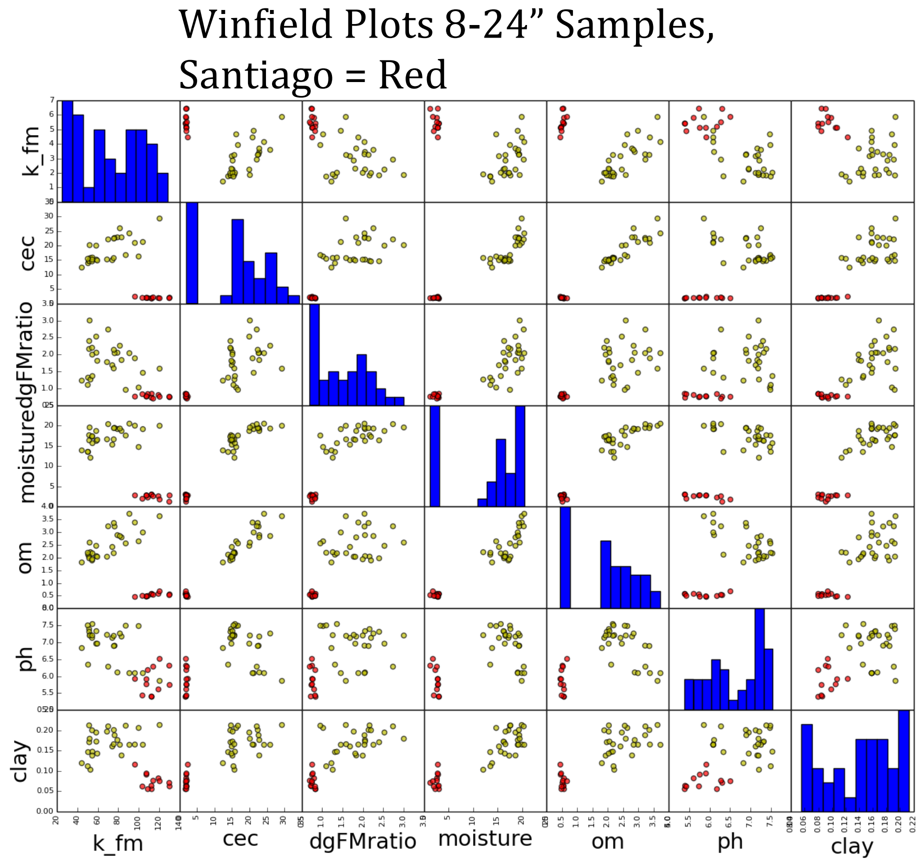
Winfield Yield Filtered for only the response plots



Winfield Plots 0-8"
Samples, Santiago = Red



As one can see, the Santiago samples have extractable potassium in line with the other plots. However, the organic matter (OM), moisture, CEC, and clay % are all much lower than the rest of the sites, indicating all of those parameters may be important in determining response to K.



VI. Conclusions and suggestions for future research

The goal of this 1 year project was to produce measurements that could be used to develop algorithms for potassium management. We produced several interesting indicators, including moisture, OM, CEC, and clay component which may impact plant available K. Unfortunately, the yield signal in our test plots was not above the noise, so it is difficult to make strong conclusions based on this work.

As a project, we leveraged the work of several institutions to put together this research project. Although incomplete due to the lack of continuation, this project did spur discussion within industry and between industry and academics. This type of project has the potential to help answer soil fertility questions that matter to the growers of the state of Minnesota, and we appreciated the opportunity to try.

For future work, increasing number of sites and the number of reps within a site will help with increasing the signal-to-noise ratio for yield. Even without the proper statistical significance, we were able to extract some interesting potential indicators which, in the future, may be used to help manage potassium. It would also be very useful to post this data somewhere for future work to use. If AFREC has any resources to create a database for the data in this work, we would gladly put all the raw data into the public sphere for other research organizations to use. The power in this type of work really starts with more data, more trials, and more years.

Appendix 1: Winfield Trial Blocks

Belgrade-MN											
Plot #		27	28	29	30	31	32	33	34	35	36
	14	2160134	2160135	2160136	2160137	2160138	2160139	2160140	2160141	2160142	2160143
R	13	2386504	2386505	2287293 Rate 2	2287281 Rate 1	2386508	2287295 Rate 1	2287289 Base	2287299	2287285 Base	2287291 Base
a n	12	2386502	2386503	2287284 Rate 1	2287287 Base	2386507	2287286 Base	2287283 Rate 2	2287298	2287294 Base	2287276 Base
g e	11	2287300	2386501	2287296 Base	2287290 Rate 2	2386506	2287280 Rate 2	2287292 Rate 1	2287297	2287282 Base	2287288 Base
Pass		14	14	15	15	16	16	17	17	18	18

Goodhue-MN										
Plot #		28	29	30	31	32	33	34	35	36
	14	2116647	2116648	2116649	2116650	2116651	2116652	2116653	2116654	2116655
	13	2287398	2287377 Rate 1	2287383 Rate 1	2287399	2287381 Rate 2	2287384 Rate 2	2287400	2287373 Base	2287385 Base
	12	2287394	2287368 Rate 2	2287380 Rate 2	2287395	2287372 Rate 1	2287378 Base	2287396	2287376 Base	2287379 Base
	11	2287390	2287374 Base	2287386 Base	2287391	2287375 Base	2287387 Rate 1	2287392	2287388 Base	2287382 Base
Pass		14	15	15	16	16	17	17	18	18

Henderson-MN										
Plot #		18	19	20	21	22	23	24	25	26
	14	2125135	2125136	2125137	2125138	2125139	2125140	2125141	2125142	2125143
	13	2330774	2330865 Base	2330862 Rate 1	2330872	2330866 Rate 2	2330863 Base	2330873	2330855 Base	2330864 Base
	12	2330772	2330847 Rate 2	2330859 Base	2330870	2330857 Rate 1	2330851 Rate 2	2330871	2330852 Base	2330858 Base
	11	2330770	2330856 Rate 1	2330853 Rate 2	2330868	2330854 Base	2330860 Rate 1	2330869	2330867 Base	2330861 Base
Pass#		9	10	10	11	11	12	12	13	13

Santiago-MN												
Plot #		26	27	28	29	30	31	32	33	34	35	36
R	3	2116243	2287553 Rate 2	2287544 Base	2287559 Rate 1	2287560 Rate 1	2287554 Rate 1	2287548 Rate 2	2287558 Base	2287561 Rate 2	2287549 Base	2287543
a n	2	2116239	2287550 Rate 1	2287562 Rate 2	2287556 Rate 1	2287551 Base	2287563 Base	2287557 Rate 2	2287564 Rate 1	2287555 Rate 2	2287552 Base	2287533
g e	1	2079635	2117524	2117525	2117526	2117527	2117528	2117529	2117530	2117531	2117532	2117533
Pass #		13	14	14	15	15	16	16	17	17	18	18