Introduction

- Dr. Smith's research is very relevant to NRCS's SMART Nutrient Management and Climate-Smart Agriculture conservation efforts.
- USDA's Conservation Effects Assessment Project (CEAP) cropland assessments quantify the effects of voluntary conservation efforts across the nation's cropland using confidential farmer surveys coupled with modeling.
- In comparing national CEAP II (2013-2016) to CEAP I (2003-2006) findings, our biggest lesson learned was related to nutrient management.
    - With the push to increase acres under Conservation Tillage, we overlooked the importance of incorporating nutrients as well as proper application timing.
- By CEAP II, we saw an increase in variable rate technology and enhanced-efficiency fertilizer usage.
- Dr. Smith's expertise and research in phosphorus fate provide an excellent resource and can help us address some of our concerns with phosphorus nutrient management and climate-smart conservation efforts.

Research on the Use of Precision Ag Technologies for Cropland Phosphorus Management

DOUGLAS R. SMITH, KABINDRA ADHIKARI, CHAD HAJDA, JOSH MCGRATH, JENNI FRIDGEN, VAUGHN REED, EDWIN RITCHEY, DENNIS BUSCH, AND MANY MORE!

USDA-ARS GRASSLAND, SOIL AND WATER RESEARCH LABORATORY, TEMPLE, TX

Conservation Effects Assessment Project

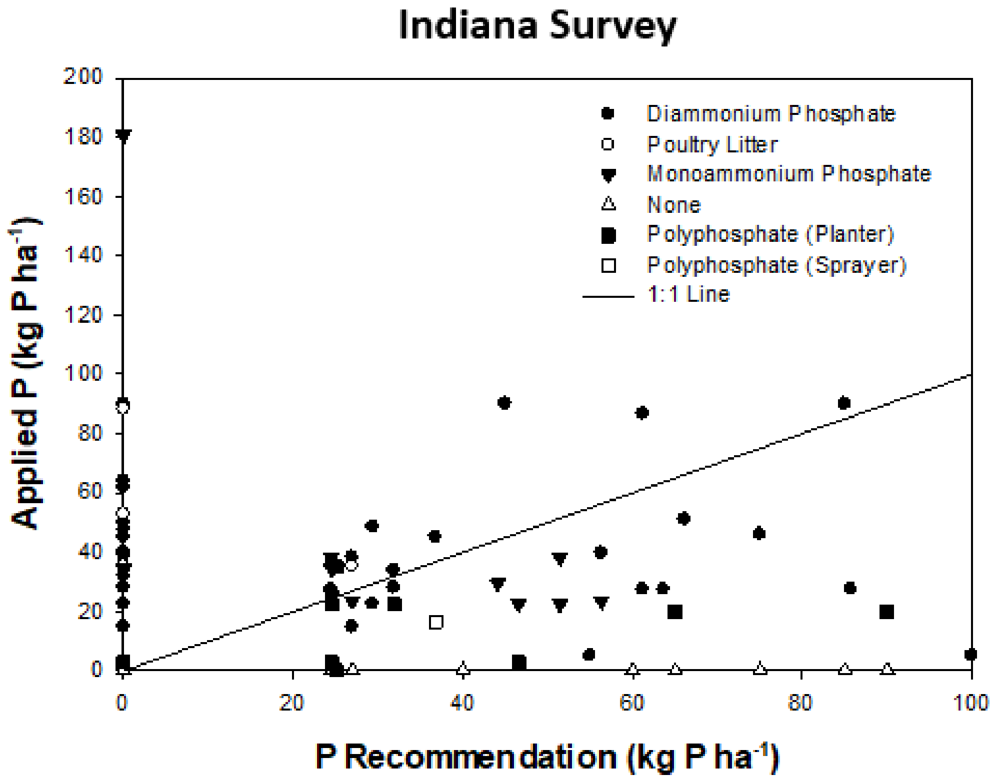
This project was supported through the U.S. Department of Agriculture's Conservation Effects Assessment Project (CEAP), a multi-agency effort led by the Natural Resources Conservation Service (NRCS) to quantify the effects of voluntary conservation and strengthen data-driven management decisions across the nation's private lands.

Lake Erie and Harmful Algal Blooms

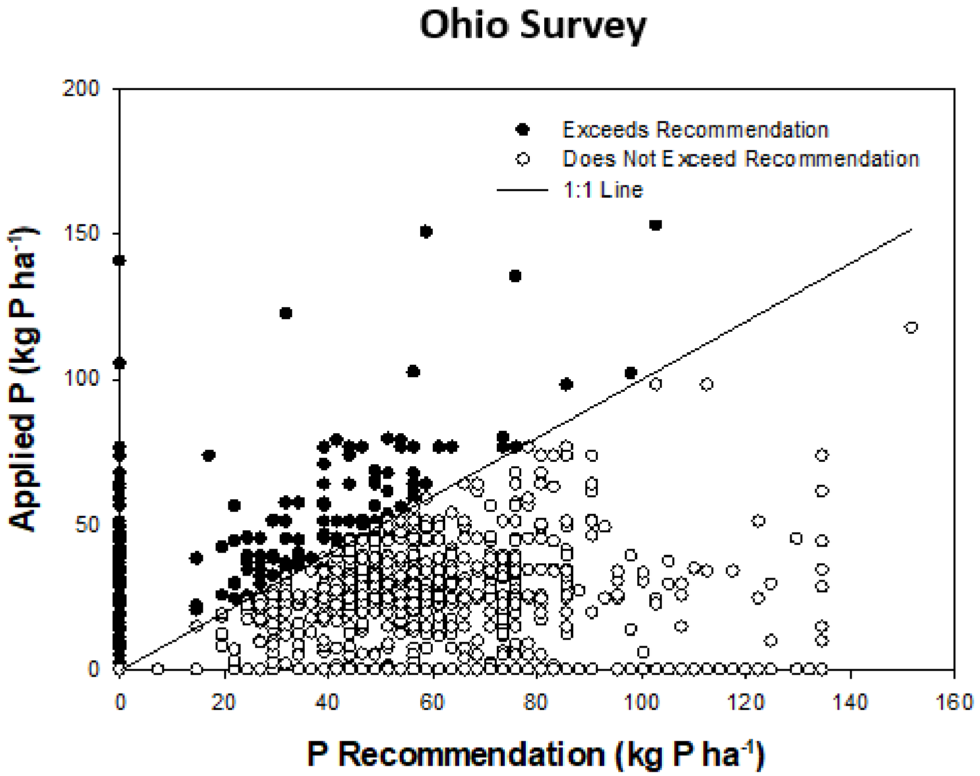
2011 Central Lake Erie Basin Microcystis-containing bloom

LOCATION	Dissolved Reactive Phosphorus (DRP) (lb P/ac)	Total Phosphorus (TP) (lb P/ac)
Maumee	0.24	1.00
Sandusky	0.28	1.26
Honey Cr.	0.33	1.15
Rock Cr.	0.22	1.23

Eutrophication and Fertility



73% fields at or below P recommendations



90% fields at or below P recommendations

Breaking News: Fields are not homogeneous!

Image Source: Doug Smith

How Should Precision Ag Guide Management?

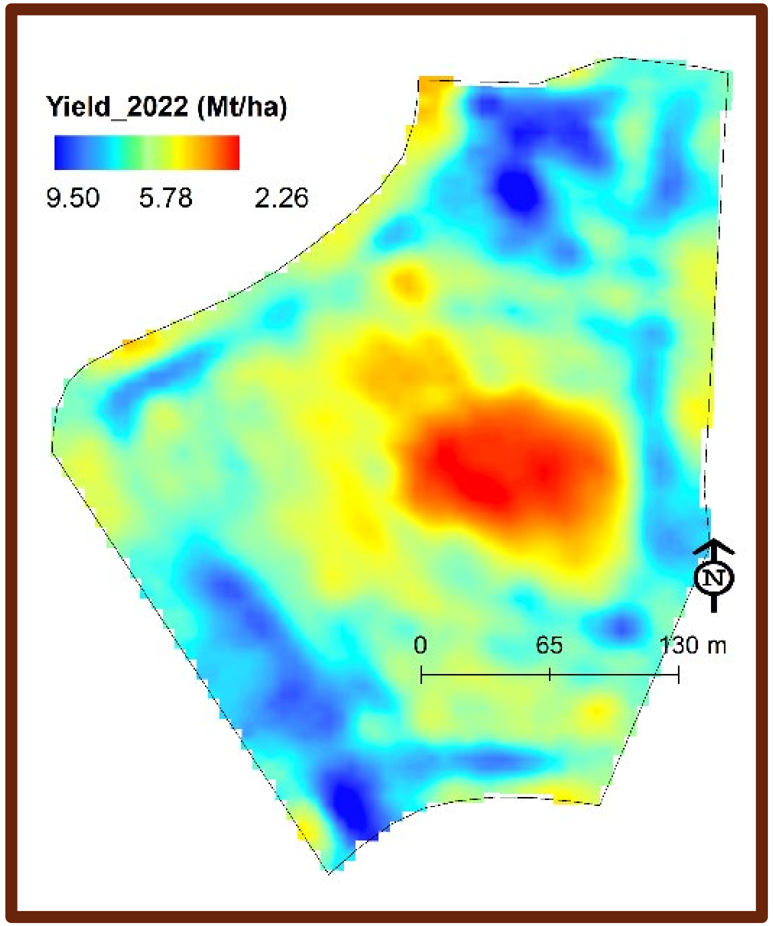
Early days of Precision Ag

- High yields marked the field's yield potential
- More inputs into the low yielding areas

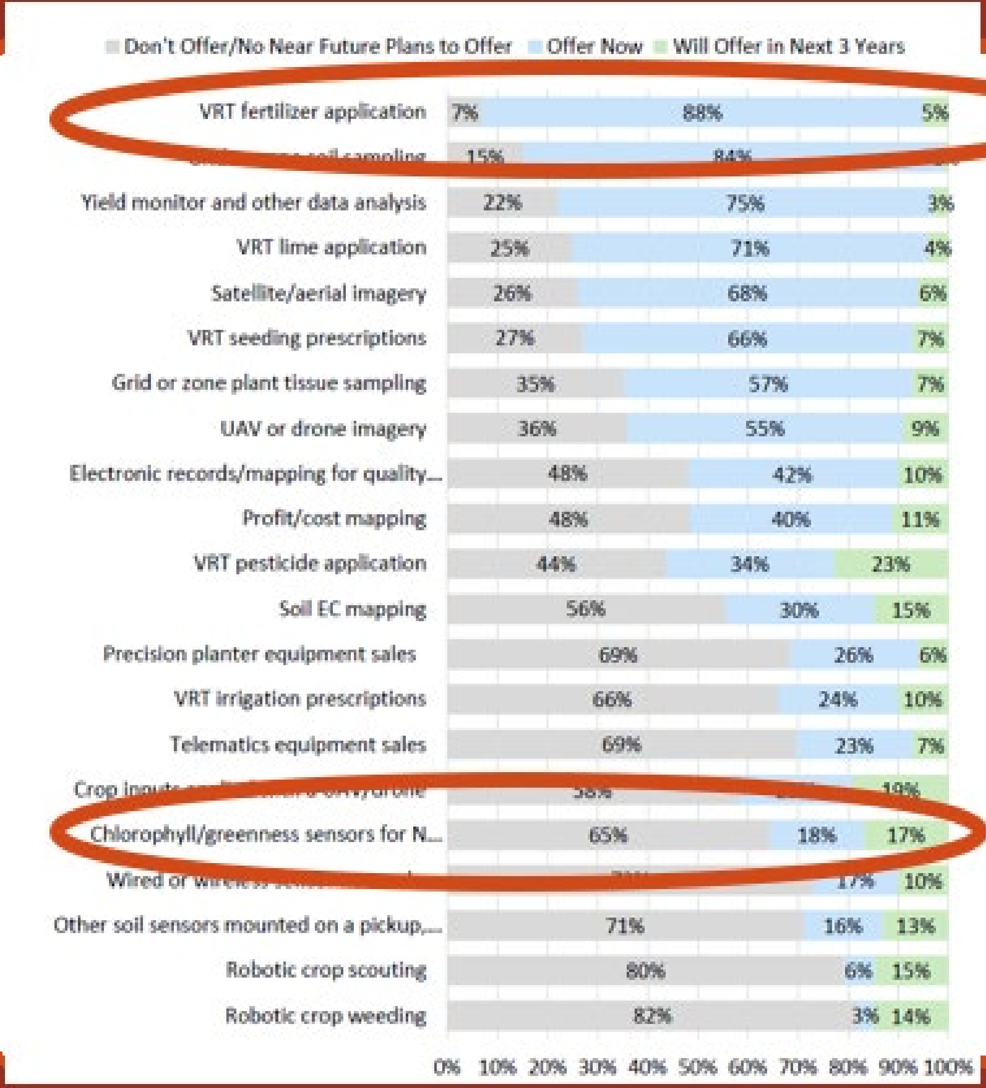
But!

- Why increase input costs to poor yielding areas?
- Why double down on resource concerns (e.g., add fertilizer to areas prone to runoff)?

Use Precision Ag to optimize production/economics/resource concerns



Precision Nutrient Management



Purdue University survey of crop input dealers.

National scope, but strong representation from corn-belt

Figure 5. Dealer offerings of precision services, ranked by current offering.

Erickson and Lowenberg-Deboer. 2022. 2022 Precision Agriculture Dealership Survey

Precision Nutrient Management

Science behind site-specific nitrogen management (e.g., GreenSeeker) is very strong, but poor uptake in industry.

Science behind site-specific phosphorus management is much weaker, but has strong uptake in industry.

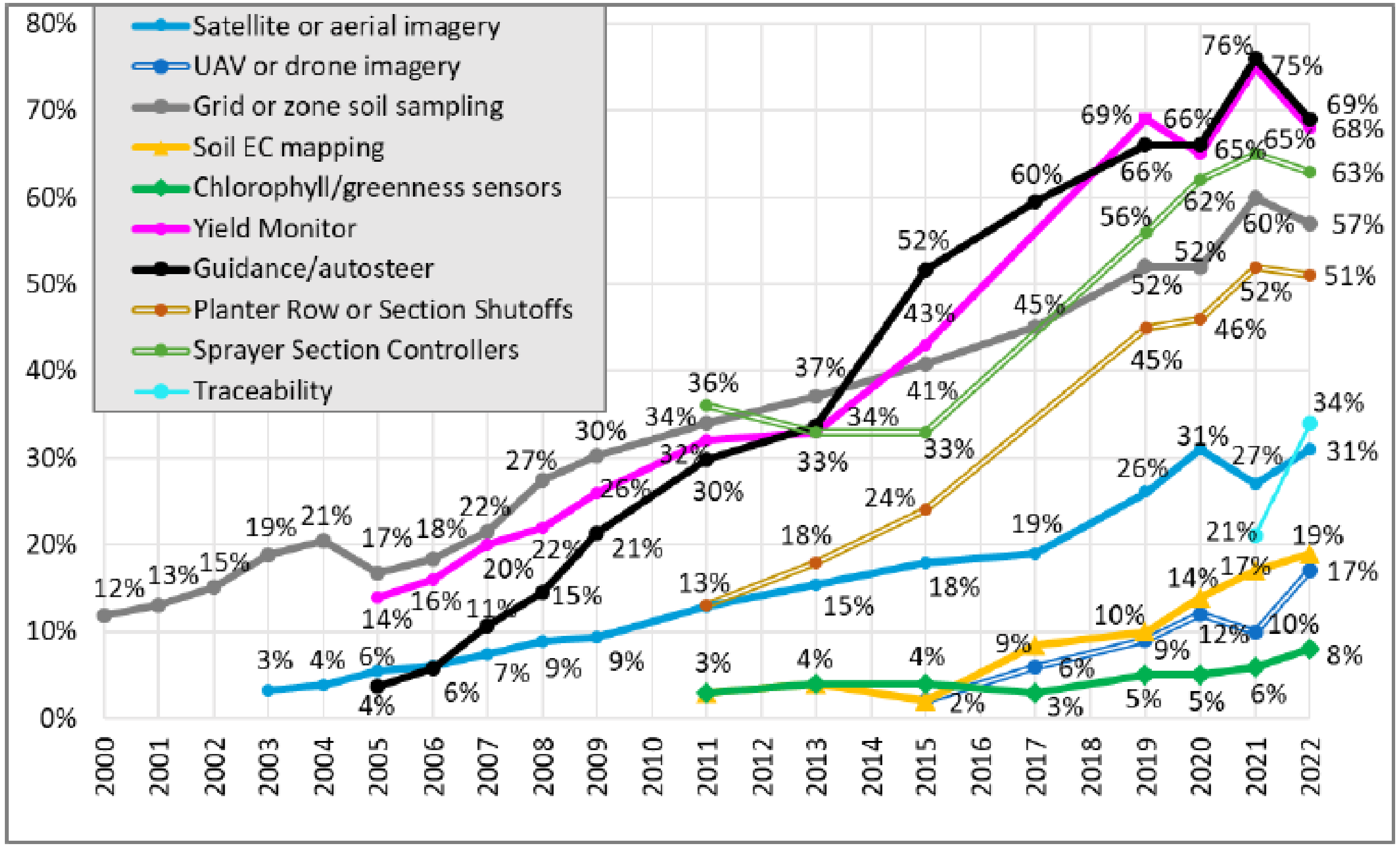
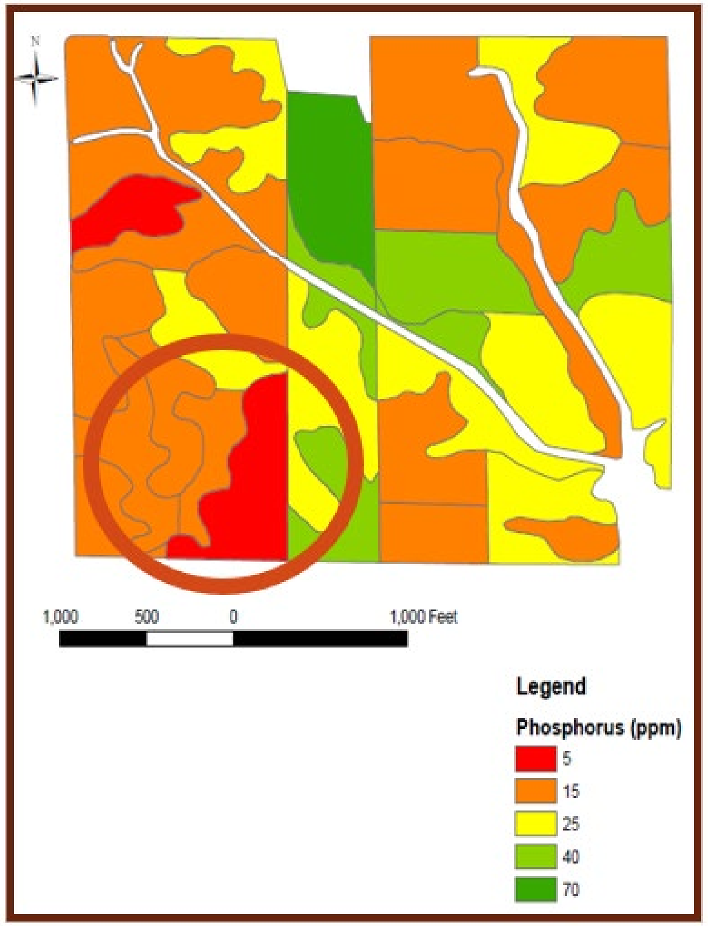


Figure 16, Q11: Producer use of precision technologies, retailers estimate of their market area. Yield monitor, sprayer section controllers, and planter row/section shutoffs were inadvertently omitted in the 2017 survey.

Erickson and Lowenberg-Deboer. 2022. 2022 Precision Agriculture Dealership Survey

Soil Test Phosphorus

- Anecdotal evidence for P recommendations being too high
- No-till farmers report that low Soil Test Phosphorus (STP) areas can produce high yields
- Soil test P zone map for a ¼ section field



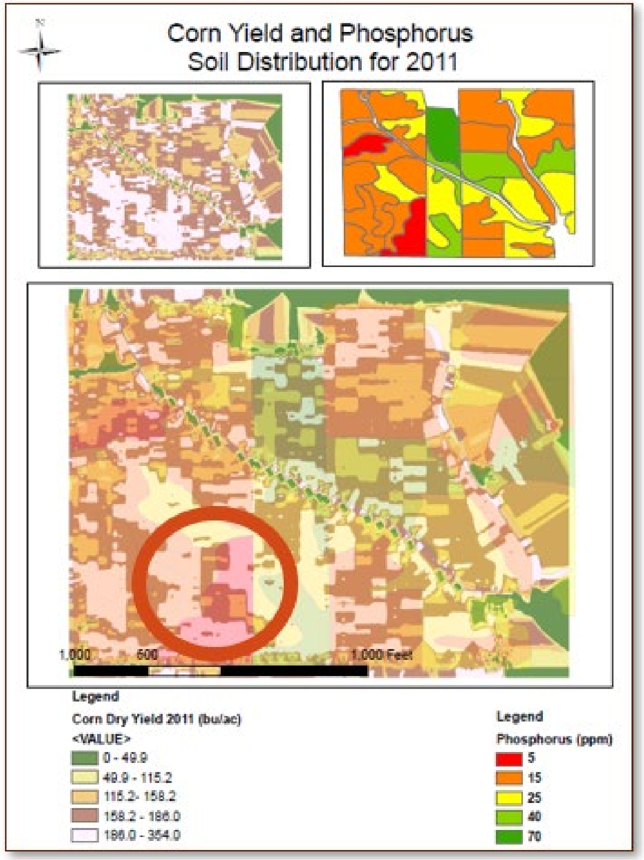
Tri-State Fertility Guide Recommendations for Phosphorus Application to Corn

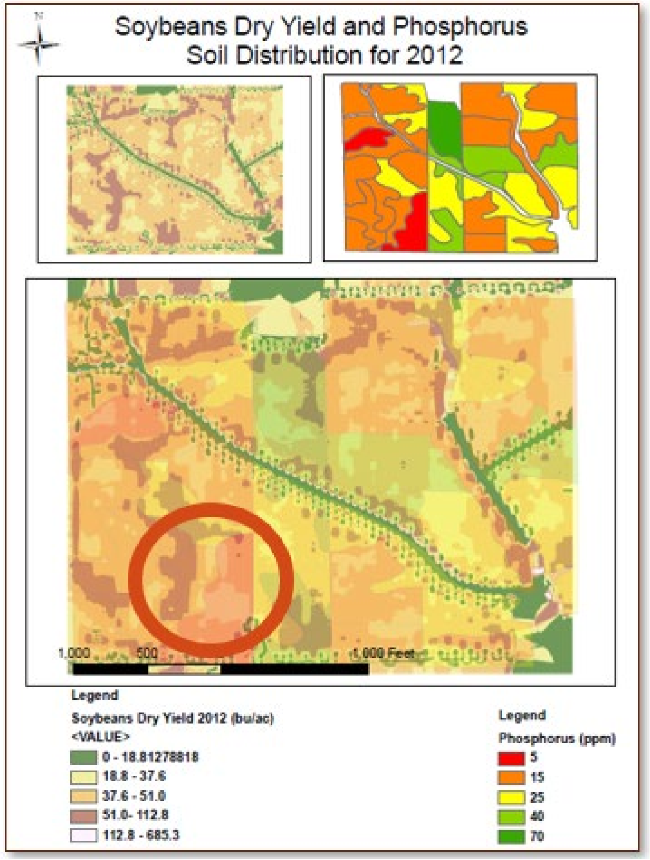
	Yield potential - bu/acre				
Soil test	100	120	140	160	180
ppm (lb/acre)			lb P_2O_5 per acre		
5 (10)[1]	85	95	100	110	115
10 (20)	60	70	75	85	90
15-30 (30-60)[2]	35	45	50	60	65
35 (70)	20	20	25	30	35
40 (80)	0	0	0	0	0

[1] Values in parentheses are lb/acre.

