Timing of P application for corn and soybean production

AFREC Final Project Report 3/31/2022 for

AFREC Project(s) R2019-L; R2020-U; R2021-U; R2022-C

Results through the 2019-2022 Growing Seasons

Principal Investigator: Daniel Kaiser

Summary Points

- Both Bray-P1 and Olsen soil P in June was impacted consistently by P application rate and timing. Soil test P was greater in June following spring P application as indicated by significant P timing main effects and significant rate by timing interaction in sites with high carbonates.
- Corn leaf P concentration were consistently impacted by P application rate in 2019 and 2021 and impacted by timing in 2020.
- Soybean trifoliate P concentration was not consistently impacted by P application rate or timing.
- Corn and soybean yield were impacted by P application rate at 6 of 10 corn and 3 of 10 soybean locations.
- Corn grain yield was greater at 7 of 10 sites when P was applied in Spring Grain yield was increased when up to 60 lb P_2O_5 were applied for corn when applied in the spring, and 90 lbs P_2O_5 applied in the fall produced similar yield as 45 lbs P_2O_5 applied in spring.
- Corn grain yield was greater for fall P application in 2 of 10 locations which were sites that were impacted by drought.
- Soybean grain yield across the nine location was linearly increased when up to 90 lbs P_2O_5 were applied and was not impacted by P application timing.
- Corn grain yield was at maximum when June Olsen soil test P was 6 ppm while soybean grain yield was at maximum when June Olsen soil test P was 20 ppm.
- Grain P concentration and P removed in the harvested grain were inconsistently impacted by P application rate and timing.
- Soybean grain quality (protein and oil concentration) were not consistently impacted by P application rate and timing.
- Corn grain yield was at maximum when leaf P concentration was 0.30% at V10 and 0.23% at R1.
- Soybean grain yield was at maximum when R1 trifoliate P concentration was 0.38%.

Introduction

Phosphorus is a plant nutrient which, if deficient, can significantly limit crop growth and development. Phosphorus is considered a primary macronutrient. Primary macronutrients are elements that are essential for plant growth which more commonly require fertilizers to be applied to satisfy crop requirements. Orthophosphate is the form of phosphorus taken up by plants. The concentration of orthophosphate in the soil solution is low as orthophosphate is highly reactive with metal elements. Iron, aluminum, and calcium all can react with orthophosphate creating compounds varying in solubility. The ion which reacts with orthophosphate depends greatly on the pH of the soil.

Soils in major cropping regions in Minnesota predominantly formed under calcareous parent materials. Carbonates deposited in the material left following glaciation are still present near the soil surface in areas of the state. These soils with greater carbonate and calcium contents present challenges when managing phosphorus as it is difficult to increase available soil test phosphorus of calcareous soils. Soils with high calcium contents can fix phosphorus. Fixation is a process where orthophosphate reacts with calcium forming compounds like di- and tri-calcium phosphate. While fixed phosphorus is not technically lost from the soil it is rendered unavailable for plant uptake.

The relative rate of phosphorus fixation is not known in soils. Short term P sorption tests can be run to determine the amount of P which a soil will sorb, which can be substantial for some calcareous soils. Management of fertilizer P is common in the fall which gives more time for P to react and potentially bind phosphorus. Studies have been conducted focused on timing of P application, but many were conducted in soils with a neutral to slightly alkaline pH which did not contain appreciable amounts of calcium carbonate.

In a previous study funded by AFREC, on-farm strip trials established to determine corn and soybean response to a single rate of phosphorous fertilizer showed that a high rate of P applied one year can have multiple years' benefits for crops in a two-year rotation. The exception was one location with a calcium carbonate equivalency of 20% where there was a yield benefit to P applied both years for a two-year corn-soybean rotation and P applied the previous year had not impact on the crop grown. Fall application provides more flexibility for farmers but there are questions as to whether spring is better under some circumstances.

Objective

The objective of this study is to establish whether there is a difference between fall and spring application of P fertilizer for corn or soybean production and whether potential differences may be tied to calcium carbonate content of the soil.

Materials and Methods

Field trials were established in farmer fields and at ag experiment stations in Minnesota (Table 1). Locations were targeted to test Low by either the Bray-P1 or Olsen tests (< 10 ppm Bray-P1 or <8 ppm Olsen P). Sites with a calcium carbonate equivalency of >5% CCE were given preference due to a greater capacity for P fixation but the exact CCE was not known until after trial establishment.

A split plot design was used where main plots consisted of four P rates and sub-plots consisted of timing (Fall or Spring). The four P rates were 0, 30, 60, and 90 lbs P_2O_5 per acre applied as MAP (11-52-0). All treatments were replicated four times. Nitrogen supplied with MAP was balanced with AMS. Gypsum was used to balance sulfur applied by AMS such that all plots received similar rates of N and S when P treatments are applied. Calcium supplied by gypsum was not expected to impact corn or soybean yield due to excessive levels of calcium already in the soil.

Corn and soybean will be the two crops utilized for this study. Additional crop species are not used as corn and soybean should provide sufficient information on potential differences in responses based on fertilizer timing which can be translated to additional crops. A total of three trials were established for each crop each year (6 trials total per year).

Table 1. Soil series information, planted crop at each location, and initial potassium soil test data from phosphorus studies conducted from 2019 through 2022. Soil test data was collected in the Fall at trial establishment from each main plot.

			Soil Test P		Soil Test†			
Year	Location	Crop	Bray-P1	Olsen	K	pH	CCE	Soil Series
				ppm			%	
2019	Crookston	Corn	3	6	258	8.0	13.8	Colvin-Perella
	Lamberton	Corn	11	5	147	5.3	0.2	Normania
	Morris	Corn	12	7	253	7.4	0.9	Flom-Aazhahl-Hamerly
	Benson	Soybean	28	23	135	7.9	2.2	Arveson
	Morris	Soybean	5	3	245	7.4	0.7	Flom-Aazhahl-Hamerly
	Stewart	Soybean	2	10	183	7.7	16.2	Harps
2020	Crookston	Corn	3	4	262	8.1	2.1	Wheatville
	Lamberton	Corn	15	8	167	5.1	0.3	Amiret
	Morris	Corn	8	4	164	7.4	1.3	Aazdahl-Formdale-Balaton
	Danvers	Soybean	9	11	271	7.9	2.5	Bearden-Quam
	Morris	Soybean	7	5	194	7.8	1.9	Aazdahl-Formdale-Balaton
	Stewart	Soybean	3	8	245	7.8	6.7	Canisteo-Glencoe
2021	Crookston	Corn	7	4	248	8.1	13.2	Wheatville
	Lamberton	Corn	4	2	171	7.4	0.7	Normania
	Morris	Corn	7	4	129	8.0	3.0	Aazdahl-Formdale-Balaton
	Holloway	Soybean	2	10	164	8.1	8.5	Marysland
	Morris	Soybean	13	8	175	7.2	0.1	Tara
	Stewart	Soybean	10	10	210	7.9	6.2	Canisteo-Glencoe
2022	Crookston	Corn	13	4	199	7.9	4.4	Wheatville
	Crookston	Soybean	14	5	223	7.9	4.9	Wheatville

† K, Soil test potassium (K-ammonium acetate); CCE, calcium carbonate equivalency.

Soil samples (0-6”) were collected from each main block prior to fall treatment application, were air dried, ground, and analyzed for P by Bray-P1, Olsen, and Mehlich-3 P tests. Samples were additionally analyzed for calcium carbonate equivalency (modified pressure calcimeter method) and pH (1:1 soil:water). Additional 0-6” soil samples were collected in June from all plots to assess change in Bray-P1 and Olsen soil test P after treatment application.

Leaf samples were collected from each corn plot at V8-V10 (uppermost fully developed leaf) and R1 (leaf opposite and below the ear), and for soybean at the R1-R2 growth stage (uppermost fully developed trifoliate). All soybean plots will be harvested with a small plot combine. Corn will either be harvested with a plot combine or by hand. Soybean grain yield is reported at 13% moisture and corn grain yield is reported at 15.5%. Grain samples were collected from each location and analyzed for total P concentration for both crops while soybean was analyzed for protein and oil concentration in grain by NIR.

Table 2. Summary of cultural practices for studies conducted in 2019, 2020, 2021, and 2022. Fall fertilization data is for the fall preceding the calendar year the trial was conducted at each location.

Year	Location	Crop	Cultivar†	Date of Fall Fert.‡	Date of Spring Fert.	Date of Planting
2019	Crookston	Corn	P 7632	2-Nov.	9-May	15-May
	Lamberton	Corn	P 0157	15-Nov.	17-May	17-May
	Morris	Corn	DK 44-80	9-Nov.	25-Apr.	14-May
	Benson	Soybean	DG 11LL48	9-Nov.	6-May	7-Jun
	Morris	Soybean	C 0716	9-Nov.	25-Apr.	17-May
	Stewart	Soybean	NS 6162	17-Oct.	6-May	13-May
2020	Crookston	Corn	DK 26-40	30-Oct.	18-May	21-May
	Lamberton	Corn	P 0157XMT	1-Nov	24-Apr.	27-Apr.
	Morris	Corn	DK 41-96	31-Oct.	11-May	8-May
	Danvers	Soybean	DG 13LL35	18-Nov.	23-Apr.	2-May
	Morris	Soybean	NK S06-T8L	31-Oct.	11-May	18-May
	Stewart	Soybean	P 15A65	29-Oct.	21-Apr.	20-Apr.
2021	Crookston	Corn	DK 26-40	21-Oct	4-May	10-May
	Lamberton	Corn	DK 49-44	4-Nov	27-Apr	28-Apr
	Morris	Corn	DK 45-65	20-Oct	6-May	12-May
	Holloway	Soybean	AG 21XF0	19-Oct	29-Apr	6-May
	Morris	Soybean	NK S06T8L	19-Oct	6-May	13-May
	Stewart	Soybean	P 10T57E	7-Oct	20-Apr	29-Apr
2022	Crookston	Corn	DK 29-89	1-Nov	27-May	27-May
	Crookston	Soybean	PFS 19EN008	1-Nov	27-May	27-May

†AG, Asgrow; C, Cropland; DG, Dyna-gro; DK, Dekalb; NK, Northrup King; NS, North Star; P, Pioneer; PFS, Peterson Farms Seed.
‡ Fall fertilizer (fert.) was applied the fall the previous year in which the study was harvested.

Results and Discussion

Location Information

Location data are summarized in Table 1. Sites were selected to have low initial soil test P (STP) and measurable carbonate levels. The exception to this was Lamberton (2019 and 2020) which was included due to a very acidic pH which is a good comparison to the remaining sites to determine the impact of free iron and aluminum on the retention of soil test P. The only location which tested above the medium STP class was Benson in 2019. The remaining sites were all within targeted parameters. Calcium carbonate equivalency (CCE) was highest at Crookston and Stewart in 2019, and Crookston in 2021. At the remaining four locations there was measurable CCE (except for Lamberton) but the levels were lower than anticipated but were still measurable at most locations. Table 2 summarizes planting information and dates of spring and fall fertilization for all the research trials.

Table 3. ANOVA summary for measured variables (phosphorus rate and timing) for the three corn trials conducted in 2019.

