2017 Project Report

for the

Saskatchewan Pulse Crop Development Board

Project Title: Developing Phosphorus Management Recommendations for Soybeans in Saskatchewan
(Project #AGR1509)

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5. **Introduction**
   Historically, soybean production in Saskatchewan has been negligible, primarily due to a lack of varieties that matured early enough for the region; however, breeders have made tremendous progress in this regard and today Saskatchewan producers now have dozens of suitable varieties to choose from. While still a relatively minor crop provincially, soybean acres initially moved into southeast Saskatchewan within the last decade and since then have, to a limited extent, been adopted throughout much of the wetter growing regions of the province. In 2013, the first year where soybean production numbers specific to Saskatchewan were recorded (Statistics Canada) producers seeded 68,800 ha (170,000) of soybeans and by 2017 that number had increased to 344,000 ha (850,000 ac). In Manitoba, farmers have adopted soybeans as a major component of their crop rotation, with 424,900 ha (1.1 million ac) seeded back in 2013 up to a reported 926,700 ha (2.3 million ac) in 2017. While crop demand obviously varies with yield, soybeans are considered to be larger users of P; therefore, incorporating this crop into rotations requires sound management of this nutrient. A study conducted near Carman, Manitoba showed that soybeans require approximately 1.35 lb P_2O_5 per bushel to grow and, at harvest, remove approximately 1.1 lb P_2O_5 per bushel (Heard 2006). For a 40 bus/ac, or 2700 kg/ha, soybean crop, this is a total P requirement of approximately 50 kg P_2O_5/ha. Consequently, appropriate P fertilization strategies must be developed and used to ensure optimal yields of both the soybeans in addition to other crops in rotation.

   Research in Illinois showed that soybean root distribution was not affected by P fertilizer rate or placement when the fertilizer was either broadcast or deep banded prior to seeding (Farmaha et al. 2012), thereby indicating that soybeans are not particularly efficient at seeking out fertilizer P bands with their roots. While it has been suggested that soybeans may yield more in soils with high P fertility than low P fertility (eg. Randall 2012), recent research suggests that this is not necessarily the case (i.e. Bardella 2016; Vetsch 2018). That said, soybeans do make excellent use of the soil's P reserves (Kalra & Soper 1967), possibly because soybeans take up a large portion of their P late in the growing season (Heard 2005) using a fully developed network of roots and mycorrhizal fungi. In many regions, surface broadcasting of P fertilizer is common and generally seen to be an effective option with this crop; however, broadcasting P is generally not recommended in western Canada for both agronomic and environmental reasons. Currently, there is conflicting evidence as to whether soybeans respond better to banded or broadcast P fertilizer or to P fertilization at all.

Given our relatively cold soils and short growing season compared to more traditional soybean regions (i.e. southern Ontario and the US Midwest), farmers in the Canadian Prairies typically band P in or near the seed-row at planting. Placing the fertilizer close to the seed ensures accessibility early in the season while banding is known to slow down reactions with Ca that convert P_2O_5 to less soluble forms over time, especially in high pH calcareous soils. That said, soybeans are considered sensitive to seed-placed fertilizer so applying the required amounts of P fertilizer directly the seed may increase the risk of reduced plant stands. In Argentina, Salvagiotti et al. (2013) found that broadcast or side-banded monoammonium phosphate did not affect plant establishment or nodulation while seed-placement of this fertilizer consistently reduced both but did not affect seed yield. Recent work in Manitoba (2013-15) occasionally showed significant plant stand reductions with seed-placed P but not to the extent that may have been expected (Bardella 2016). The damage was generally worse on coarse textured soils and was only significant at 1, 2 and 5 out of 28 site-years at the 22, 45 and 90 kg P2O5/ha rates, respectively (Bardella 2016). These results suggest that soybeans may be less sensitive to seed-placed P in western Canadian soils than anticipated, but the authors still advise caution as soil moisture was always abundant at their sites and seedling injury due to P fertilizer can be difficult to predict. With concerns about seedling sensitivity combined with the fact that soybeans can be large users of P, growers may either face long-term fertility issues or risk seedling injury and possible yield reductions if relying solely on seed-placed P for this crop.