[2] Maintenance recommendations are given for this soil test range

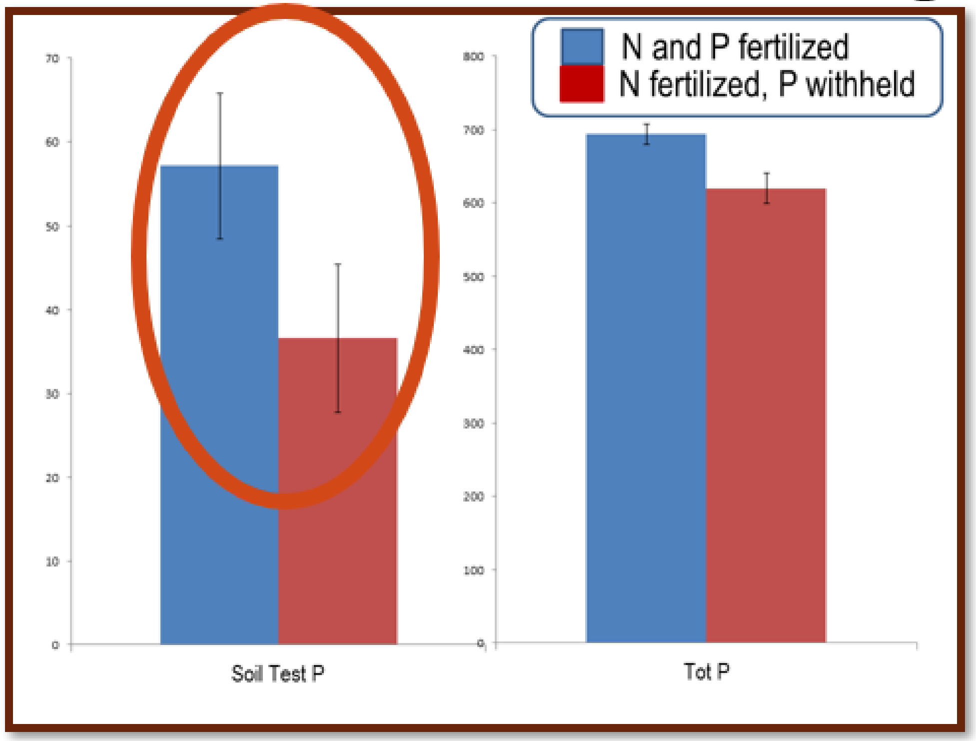
Soil Test Phosphorus and Yield

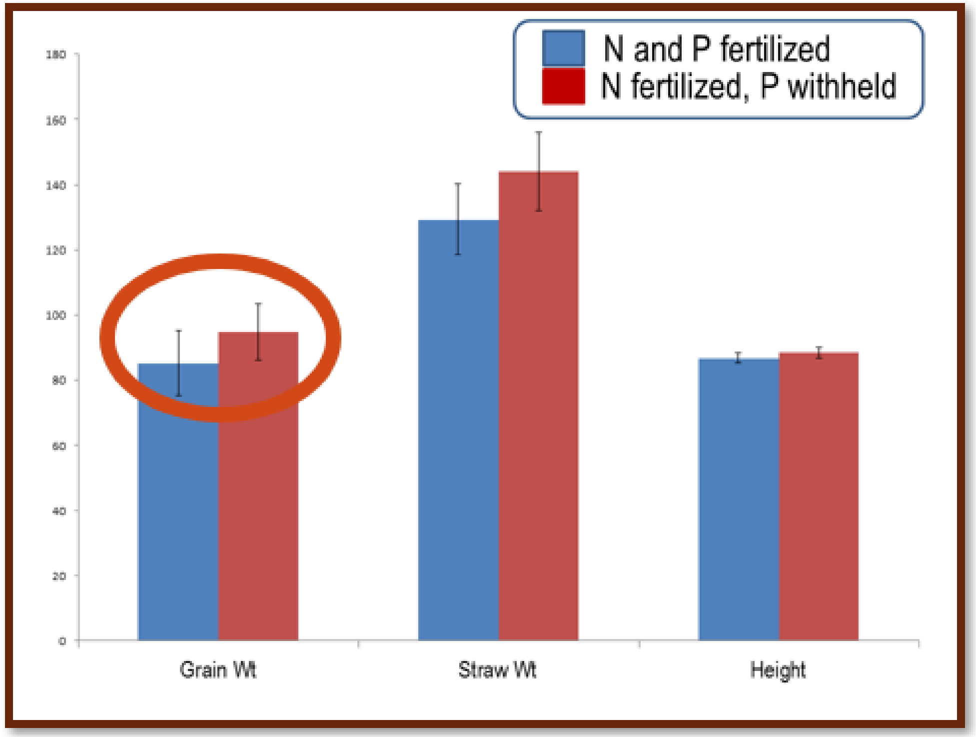




Canadian Experience with Wheat

Mining P since 1995





Despite lower levels of STP, it does not appear that organic P is being mineralized as the P source to maintain wheat P Uptake.

Informational Survey of Farmers and Certified Crop Advisors

- Manage or advise > 85,000 ac
- Asked about N, K and P deficiency
- N and K deficiency common
- P deficiency only when:
  - Sidewall compaction
  - Cool/wet post-emerge
  - Herbicide damage

P supply to the plant is known to impact crop yield up to about V4 for corn. Early supply is critical.

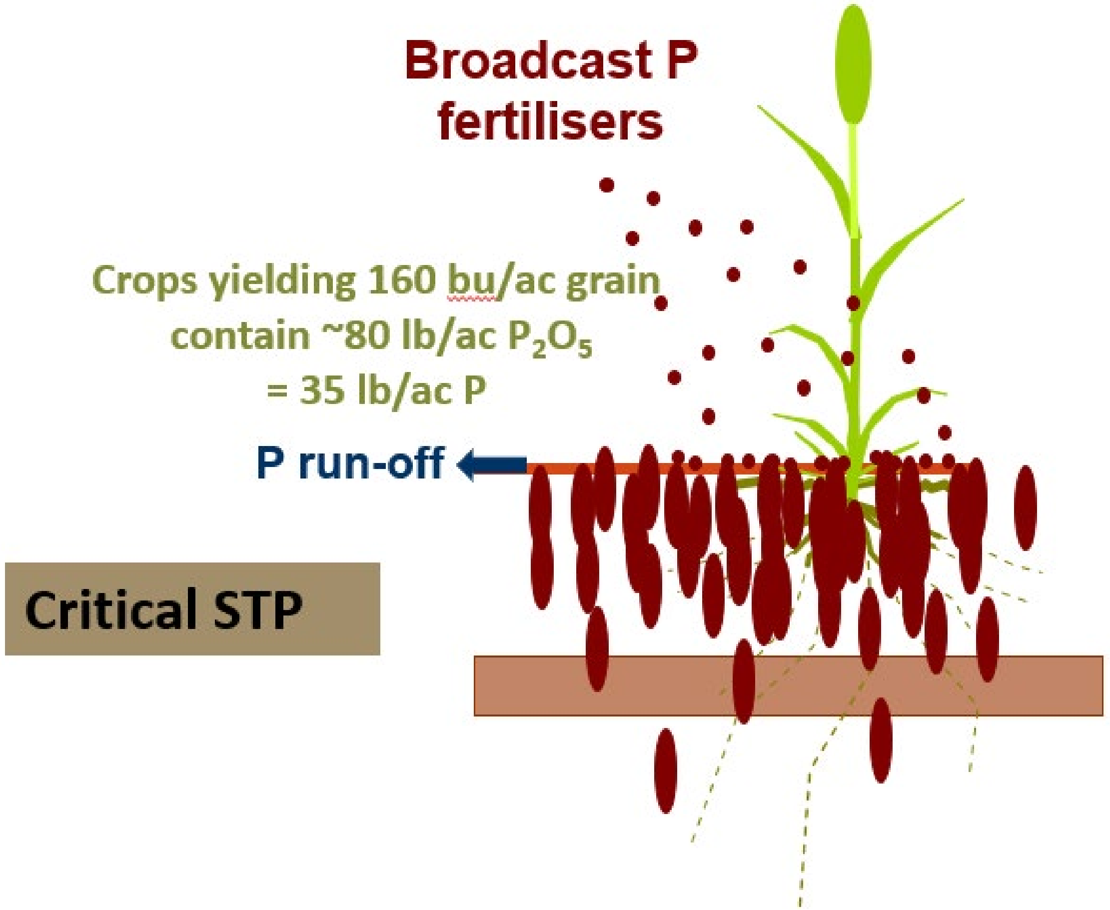
Image Source: Doug Smith

Corn Growth Development Stages

Phosphorus impacts corn yield early in the season

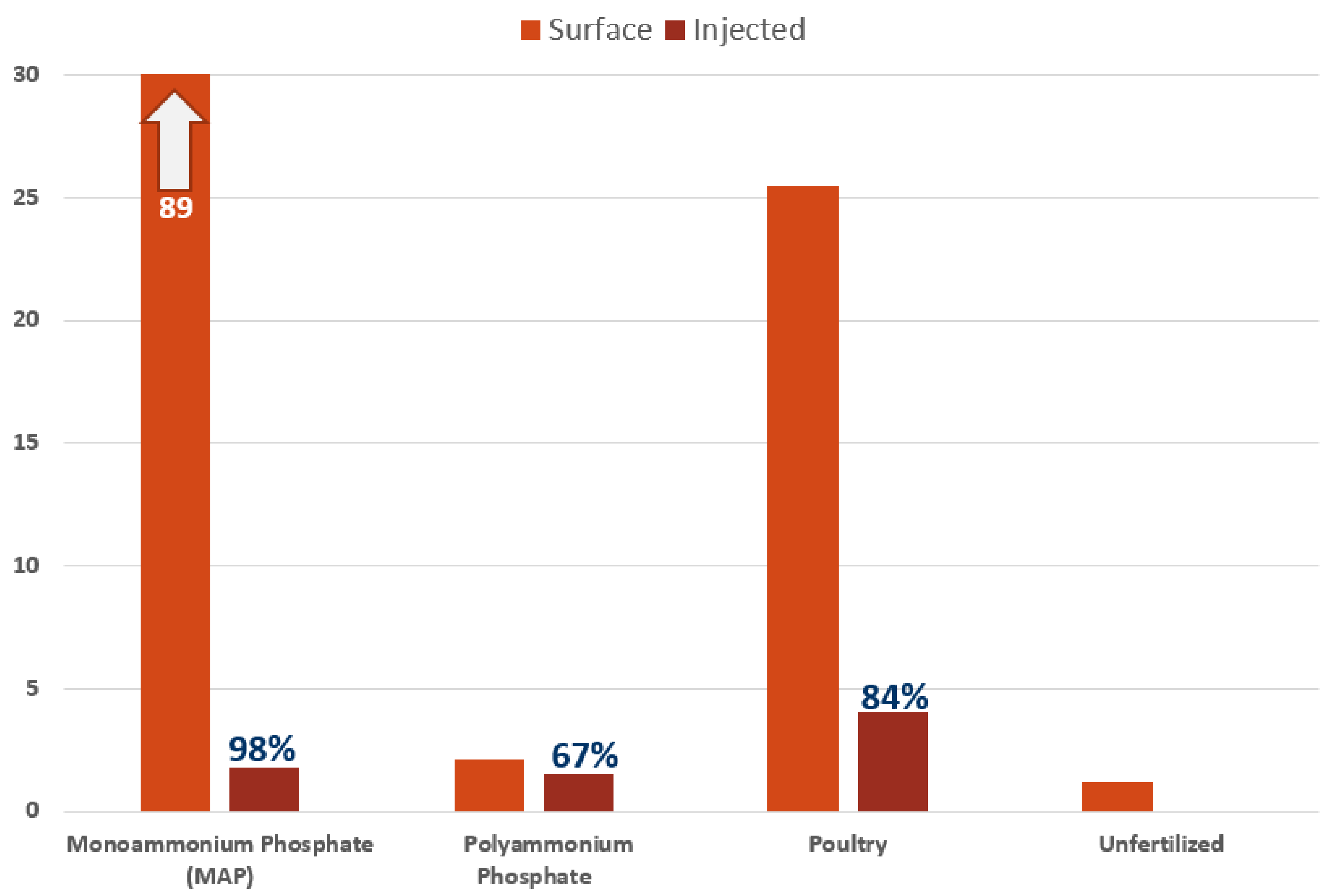
What's Wrong with the Current System?

Feeding the Soil to Feed the Crop



Fertilizer Source and Placement Affect Soluble P Runoff Loss

Smith et al., 2016. AEL



Immediate impact of precision ag technologies

With "dumb" planters you have to start planting and then go check seed spacing/depth

Image Source: Doug Smith

Immediate impact of precision ag technologies

Image Source: Doug Smith

Precision Planters give you information about the spacing on the fly.

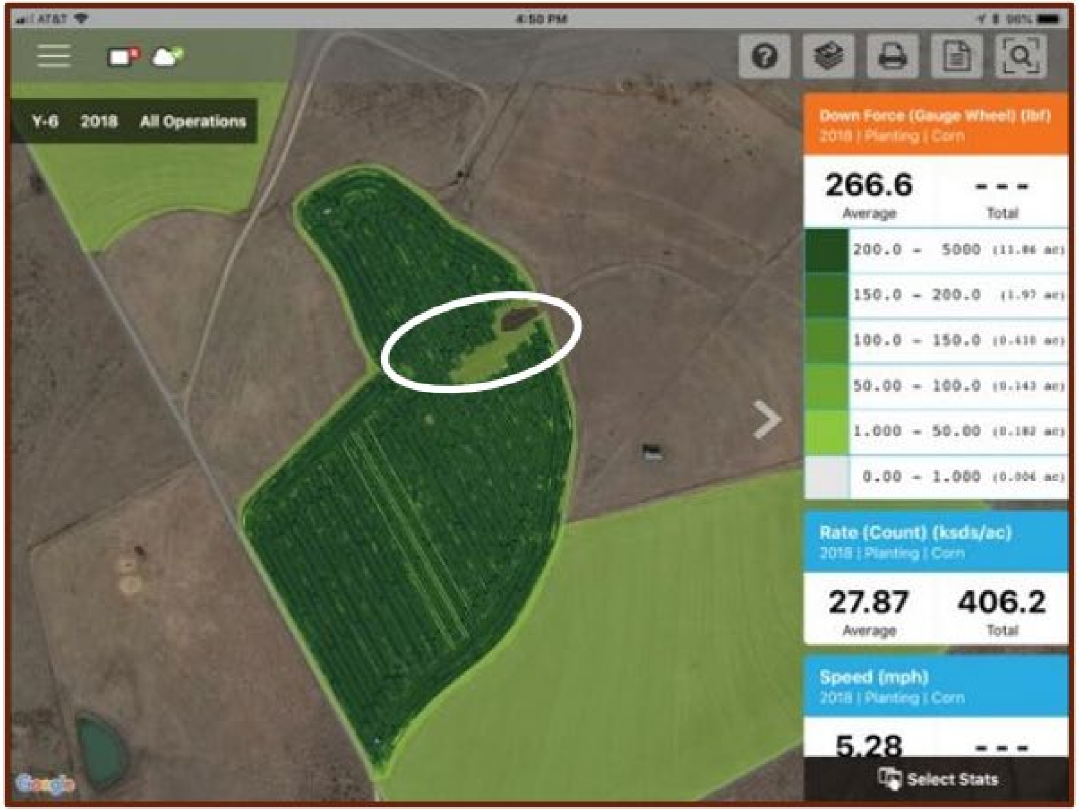
Immediate impact of precision ag technologies

Image Source: Doug Smith


Image Source: Doug Smith

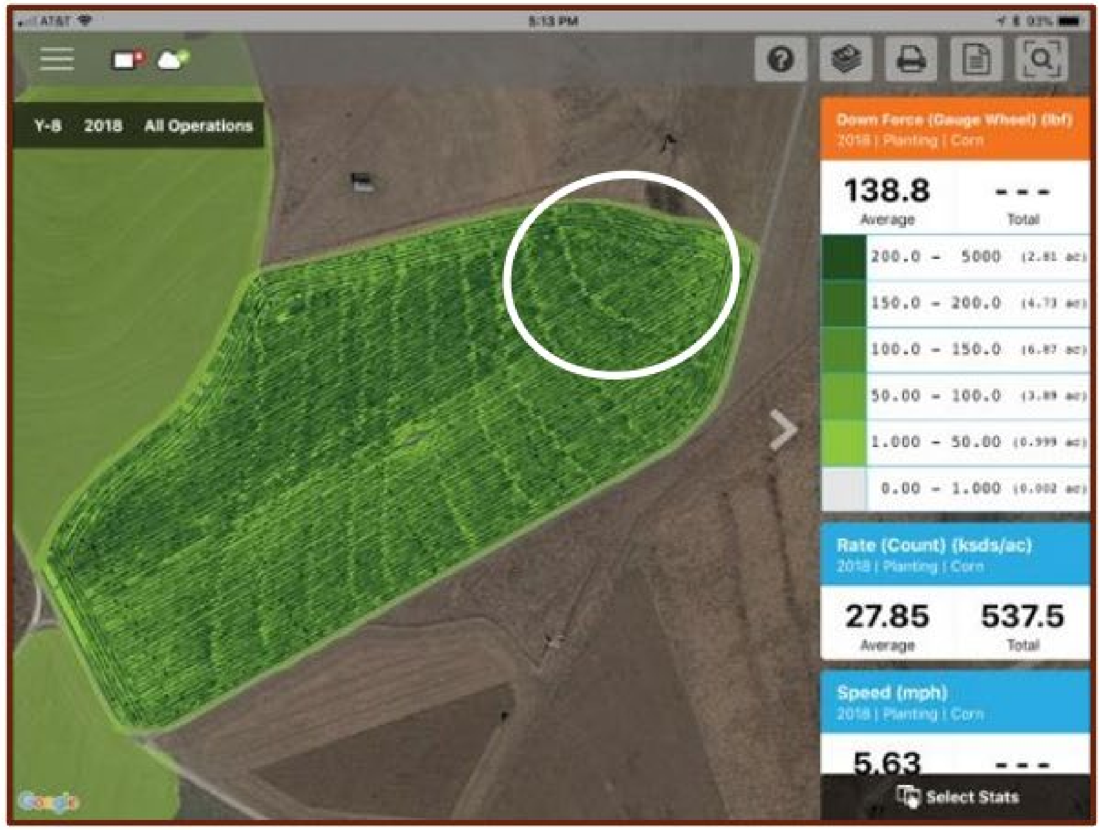
Relating Precision Agriculture to Conservation

Case 1 – Soil too wet to harvest in 2017 or plant in 2018



Relating Precision Agriculture to Conservation

Case 2 – Soil too wet to harvest in 2017 but supported planting in 2018

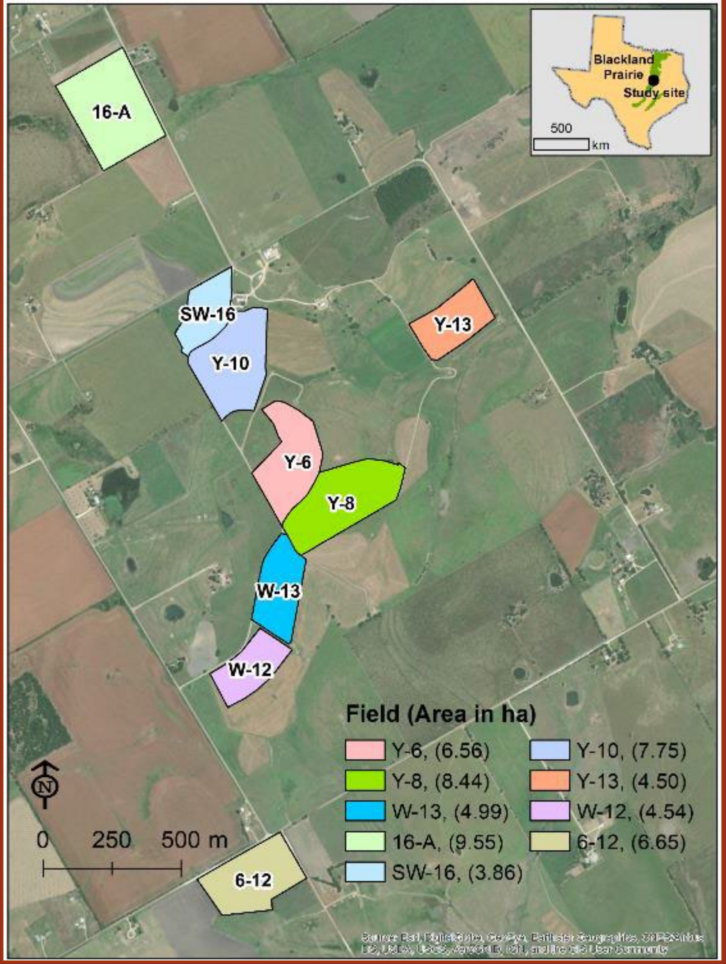


Immediate Impact of Precision Technologies

Image Source: Doug Smith

- Producers get immediate feedback through visualization
- Producers prone to pay special attention to new-found problems with equipment
- Hard data to focus on resource concerns

Methodology



Steps

1. Study Site
- Location: Riesel, TX
- 9 fields (Area; 57 ha)
- Different field mgmt

2. Multi-year yield measurement
- Yield data (Combine harvester)
- Year 2018, 2019, and 2020

3. Data cleaning
- Geographical and feature space

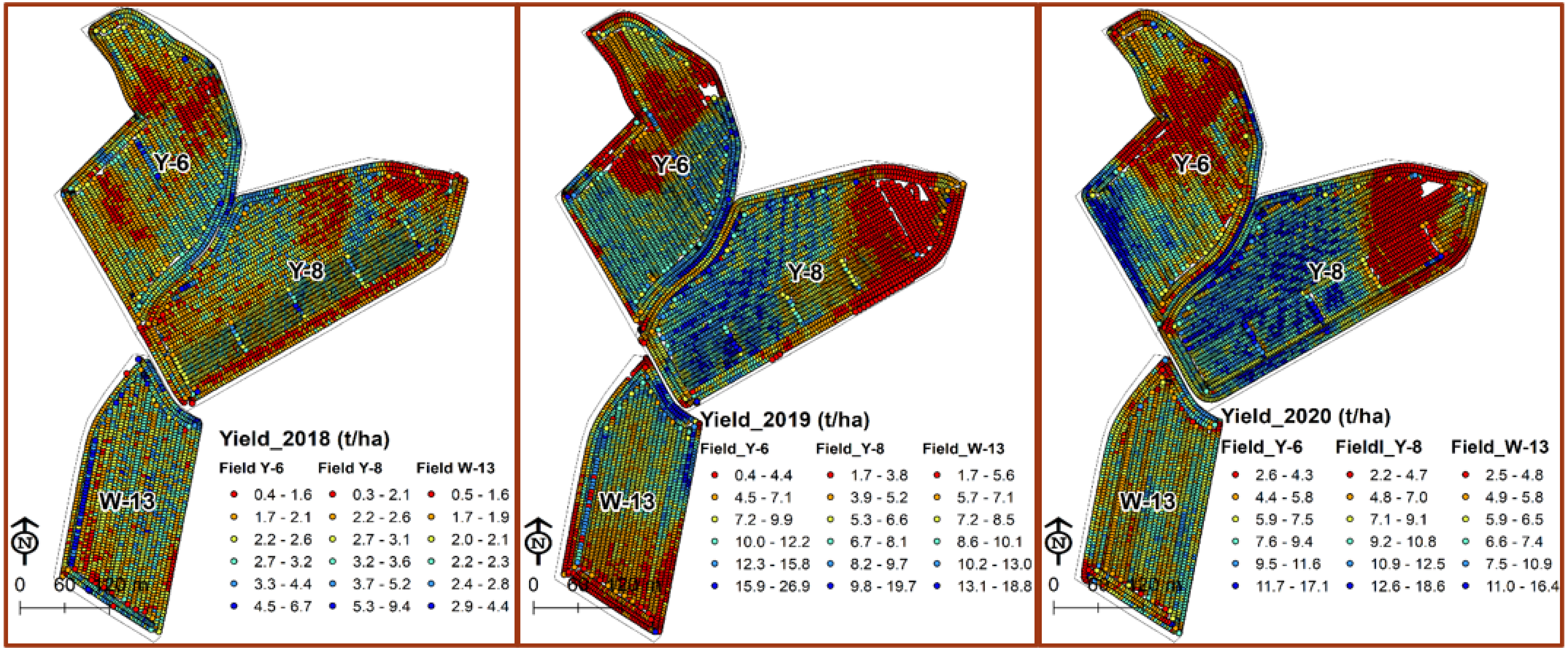
4. Yield mapping
- Block kriging (16 x 16 ft) with local variogram
- Prediction uncertainty