Main Effect	Bray P Change	Olsen P Change	V10 Leaf	R1 Leaf P	Grain Moisture	Grain Yield	Grain %P	Grain P Removal
	--------------------	----------	----------	*P*>F	----------	----------	--------------------	
				Crookston				
P rate	0.42	**	*	***	0.56	0.45	*	0.44
Timing	0.22	*	0.15	0.07	0.11	0.68	0.34	0.94
P rt. x Time	0.49	0.23	0.89	0.63	0.52	0.90	0.18	0.29
				Lamberton				
P rate	*	*	***	**	**	*	*	0.10
Timing	0.10	0.07	0.36	0.57	0.46	0.08	0.37	0.14
P rt. x Time	0.64	0.58	0.71	0.59	0.07	0.42	0.09	0.07
				Morris				
P rate	***	**	0.09	0.28	0.19	0.39	0.88	0.72
Timing	**	**	0.23	0.63	**	*	0.38	*
P rt. x Time	0.17	*	0.63	0.31	0.71	**	0.68	0.18

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 4. ANOVA summary for measured variables (phosphorus rate and timing) for the three soybean trials conducted in 2019.

Main Effect	Bray P Change	Olsen P Change	R1 Leaf P	Grain Yield	Grain %P	Grain P Removal	Grain Protein	Grain Oil
	---			*P*>F		---		
				Benson				
P rate	0.27	0.20	0.15	0.31	0.36	0.10	0.82	0.16
Timing	0.33	0.89	1.00	0.74	0.11	0.28	0.26	0.71
P rt. x Time	0.78	0.44	0.95	0.08	0.98	0.40	0.73	0.68
				Morris				
P rate	***	***	0.29	**	***	*	*	0.19
Timing	**	**	0.74	0.81	*	0.90	0.10	0.29
P rt. x Time	**	**	0.40	0.11	0.55	0.71	0.91	0.77
				Stewart				
P rate	0.98	**	0.91	*	0.13	0.08	0.13	*
Timing	0.64	**	0.67	0.78	0.25	0.31	0.07	0.74
P rt. x Time	0.09	0.25	0.48	0.18	0.80	0.35	*	0.53

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 5. Summary of treatment main effects for three corn locations where P fertilizer rates were applied in Fall or spring ahead of the 2019 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	------------------------------------ V10 Upper Leaf %P	-------------------------------------				
Crookston	0.31b	0.32b	0.35a	0.34a	0.33	0.32
Lamberton	0.25c	0.30b	0.30b	0.32a	0.29	0.29
Morris	0.23a	0.24ab	0.25ab	0.27a	0.26	0.25
	--------------------------------------- R1 Leaf %P	---------------------------------------				
Crookston	0.23b	0.24b	0.28a	0.28a	0.26a	0.25b
Lamberton	0.23c	0.25bc	0.26b	0.28a	0.25	0.25
Morris	0.24	0.25	0.25	0.26	0.25	0.25
	------------------------------ Moisture in harvested grain %	--------------------------------				
Crookston	26.0	25.4	26.1	24.6	25.1	26.0
Lamberton	20.2a	19.4b	19.3b	19.1b	19.6	19.4
Morris	19.3	19.7	19.5	19.8	19.3b	19.8a
	----------------------- Corn grain yield at 15.5% bushels per acre	------------------------				
Crookston	133	120	129	143	132	130
Lamberton	175b	192a	200a	194a	187b	193a
Morris	233	223	235	233	225b	238a
	-------------------------------- Corn Grain %P	--------------------------------				
Crookston	0.24b	0.24b	0.27a	0.27a	0.25	0.26
Lamberton	0.17b	0.18b	0.19ab	0.21a	0.18	0.19
Morris	0.19	0.18	0.19	0.18	0.18	0.19
	------------------------- P Removed in Corn Grain (lb P_2O_5/ac)	-------------------------				
Crookston	34	33	36	38	35	35
Lamberton	34b	37ab	40a	42a	37	39
Morris	48	43	48	46	44b	48a

2019 Data Summary

Table 2 and 3 summarizes main effects and main effect interactions for the ANOVA for the measured variables for the 2019 corn and soybean trials, respectively. Tables 4 and 5 summarize the phosphorous (P) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant, and the interaction data are not summarized for the majority of the measured variables. A lack of a significant interaction is an indication that there is no impact of P timing on fertilizer use by either crop. Exceptions however will be noted.

Soil samples were collected in June to assess potential loss of P availability following the fall application. In general, main effect significance was similar when P was analyzed by either the Bray P1 or Olsen P tests. The two exceptions were the corn location at Crookston and soybean location at Benson where the high level of carbonates neutralized the Bray solution and resulted in Very Low soil P tests which did not change with application rate. Benson was the only location where neither main effect was significant which could be due to greater variability in soil P due to the higher initial P soil tests. For Lamberton and both Morris sites, both main effects were significant for both soil tests while both main effects were also significant for the Olsen P test only at Crookston and Stewart. Since most sites were high pH where the Olsen P test is typically used, the Data in Figures 3 and 4 will be discussed for the corn and soybean locations, respectively.

The interaction between P source and rate was significant for the change in Olsen soil test P at the Morris corn and soybean locations. This indicates a difference in slope in the relationship between soil test P change and P application rate for the fall and spring applications. In all cases, Olsen soil test P was greater in June following spring application which is not surprising considering the greater time the P had to react with the soil from the fall application. From the relationships in Figures 3 and 4 it is surprising that more of the interactions were not significant. However, since most of the timing main effects were significant we have strong evidence that P is being tied up following fall application including at Lamberton which had an acidic pH. Sites like the soybean trial at Morris exhibited very little change in soil test P when up to 60 lbs P_2O_5 were applied.

Corn data are summarized in Table 5. Phosphorus application rate more consistently impacted measured variable compared to P application timing. Corn leaf P at V10 and R1 were generally increased linearly at most locations except for R1 leaf P at Morris which was no affected by P application. The only timing effect occurred for R1 leaf P concentration, which was greater for the fall application, but the difference was negligible. Expected concentration of P in corn leaves at R1 is between 0.2 and 0.4 %. All locations tested within that range with the lowest concentrations of P combing back at 0.23 %.

Corn grain harvest moisture was inconsistently affected by P application. Yield, however, was increased by P application at Lamberton and was impacted by timing at two locations, Lamberton and Morris. Corn grain yield favored spring application at both locations which were significant. The P rate by timing interaction was also significant at Morris indicating a significant impact of P rate that varied based on timing. The interaction is not shown in figures, but the analysis of data showed no yield difference between timing at the 0 and 90 lb application rates while spring application resulted in greater yield when 30 or 60 lbs P_2O_5 were applied. A regression was not run on the data but the ANOVA would indicate that application of 90 lbs would result in similar yield and that a small reduction in P could be taken if the P were applied at a rate greater than 60 lbs P_2O_5. The lack of a response to P at Crookston was likely due to high levels of Goss' Wilt which reduced yield potential in the trial. Overall yield potential was significantly lower at Crookston compared to the remaining sites. Corn grain P concentration and P removed in the harvested grain were also inconsistently impacted by P rate and timing effects.

Soybean data are summarized in Table 6. Phosphorus rate and timing did not affect the concentration in the uppermost fully developed trifoliate at R1. In addition, P concentration in the harvested grain, soybean protein and oil concentration were inconsistently impacted by treatments.

Soybean grain yield was affected by P rate at Morris and Stewart and was not impacted by timing. Soybean yield was increased when up to 60 lbs P_2O_5 were applied at both locations. Removal of P in the harvested grain was increased by P application rate at all three locations, even Benson where yield was not affected which contrasts with corn where P removal was seldom impacted. Yield increase to P was greater at Morris where yield was nearly doubled with the 60 lb P_2O_5 application rate compare to the control, and grain yield was increased 2 bu/ac at Stewart.

Table 6. Summary of treatment main effects for three soybean locations where P fertilizer rates were applied in Fall or spring ahead of the 2019 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	------------- R1 Trifoliate %P -------------					
Benson	0.37	0.38	0.40	0.42	0.39	0.39
Morris	0.42	0.35	0.44	0.45	0.41	0.42
Stewart	0.39	0.39	0.39	0.40	0.39	0.39
	------------- Soybean grain yield at 13% bushels per acre-------------					
Benson	56.3	55.9	58.7	56.2	56.9	56.7
Morris	32.7c	39.3b	47.5a	43.0ab	40.8	40.4
Stewart	57.1c	58.2bc	59.8a	58.8ab	58.4	58.6
	------------- Soybean Grain %P -------------					
Benson	0.72	0.69	0.73	0.73	0.71	0.72
Morris	0.46b	0.47b	0.52a	0.54a	0.49b	0.51a
Stewart	0.56	0.57	0.58	0.60	0.57	0.58
	------------- P Removed in Soybean Grain (lb P_2O_5/ac)-------------					
Benson	48ab	46b	51a	50a	48	49
Morris	16c	23b	27ab	28a	24	24
Stewart	38c	39bc	41ab	42a	40	41
	------------- Soybean Grain Protein % -------------					
Benson	45.7	45.7	45.8	45.9	45.9	45.7
Morris	45.1b	45.0b	45.8a	45.9a	45.3b	45.6a
Stewart	45.8	46.2	46.0	46.0	45.9b	46.1a
	------------- Soybean Grain Oil % -------------					
Benson	21.5	21.5	21.2	21.5	21.4	21.4
Morris	20.7	20.9	20.5	20.6	20.7	20.6
Stewart	22.8a	22.5b	22.4b	22.6b	22.6	22.6

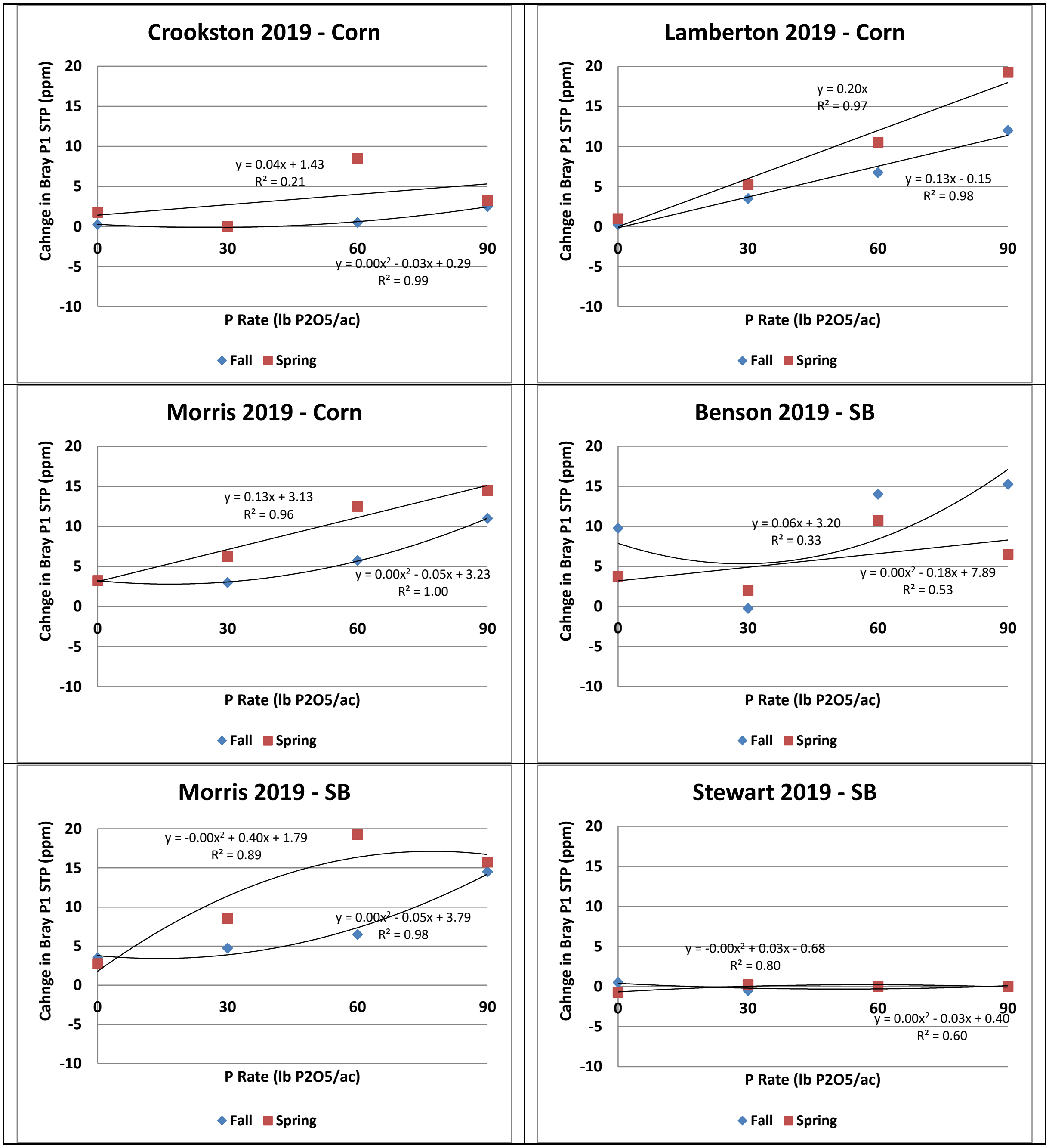


Figure 1. Summary of change in June Bray-B1 P following P application ahead of corn or soybean in Fall 2018 or Spring 2019.