Yield responses to P fertilization can be elusive for soybeans – Bardella (2016) only observed higher yields with P at 1/28 sites and Manitoba while there two sites where a negative effect was detected. In contrast, research in Iowa showed that soybeans respond to P fertilizer when soil-test P is low and that P uptake tended to be higher with side-banded versus broadcast P; however, fertilizer placement did not affect yield (Borges and Mallarino 2000). Due to concerns of potential seedling injury and inconsistent yield responses to banded P, broadcast P fertilizer is not uncommon in traditional soybean growing regions and is a particularly good fit to those using planters with limited options for fertilizer placement. The concern is that broadcasting may not be as agronomically efficient as subsurface banding (due to both low mobility and soil reactions that reduce P solubility/availability) and doing so may leave unutilized P fertilizer vulnerable to runoff losses with surface water, especially if broadcast in fall.

The current project aims to expand upon the current research base by investigating soybean response to P fertilizer rates and placement methods in Saskatchewan with the overall objective of improving P management recommendations for the growing number of soybean producers in this province.

6. **Objective(s) or purpose of the project**
   Broadly, the objective of this project was to improve upon current P fertilizer recommendations for soybean production in Saskatchewan. More specific objectives were:

   1) To evaluate the sensitivity of soybeans to seed-applied monoammonium phosphate for soybeans grown on 25-30 cm (10-12") row spacing.

   2) To evaluate the overall response of soybeans to P fertilizer applications across a range of placement methods and environmental conditions and for individual sites as a function of residual soil P levels.

   3) To compare crop response to contrasting placement options for granular monoammonium phosphate (seed-placed, side-banded and pre-seed broadcast)

   4) To quantify P removal in the harvested seed in order to help soybean growers determine optimal P fertilizer rates for achieving their long-term soil fertility goals.

7. **Materials and Methods**
   Phosphorus (P) fertility trials with soybeans were initiated at four Saskatchewan locations in 2015 and continued through the next two seasons for a total of twelve site-years. The locations were selected to represent a broad range of soils / environments and included: 1) Indian Head (Black soil zone), 2) Melfort (Moist Black soil zone) 3) Scott (Moist Dark Brown soil zone) and 4) Outlook (Dark Brown soil zone). The treatments were three P rates (22, 45 or 90 kg P_2O_5/ha) and three placement methods (seed-placed, side-banded or pre-seed broadcast) plus a control where no P fertilizer was applied. These 10 treatments were arranged in a Randomized Complete Block

Design (RCBD) with four replicates. The protocol followed was originally developed by Don Flaten and a team of researchers who followed the same protocol at 28 site-years over three years in Manitoba (Bardella 2016).

Seeding equipment, plot size, and basic crop management varied from site-to-site depending on equipment and the specific environmental conditions encountered; however, all factors other than those being evaluated were held constant within each site and were intended to be non-limiting. Row spacing ranged from 19-30 cm; however, the drill on 19 cm spacing was used at only one site-year (Melfort 2015); therefore, the row spacing was between 25-30 cm in 11/12 possible cases. The widest knife opener width was 25 mm and seed-bed utilization ranged from below 5% to about 10%. The variety at all locations was Dekalb® 23-10 RY in 2015-16 and 23-60 RY in 2017. The soybeans were always double inoculated (seed-applied plus 1-2x label rate of *Bradyrhizobium japonicum* granular inoculant). Weeds were controlled using registered herbicide applications tailored to each site and the plots were harvested with small plot combines when mature and dry. Selected site information and other agronomic details are provided in Tables 1 (2015), 2 (2016) and 3 (2017) of the Appendices. Weather data were acquired from the closest private or public weather station for each site-year and is reported along with the long-term averages (1981-2010) in Table 4.

The response data collected included background residual soil nutrients (Olsen-P) and other characteristics, emergence measurements, mid- to late-season above-ground biomass measurements, whole plant tissue P concentrations, in-season P_2O_5 uptake, seed yield, seed P concentrations, and seed P_2O_5 exports. Response data from all site-years were combined for mixed model analyses (PROC MIXED, SAS 9.3) with the effects of site-year, P treatment, and their interaction considered fixed and the effects of replicate (within site-year) considered random. When doing so improved model convergence, which was usually the case, heterogeneous variance estimates for each site-year were permitted. Individual treatment means, within individual site-years and on average, were separated using Fishers protected LSD test. Contrast comparisons were used to evaluate specific groups of treatments (i.e. control vs. fertilized, seed-placed vs. side-banded, seed-placed vs. broadcast and side-banded vs. broadcast) and orthogonal contrast equations were used to test whether P rate responses were non-significant, linear or quadratic (curvilinear). Treatment effects and differences between means were considered significant at P ≤ 0.05.