5. Temporal yield variation
- Mean and CV (2018, 2019, and 2020)

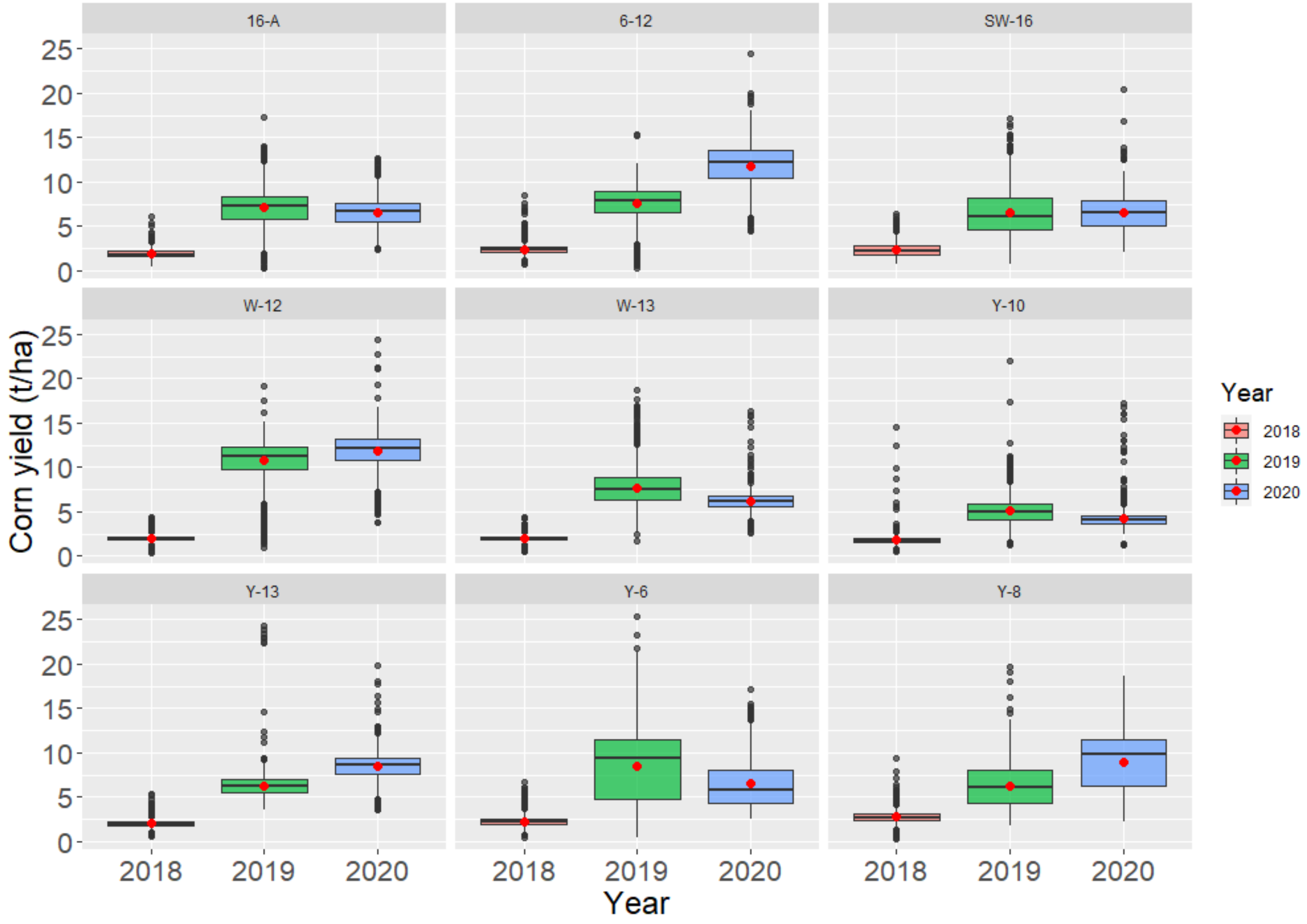
6. Stability Zones
- High yield-Low CV (Zone A)
- High yield-High CV (Zone B)
- Low yield-High CV (Zone C)
- Low yield-Low CV (Zone D)