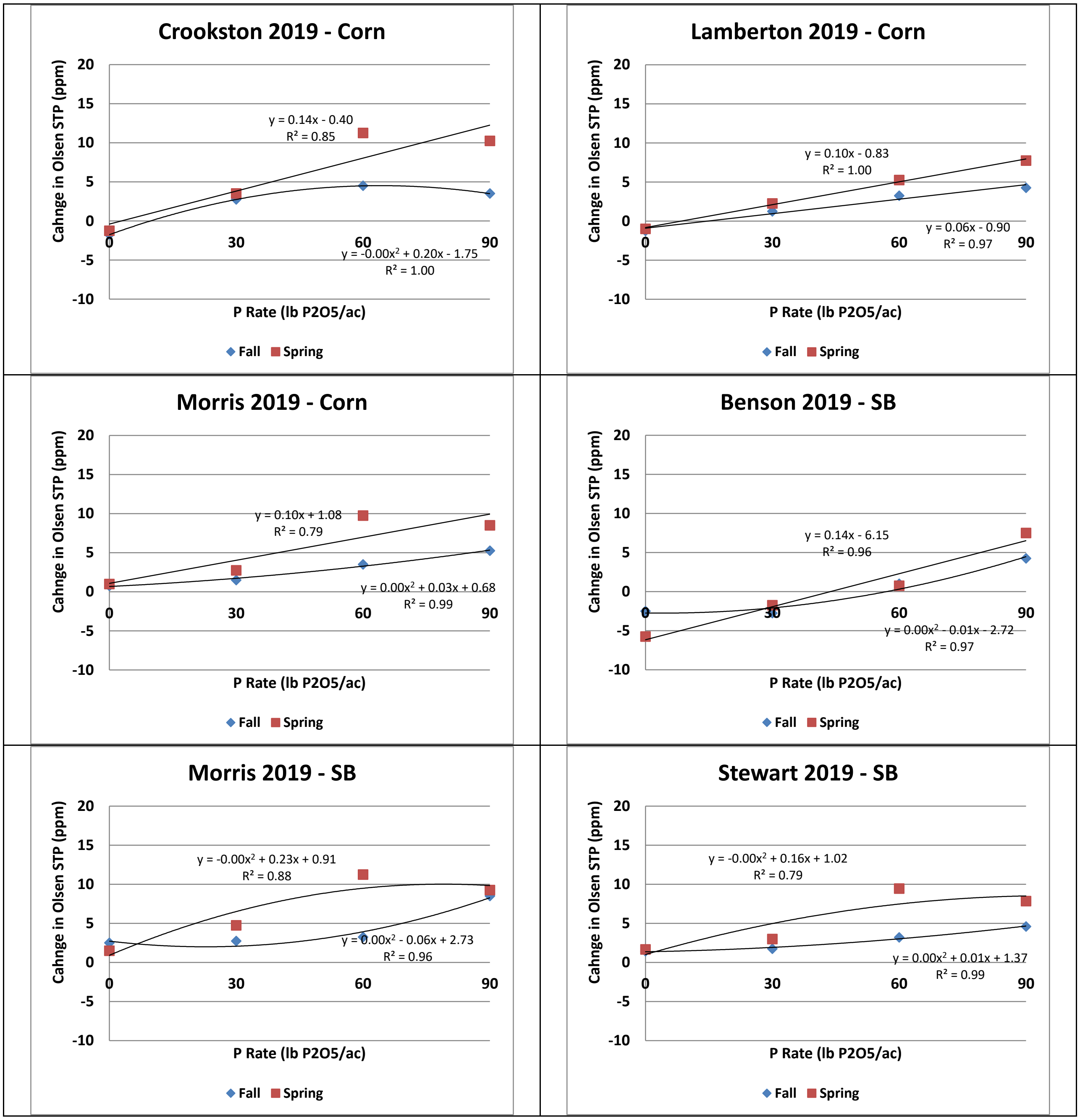


Figure 2. Summary of change in June Olsen P following P application ahead of corn or soybean in Fall 2018 or Spring 2019.

2020 Data Summary

Table 7 and 8 summarizes main effects and main effect interactions for the ANOVA for the measured variables for the 2020 corn and soybean trials, respectively. Tables 9 and 10 summarize the phosphorous (P) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant for soybean and mostly for corn. The interaction data are not summarized for many of the measured variables. A lack of a significant interaction is an indication that there is no impact of P timing on fertilizer use by either crop. Exceptions however will be noted.

Soil samples were collected in June to assess potential loss of P availability following the fall application. In general, main effect significance was similar when P was analyzed by either the Bray P1 or Olsen P tests. There was only one location in 2020, Stewart, where carbonates were relatively high, and the Bray P test was not impacted. There were three significant interactions between time and rate for Bray P (Crookston, Lamberton, and Stewart) and there was a significant interaction for Olsen P only at Crookston and Stewart (Figures 3 and 4). The Bray-P interaction was a result of no change in June Bray-P when P for P applied in the fall. The same was true for the significant interaction for Olsen P at Crookston but for Stewart Olsen soil test change differed between timing for the 30 and 60 lb application rates but not for the 0 and 90 lb rate. Timing did differ but, in all cases, the two-way interaction was also significant as well.

Corn data are summarized in Table 9. Phosphorus application rate more consistently impacted measured variable compared to P application timing. Corn leaf P at V10 and R1 were impacted by timing but not by rate, which contrasts with 2019 where rate generally impacted leaf P concentration.

Corn grain harvest moisture was greater when P was applied in the Fall at Crookston and Lamberton but did not differ at Morris (Table 9). At Morris, grain moisture decreased with increasing P application rate. Grain yield as greater with spring application at both Crookston and Lamberton while P application rate increased yield at Morris with 60 lb P_2O_5 application rate. In all cases decreased moisture in the grain at harvest was accompanied by an increase in grain yield.

Soybean data are summarized in Table 10. Phosphorus timing did not affect the concentration in the uppermost fully developed trifoliate at R1, while trifoliate P concentration increased with increasing rate of P applied at Danvers. In addition, P concentration in the harvested grain, soybean protein and oil concentration were seldom impacted by treatments. The exception was grain P and protein concentration at Morris which was increased by the rates of P applied.

Soybean grain yield was affected by P rate at Danvers (Table 10). Rate and timing of P application did not affect soybean grain yield in all other cases. Yield was relatively low at Morris and Stewart. The low yield at Morris could not be explained while two separate hail events in July reduced soybean yield potential at Stewart. Grain P removal was increased by P application rate at both Danvers and Stewart. At Danvers, soybean grain yield and grain P removal were greater for the 90 lb and there was no difference among the remaining treatments. At Stewart, all rates of P increased P removal similarly compared to the no P control.

Table 7. ANOVA summary for measured variables (phosphorus rate and timing) for the three corn trials conducted in 2020.

Main Effect	Bray P Change	Olsen P Change	V10 Leaf	R1 Leaf P	Grain Moisture	Grain Yield	Grain %P	Grain P Removal
	--			*P*>F	--			
				Crookston				
P rate	0.07	**	0.86	0.99	0.21	0.33	0.40	0.29
Timing	***	***	0.27	0.11	***	***	***	***
P rt. x Time	**	**	0.50	0.55	0.85	0.28	0.08	*
				Lamberton				
P rate	0.08	0.16	0.41	0.24	0.95	0.15	0.23	0.49
Timing	***	***	**	***	*	***	**	**
P rt. x Time	*	0.24	0.83	0.32	0.06	0.13	*	0.08
				Morris				
P rate	*	***	0.33	0.39	*	*	0.09	0.08
Timing	0.38	0.44	**	**	0.47	0.73	0.96	0.88
P rt. x Time	0.38	0.21	**	**	0.40	0.61	0.41	0.72

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 8. ANOVA summary for measured variables (phosphorus rate and timing) for the three soybean trials conducted in 2020.

Main Effect	Bray P Change	Olsen P Change	R1 Leaf P	Grain Yield	Grain %P	Grain P Removal	Grain Protein	Grain Oil
	--			*P*>F		--		
				Danvers				
P rate	**	**	*	0.07	0.49	0.07	0.17	0.30
Timing	*	0.33	0.43	0.32	0.27	0.54	0.92	0.87
P rt. x Time	0.78	0.60	0.18	0.55	0.08	0.75	0.55	0.25
				Morris				
P rate	0.14	0.06	0.34	0.91	0.05	0.51	0.06	0.67
Timing	0.28	0.15	0.29	0.40	0.41	0.28	0.17	0.10
P rt. x Time	0.18	0.33	0.91	0.45	0.47	0.28	0.89	0.41
				Stewart				
P rate	*	**	0.22	0.28	0.15	*	0.35	0.33
Timing	0.12	0.32	0.26	0.13	0.63	0.27	0.86	0.34
P rt. x Time	**	0.10	0.39	*	0.54	0.30	0.25	0.99

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 9. Summary of treatment main effects for three corn locations where P fertilizer rates were applied in Fall or spring ahead of the 2020 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	V10 Upper Leaf %P					
Crookston	0.27	0.27	0.28	0.32	0.29	0.27
Lamberton	0.33	0.36	0.34	0.36	0.33b	0.36a
Morris	0.27	0.32	0.27	0.31	0.32a	0.26b
	R1 Leaf %P					
Crookston	0.23	0.23	0.23	0.24	0.25	0.22
Lamberton	0.30	0.31	0.30	0.33	0.28b	0.33b
Morris	0.25	0.28	0.23	0.27	0.28a	0.23b
	Moisture in harvested grain %					
Crookston	13.6	13.3	13.5	13.0	13.8a	12.9b
Lamberton	18.1	18.0	17.9	18.1	18.3a	17.8b
Morris	17.0a	16.4ab	16.1bc	15.5c	16.1	16.4
	Corn grain yield at 15.5% bushels per acre					
Crookston	143	158	156	162	143b	166a
Lamberton	195	195	202	197	193b	202a
Morris	188c	201bc	207ab	223a	206	204
	Corn Grain %P					
Crookston	0.25	0.27	0.27	0.28	0.24b	0.29a
Lamberton	0.21	0.22	0.21	0.22	0.20b	0.22a
Morris	0.19b	0.19b	0.22a	0.23a	0.21	0.21
	P Removed in Corn Grain (lb P_2O_5/ac)					
Crookston	41	48	48	49	38b	55a
Lamberton	43	45	45	47	42b	48a
Morris	40b	40b	54a	55a	47	47