8. **Results & Discussion**

The weather conditions encountered varied widely from site to site with growing season (May-August) precipitation totals ranging from as low as 117 mm (Indian Head 2017) to 367 mm at Outlook in 2016. In general, conditions were wet in 2016, intermediate in 2015 and driest in 2017. The fields were also generally considered low in residual P with values below 15 ppm (Olsen) at 83% of the trial sites, the exceptions being Melfort in 2015 and 2017 where residual levels were moderately high at 22-24 ppm (Table 5). This combination of variable moisture conditions and predominantly low P soils provided a robust evaluation of the P fertilizer treatments being evaluated.

The soybean plant density values presented were determined late in the spring after emergence was considered complete. Emergence was affected by both site-year and P treatment with a significant interaction between the two effects (P < 0.001-0.001; Table 6). Although all sites used similar rates and the same source of seed, emergence varied widely from 35-65 plant/m^2 for individual site-years when averaged across P treatments. The significant interaction indicated that P treatment effects on emergence varied across site-years, with closer inspection revealing evidence of treatment effects on emergence approximately 50% of the time. While there were inconsistencies, in most cases where treatment effects were detected the means comparisons and orthogonal contrasts showed reduced emergence at the highest rates of seed-placed mono-ammonium phosphate (Table 7). The overall F-test was significant at 5/12 site-years, while the linear orthogonal contrast for seed-placed P rate was significant at 6/12 site-years. Soil moisture and texture were not always good predictors of seedling injury; however, injury tended to be worse under dry conditions. At Indian Head, where the soil is fine-textured with moderate organic matter, injury was detected with both side-banded and seed-placed P in 2017, but there was no injury in and only very slight reductions with high rates of seed-placed P in 2016. The injury for both side-band and seed-placement in 2017 was attributed to wet soils during seeding, which can compromise seed/fertilizer placement in heavy clay soils, followed by extremely dry conditions. When emergence data were averaged across all site-years, similar plant densities were achieved with all P rate by placement combinations (45-48 plants/m^2) except for the highest rate (90 kg P_2O_5/ha) of seed-placed P which

was 18% lower (38 plants/m^2; Table 7, Fig. 1). While results varied from site-to-site, the combined results are a reasonable indication of the response that might be expected when averaged across a wide range of soil environments. While the frequency of stand reductions was higher in the current, Saskatchewan project, these results are not necessarily considered inconsistent with those of the Manitoba trials. Bardella (2016) observed stand reductions at 1, 2 and 5 out of 28 site-years for 22, 45 and 90 kg P_2O_5/ha of seed-placed P; however, the authors noted that soil moisture was generally not limited in their study and that results may have differed under dry conditions.
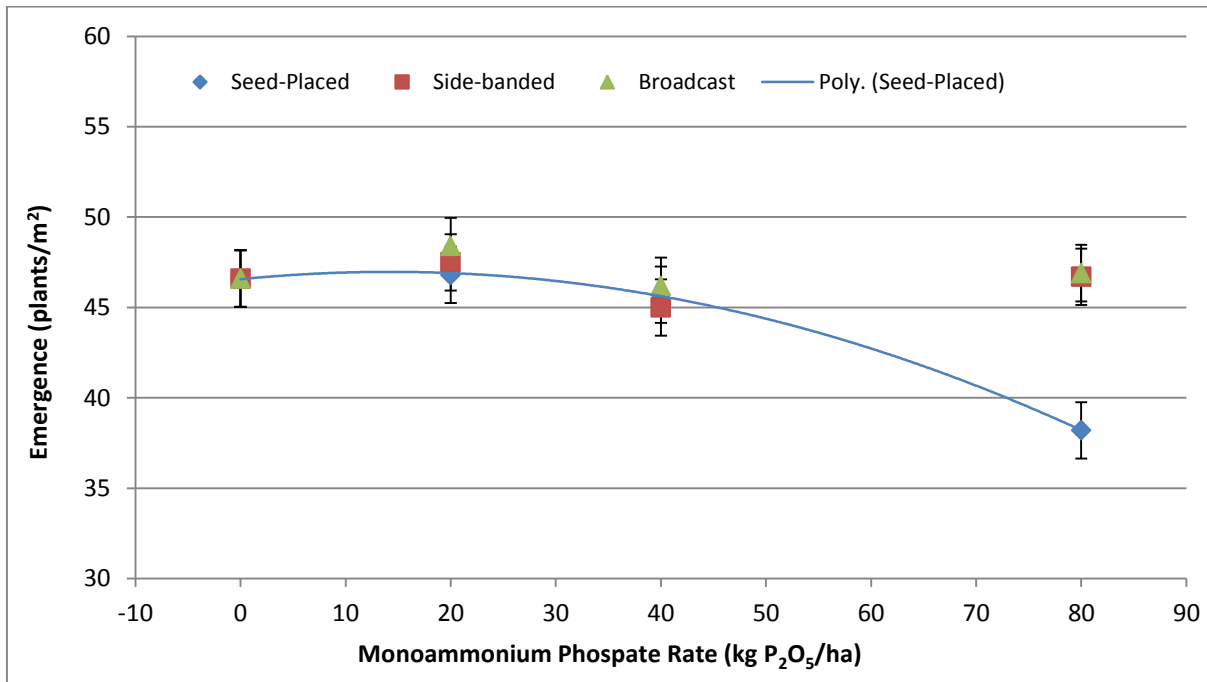