7. Gross margin and Stability Zones

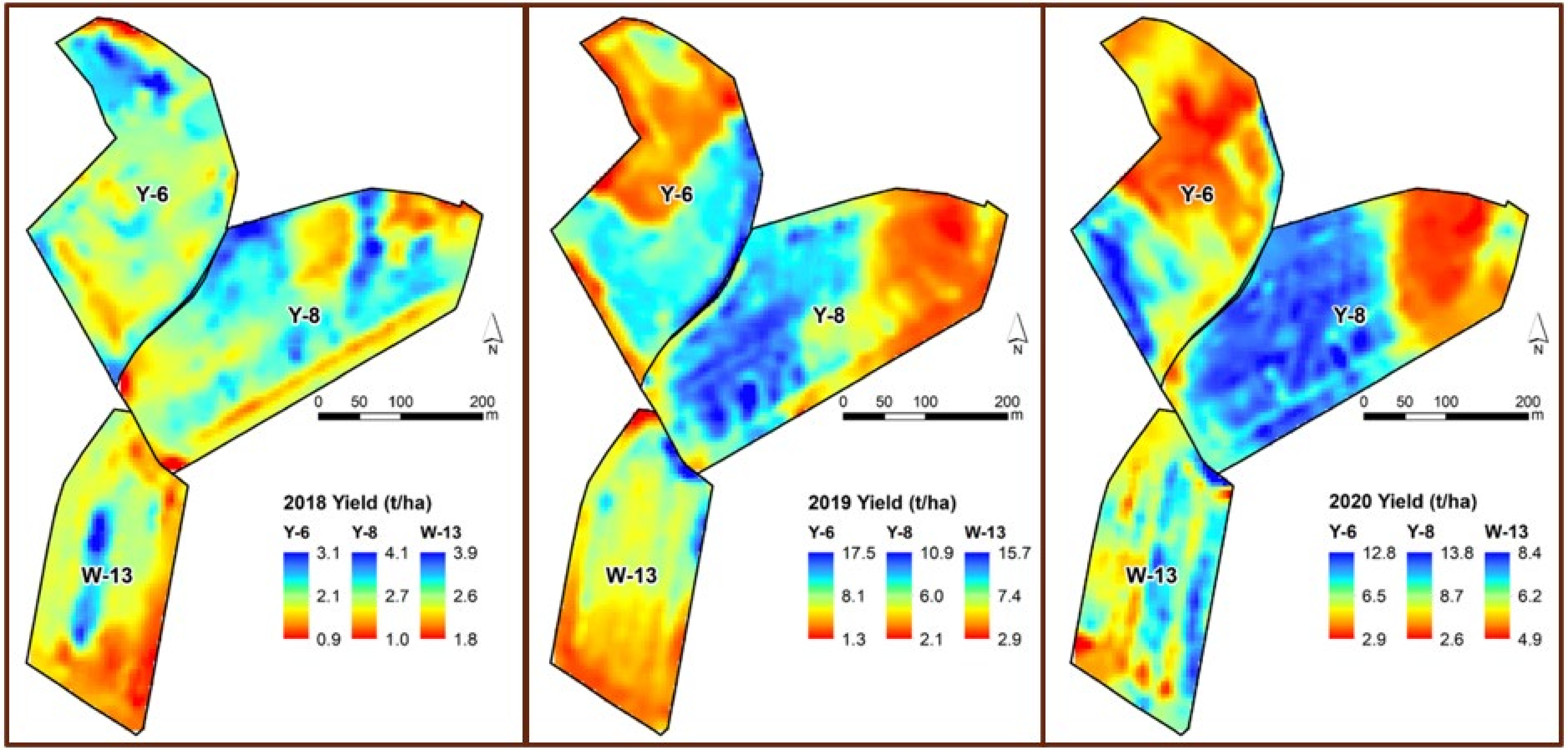
Yield Measurement



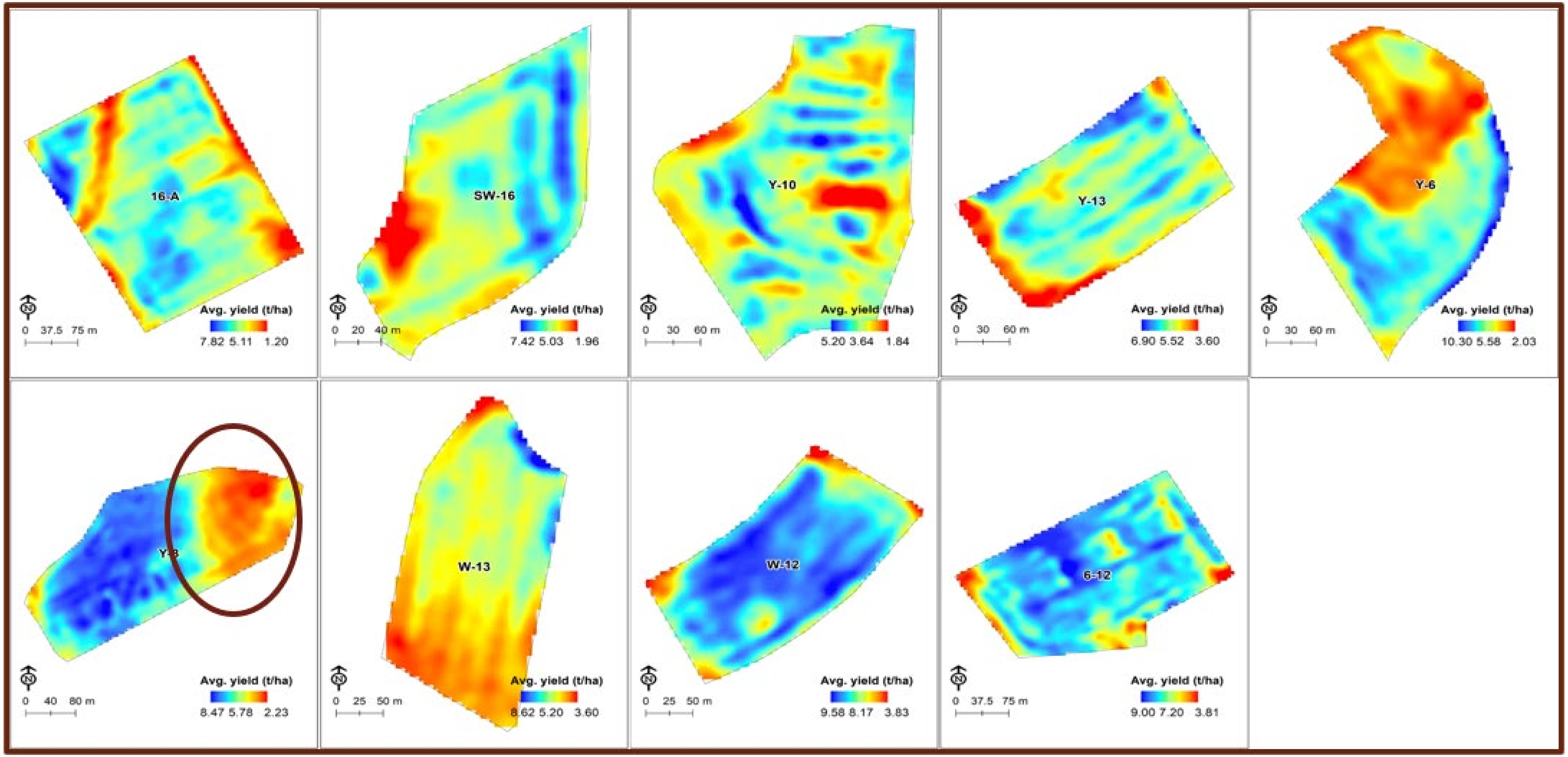
Corn Yield by Field and Year



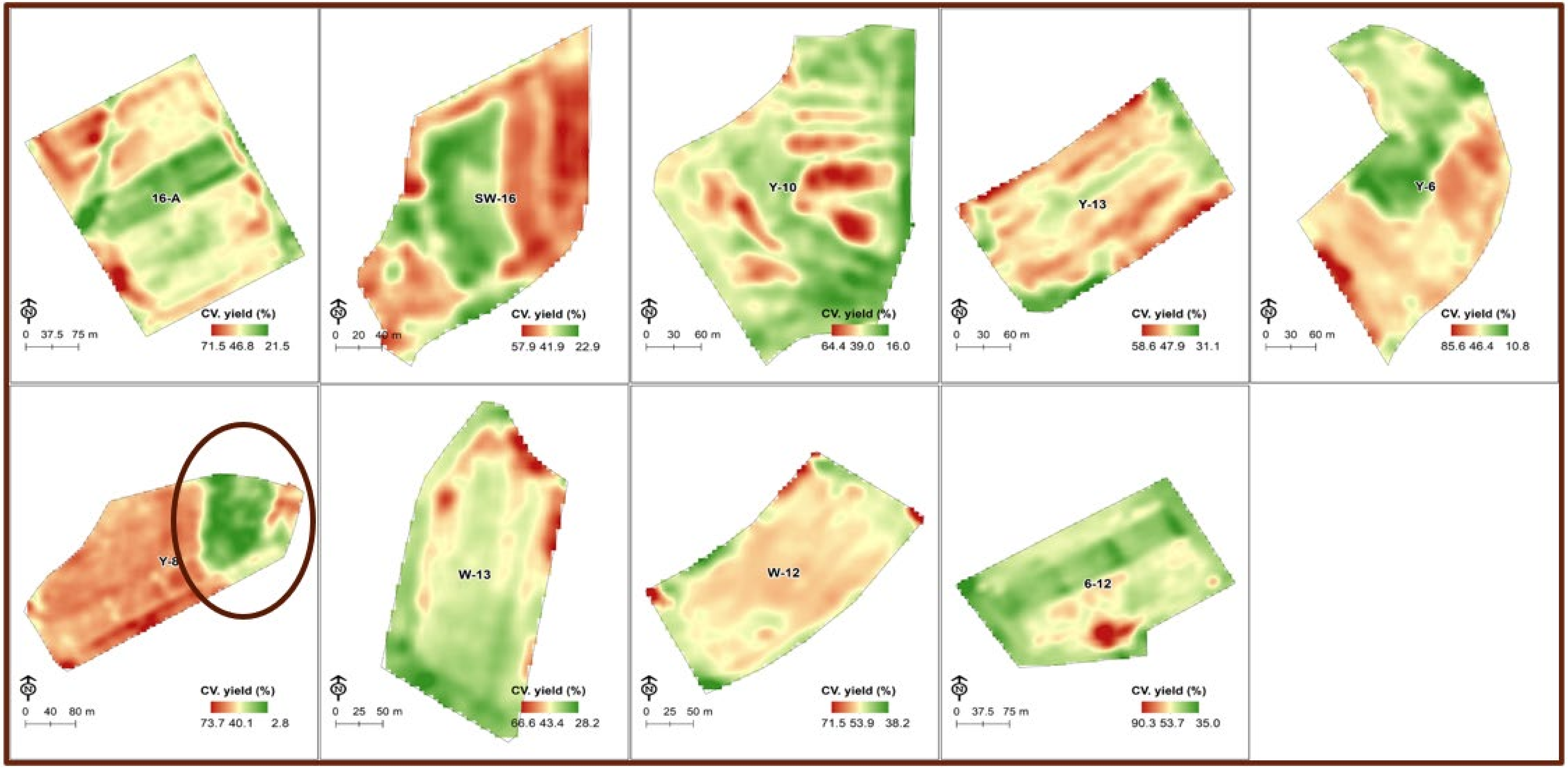
Yield Mapping



Average yield for 2018, 2019, and 2020

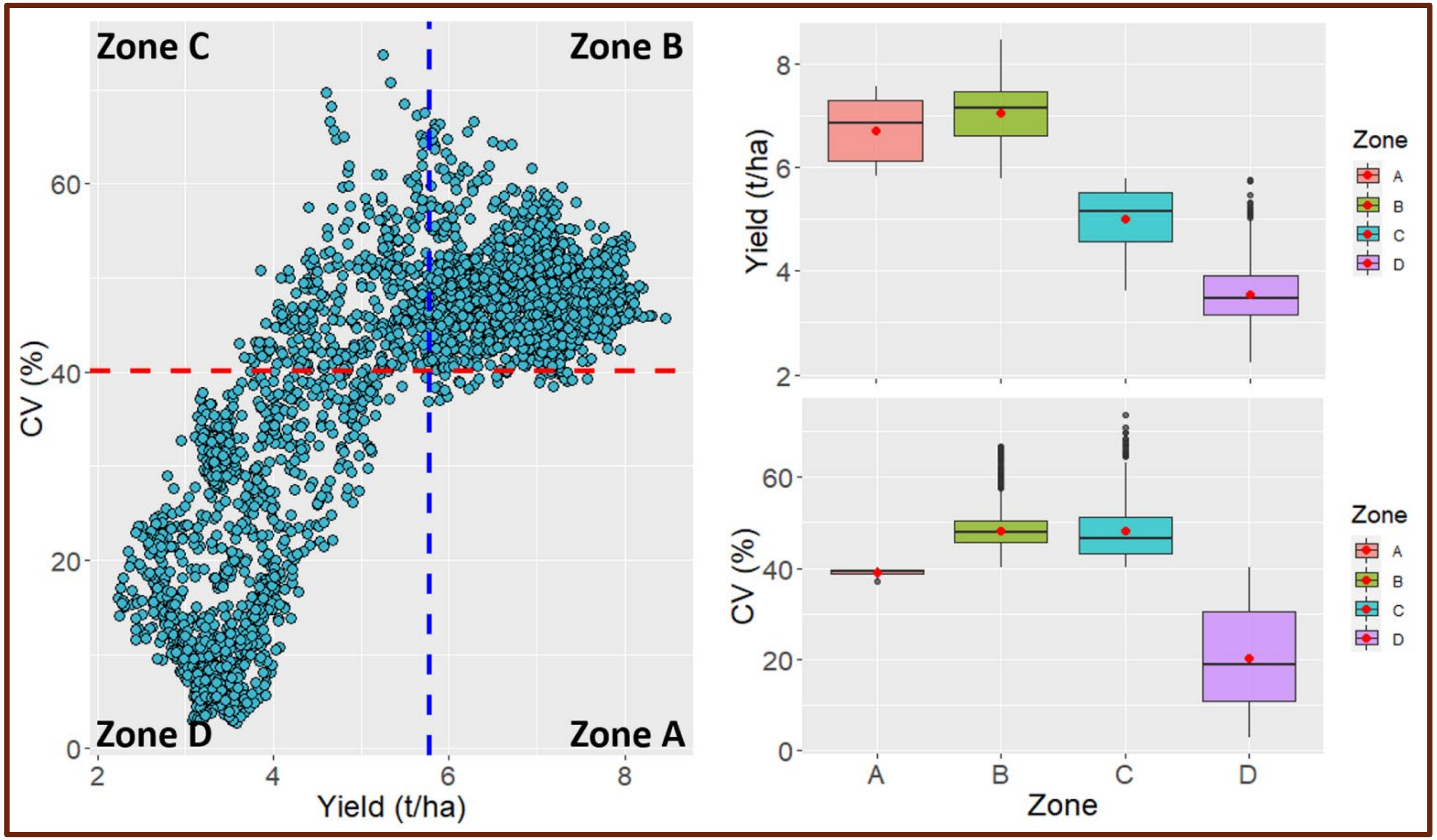


Yield Variability for 2018 – 2020 Growing Seasons

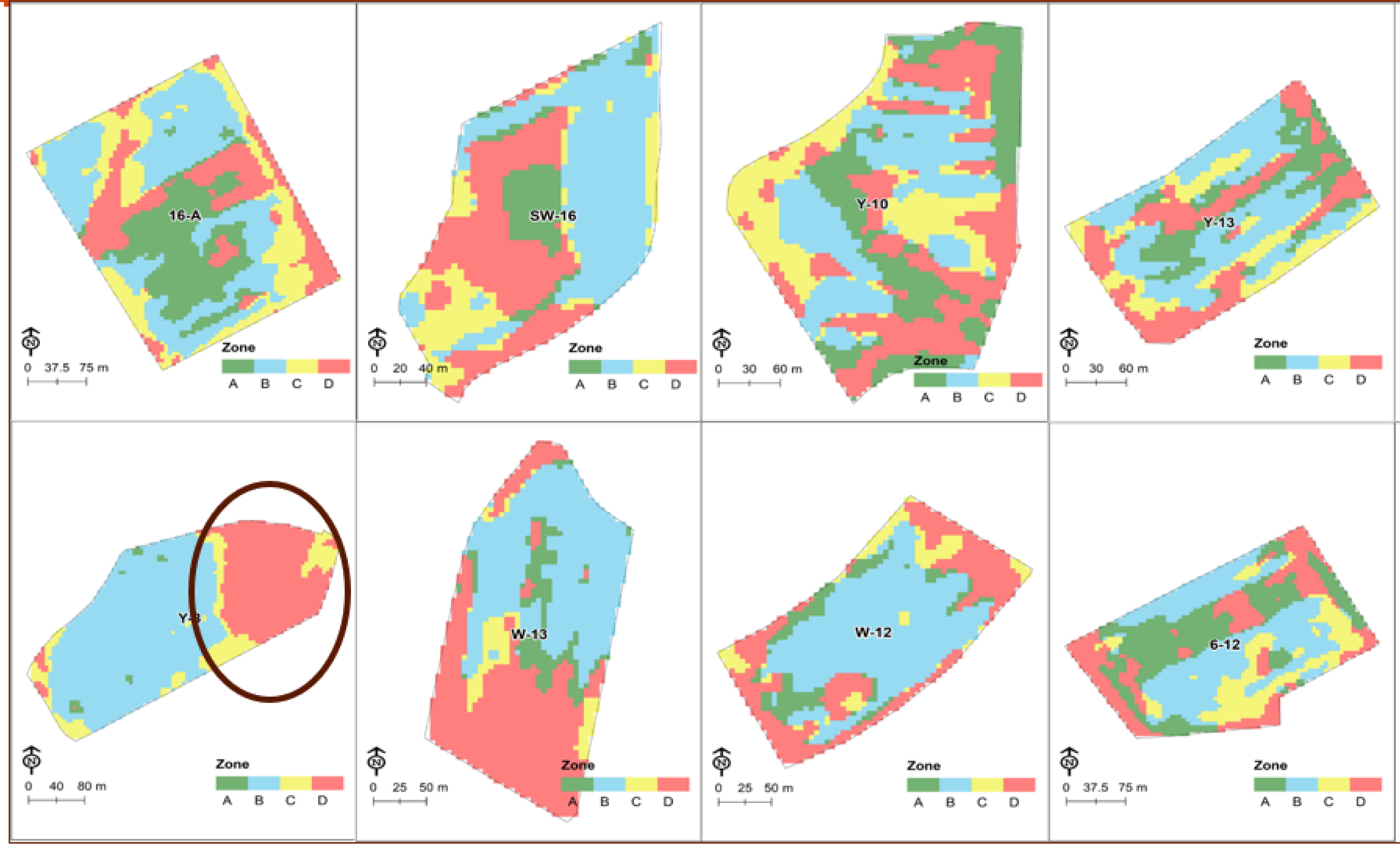


Yield Stability Zonation

Example: Field Y-8



Yield Stability Zones



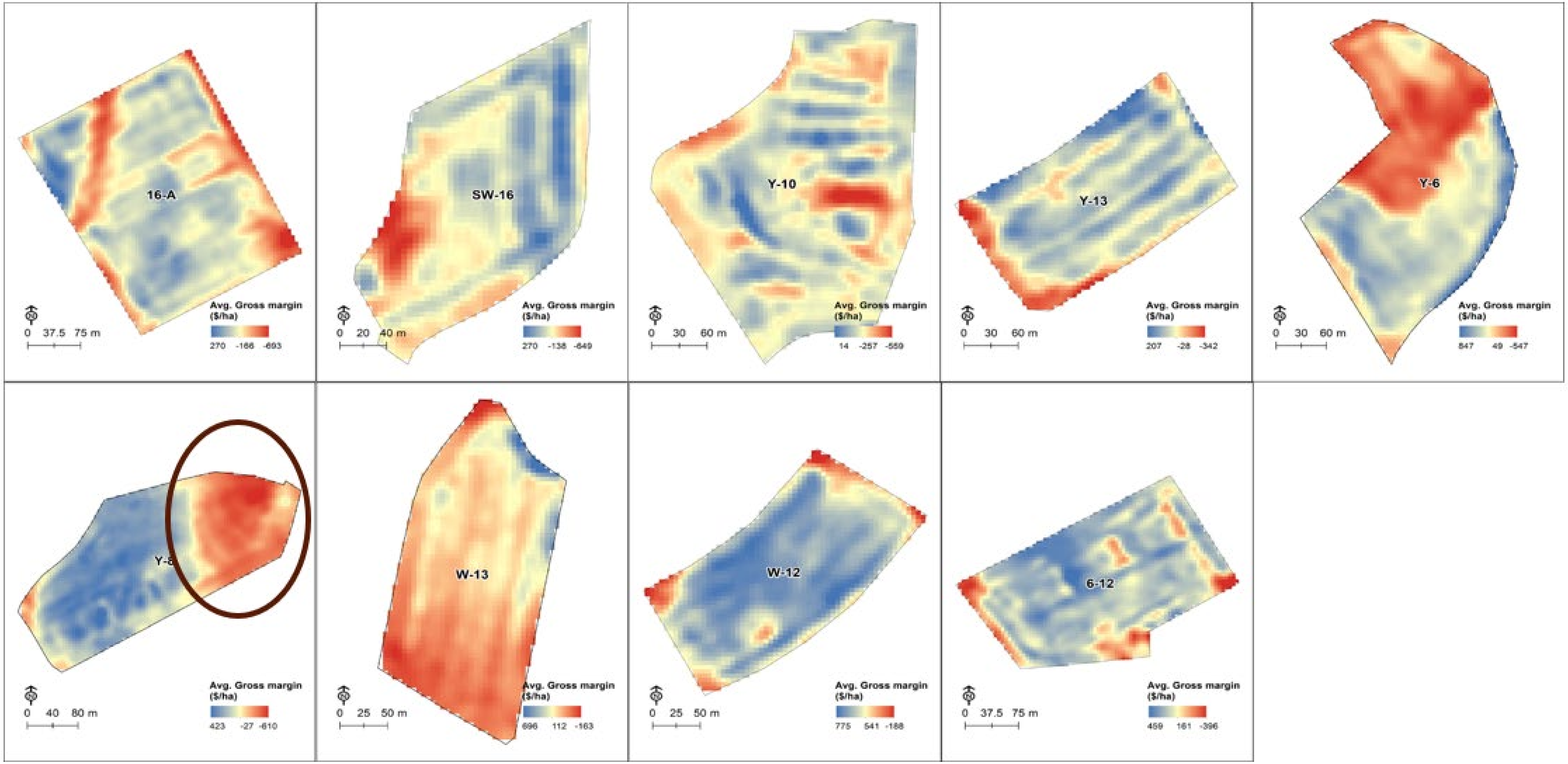
Zone A – High Yield, Low Variability

Zone B – High Yield, High Variability

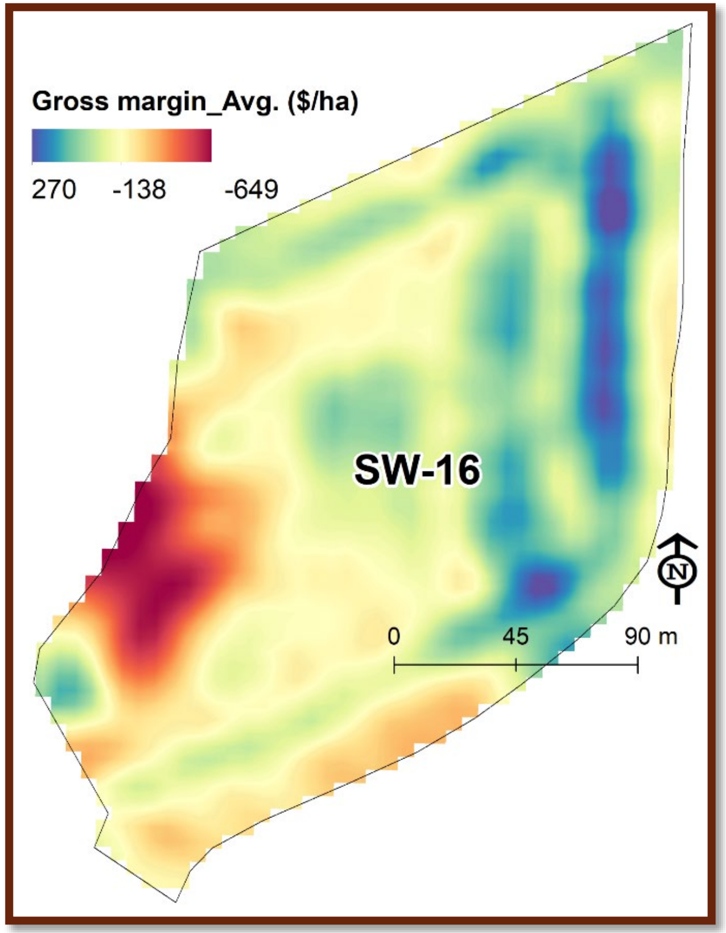
Zone C – Low Yield, High Variability

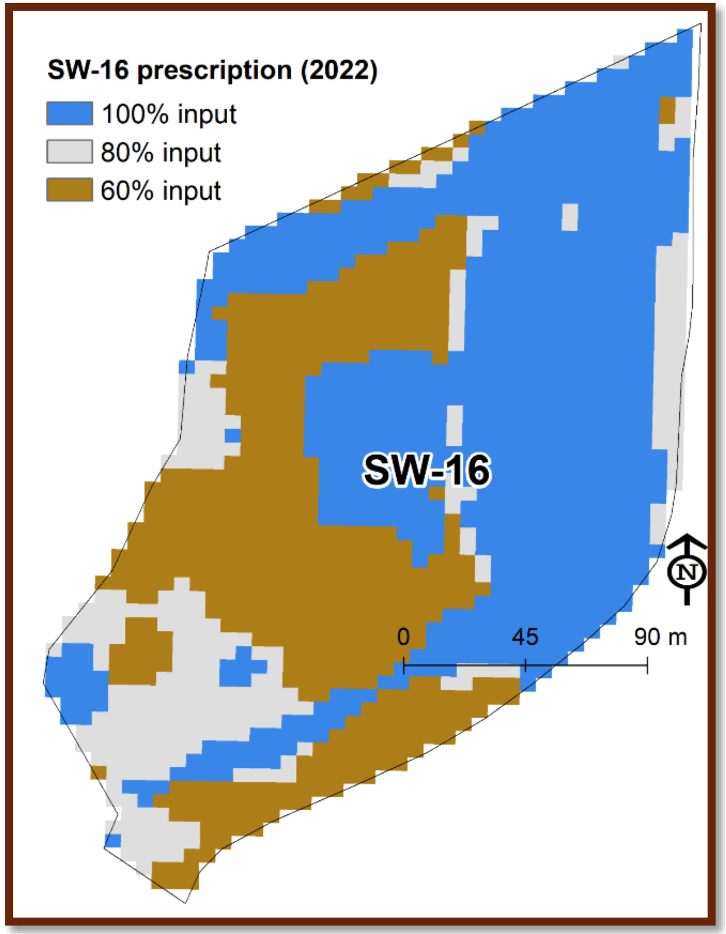
Zone D – Low Yield, Low Variability

Mapping Gross Margin ($GM_i = (Y_i\_t/ha \times CSP\_\$/t) - (VC\_t/ha - FC\_t/ha)$)

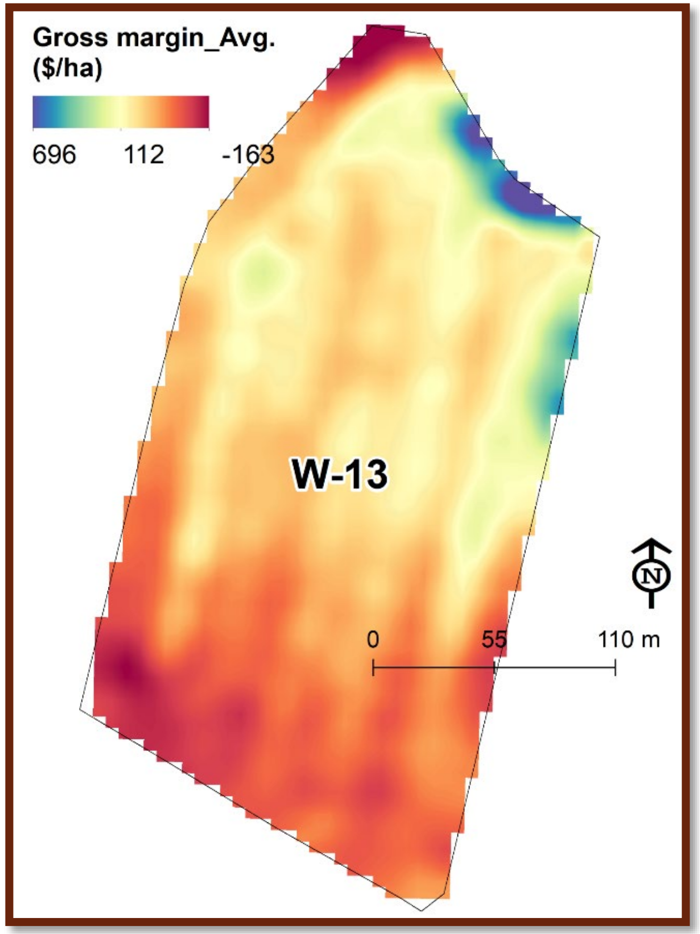


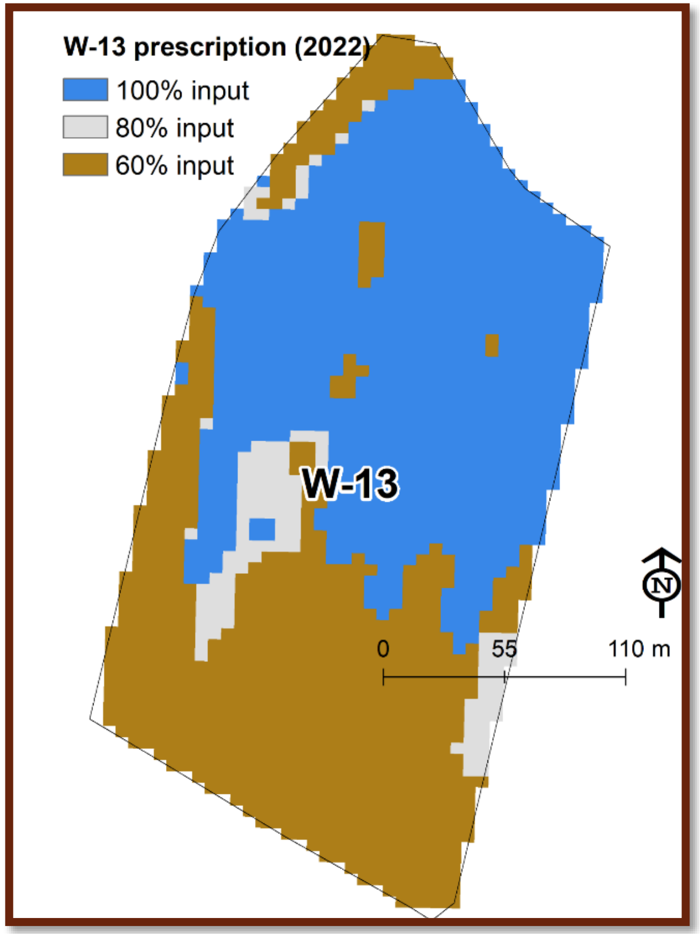
Developing Conservation Prescriptions for Phase 2



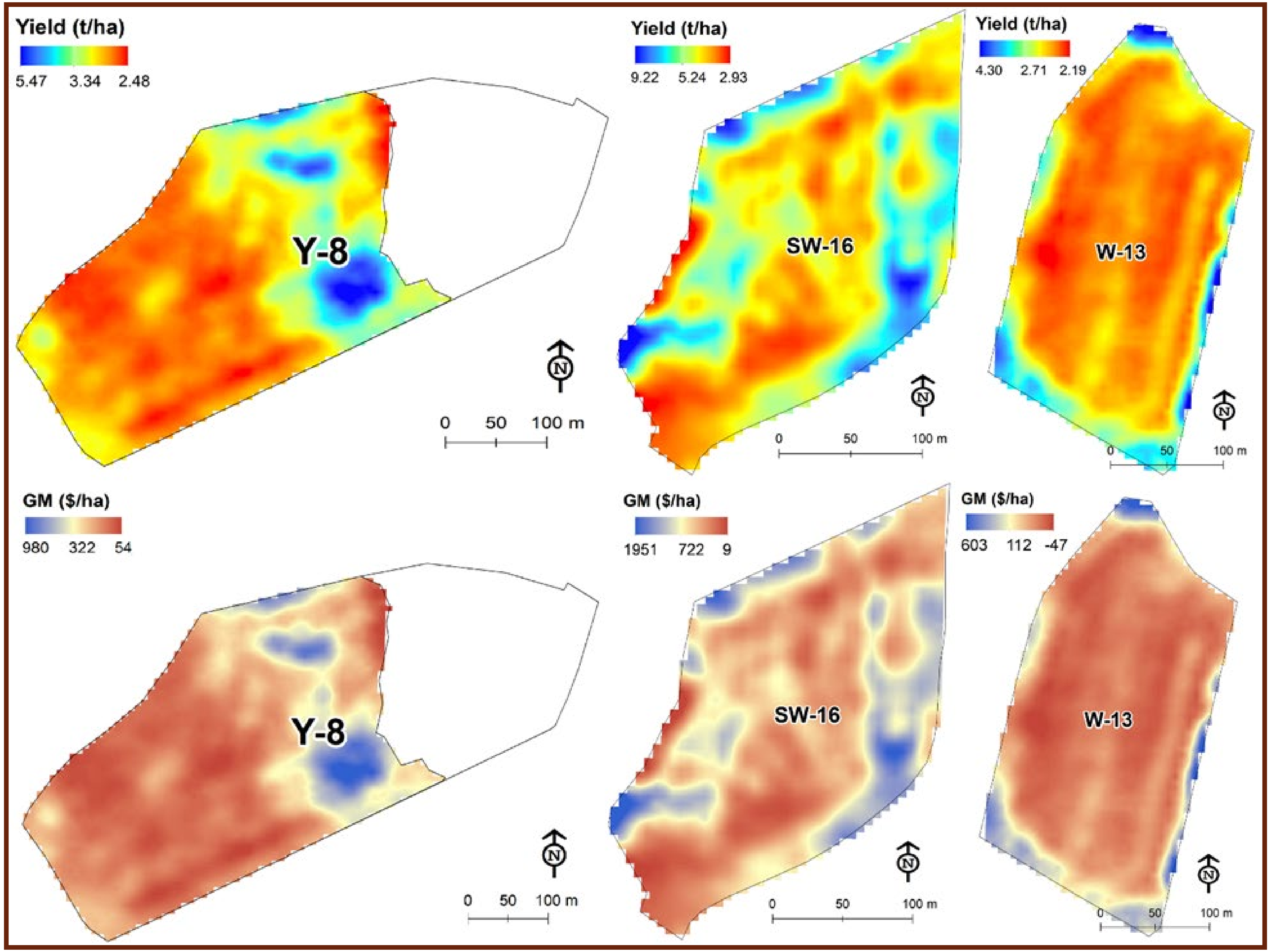


Developing Conservation Prescriptions for Phase 2

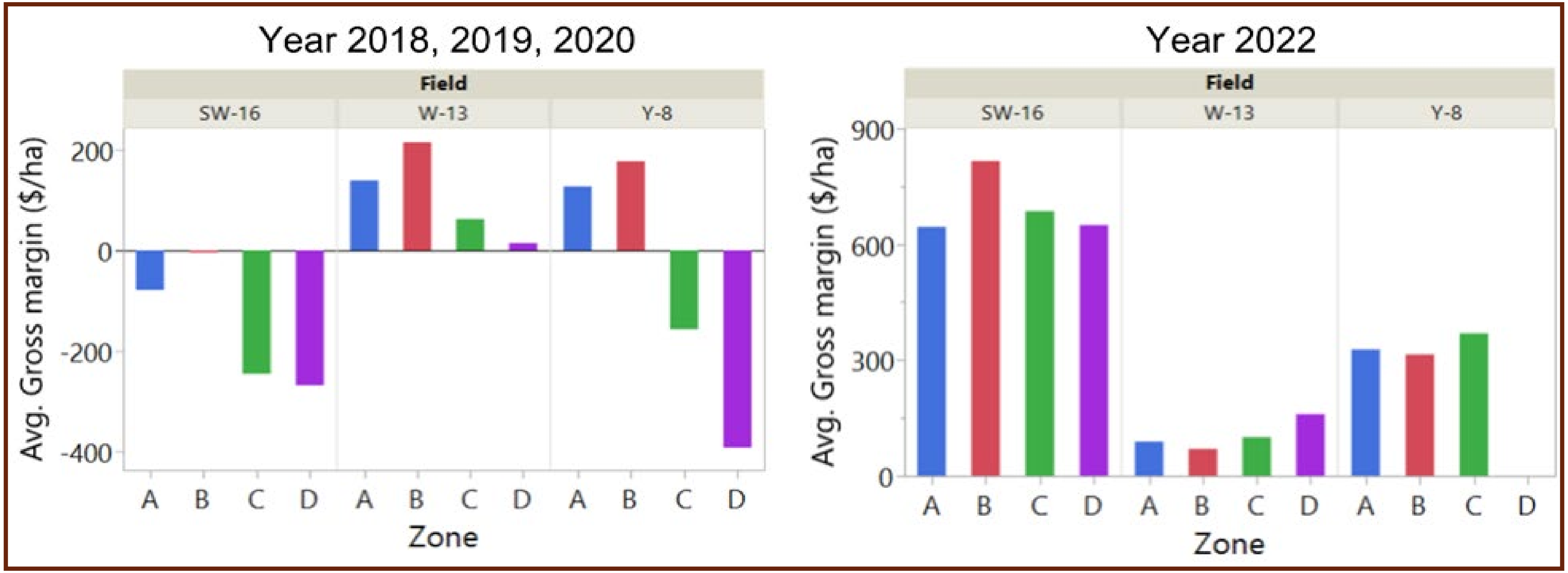




Geospatial Effects of Precision Conservation



How Does Precision Conservation Affect Profitability?



Zone A – High Yield, Low Variability, **Zone B** – High Yield, High Variability, **Zone C** – Low Yield, High Variability,
Zone D – Low Yield, Low Variability

Can Precision Conservation Impact Water Quality?

Treatment/Field	Before (2019)			After (2023)			Relative Change		
	NO_3-N	NH_4-N	SRP	NO_3-N	NH_4-N	SRP	NO_3-N	NH_4-N	SRP
Control	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac
Y6	14.2	0.77	0.17	3.71	0.10	0.27	74%	87%	-59%
W12	11.5	1.97	0.60	2.39	0.11	0.05	79%	94%	92%
Reduced Inputs									
W13	4.02	1.03	0.46	0.25	0.23	0.01	94%	78%	98%
Eliminate Inputs									
Y13	14.4	1.66	0.78	0.58	0.3	0.12	62%	82%	85%
Y8	15.1	3.26	1.13	2.09	0.22	0.03	86%	93%	97%

Note: NO_3-N (Nitrate), NH_4-N (Ammonia), SRP (Soluble Reactive Phosphorus)
Precision Conservation Treatments were established in 2022, which was a drought year. Corn was the primary crop in 2019 and 2023 and both years had wet springs following a drought.

Precision Ag Intermediate Term Benefits

Takes several years to understand systems

Annual yield, variability and economics provide some power to adjusting agronomic management

Economic benefit to reducing inputs where low yield occurs

Preliminary work shows there may be some benefit to water quality

Will need more years of data to gather the full picture

Image Source: Doug Smith

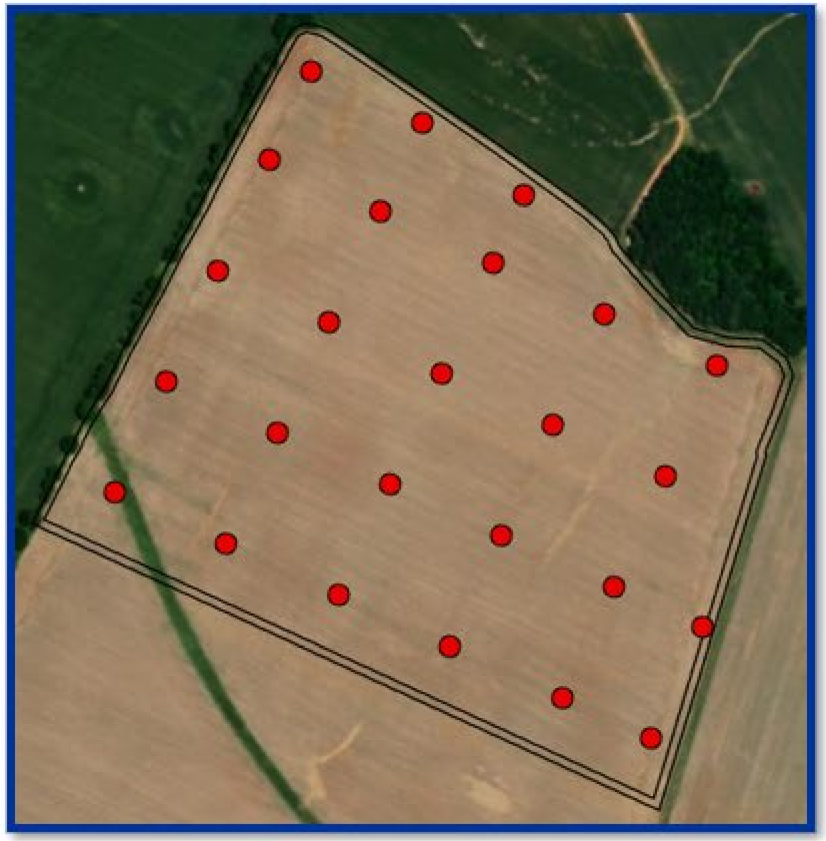
Precision Fertility

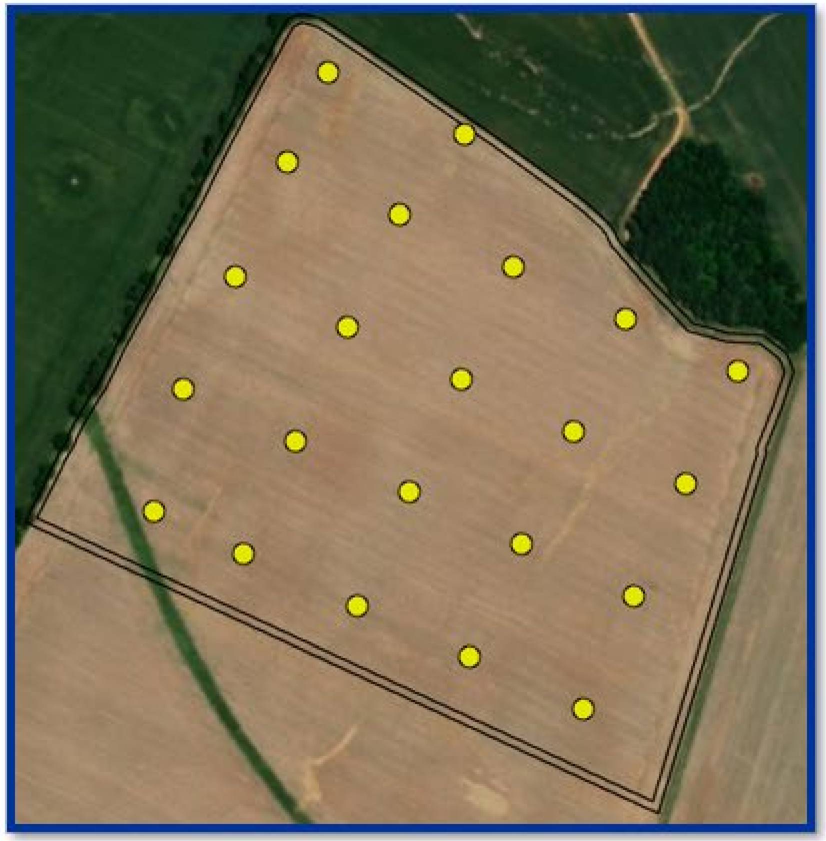
Image Source: Doug Smith

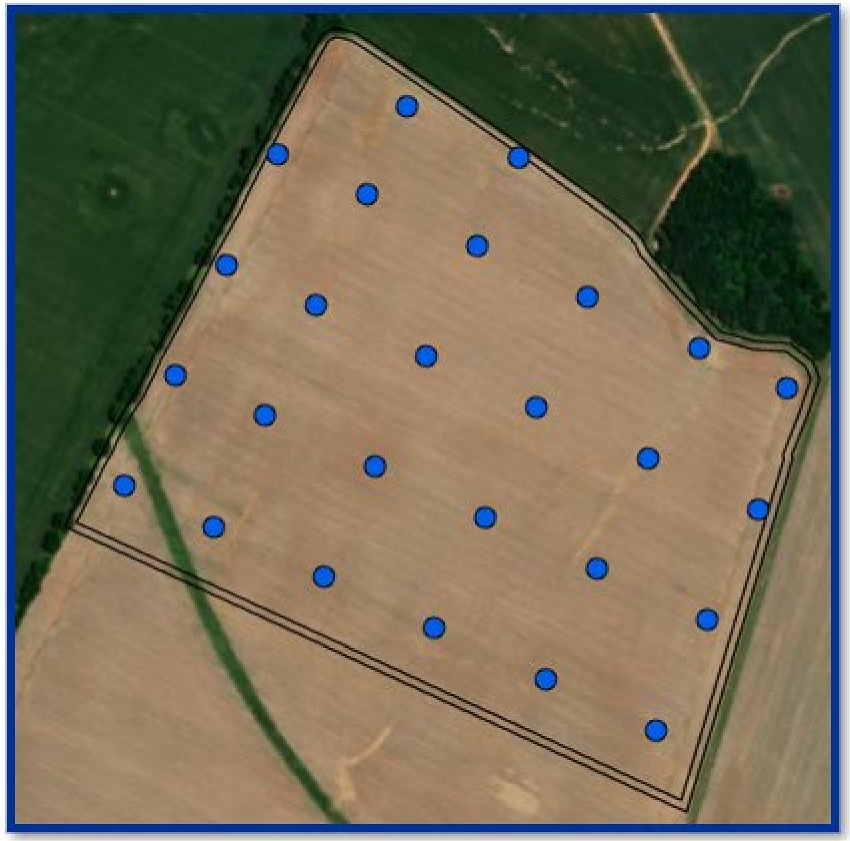
What do we really know about fertility?