Table 10. Summary of treatment main effects for three soybean locations where P fertilizer rates were applied in Fall or spring ahead of the 2020 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	------------------------------------- R1 Trifoliate %P -------------------------------------					
Danvers	0.52b	0.48c	0.54ab	0.55a	0.52	0.53
Morris	0.39	0.37	0.39	0.42	0.40	0.39
Stewart	0.58	0.55	0.53	0.57	0.55	0.56
	---------------------- Soybean grain yield at 13% bushels per acre-----------------------					
Danvers	56.1b	54.5b	54.0b	60.7a	56.7	55.9
Morris	22.7	22.9	24.8	24.6	24.5	23.0
Stewart	42.2	44.2	44.0	44.0	44.2	43.0
	---------------------------------- Soybean Grain %P ----------------------------------					
Danvers	0.62	0.64	0.63	0.62	0.62	0.63
Morris	0.49b	0.52ab	0.54a	0.55a	0.53	0.52
Stewart	0.48	0.50	0.51	0.51	0.50	0.50
	------------------------ P Removed in Soybean Grain (lb P_2O_5/ac)-----------------------					
Danvers	41b	41b	40b	46a	42	42
Morris	13	14	15	17	15	14
Stewart	24b	26a	27a	27a	26	26
	--------------------------------- Soybean Grain Protein % ---------------------------------					
Danvers	36.2	36.0	35.7	35.7	35.8	35.9
Morris	35.0b	35.6a	35.8a	35.8a	35.4	35.7
Stewart	34.4	34.2	34.2	34.2	34.3	34.2
	--------------------------------- Soybean Grain Oil % ---------------------------------					
Danvers	16.5	16.1	16.4	16.4	16.3	16.4
Morris	16.4	16.4	16.3	16.5	16.4	16.3
Stewart	17.5	17.7	17.7	17.6	17.6	17.7

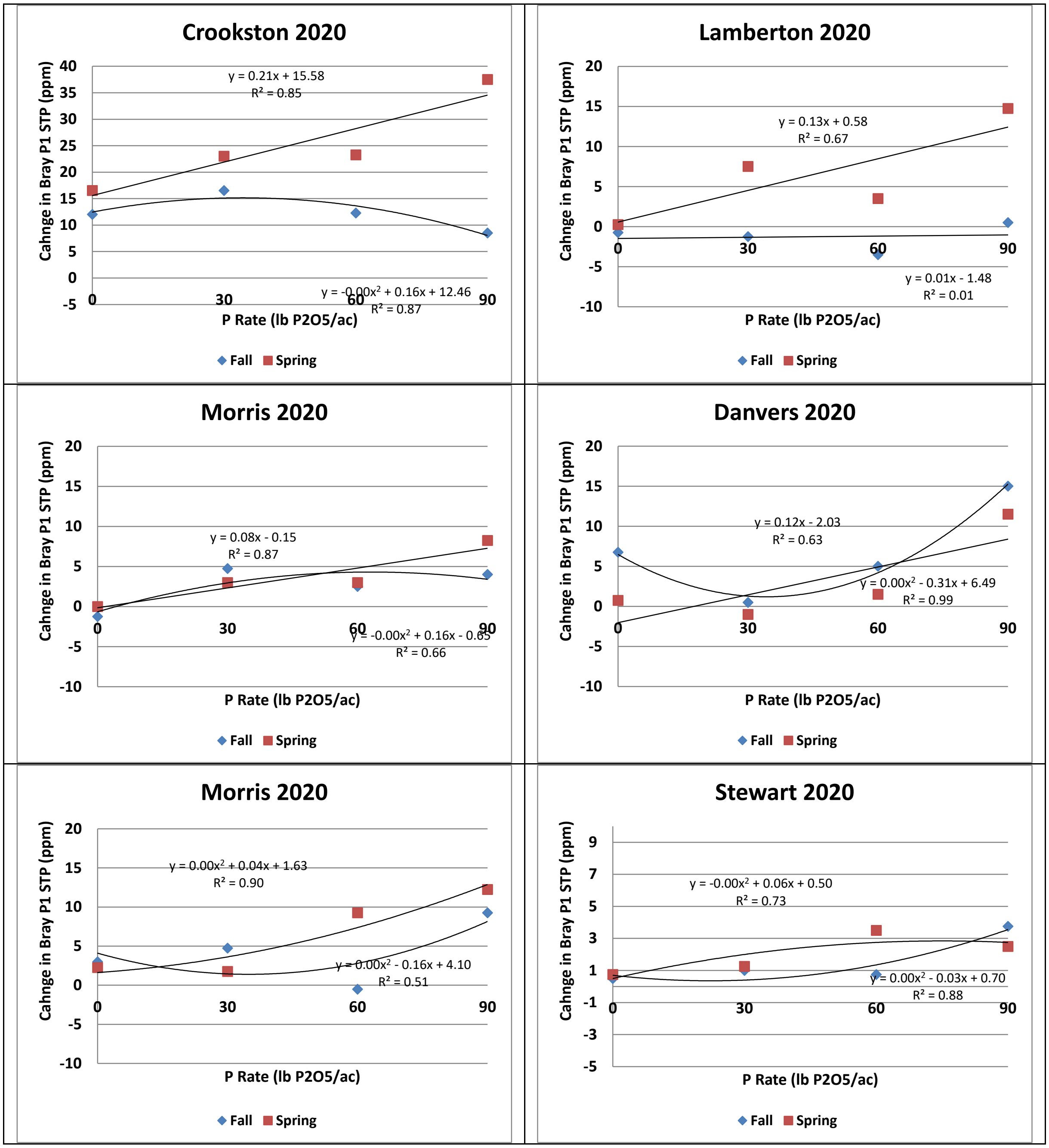


Figure 3. Summary of change in June Bray-B1 P following P application ahead of corn or soybean in Fall 2019 or Spring 2020.

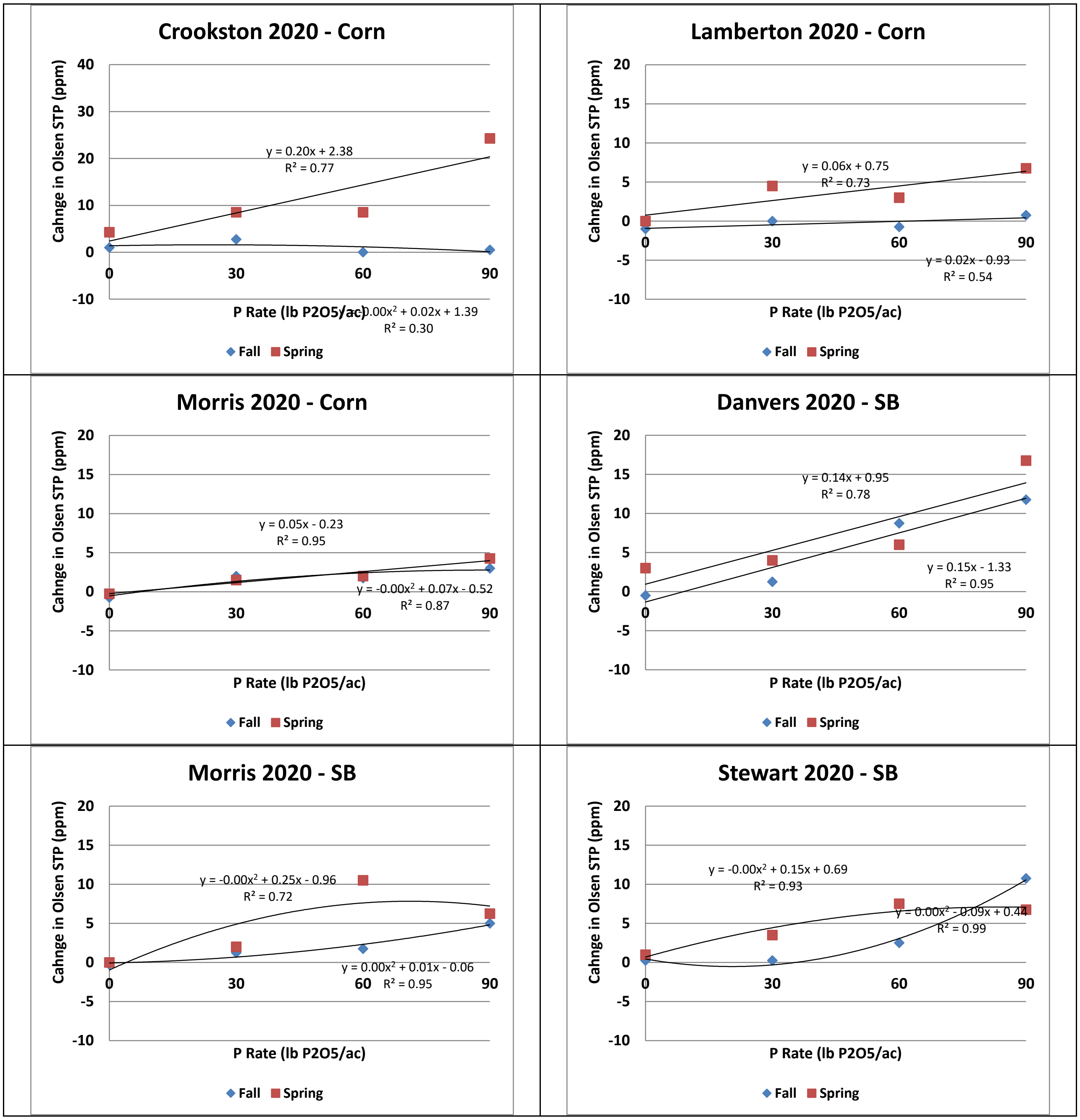


Figure 4. Summary of change in June Olsen P following P application ahead of corn or soybean in Fall 2019 or Spring 2020.

2021 Data Summary

Table 11 and 12 summarizes main effects and main effect interactions for the ANOVA for the measured variables for the 2021 corn and soybean trials, respectively. Tables 13 and 14 summarize the phosphorous (P) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant for soybean and mostly for corn. The interaction data are not summarized for many of the measured variables. A lack of a significant interaction is an indication that there is no impact of P timing on fertilizer use by either crop. Exceptions however will be noted.

Soil samples were collected in June to assess potential loss of P availability following the fall application. In general, main effect significance was similar when P was analyzed by either the Bray P1 or Olsen P tests. Carbonates were high at one corn location, Crookston, and at two soybean locations, Holloway, and Stewart. Carbonates in the soil impacted the Bray-P1 test more significantly at Crookston and Holloway and had less of an impact at Stewart. There were three significant interactions between time and rate for Bray P and Olsen P only at Morris. However, P application increased STP, but the increase was greater for spring applied P (Figures 5 and 6). Timing main effect was generally significant, and the two-way interaction wasn’t always significant when the timing main effect was significant. When timing was significant spring P application always resulted in a higher average STP concentration compared to fall.

Corn data are summarized in Table 12. Phosphorus application rate more consistently impacted measured variable compared to P application timing. Corn leaf P at V10 and R1 were impacted by timing and by rate at all locations except for the R1 leaf P concentration at Crookston like 2019 were rate generally impacted leaf P concentration. Moisture in the harvested corn grain was seldom impacted by P timing or rate. Phosphorus concentration in grain and P removed by harvested grain were impacted by timing and rate to Lamberton and Morris, but not at Crookston. Corn grain yield was impacted by P rate at Lamberton and Morris but timing only impacted corn grain yield at Lamberton. Unlike other years, corn grain yield was greater with the fall application at Lamberton. Grain yield was relatively low due to dry weather conditions at Lamberton in 2021 so the greater impact of fall P application may be a result of better mixing of P in the soil profile with more aggressive fall tillage. It’s likely that more of the P with the spring application may be closer to the soil surface in soils that are drier that may have limited P uptake. This cannot be proven with the data generated.