Figure 1. Phosphorus placement and rate effects on soybean emergence averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.

The overall F-tests for above-ground biomass yields were significant for site ($P < 0.001$), treatment ($P = 0.006$) and their interaction ($P = 0.011$). Due to variation in both the timing of measurements and environmental conditions, above-ground biomass yields were extremely variable across site-years, from less than 2 Mt/ha at Scott in 2015 to as high as 9.5 Mt/ha at the same location in 2016 (Table 8). Due to this variation and the sensitivity to timing, the differences in biomass yields (in addition to subsequent P_2O_5 uptake measurements) across sites are not of particular interest; however, treatment effects within individual site-years are still valid. Significant P fertilizer treatment effects on biomass were rare with a significant F-test at only 3/12 sites and only a few, somewhat inconsistent, significant orthogonal contrasts. At one of the these sites the response appeared to be due to lower dry matter yields relative to the control (presumably due to seedling injury) while for the other two the response appeared to be to a positive P response. Averaged across site-years, although the overall F-test was significant, the responses were weak with very few individual treatment differences according to the multiple comparisons test. The key significant contrast comparisons compared side-band to seed-placement (5415 versus 5009 kg/ha; $P = 0.001$) and side-band to broadcast placement (5415 versus 5154 kg/ha; $P = 0.032$), both of which indicated slightly higher biomass yields with side-banded P when averaged across a range of fertilizer rates and environmental conditions. The control did not differ from the fertilized plots when averaged across site-years, rates, and placement methods ($P = 0.662$).

The overall F-test for whole plant P concentration was significant for site-year, P treatment, and their interaction ($P < 0.001$) and the effects were more consistent for this variable than for biomass yield. Significant F-tests were detected at 7/12 individual sites along with significant contrasts comparing the control to all fertilized treatments at 6/12 sites and significant linear responses (across placement methods) at 10/12 possible sites (Table 9). The exceptions were Melfort in 2017 which was the site with the highest residual P levels and Indian Head in 2017

where the site was low in P but drought was a major factor. With some variation, the responses were reasonably consistent across placement methods and, when averaged across site-years, percent tissue P was not affected by P placement according to the contrast comparisons (P = 0.107-0.860). Whole plant tissue P was increased with P fertilizer regardless of placement method ($P < 0.001$) from 0.23-0.27% when all site years were averaged together (Fig. 2).
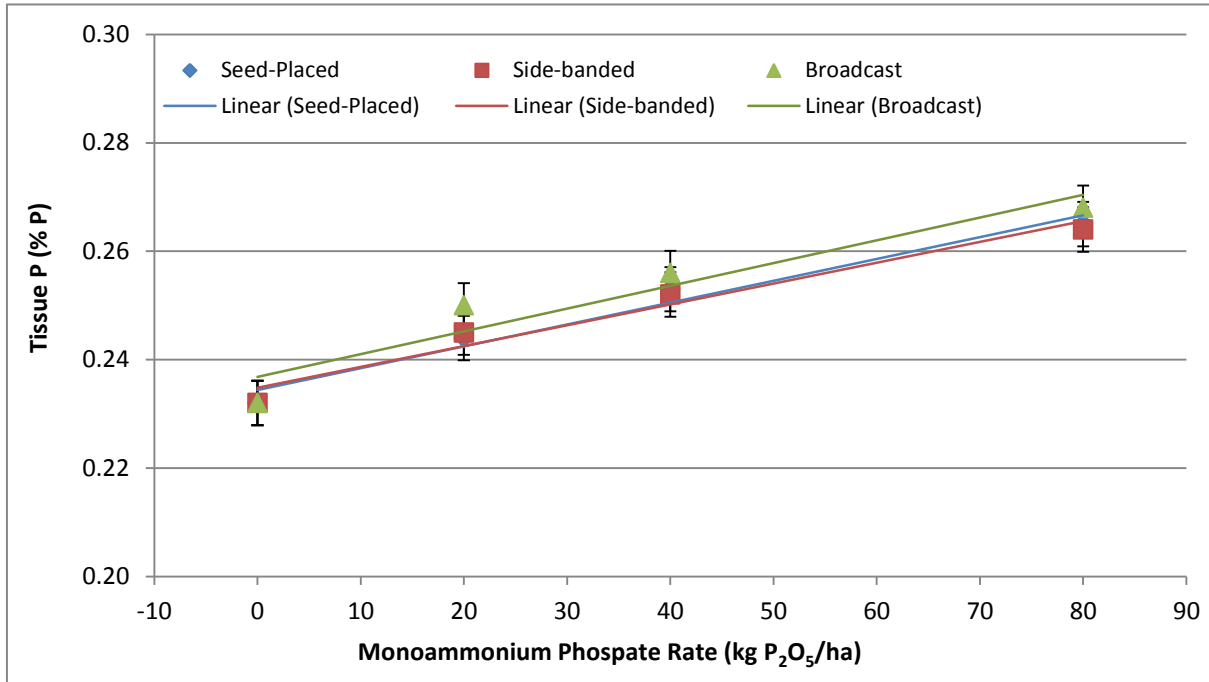
Figure 2. Phosphorus placement and rate effects on soybean (whole plant) tissue P concentrations averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.