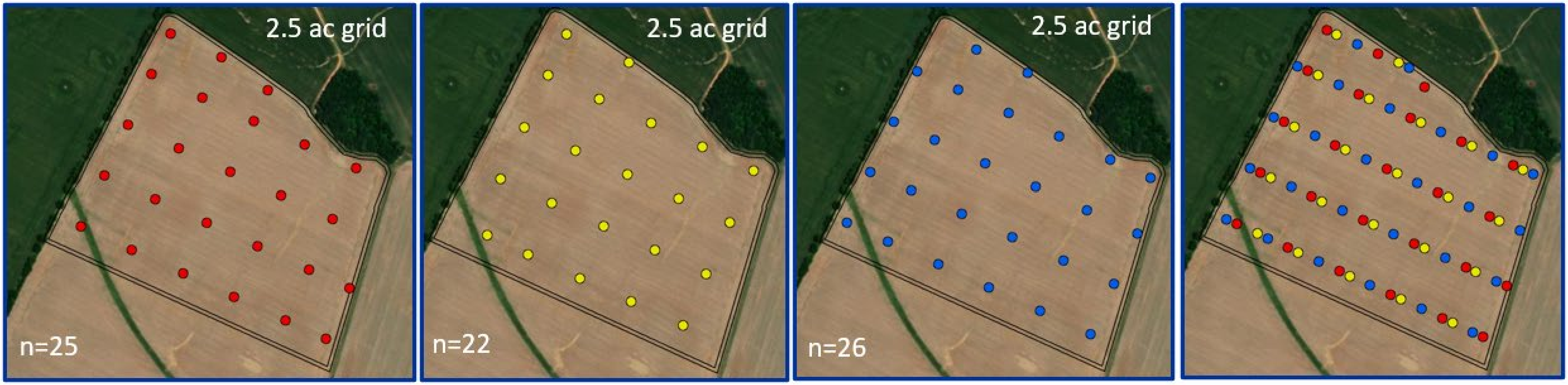
Are fertility recommendations correct?

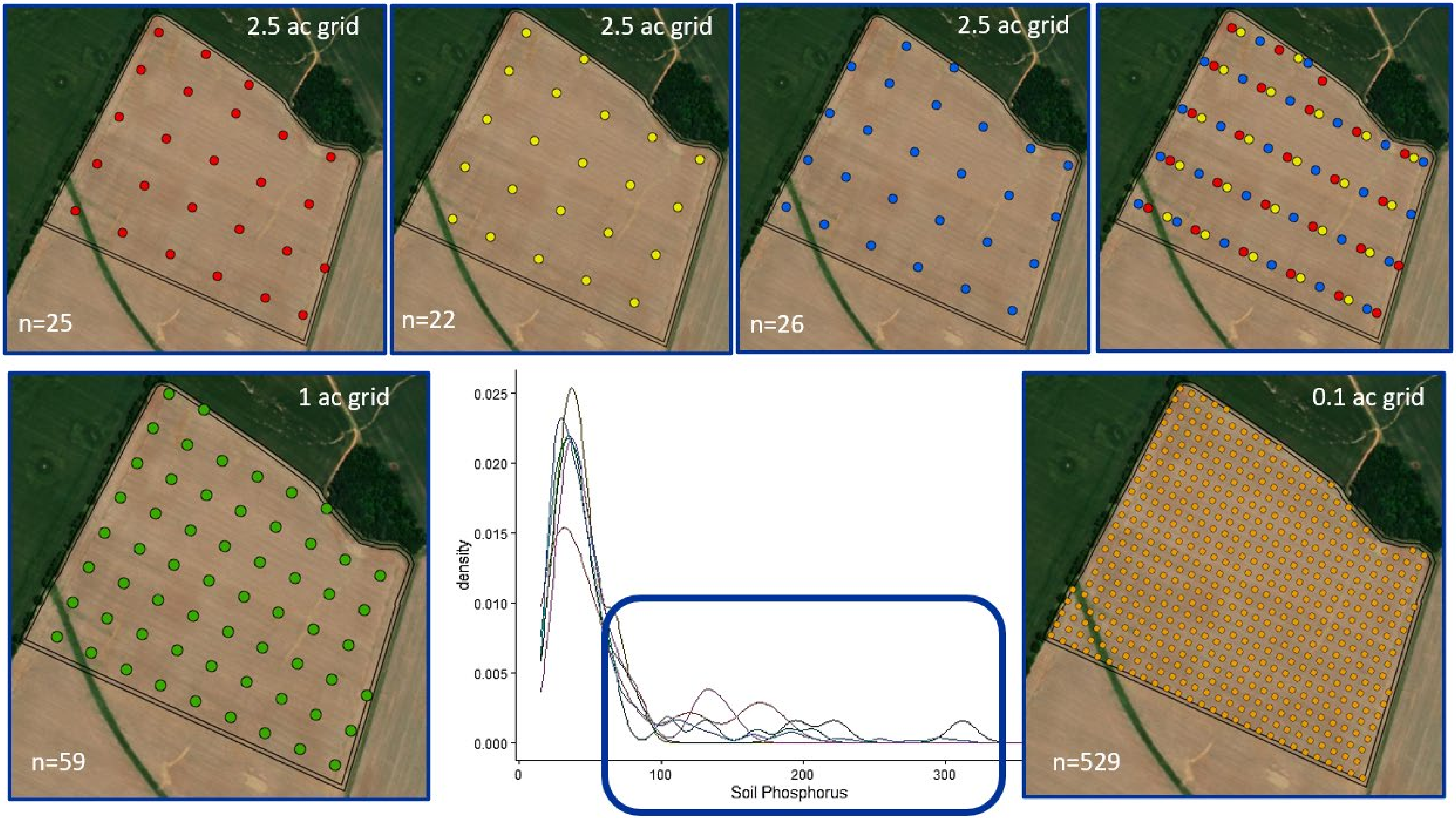
How precise can we get with fertility applications?








2.5 ac grid
n=25
2.5 ac grid
n=22
2.5 ac grid
n=26

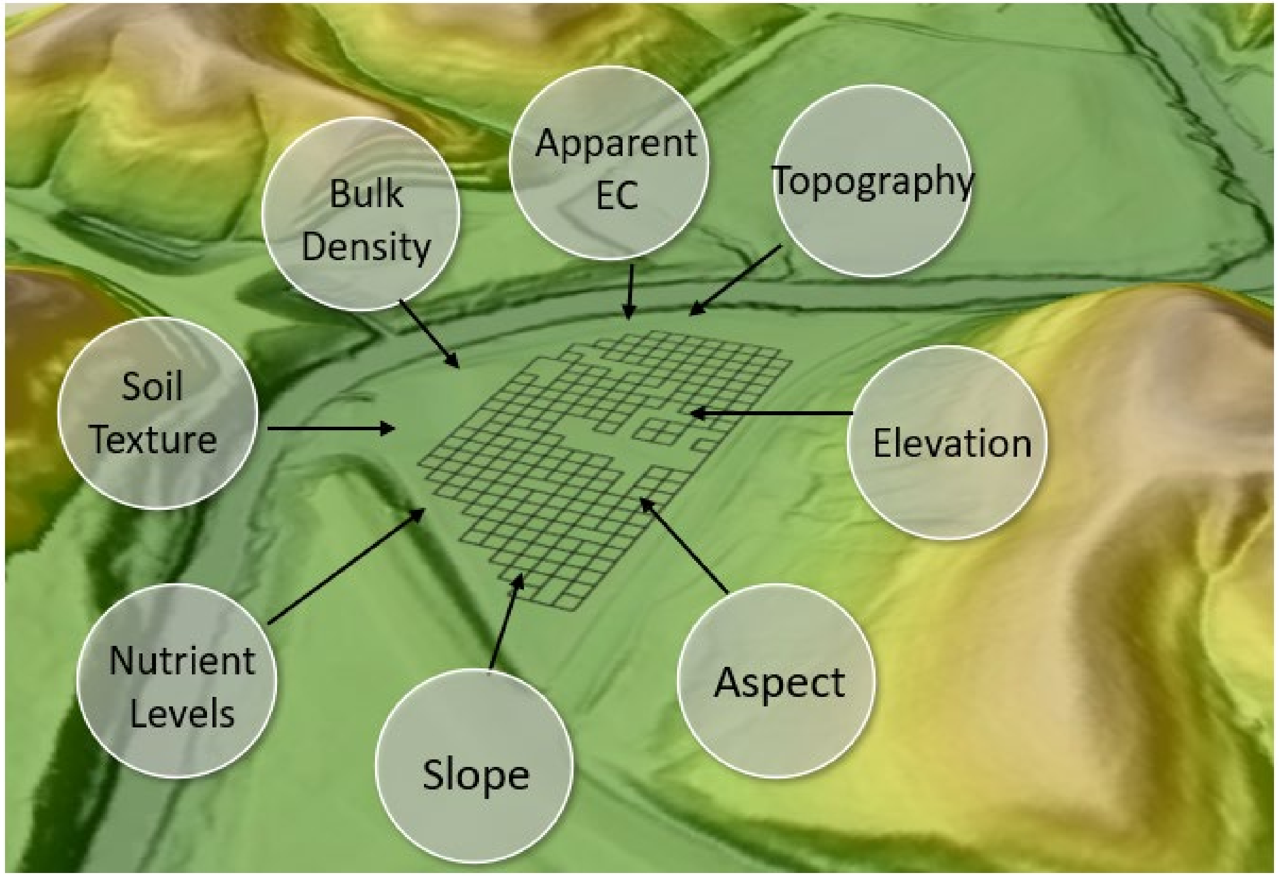


Courtesy University of Kentucky

Grid Sampling Comparisons – Phosphorus

Grid Type	Mean, lbs/ac	Std dev, lbs/ac	Minimum, lbs/ac	Maximum, lbs/ac	CV, %
1 acre	51.8	39.8	**18**	**207**	**76.9**
2.5 acre (1)	60.9	49.7	**17**	**184**	**81.6**
2.5 acre (2)	43.8	17.3	18	85	39.5
2.5 acre (3)	65.8	69.2	**22**	**312**	**105.2**
0.1 acre	53.7	46.6	**15**	**367**	**86.8**

Simple Zone From Topography and Texture



Nutrient response trends with soil and topography

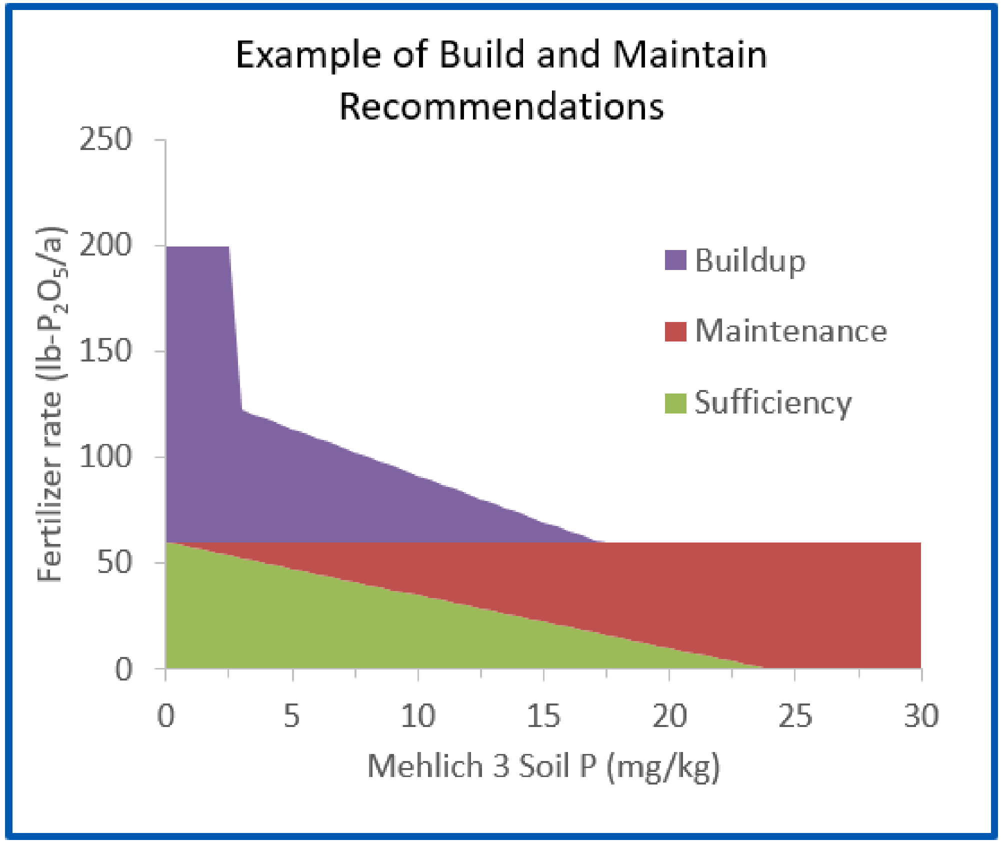
Use slope, aspect, elevation, soil map (apparent EC or NRCS), grid data…

Yield can be used to check zones – but not necessarily to make fertilizer recommendations

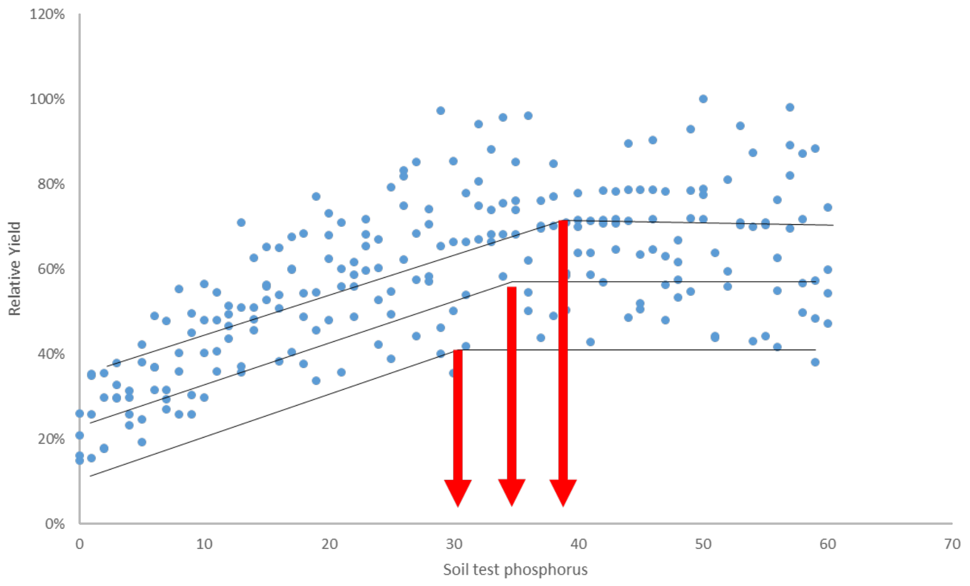
Even if we can map the field, do we have precise recommendations?

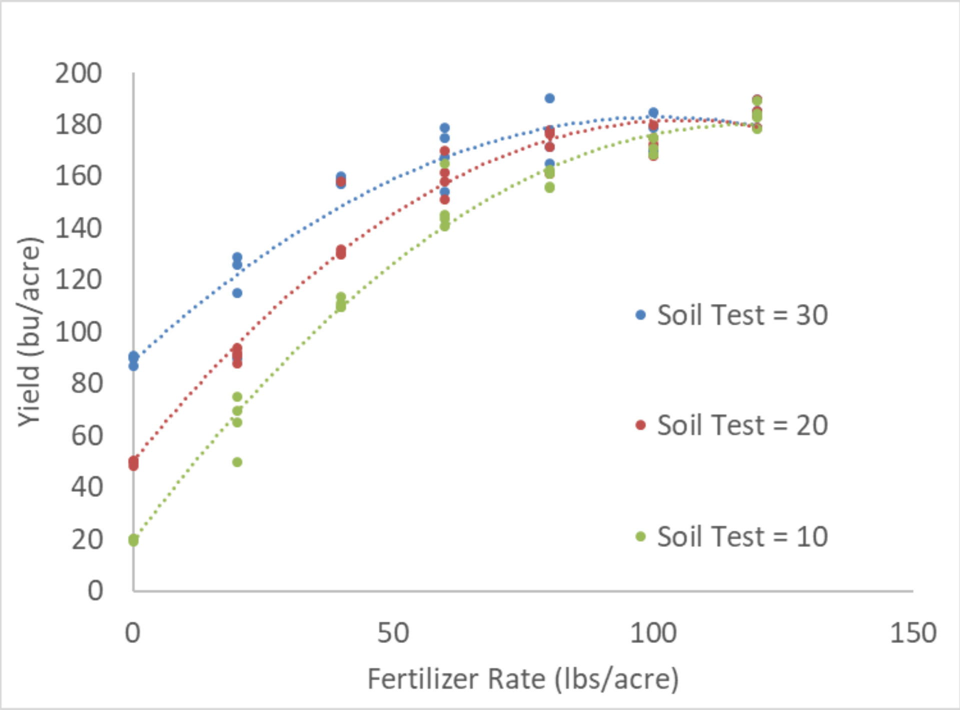
Making Recommendations

1. Sufficiency approach
   - When soil test level is below optimum, apply only enough nutrients to meet crop needs
2. Buildup and maintenance approach
   - Rapidly build low soil test concentrations to optimum level
   - Replace nutrients removed by crop at higher soil test levels where response is not expected
3. Hybrid Approach



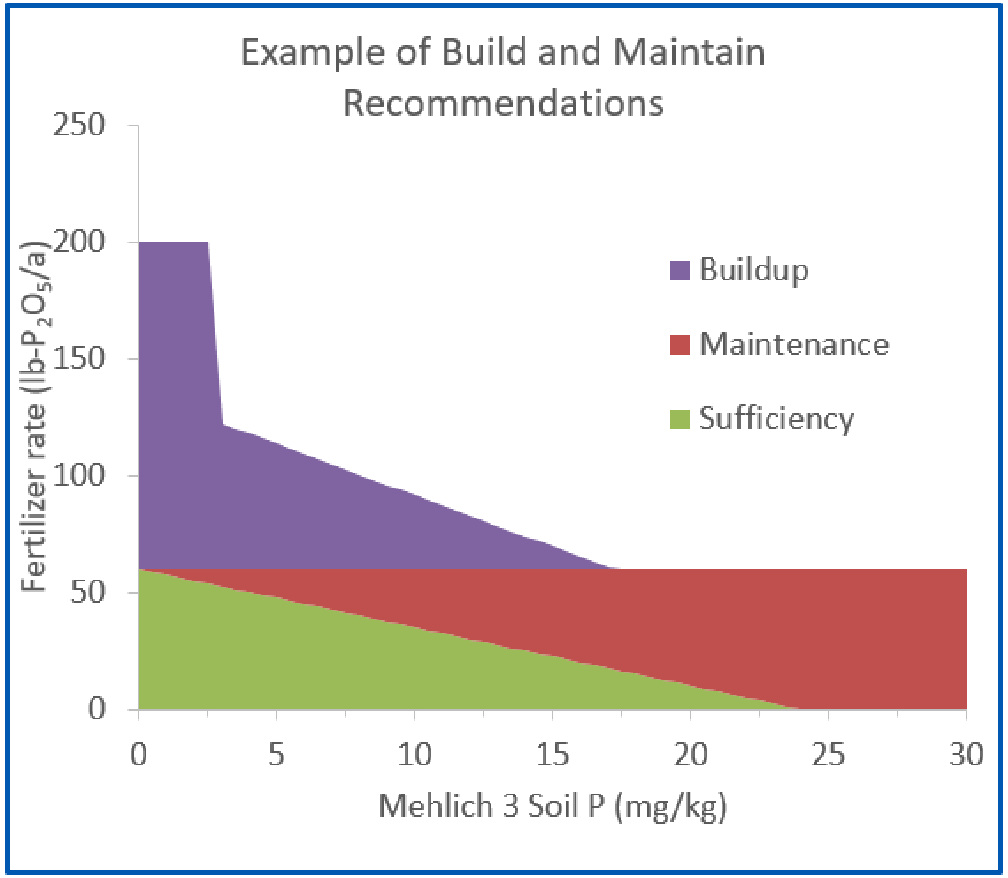
Variability in correlation and calibration results?





Partly responsible for the "extra" we have built into recommendations

How should we make precise recommendations?

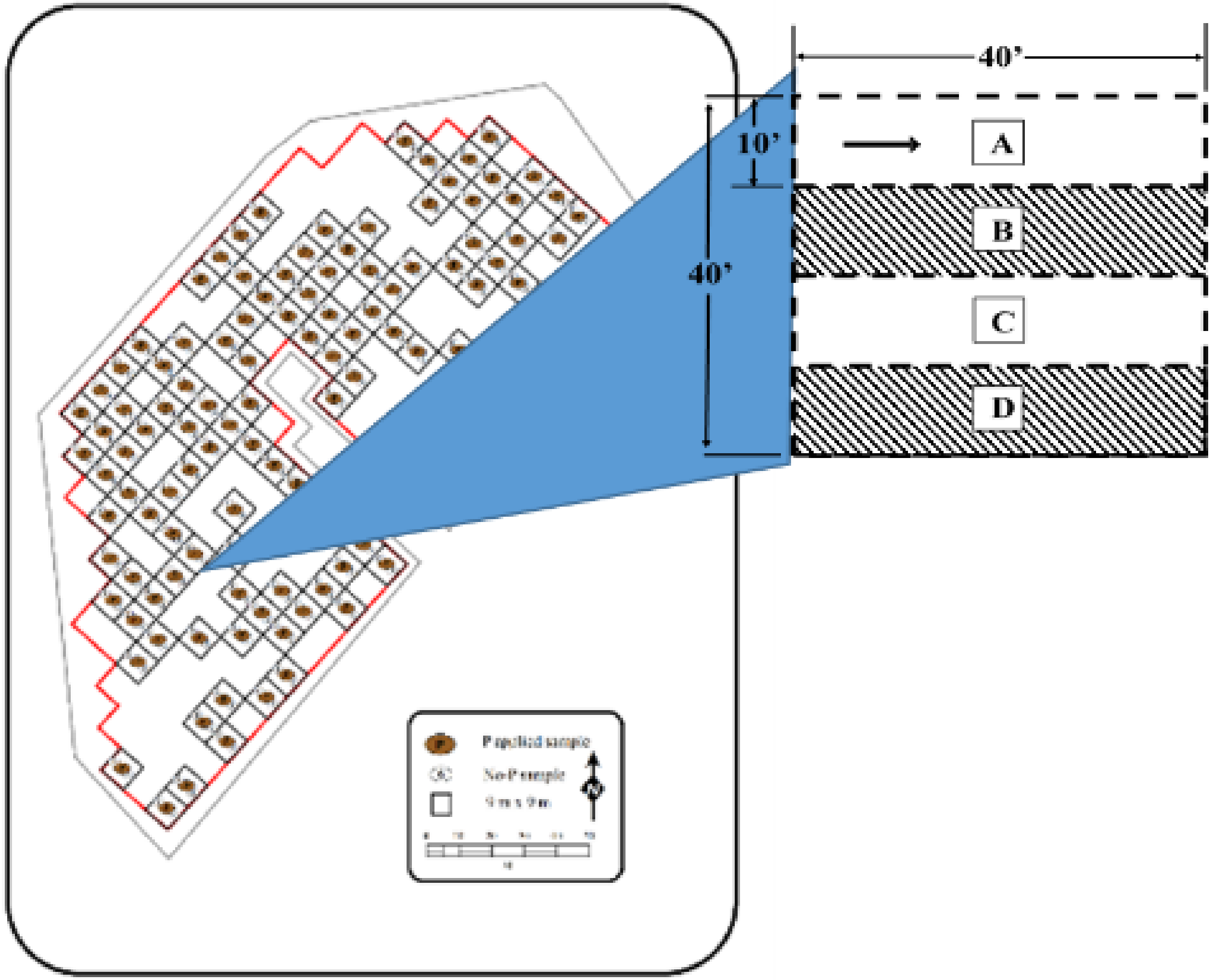


Precision ag – Hybrid approach
- Frequent soil tests and sufficiency rates
- We need to know the yield maximizing (sufficiency) rate
- Sufficiency rate < build & maintain