Soybean data are summarized in Table 13. Phosphorus timing did not affect the concentration in the uppermost fully developed trifoliate at R1, while trifoliate P concentration increased with increasing rate of P applied at Morris. Phosphorus concentration in the harvested grain was impacted by P rate at all soybean locations while timing only impacted grain P concentration at Morris and Stewart. Soybean protein and oil concentration were seldom impacted by treatments. Soybean grain yield was not impacted by P rate or timing at any location.

Table 11. ANOVA summary for measured variables (phosphorus rate and timing) for the three corn trials conducted in 2021.

Main Effect	Bray P Change	Olsen P Change	V10 Leaf	R1 Leaf P	Grain Moisture	Grain Yield	Grain %P	Grain P Removal
	-------------------------------------			*P*>F	-------------------------------------			
				Crookston				
P rate	0.98	*	0.08	0.73	0.92	0.84	0.50	0.94
Timing	0.22	0.32	*	0.23	0.72	0.93	0.13	0.34
P rt. x Time	0.65	0.39	0.49	0.91	0.21	0.69	0.91	0.89
				Lamberton				
P rate	**	*	***	***	0.12	***	*	***
Timing	0.41	0.33	*	***	*	***	*	***
P rt. x Time	0.42	0.53	*	0.12	0.84	**	0.16	**
				Morris				
P rate	**	**	*	*	0.40	*	***	***
Timing	**	**	*	0.74	0.66	0.97	**	0.18
P rt. x Time	*	*	*	0.39	0.45	*	0.16	0.14

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 12. ANOVA summary for measured variables (phosphorus rate and timing) for the three soybean trials conducted in 2021.

Main Effect	Bray P Change	Olsen P Change	R1 Leaf P	Grain Yield	Grain %P	Grain P Removal	Grain Protein	Grain Oil
	--------------------------------	---------	---------	*P*>F	---------	---------	--------------------------------	
				Holloway				
P rate	0.52	*	0.63	0.77	**	0.09	0.58	0.98
Timing	0.34	0.31	0.92	0.51	0.92	0.57	1.00	0.87
P rt. x Time	0.43	0.22	0.17	0.75	0.31	0.64	0.34	0.21
				Morris				
P rate	**	**	*	0.82	**	0.17	0.93	0.78
Timing	*	*	0.14	0.96	***	0.36	0.48	0.15
P rt. x Time	0.17	0.26	0.18	0.14	0.33	0.14	0.54	0.55
				Stewart				
P rate	0.06	*	0.50	0.13	*	0.29	0.27	0.18
Timing	0.17	0.26	0.35	0.72	0.40	0.53	*	**
P rt. x Time	0.73	0.39	0.79	0.92	0.45	0.57	*	0.10

Asterisks denote significance at $P \leq 0.001$ (***), $P \leq 0.01$ (**), and $P \leq 0.05$ (*) probability levels.

Table 13. Summary of treatment main effects for three corn locations where P fertilizer rates were applied in Fall or spring ahead of the 2021 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	V10 Upper Leaf %P					
Crookston	0.22b	0.22b	0.23ab	0.24a	0.24a	0.22b
Lamberton	0.17b	0.19b	0.22a	0.23a	0.22a	0.19b
Morris	0.25b	0.27b	0.32a	0.32a	0.30a	0.28b
	R1 Leaf %P					
Crookston	0.19	0.18	0.19	0.19	0.19	0.18
Lamberton	0.09c	0.10b	0.13a	0.14a	0.13a	0.10b
Morris	0.16b	0.16b	0.21a	0.24a	0.19	0.19
	Moisture in harvested grain %					
Crookston	13.8	13.6	13.9	13.8	13.7	13.9
Lamberton	13.6	13.5	14.0	14.0	14.0a	13.5b
Morris	16.7	16.2	16.6	16.4	16.4	16.5
	Corn grain yield at 15.5% bushels per acre					
Crookston	88	90	84	89	88	88
Lamberton	66c	87b	101a	106a	98a	82b
Morris	172b	177b	189ab	210a	187	187
	Corn Grain %P					
Crookston	0.22	0.21	0.23	0.22	0.23	0.21
Lamberton	0.13b	0.15a	0.16a	0.16a	0.16a	0.15b
Morris	0.16c	0.18b	0.23a	0.23a	0.21a	0.19b
	P Removed in Corn Grain (lb P_2O_5/ac)					
Crookston	19	20	20	21	19	21
Lamberton	9c	14b	18a	20a	17a	13b
Morris	32b	34b	46a	54a	43	40

Table 14. Summary of treatment main effects for three soybean locations where P fertilizer rates were applied in Fall or spring ahead of the 2021 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	------- R1 Trifoliate %P -------					
Holloway	0.47	0.48	0.47	0.45	0.47	0.47
Morris	0.32bc	0.36a	0.30c	0.33ab	0.33	0.32
Stewart	0.40	0.37	0.37	0.40	0.39	0.38
	------- Soybean grain yield at 13% bushels per acre-------					
Holloway	62.9	62.5	62.1	64.8	63.7	62.4
Morris	24.4	25.6	26.4	26.0	25.6	25.6
Stewart	65.5	66.8	63.4	70.5	66.9	66.2
	------- Soybean Grain %P -------					
Holloway	0.65b	0.53c	0.59ab	0.60a	0.57	0.57
Morris	0.50b	0.55a	0.55a	0.54a	0.55a	0.52b
Stewart	0.47bc	0.46c	0.50a	0.49ab	0.49	0.48
	------- P Removed in Soybean Grain (lb P_2O_5/ac)-------					
Holloway	42b	40b	44ab	46a	43	42
Morris	14	16	17	17	17	16
Stewart	38	37	36	41	39	38
	------- Soybean Grain Protein % -------					
Holloway	34.0	33.8	34.1	34.3	34.1	34.1
Morris	34.7	34.6	34.8	34.7	34.7	34.6
Stewart	32.0	33.0	32.7	33.2	33.0a	32.5b
	------- Soybean Grain Oil % -------					
Holloway	18.6	18.6	18.6	18.6	18.6	18.6
Morris	17.6	17.6	17.5	17.4	17.4	17.6
Stewart	19.6	19.3	19.3	18.9	19.1b	19.4a

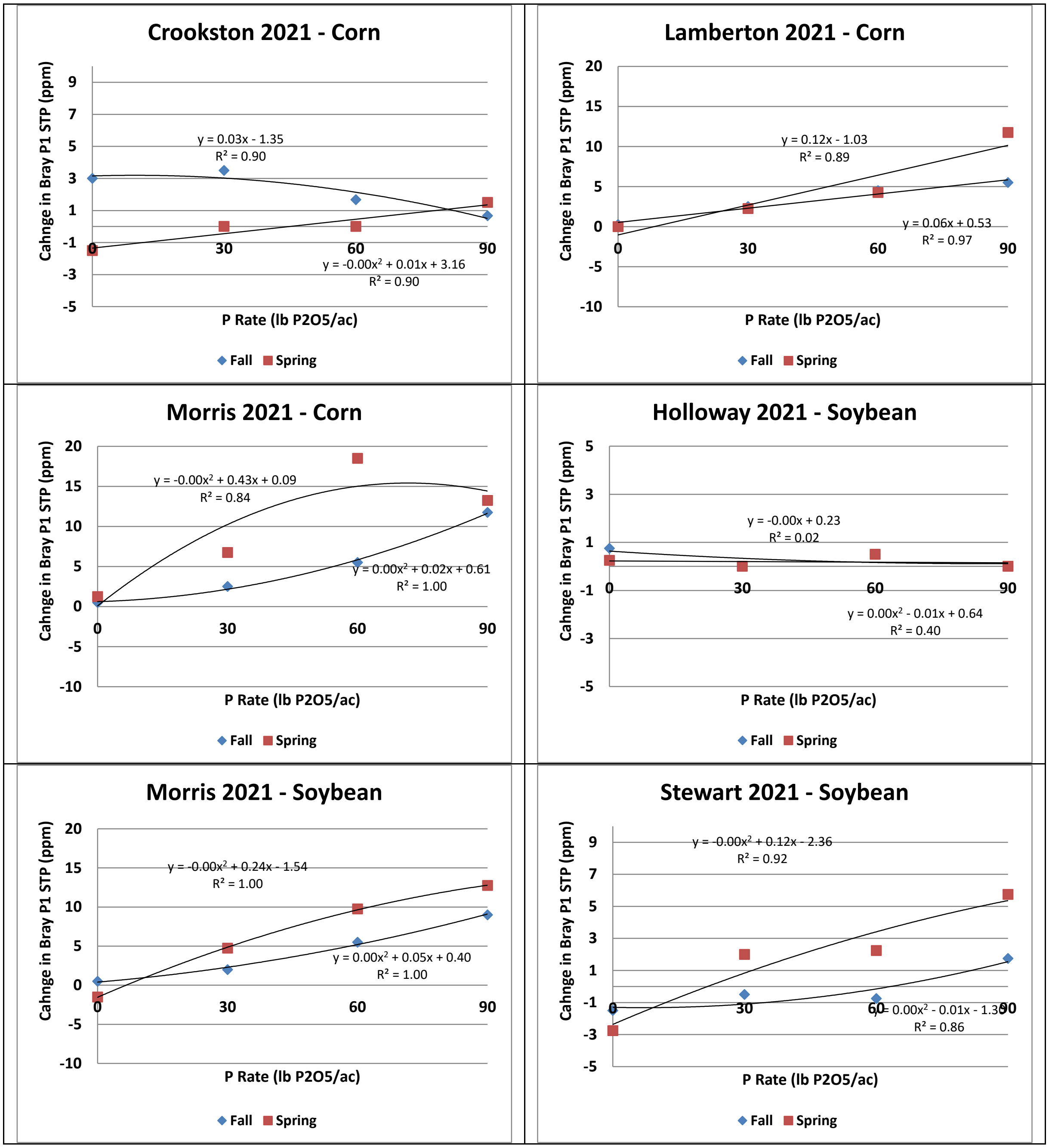


Figure 5. Summary of change in June Bray-B1 P following P application ahead of corn or soybean in Fall 2020 or Spring 2021.

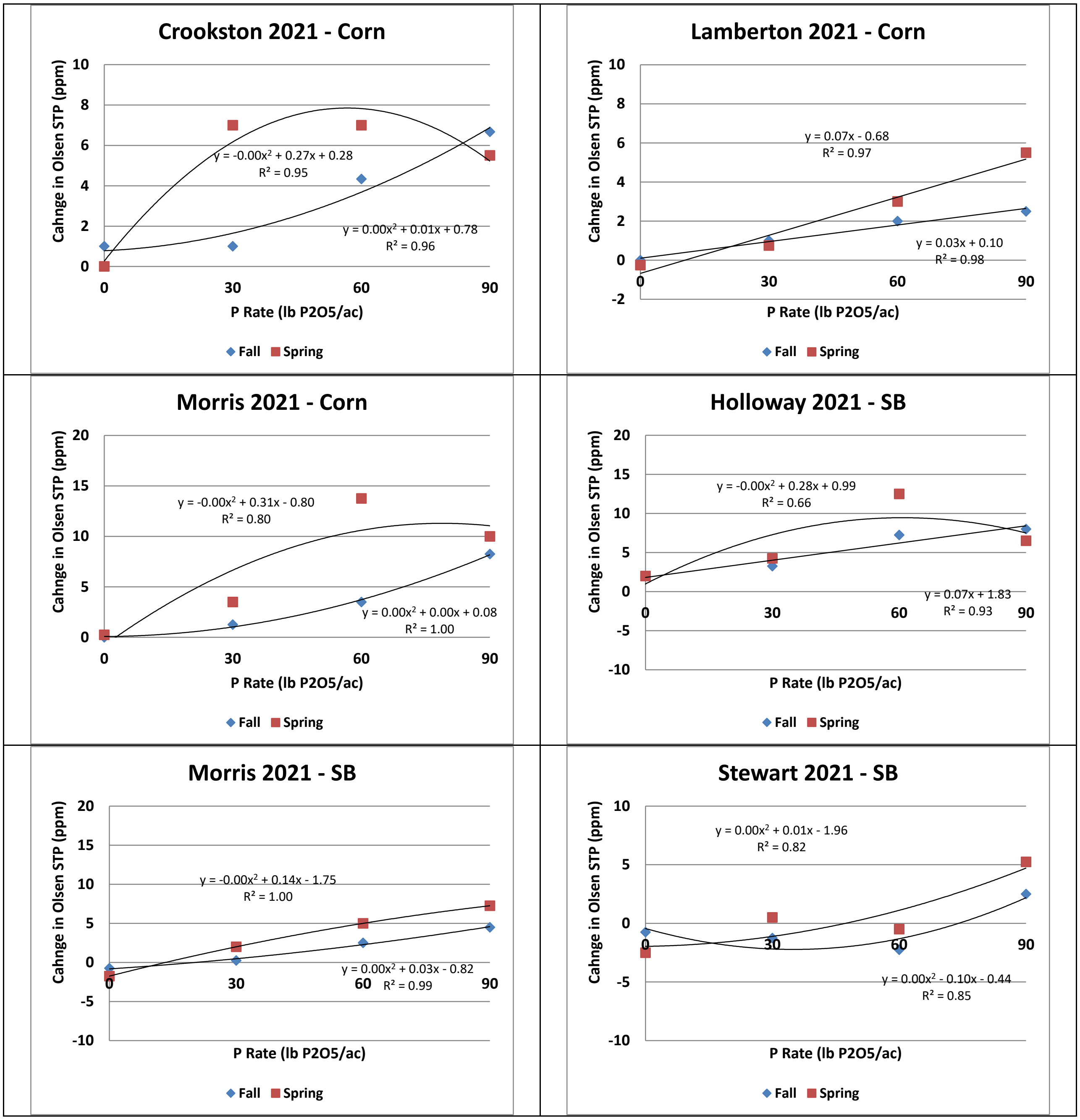


Figure 6. Summary of change in June Olsen P following P application ahead of corn or soybean in Fall 2020 or Spring 2021.

2022 Data Summary

Tables 15 and 16 summarize main effects and main effect interactions for the ANOVA for the measured variables for the 2022 corn and soybean trials, respectively. Tables 17 and 18 summarize the phosphorous (P) rate and timing main effects for corn and soybean, respectively. Interactions were generally not significant for both crops. The interaction data are not summarized for many of the measured variables. A lack of a significant interaction is an indication that there is no impact of P timing on fertilizer use by either crop. Exceptions however will be noted.

Soil samples were collected in June to assess potential loss of P availability following the fall application. Corn and soybean trials were located within the same block at the Northwest Research and Outreach center resulting in similar preliminary soil test results for both crops. Unlike past years, soil test P responded similarly to fall or spring applied P. This effect was the same for both the Bray-P1 and Olsen P tests. Soil carbonates were not that high compared to some other sites, but I would have expected some reaction of the fall applied P with the soil resulting in a lower soil test P in June. There was only one significant interaction which was between P rate and timing for the Corn study. It did appear that the Olsen soil test P did increase more at the lower rates for spring applied P, but results were similar for the highest rate of P applied.

Corn data are summarized in Table 17. Phosphorus rate affected all measured variables except for R1 leaf P concentration and grain moisture at harvest. Application timing only affected R1 leaf P concentration and corn grain yield. Corn grain yield was greater for fall applied P which is like what happened at Lamberton in 2021, but different from most other corn sites were spring application outyielded fall. The 90 lb P_2O_5 rate did result in the greatest grain yield and since no other rates were applied, we don't know whether 90 lbs was enough for this site to maximize yield.

Soybean data are summarized in Table 18. Phosphorus timing did not impact any of the measured variables in the soybean plots but rate did impact the concentration of P in the uppermost fully developed trifoliate at R1 and the amount of P removed in grain at harvest. Soybean grain yield was not impacted by P rate or timing in-spite of a significant response to P in the corn plot adjacent to the soybean trial.

Table 15. ANOVA summary for measured variables (phosphorus rate and timing) for the Crookston corn trial conducted in 2022.

Main Effect	Bray P Change	Olsen P Change	V10 Leaf	R1 Leaf P	Grain Moisture	Grain Yield	Grain %P	Grain P Removal
	------------------------------------			*P*>F		------------------------------------		
				Crookston				
P rate	***	***	*	0.51	0.39	**	**	***
Timing	0.49	0.39	0.55	*	0.58	*	0.18	0.15
P rt. x Time	0.20	0.09	0.79	0.57	0.45	0.56	0.92	0.93

Asterisks denote significance at *P*≤0.001 (***), *P*≤0.01 (**), and *P*≤0.05 (*) probability levels.

Table 16. ANOVA summary for measured variables (phosphorus rate and timing) for the Crookston soybean trial conducted in 2022.

Main Effect	Bray P Change	Olsen P Change	R1 Leaf P	Grain Yield	Grain %P	Grain P Removal	Grain Protein	Grain Oil
	------------------------------------			*P*>F		------------------------------------		
				Crookston				
P rate	***	***	0.63	0.23	*	*	0.72	0.94
Timing	0.96	0.76	0.97	0.42	0.15	0.65	0.59	0.43
P rt. x Time	0.55	0.28	0.12	0.61	0.34	0.34	0.65	0.62

Asterisks denote significance at *P*≤0.001 (***), *P*≤0.01 (**), and *P*≤0.05 (*) probability levels.

Table 17. Summary of treatment main effects for Crookston corn where P fertilizer rates were applied in Fall or spring ahead of the 2022 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	V10 Upper Leaf %P					
Crookston	0.32	0.36	0.36	0.35	0.35	0.34
	R1 Leaf %P					
Crookston	0.27	0.28	0.29	0.28	0.29a	0.27b
	Moisture in harvested grain %					
Crookston	14.2	14.3	14.3	14.4	14.3	14.3
	Corn grain yield at 15.5% bushels per acre					
Crookston	156c	166b	167b	174a	167a	164b
	Corn Grain %P					
Crookston	0.19b	0.21b	0.24a	0.26a	0.23	0.22
	P Removed in Corn Grain (lb P_2O_5/ac)					
Crookston	32c	38b	45a	49a	42	39

Table 18. Summary of treatment main effects for Crookston soybean where P fertilizer rates were applied in Fall or spring ahead of the 2022 cropping season. Treatments are considered significantly different at $P \leq 0.10$. Numbers followed by the same letter for individual site treatment main effects are not significantly different.

	P application rate (lb P_2O_5 ac^{-1})				Application Time	
Location	0	30	60	90	Fall	Spring
	R1 Trifoliate %P					
Crookston	0.44	0.43	0.44	0.47	0.45	0.45
	Soybean grain yield at 13% bushels per acre					
Crookston	42.5	44.9	46.6	45.8	44.6	45.4
	Soybean Grain %P					
Crookston	0.39c	0.46bc	0.52ab	0.54a	0.49	0.47
	P Removed in Soybean Grain (lb P_2O_5/ac)					
Crookston	20b	25bc	29ab	30a	26	26
	Soybean Grain Protein %					
Crookston	33.3	33.0	33.3	33.2	33.1	33.2
	Soybean Grain Oil %					
Crookston	18.3	18.4	18.4	18.4	18.3	18.5

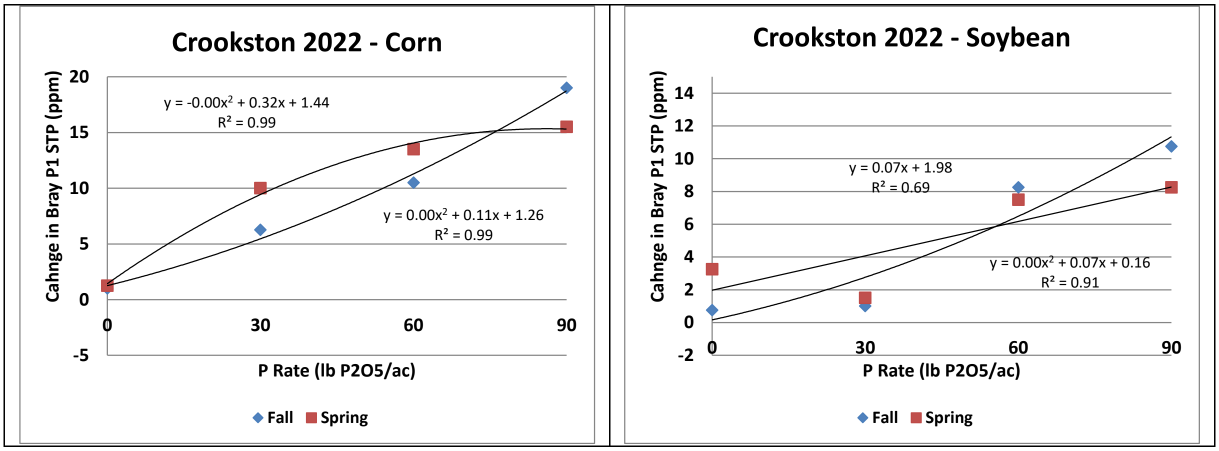


Figure 7. Summary of change in June Bray-B1 P following P application ahead of corn or soybean in Fall 2021 or Spring 2022.

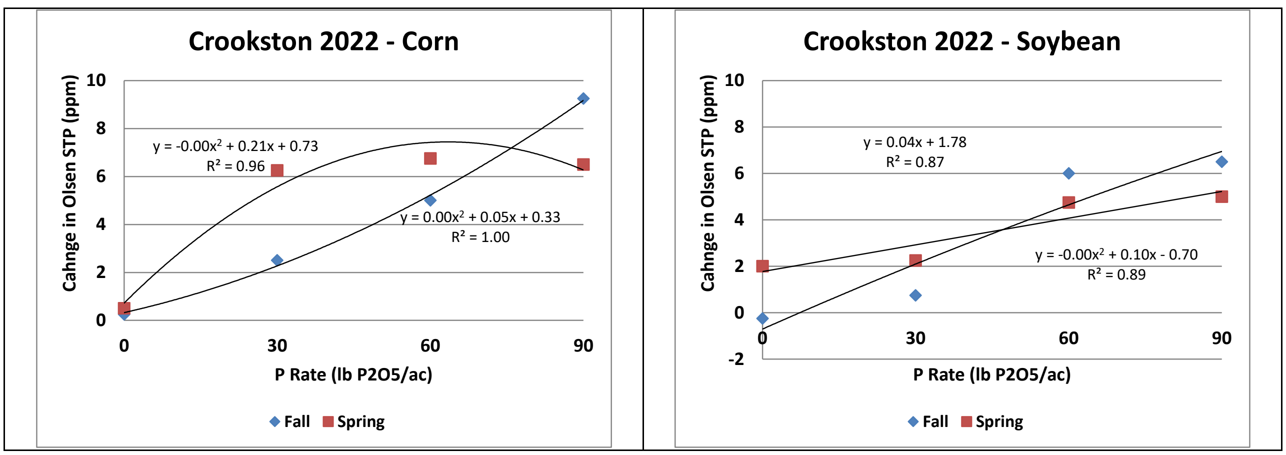


Figure 8. Summary of change in June Olsen P following P application ahead of corn or soybean in Fall 2021 or Spring 2022.