Sufficiency probably < crop removal
- Buffer capacity makes up difference

Site Specific Management research –spatially explicit correlation

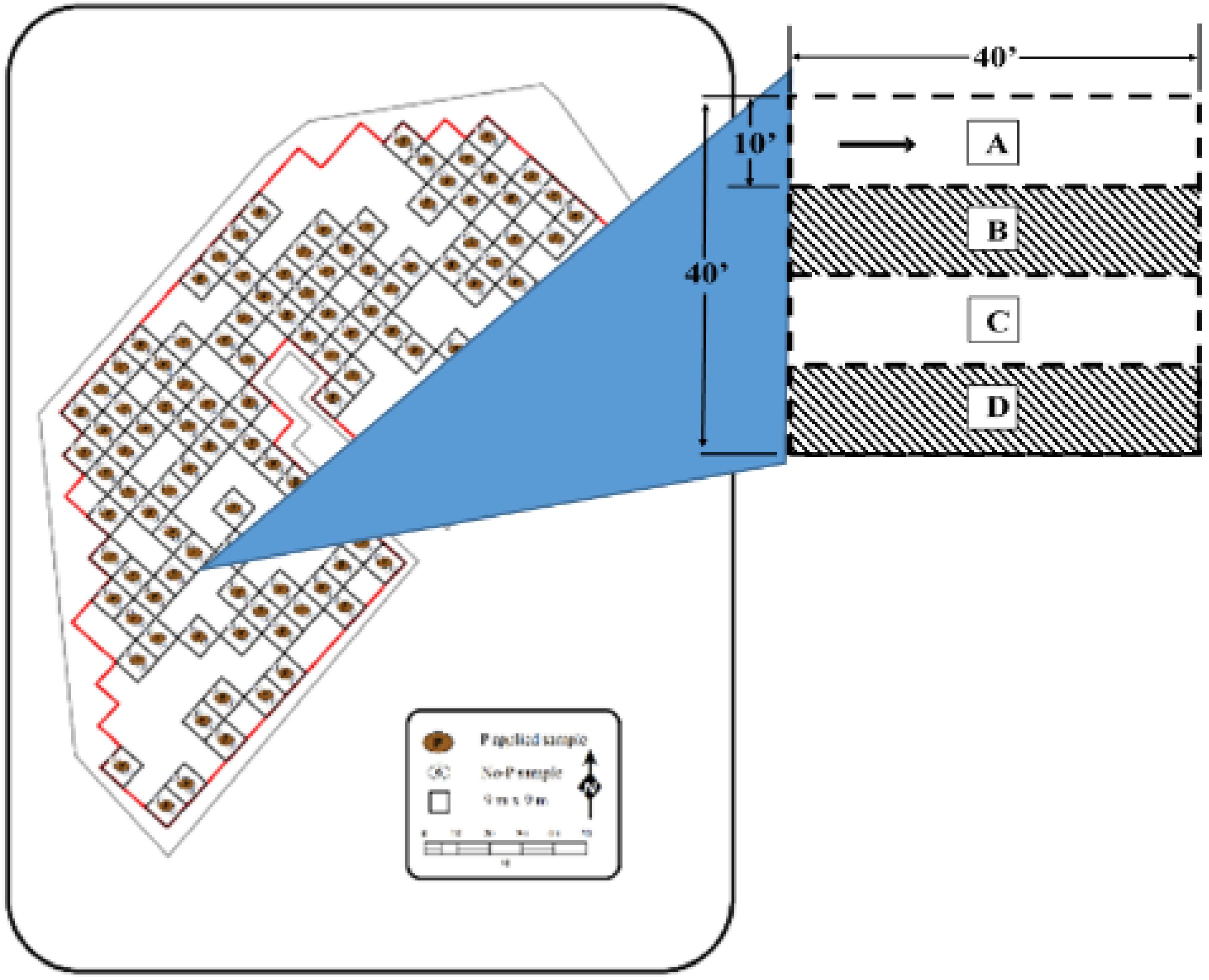
Reduced plot size to limit variability



Site Specific Management research –spatially explicit correlation

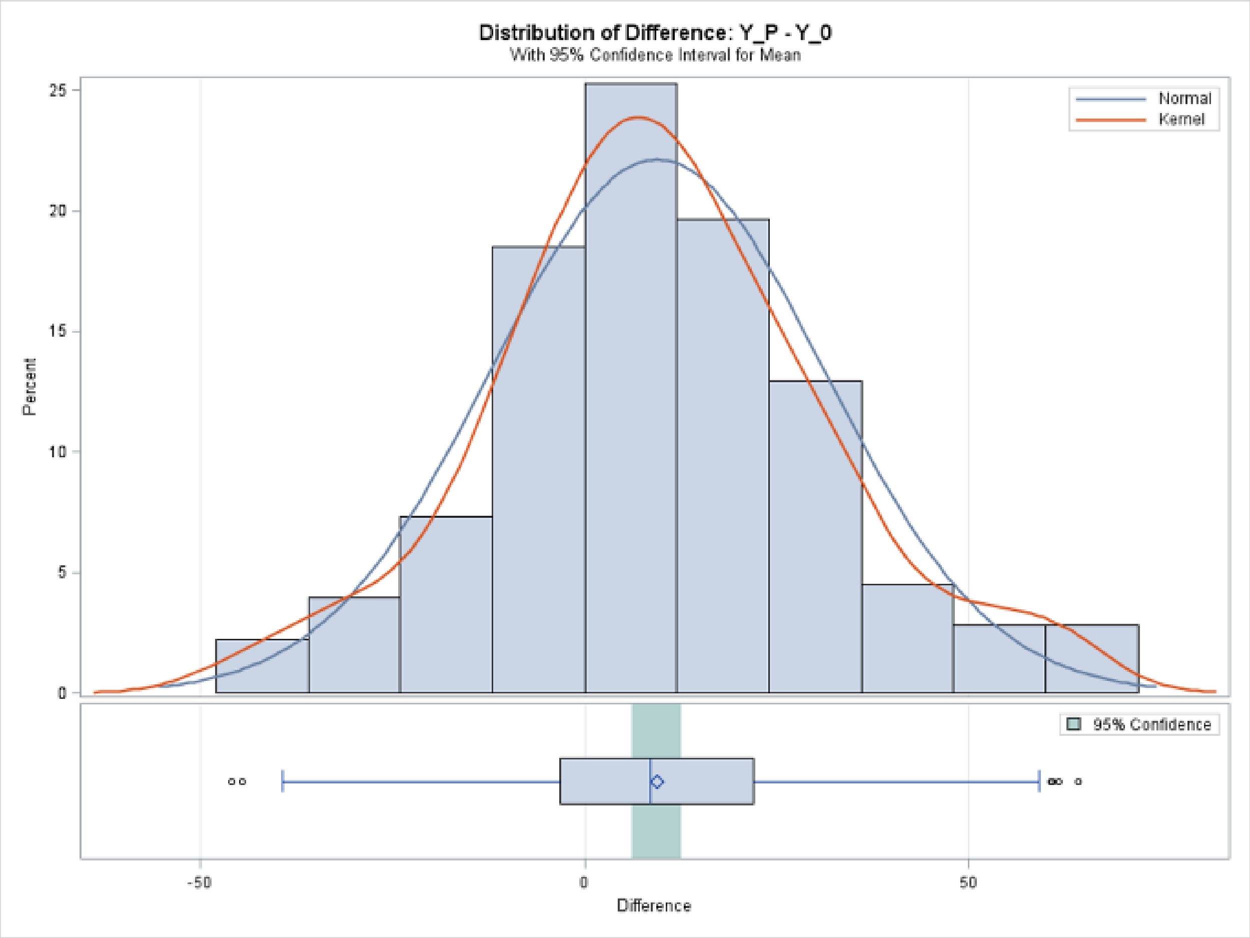
Used APP and UAN (55 lb/a N) in 2x2 with rest of N at sidedress

Two treatments: None or 60 lb/a P_2O_5



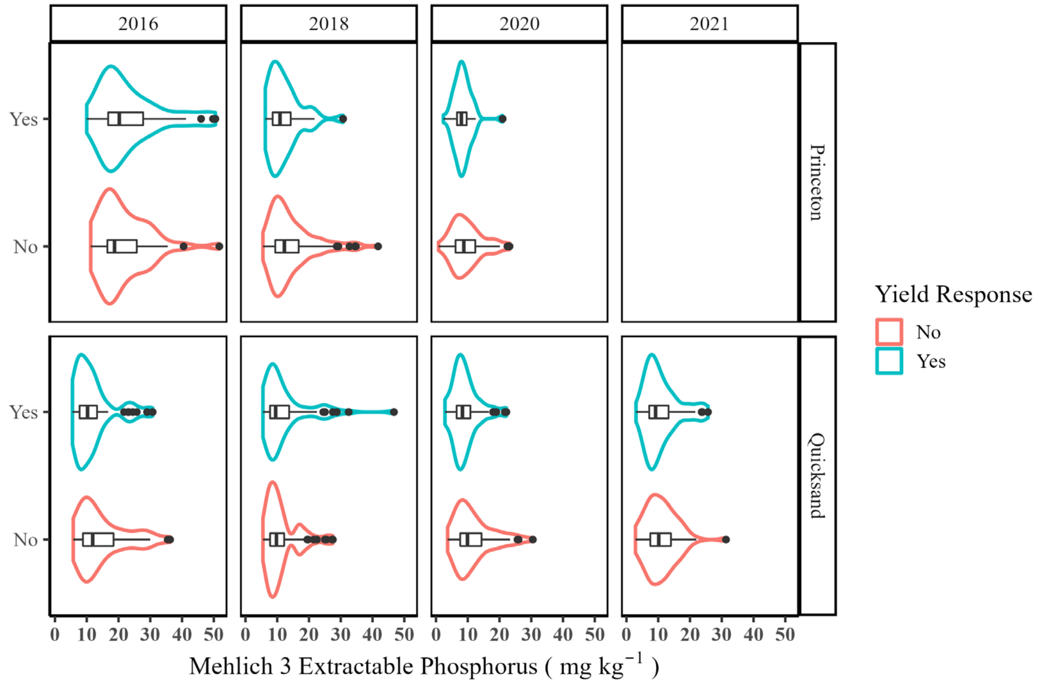
On Average, Soil test worked

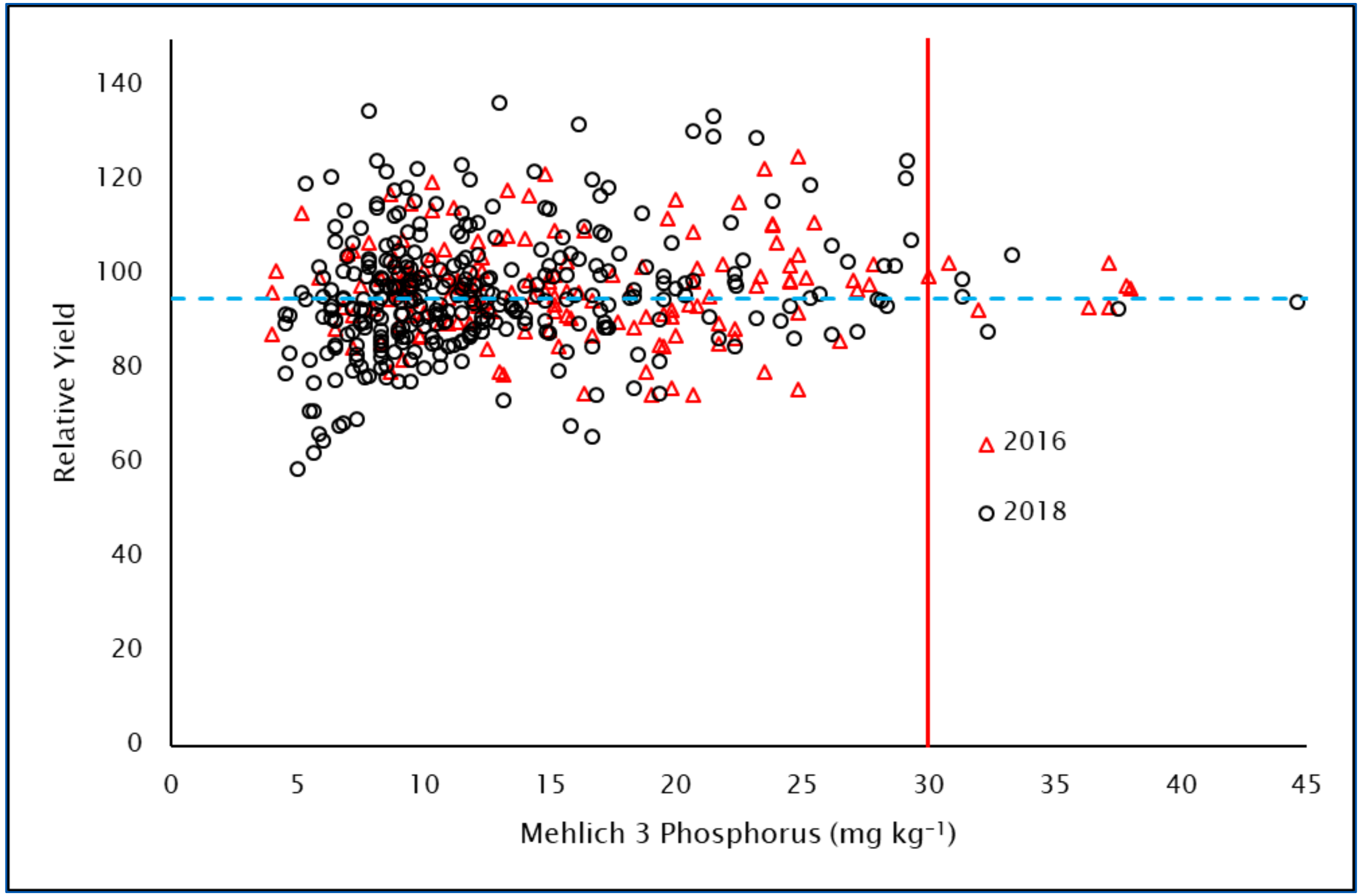
- On **average significant corn yield response** to P fertilizer
- Δ yield = 9 to 18 bu/a in 3 of 4 site-years
  - Disease pressure muted response in one year
- Wheat and soy residual response 1 out of 2 years each



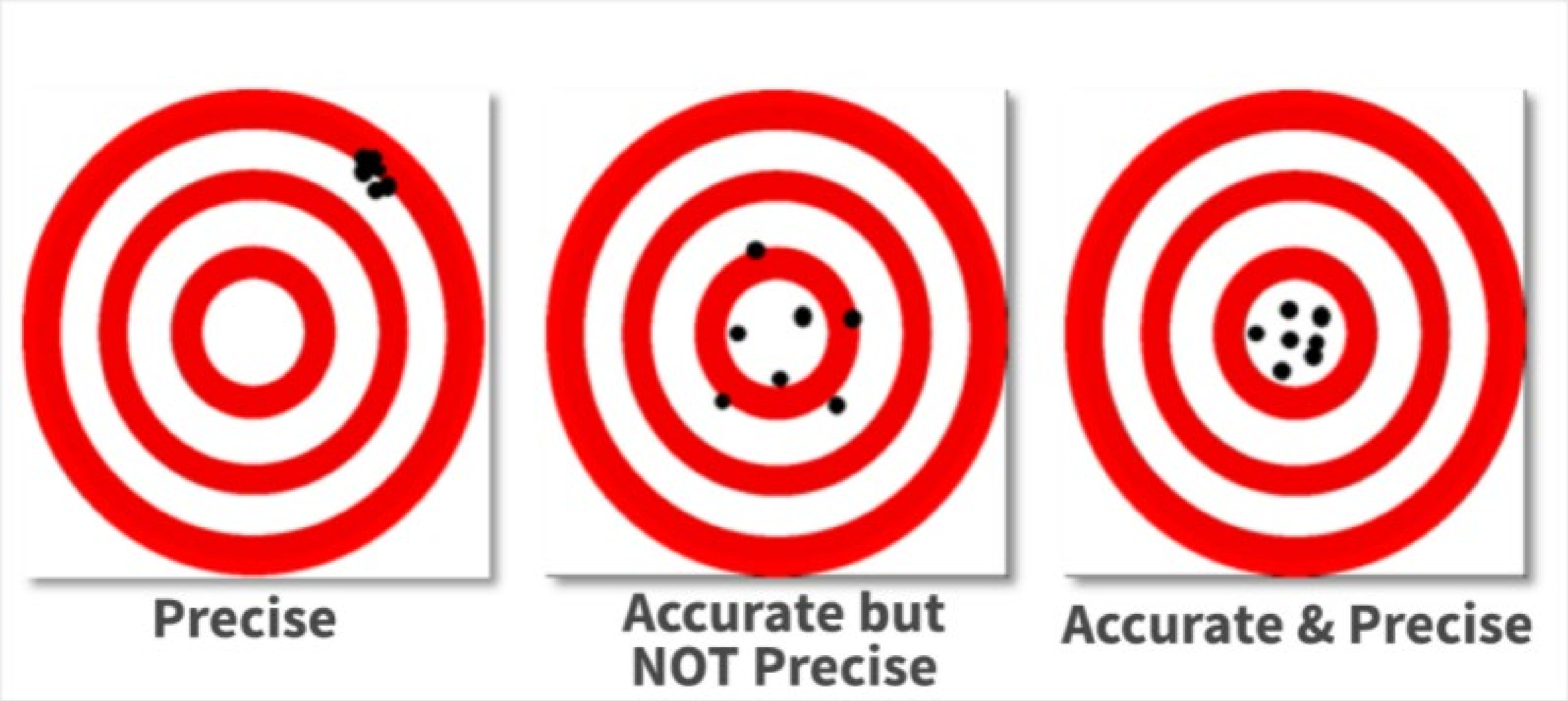
On average soil test worked…but failed 50% of the time

Regardless of soil test
only half the plots responded to phosphorus fertilizer





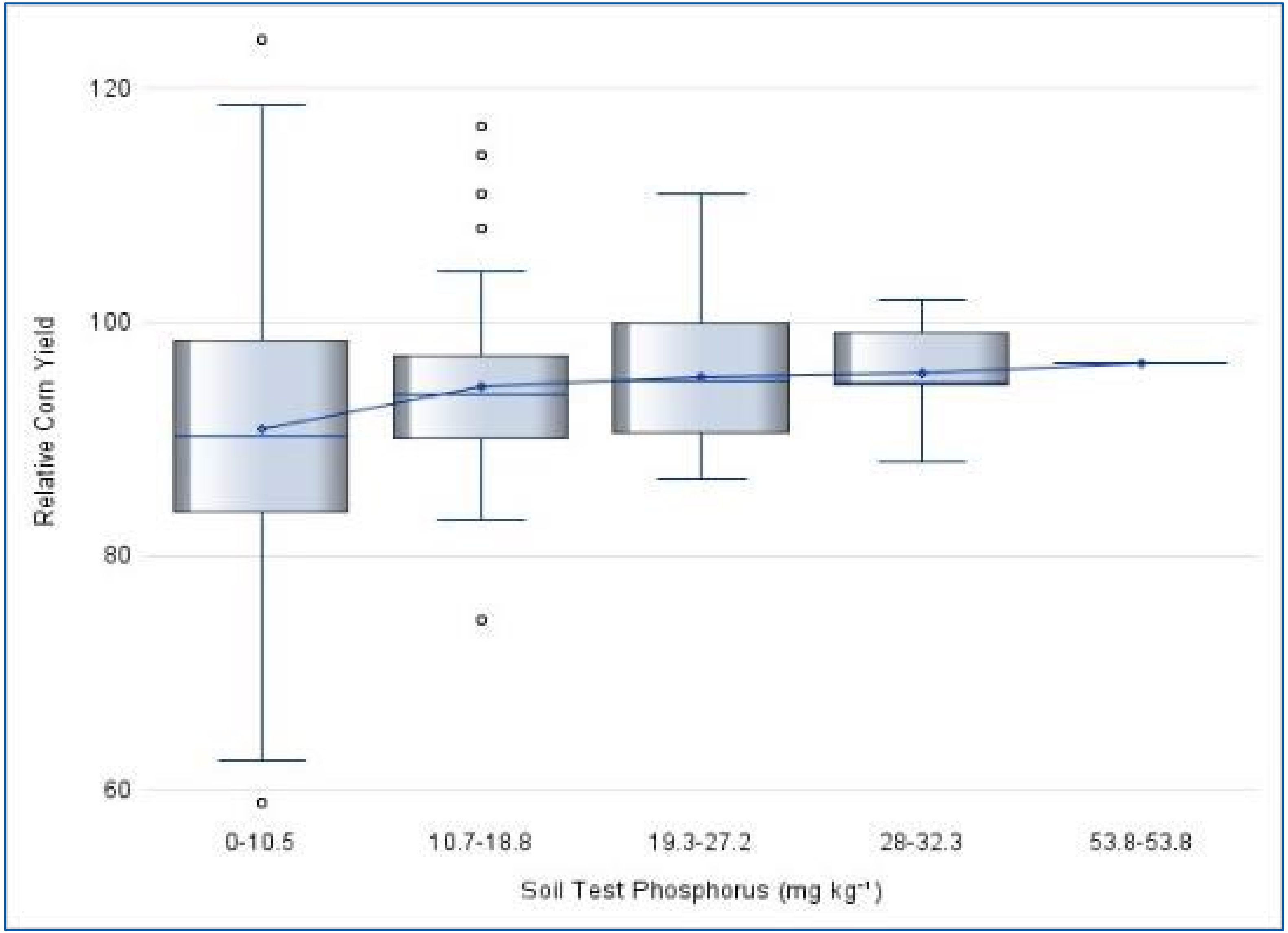
Reminder: Accurate vs Precise



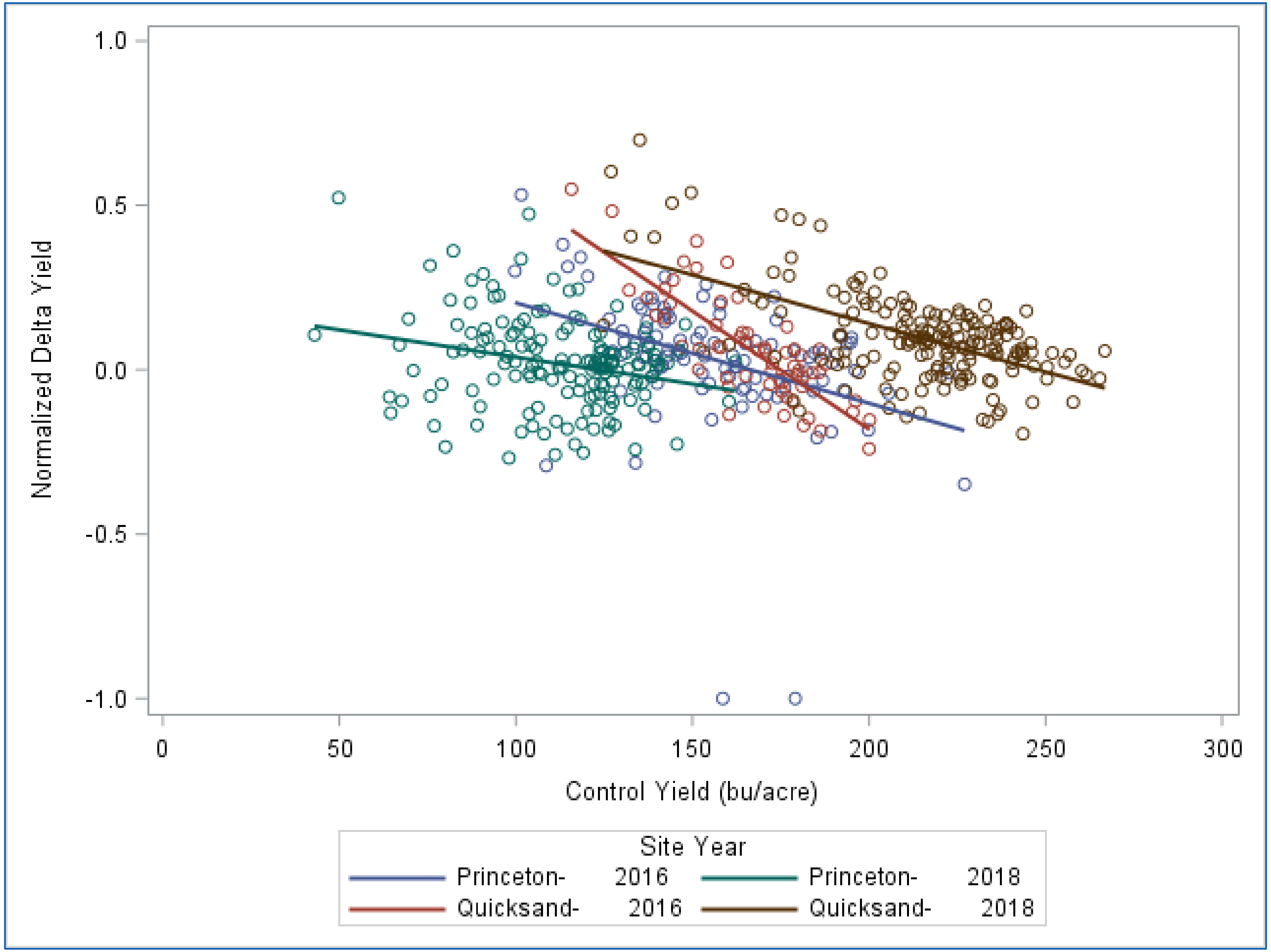
https://www.cardioserv.net/wp-content/uploads/2018/07/Bullseye.jpeg

Variance in Relative Yield decreases as soil P increases

Soil testing is good at predicting where there is no response



As yield potential increase, fertilizer response decreases

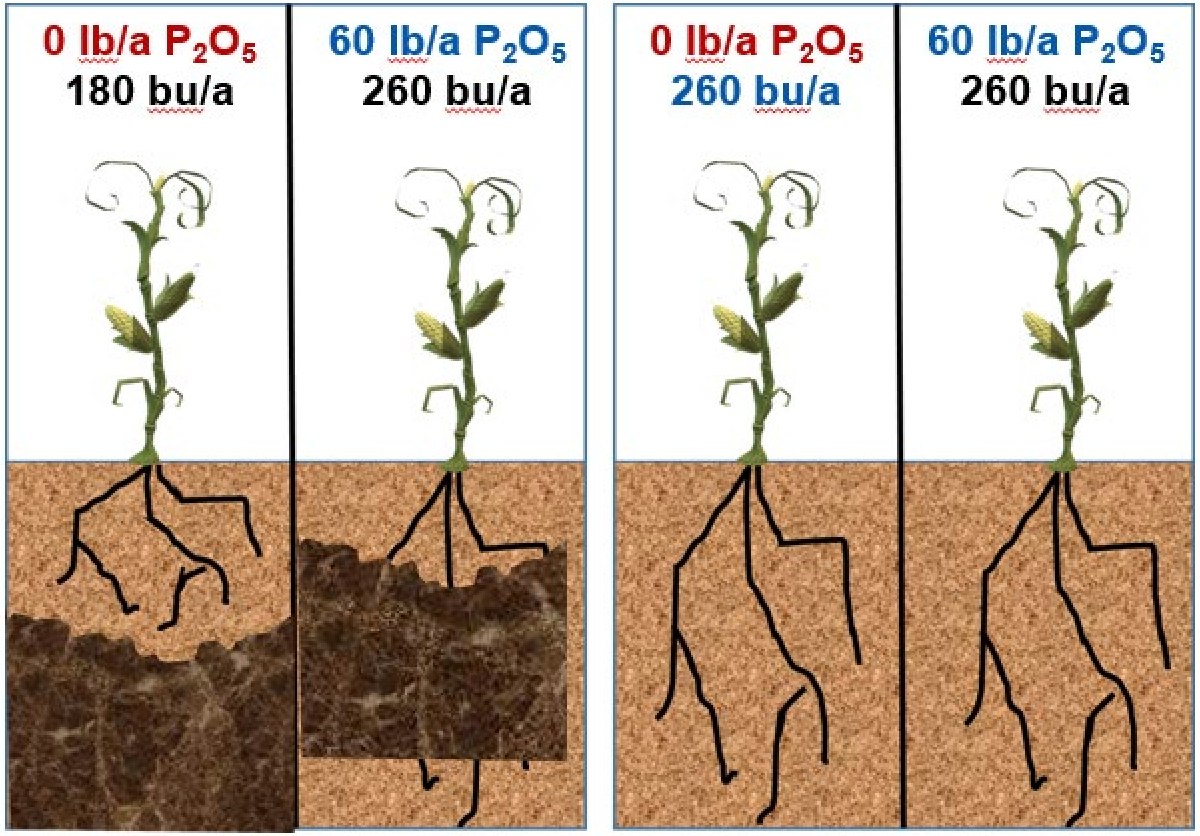


Relative Importance of Fertilizer Response in Eastern KY

2016*		2018		2020*		2021	
Variable	Importance	Variable	Importance	Variable	Importance	Variable	Importance
M3P	1.51	Sand	2.02	M3P	2.11	Elevation	1.69
pH	1.51	Silt	1.54	pH	1.47	PR	1.55
Elevation	1.48	PR	1.24	EC_a	1.44	Silt	1.41
EC_a	1.43	TWI	1.13	Elevation	1.35	Sand	1.24
TWI	1.31	NDVI	1.01	Slope	0.84	SOM	1.18
PR	1.13	Elevation	0.98			Clay	0.98
		Clay	0.90			SWI	0.86
		SOM	0.90				

*M3P is a significant predictor of yield response to applied P fertilizer at 0.10 significant level

Hypothesis: *Predict roots to predict yield response*



Paired plots with very low STP. One plot receives P fertilizer, the other doesn't

Yield response to P occurs in ***half*** the plots

We believe this yield response occurs early

We ***hypothesize*** early ***root*** growth might be key

Soil testing for Site Specific Management: *New challenges*

We have focused on mapping soil P status spatially

New correlation/calibration needed for Site Specific Management

- Critical level is varying, not just P content

Better areas (higher yields) less responsive

- Need additional “model” inputs beyond STP
- Hypothesize that rooting depth/soil physical properties might be important inputs

Precision probably means going closer to “sufficiency” and removing “build” components

What can you do now?

Interpolated soil sample maps (>1/4-acre grid) are unreliable **AT BEST**.

- Nothing wrong with grid sampling, the problem is interpolation
- More frequent sampling better use of money

Intensively sampled zones might work

- Look at summary statistics from grids by zone

Recommendations are average

- Use tech to do on-farm research

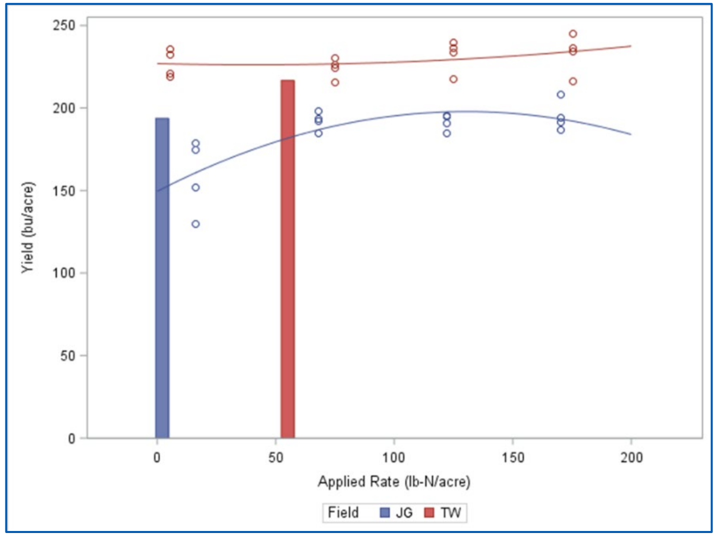


Image Source: Doug Smith

Precision Fertility

Image Source: Doug Smith

Fertility recommendations are directionally correct

Still have a long way to go before we have solid precision fertility guidance

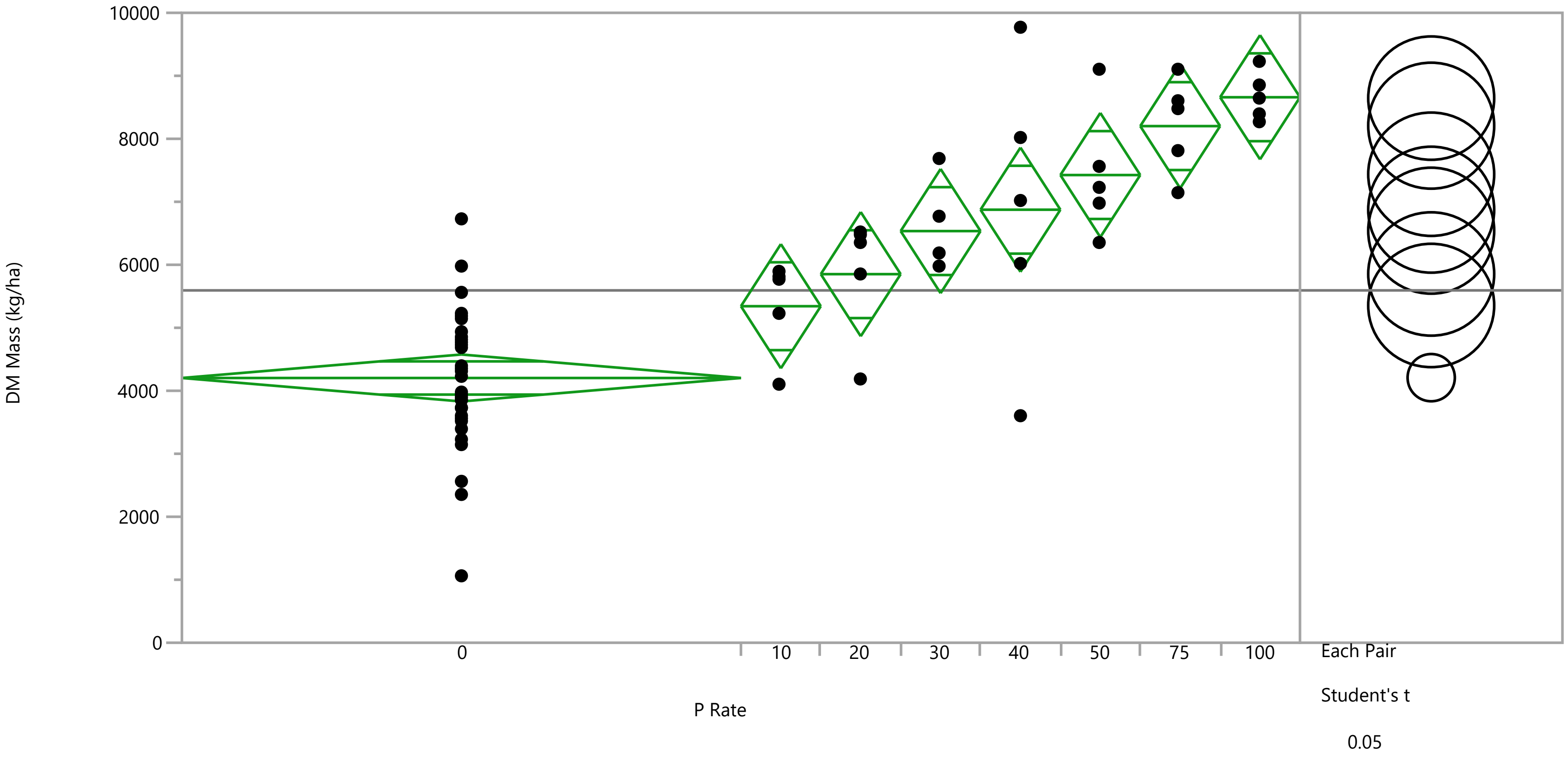
IF we can predict where response is going to occur, how precise can we get with application?

How Precise Can We Get With Fertilizers?

Image Source: Doug Smith

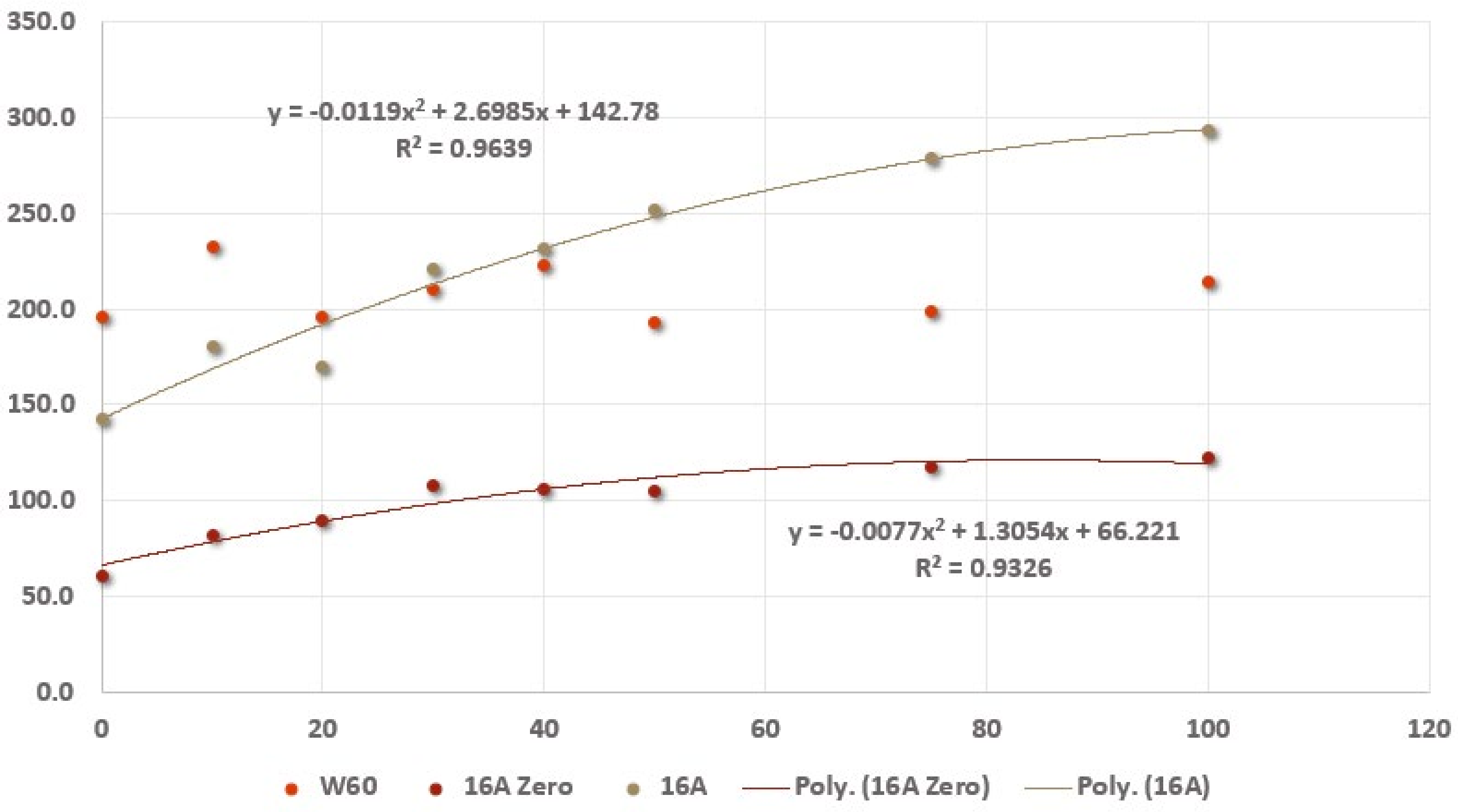
Image Source: Doug Smith

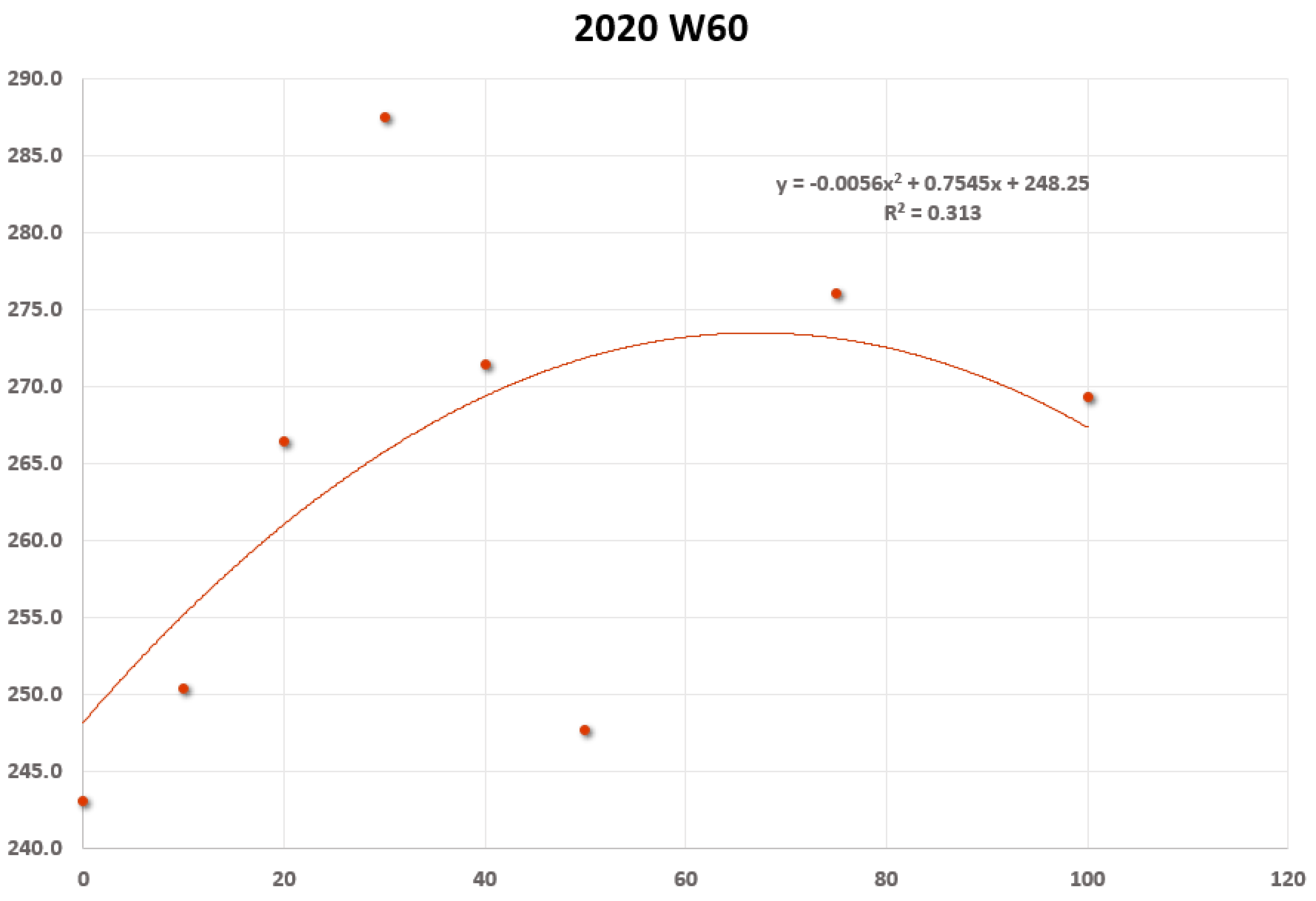
Proof of Concept – Individual Plant Treatment



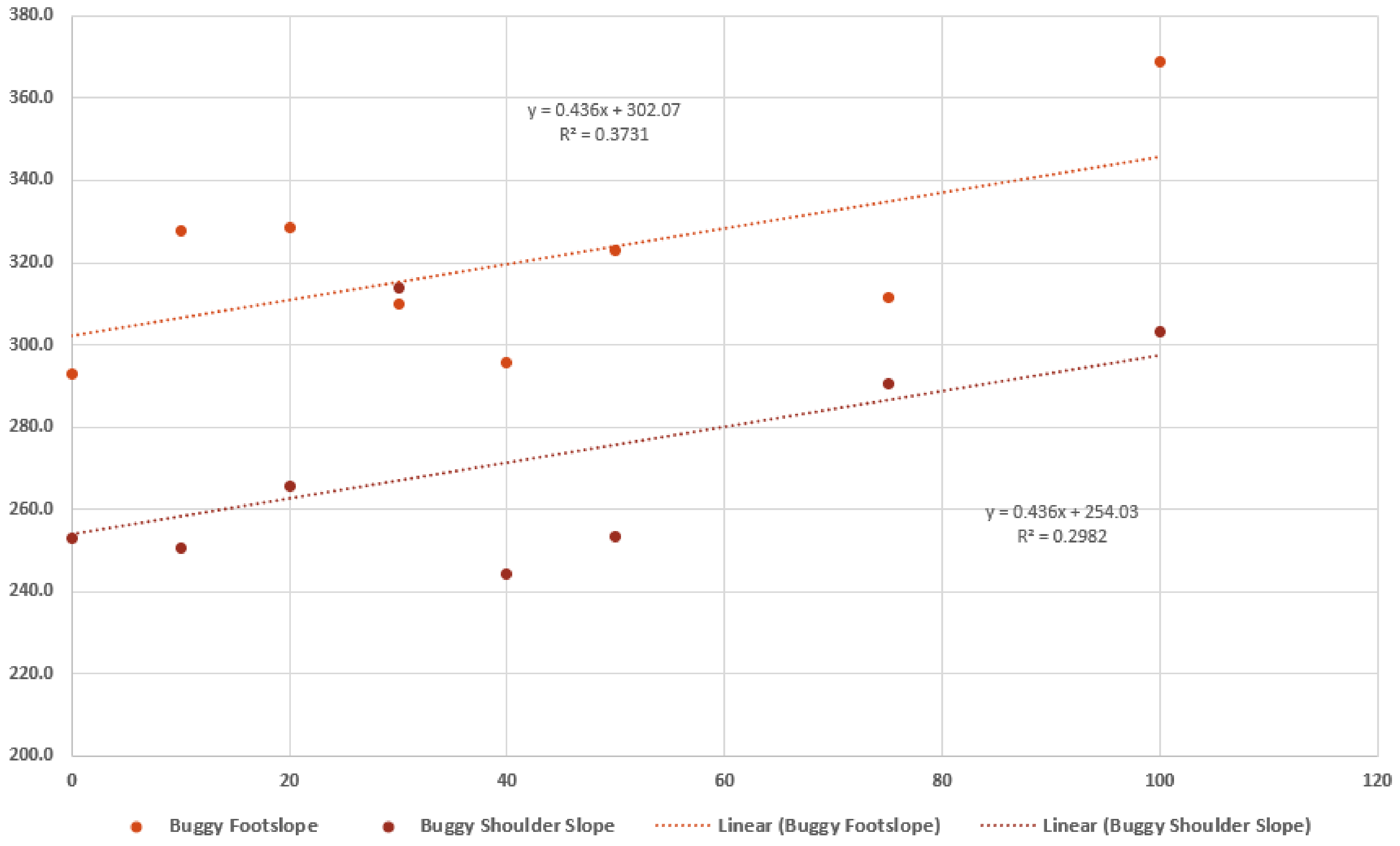
Data from precision P applications in a field at Riesel. This is for grain dry matter in 2019.