Overall Summary and Conclusions

A summary of corn and soybean P response across the six individual locations is given in Figure 9 and 10, respectively. For corn, there were two different response scenarios. Most site when averaged together favored spring application compared to fall. For fall application, corn grain yield increased linearly to the 90 lb application rate which yield was increased up to 60 lbs of applied P for the spring application. The yield produced by the 90 lb fall rate was roughly equivalent to 45 lbs of P_2O_5 applied in the spring across 7 of the 10 locations. The data indicates that for corn, P application in the spring should be favored with low P soils and that some of the P was likely tied up in the soil and rendered unavailable following application in the fall.

At two locations, Lamberton 2021 and Crookston 2022, corn grain yield was greater for P applied in the fall compared to spring. Both sites had low yield potential due to dry weather. It is plausible that the incorporation of P at a potentially deeper depth or more time to dissolve P in the soil following fall application may result in higher grain yield compared to shallow incorporation of P in dry years. Seven of the nine remaining sites favored spring application and soil test P tended to be less in June to the point where at times the rate of P applied could not be seen in the change in STP. I cannot be sure that the dry weather caused this difference as it is not possible to measure P response in soils with differing soil moisture levels.

Soybean grain yield did not differ based on fertilizer timing (Figure 10). Soybean grain yield was increased linearly up to the 90 lb P_2O_5 application rate across the sites. Unlike corn, P fertilizer application timing is less of a consideration for soybean compared to corn.

A simple economic analysis was conducted using the corn data in Figure 9. Assuming 175 bu/ac yield took either 71 lbs P_2O_5 in fall compared to 38 lbs in the spring, \$0.50/ lb P_2O_5 for fall application and \$0.55 in spring, and \$5/bu corn cash price there would be a \$14 per acre profit for spring application. Increasing the fall P price to \$0.80 resulted in greater profitability, \$23 per acre profit, for spring application. Since there was no difference between fall and spring P application for soybean profitability would be slightly less for spring application of P if the cost per pound P205 is higher in spring. Historically the cost per lb P_2O_5 is roughly 10% greater for spring application. Decisions for timing of P application for soybean should be made solely on cost and logistics while corn grown on soil with high pH would favor spring application of P.

June Olsen soil test P (STP) was regressed with relative corn and soybean grain yield (Figure 11). There was a better relationship between June STP and corn yield as there was much greater variability in relative soybean grain yield. For corn, relative grain yield was at maximum when Olsen P was 6 ppm which is in the medium soil P classification. In contrast, soybean grain yield was at maximum when soybean grain yield was near 20 ppm which is the upper end of the high soil test classification. Responses were separated by fall and spring application but the soil test at maximum yield was similar for both corn and soybean. The STP level that maximized soybean yield was much greater than expected but with the amount of variability in the data it is likely that the actual STP concentration needed to maximize yield is much closer to that of corn. Soybean yield response is not likely with Olsen STP is greater than 11 ppm.

Figure 12 summarizes the relationship between relative corn yield and V10 and R1 leaf P concentrations. There was a relationship between leaf P concentration and relative yield in both cases. For uppermost fully developed leaves at V10, grain yield was maximized when leaf P concentration was near 0.3%, while the concentration of P needed for maximin yield for the leaf opposite and below the ear was 0.23% at R1. The relationship between the concentration of P in the uppermost fully developed trifoliate in soybean at R1 was more poorly correlated with relative soybean yield. However, soybean grain yield was at maximum with R1 trifoliate P concentration was near 0.38% (Figure 13). When the study is completed, I will compile data with other trials upon completion of the study. The relationship between soybean grain yield and trifoliate P concentration has generally been poor compared to corn leaf P concentration.

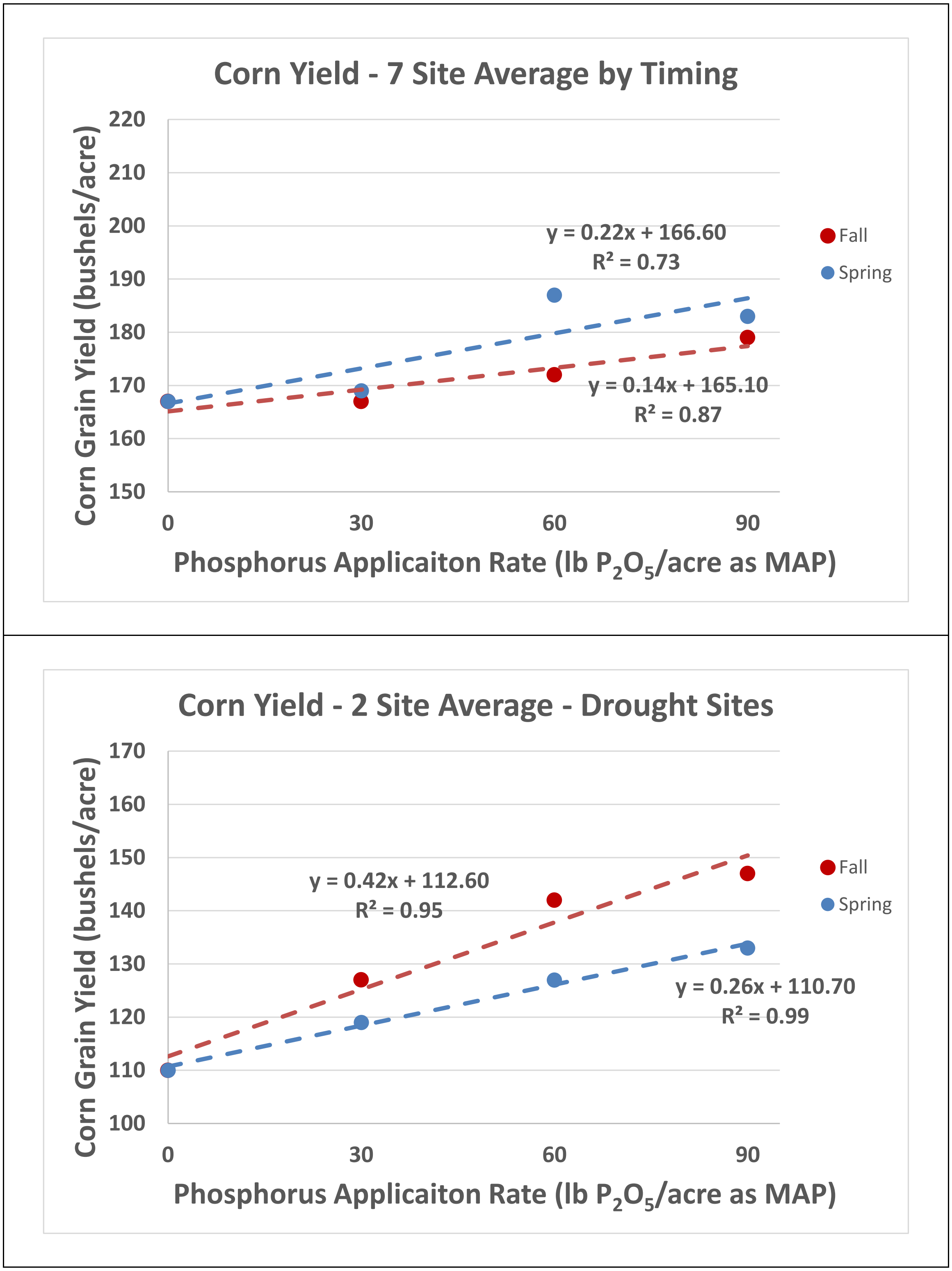


Figure 9. Summary of yield response to P across the six corn and six soybean locations conducted in 2019 to 2021.

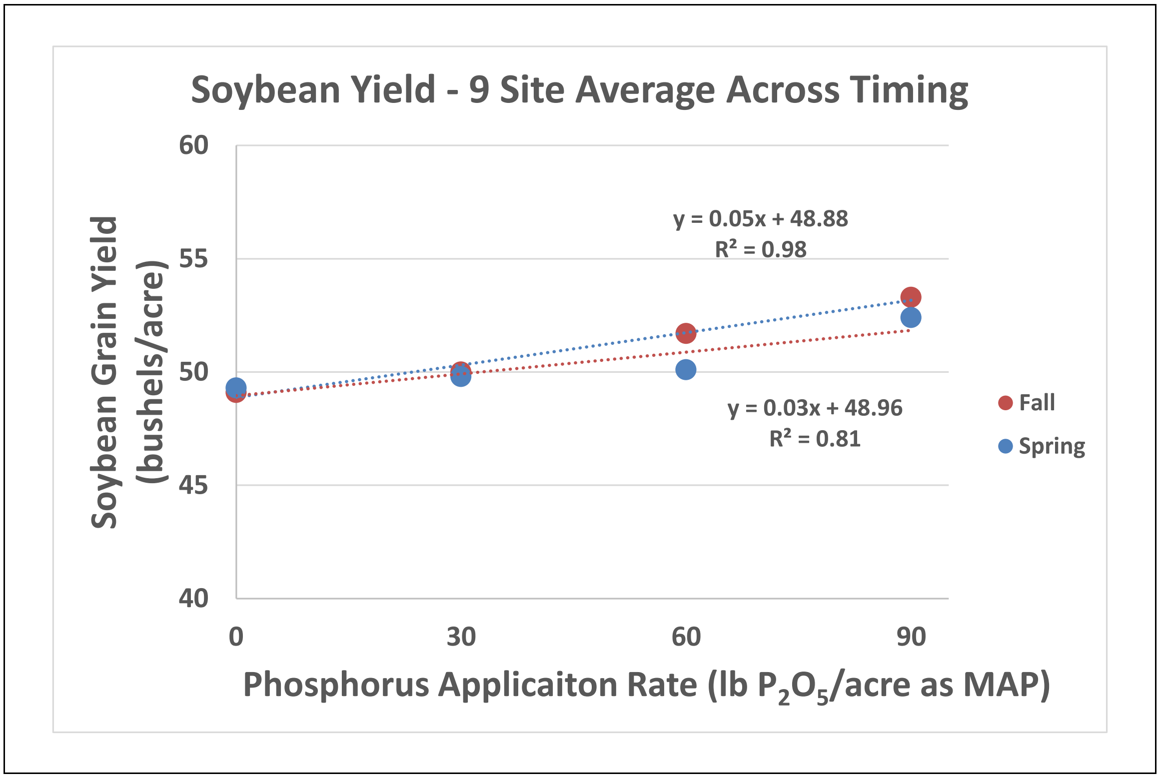


Figure 10. Summary of yield response to P across nine soybean locations conducted in 2019 to 2022.