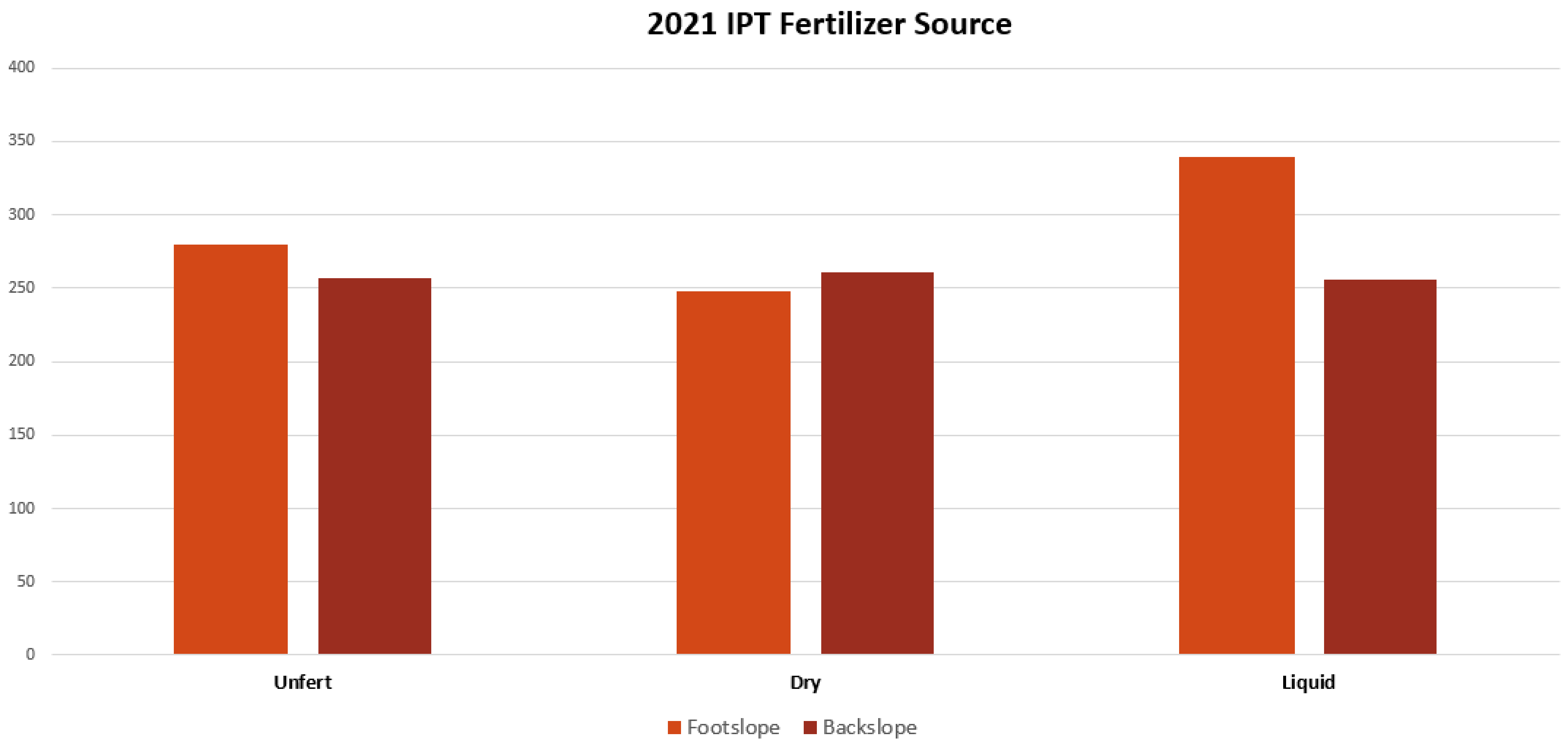
Individual Plant Treatment P Fertility Study

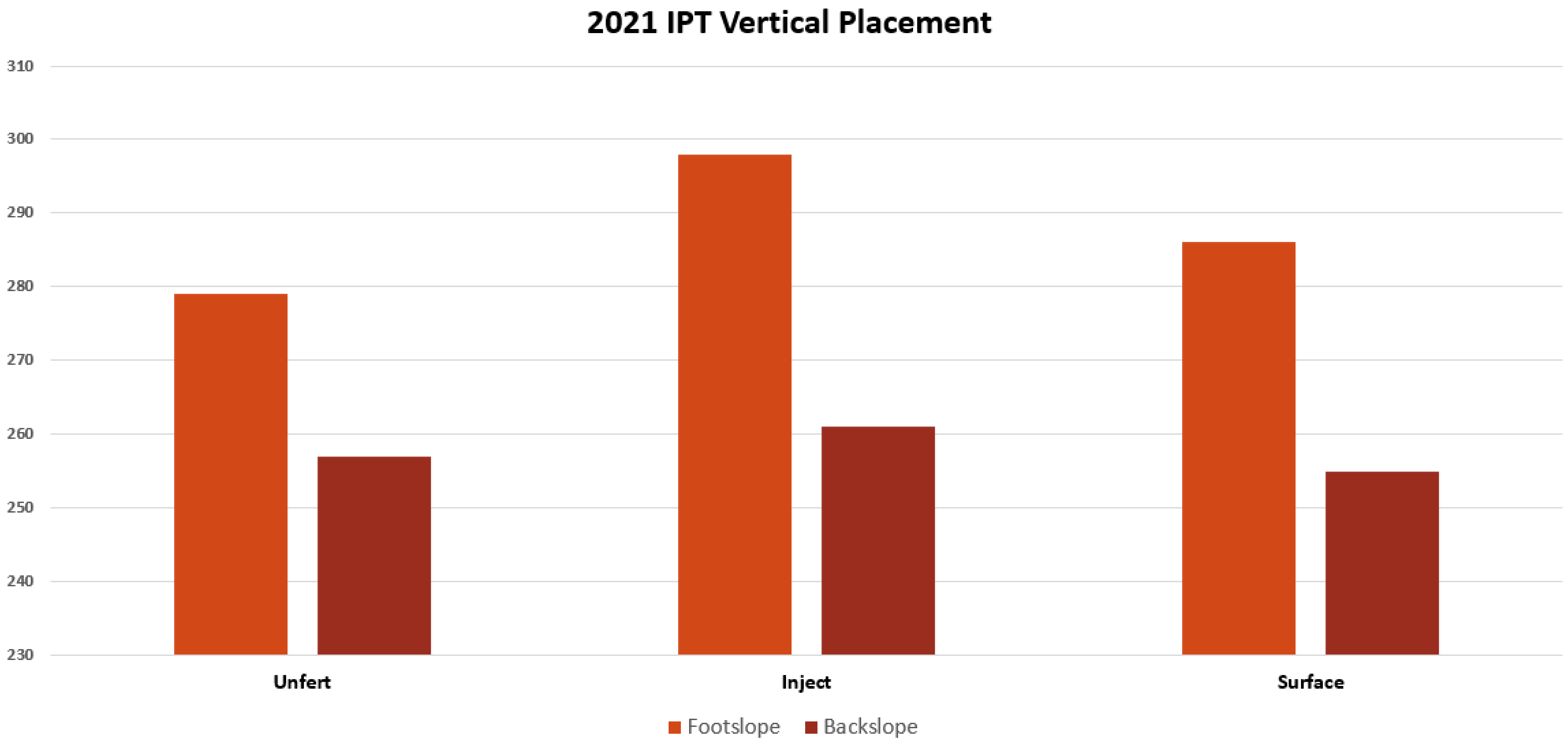


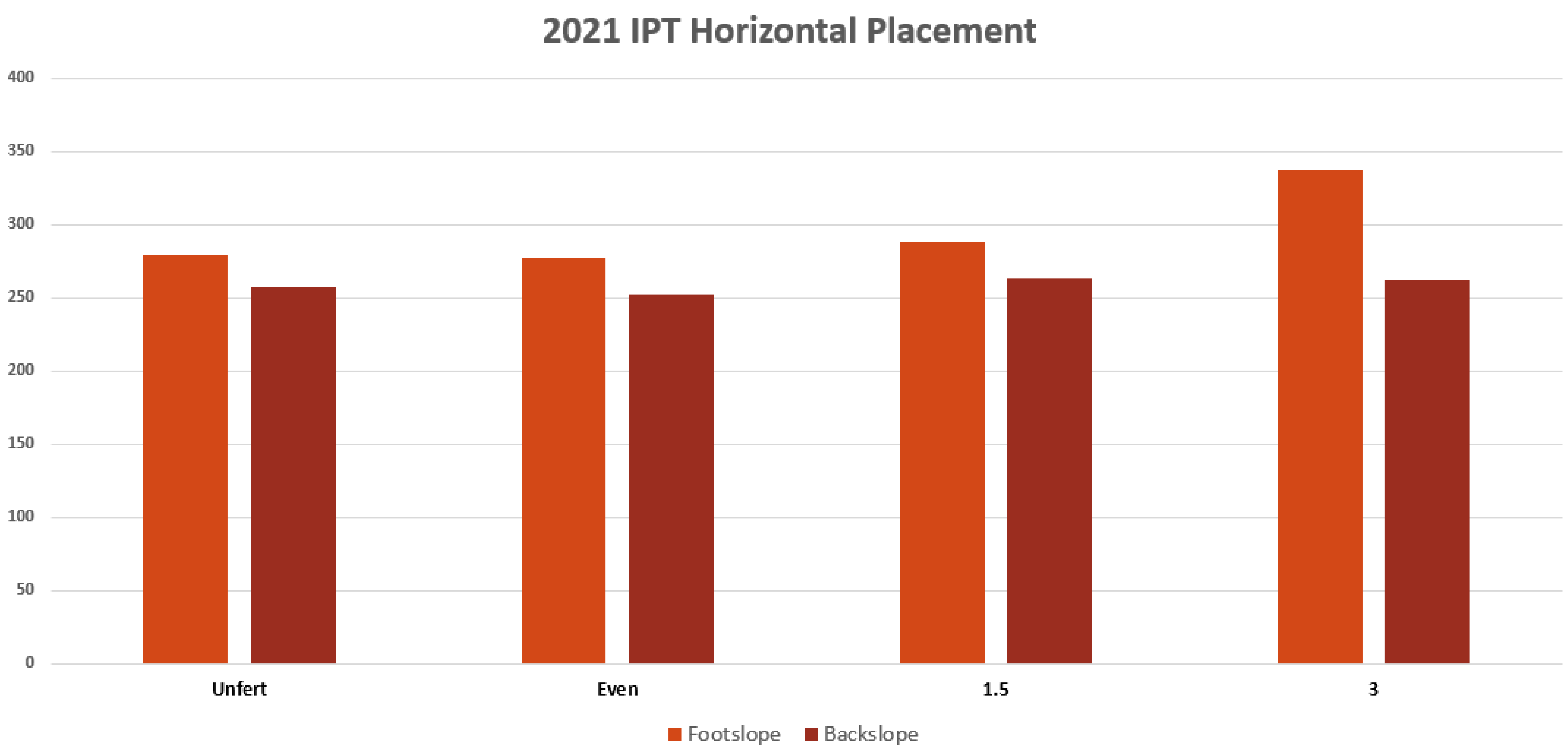

2020 W60
y = -0.0056x2 + 0.7545x + 248.25
R2 = 0.313
290.0
285.0
280.0
275.0
270.0
265.0
260.0
255.0
250.0
245.0
240.0
0
20
40
60
80
100
120

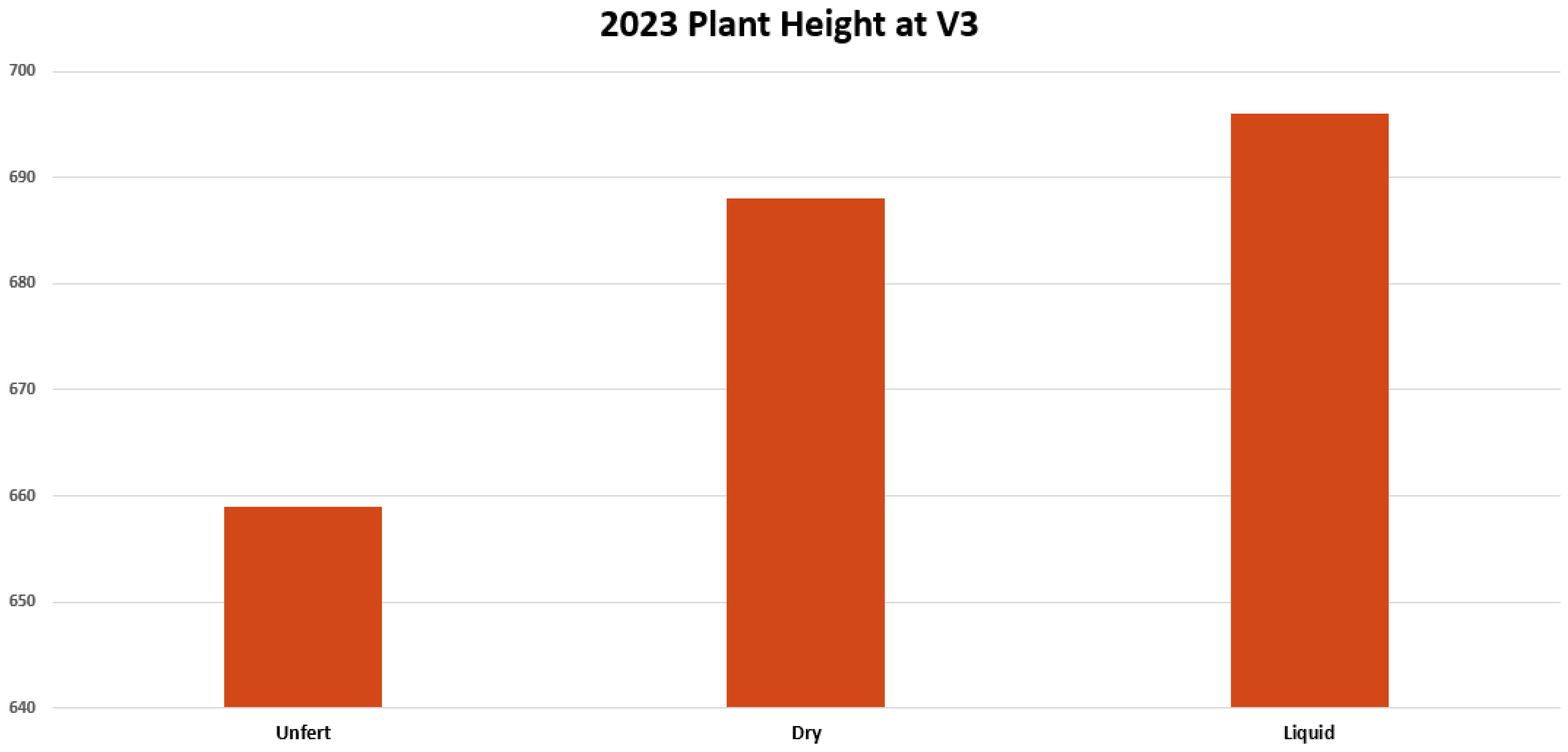
2021 Buggy 50

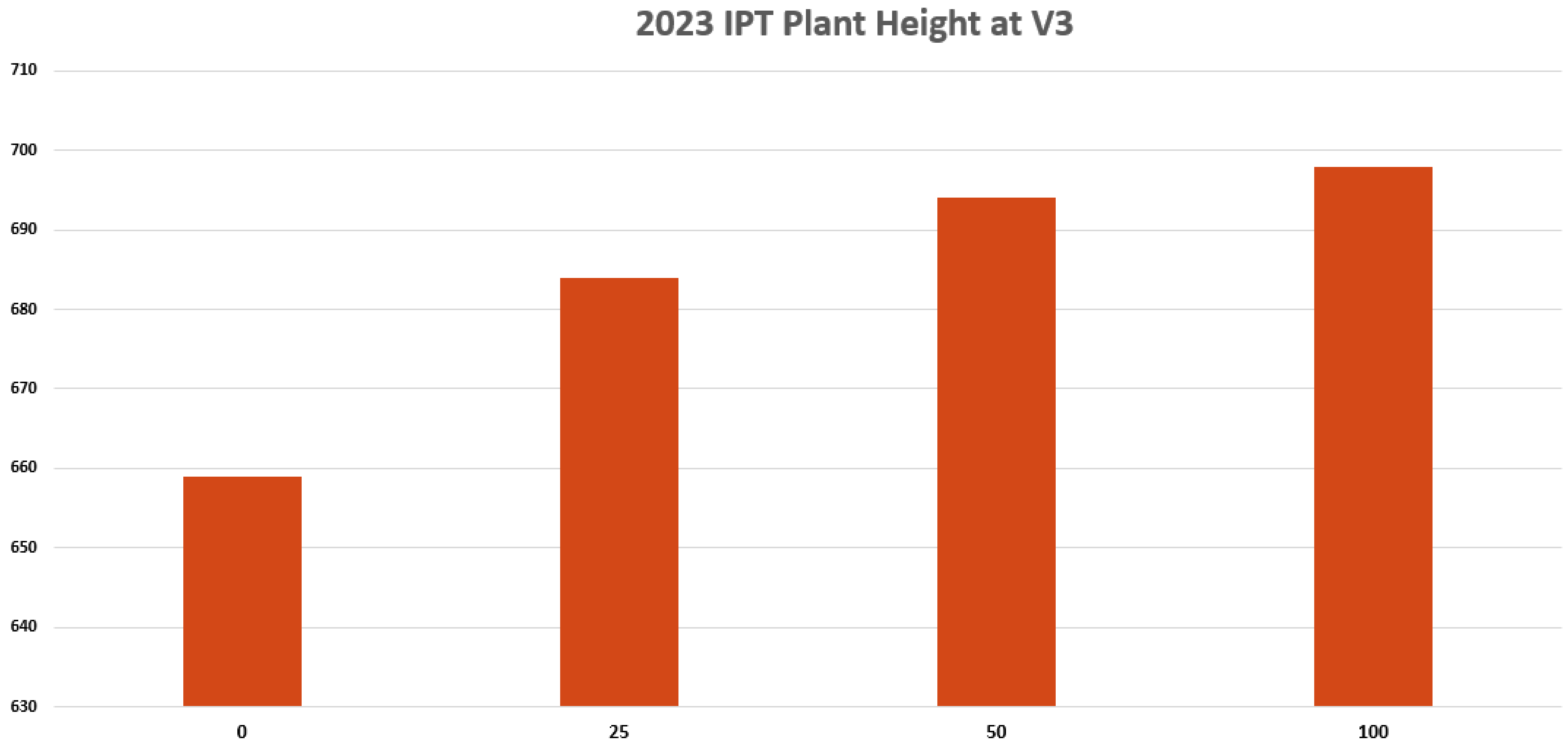


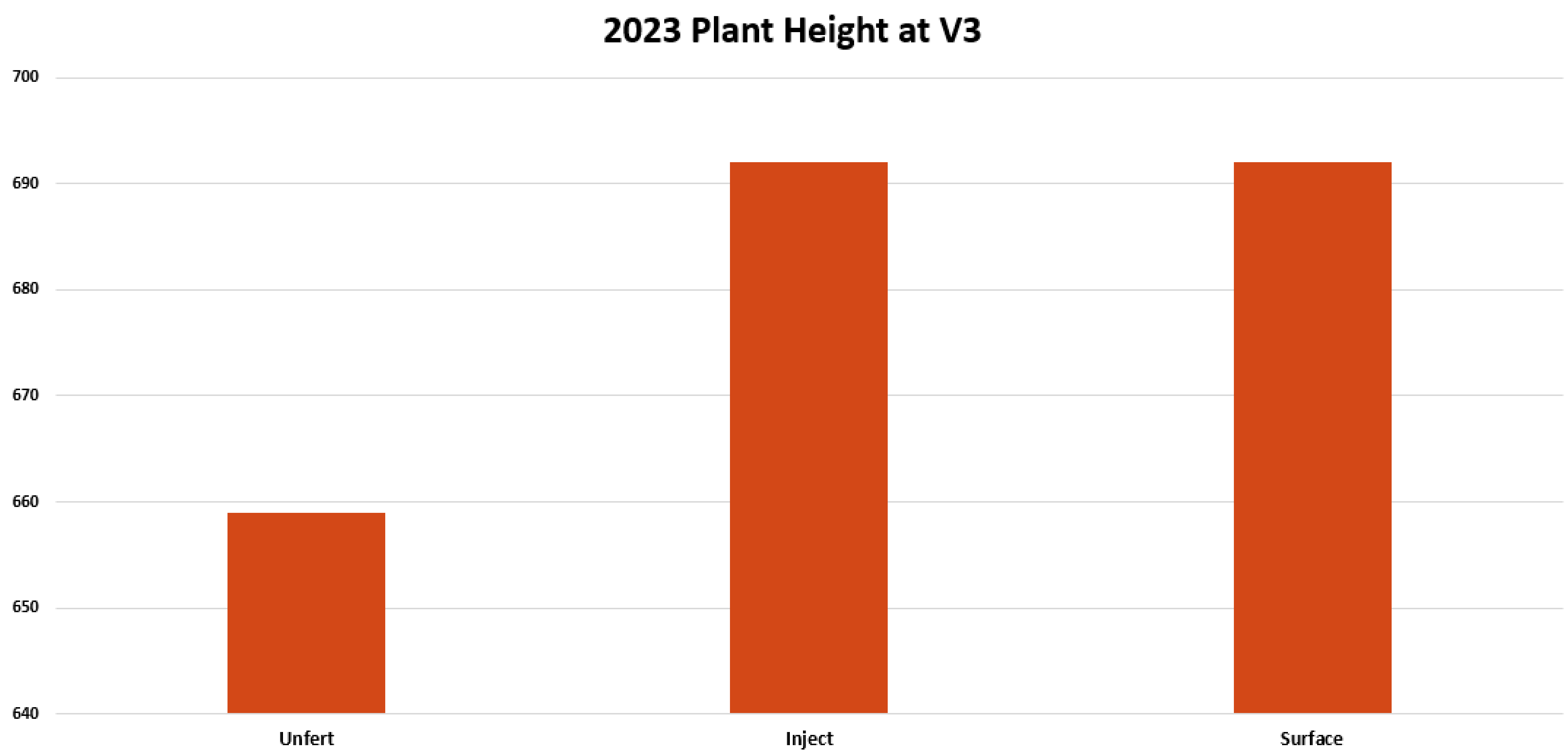

2021 IPT Fertilizer Source
400
350
300
250
200
150
100
50
0
Unfert
Dry
Liquid
Footslope
Backslope

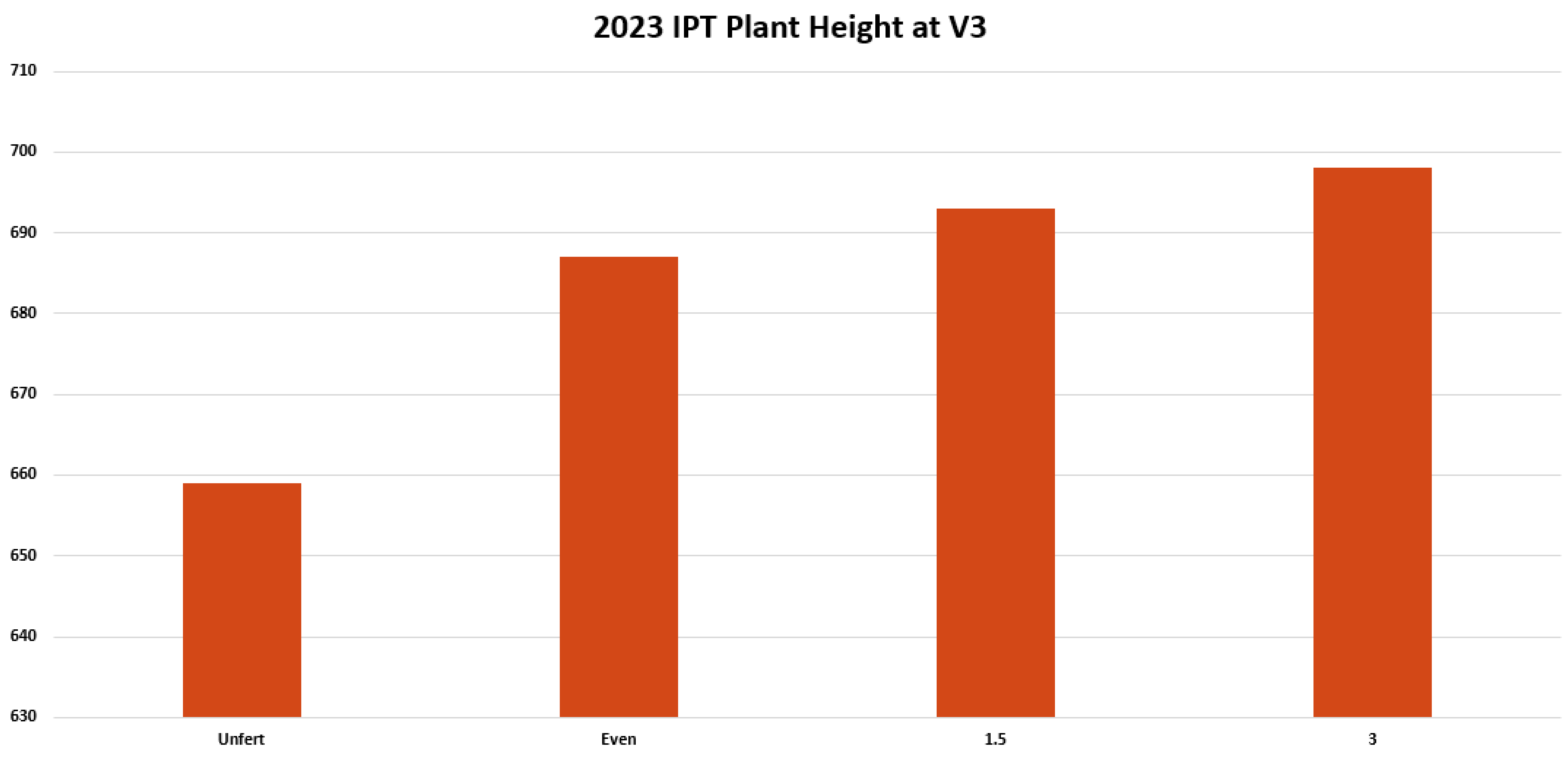

2021 IPT Vertical Placement
310
300
290
280
270
260
250
240
230
Unfert
Inject
Surface
Footslope
Backslope


2021 IPT Horizontal Placement
400
350
300
250
200
150
100
50
0
Unfert
Even
1.5
3
Footslope
Backslope


2023 Plant Height at V3
700
690
680
670
660
650
640
Unfert
Dry
Liquid


2023 IPT Plant Height at V3
710
700
690
680
670
660
650
640
630
0
25
50
100


2023 Plant Height at V3
700
690
680
670
660
650
640
Unfert
Inject
Surface


2023 IPT Plant Height at V3
710
700
690
680
670
660
650
640
630
Unfert
Even
1.5
3

Individual Plant Treatment Studies

- We can get a yield response by fertilizing each individual plant
  - Sometimes!
- Results seem promising, but more work to do
- Rate/Form/Time/Placement

Image Source: Doug Smith

Conclusions

Precision ag helps producers visualize and provides hard data for them to process

Understanding how the system works may provide

- Economic benefit to producer
- Environmental benefit to society

Fertility recommendations are right, except where they are not

Working toward precision fertility guidance

Image Source: Doug Smith

Next Steps – Automation and Precision

Image Source: Nathan Dorn, Farm_NG

Can we predict where in a field we will get yield response?

Use automation for precision agriculture (e.g., fertility)?

Will precision fertility application reduce runoff losses even further than banding?

Each year is one data point… look forward to 2025/2026.

Image Source: Doug Smith

Importance of This Research to NRCS Conservation Efforts

- A systems approach to conservation recognizes in-field variability, productivity, and the impacts to surrounding natural resources.
  - Goal of precision agriculture shouldn’t necessarily be to increase the yield in all areas of the field, but rather to maximize the overall profit of the field while considering the impacts to the surrounding environment.
  - Use of yield mapping, soil testing, and knowledge of individual field characteristics better enable the NRCS conservation planner and producer to apply precision conservation (reduced application rates, removal of land from production, etc.), resulting in overall economic gains for the producer as well as environmental benefits.
- Proper phosphorus (P) nutrient management is critical for enhanced plant growth as well as improved water quality in the surrounding ecosystems.
  - Source of P and method of application – impacts the amount of soluble P in runoff.
  - Injection or incorporation of P greatly reduces runoff losses.
  - Proper timing – plant is able to utilize P more readily leading to enhanced yield.