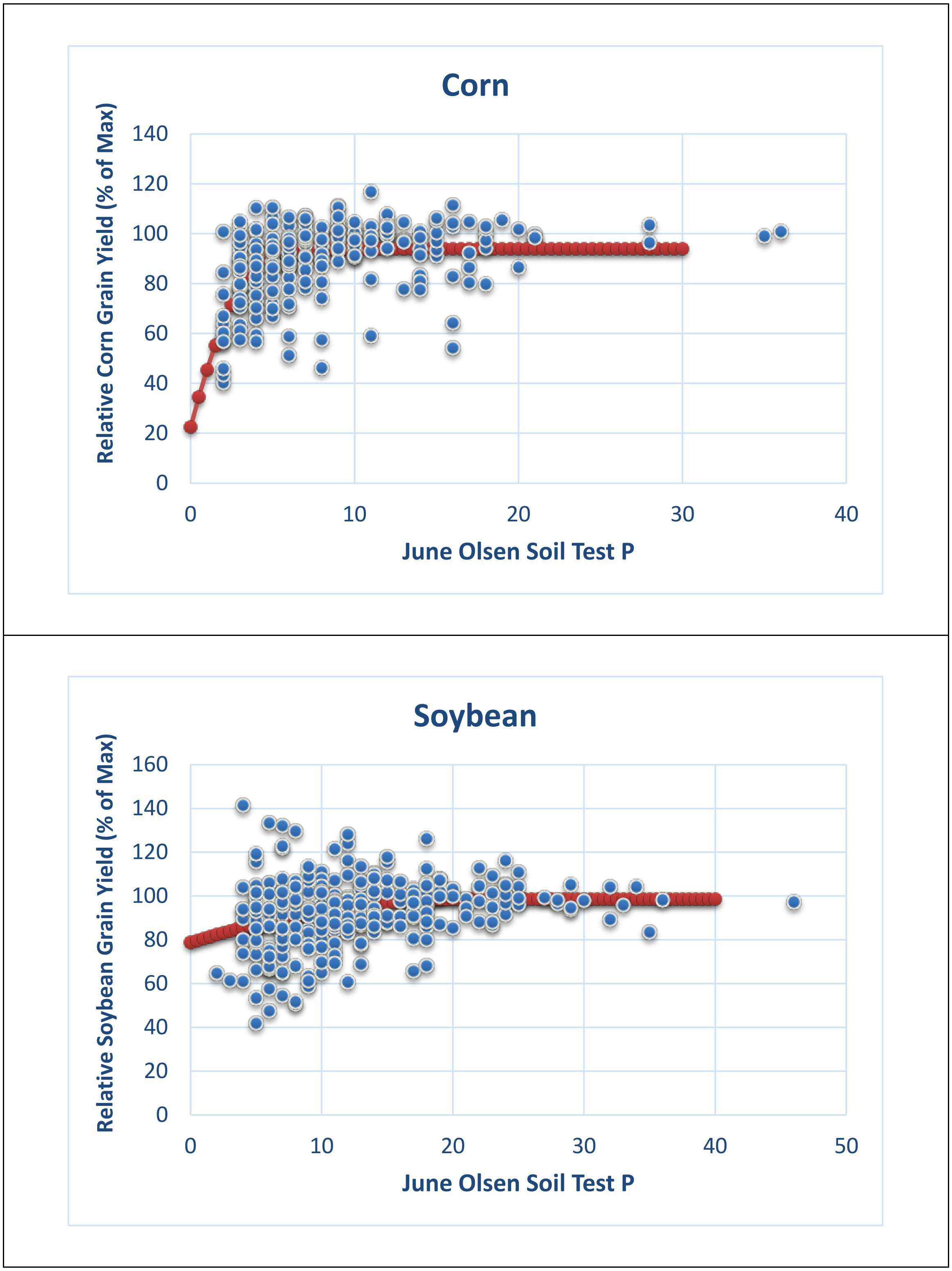
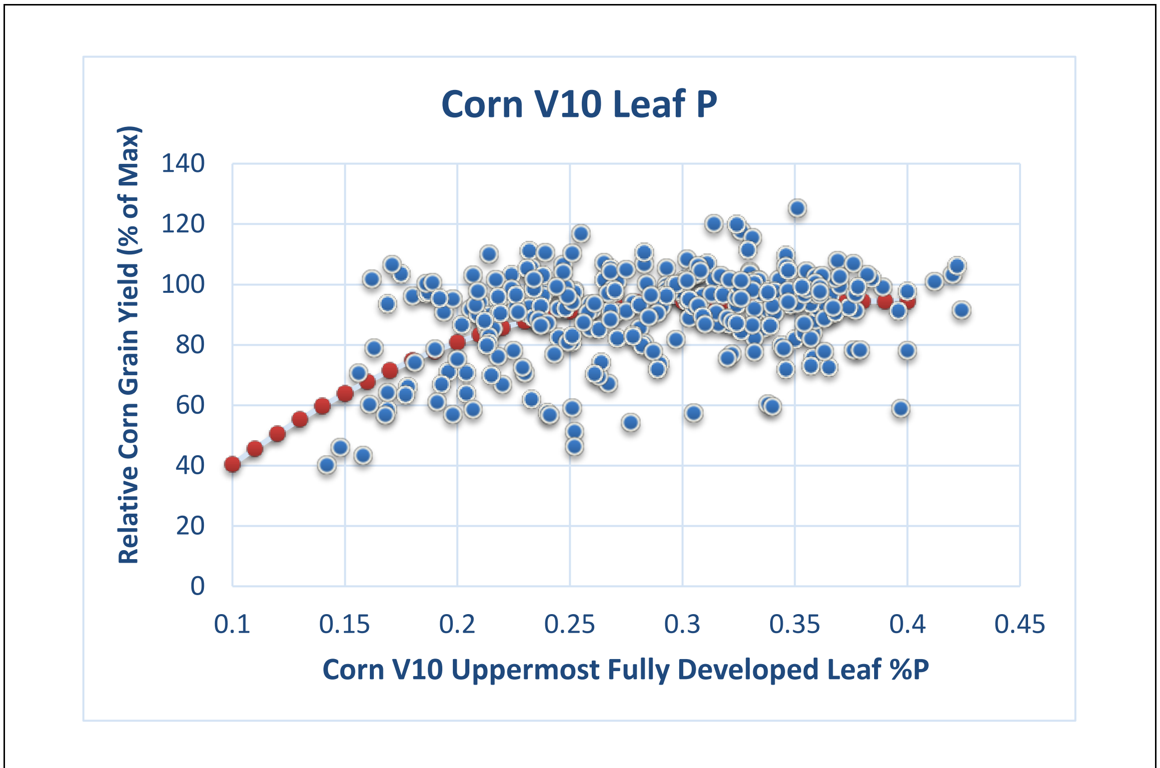


Figure 11. Summary of relative corn or soybean yield (% of maximum) based on June Olsen soil test P level.



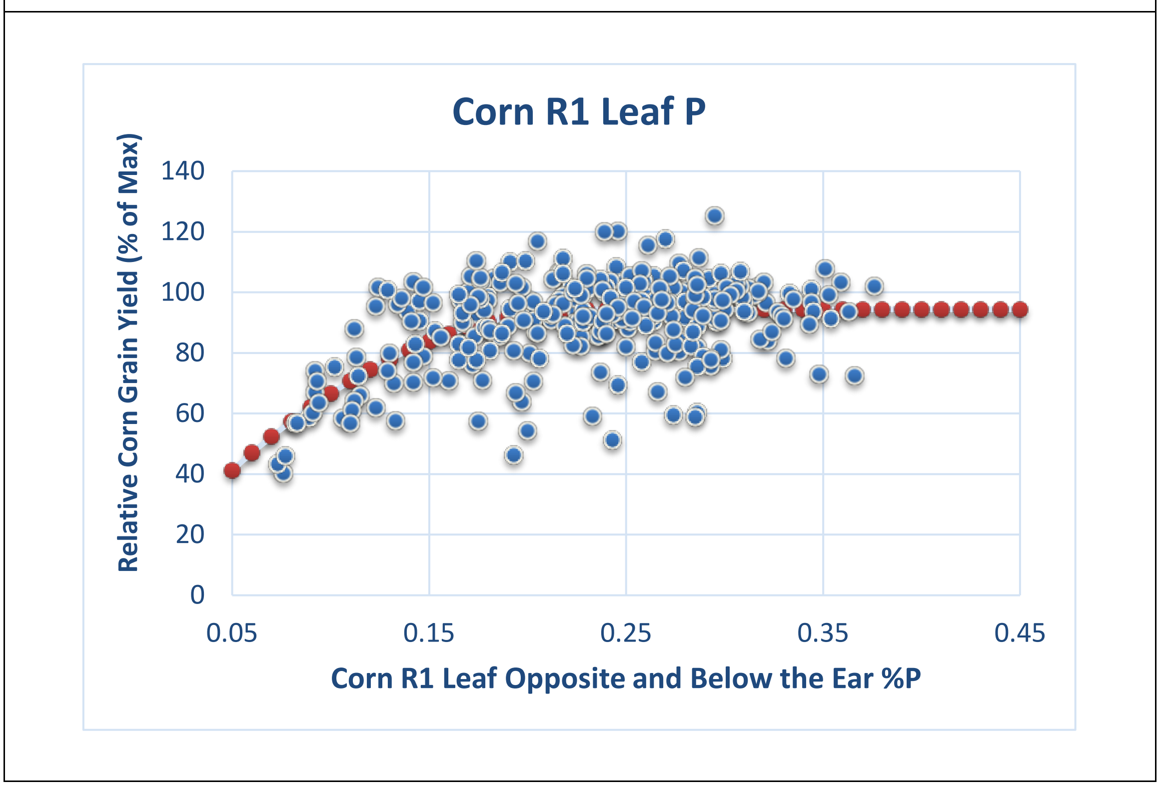


Figure 12. Relationship between corn leaf P concentration and relative corn grain yield across nine locations in Minnesota.

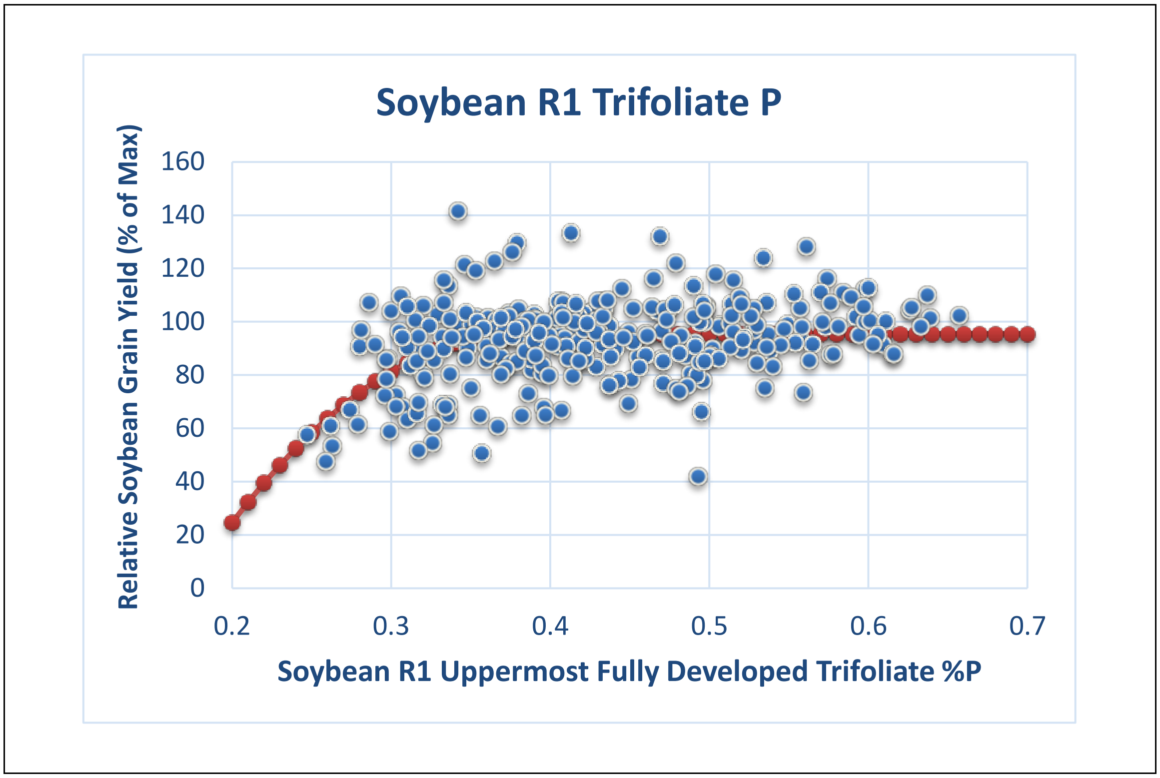


Figure 13. Relationship between soybean trifoliate P concentration and soybean relative yield across nine Minnesota P research locations.