Albeit much more variable, treatment effects on in-season P_2O_5 uptake were generally consistent with those of the tissue P concentrations with highly significant F-tests for site, treatment and their interaction ($P < 0.001$). Since tissue P concentrations were reasonably consistent across sites, most of the variation in uptake from site-to-site (15-51 kg P_2O_5/ha; Table 10) was attributed to the previously discussed differences in biomass yields. For this variable, the overall treatment effect was significant at only 5/12 sites, with linear or quadratic responses to P (across placement methods) detected at half of the individual sites. When averaged across sites and rates, P_2O_5 uptake was higher with P fertilizer (26.7 versus 29.5 kg P_2O_5/ha) and with side-banding versus seed-placement (30.4 versus 28.7 kg P_2O_5/ha; P = 0.009); however, no other differences between placement methods were detected (P =0.099-0.337). Averaged across all sites, linear responses to P rate were detected both when averaged across P placement options and for each placement method individually (Fig. 2; $P < 0.001$); however, the quadratic effects were never significant (P = 0.271-0.896).

Figure 3. Phosphorus placement and rate effects on soybean in-season P_2O_5 uptake averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.

Past research has shown that soybean seed yield responses to P fertilizer tend to be elusive. For example in Manitoba, out of 28 possible cases, Bardella (2016) observed yield increases with P fertilization at only one site while, in contrast, negative responses were detected at two sites. The combined analyses of the current results indicated that seed yields were affected by site ($P < 0.001$), P treatment ($P = 0.006$) and their interaction ($P < 0.001$). Across P treatments, yields at the sites ranged from 1510-4222 kg/ha (Table 11), thus providing a wide range of yield environments to evaluate P response under. Amongst individual sites, the overall F-test for P treatment effects on seed yield were significant in 5/12 possible cases; however, the effect was due to a positive yield response at only three of the sites where the F-test was significant. In one of the significant cases (Melfort 2016), yields were variable and the differences were difficult to explain; however, yields in the control were amongst the highest. At Outlook in 2015, yields at the highest rate of seed-placed P were lower than all other treatments but those observed in the control did not generally differ from any other treatments. Despite the fact that seed-placed P frequently affected emergence, the lack of a negative effect on yield was attributed to the fact that plant populations nearly always exceeded the 25 plants/m^2 threshold that is considered critical for soybeans (Lee et al. 2008; Mohr et al. 2014; Conley and Gaspar 2015). The sites where a positive yield responses were detected were Indian Head in 2016 and Outlook in both 2016 and 2017 – all of these sites had low residual P (4, 5 and 12 ppm Olsen-P, respectively) combined with reasonably high yield potential. At Indian Head in 2016, the response was strong but quadratic with yields levelling off between 40-80 kg P_2O_5/ha and no differences amongst placement methods. At Outlook in both years, the control yielded lower than the majority of individual fertilized treatments but yields were mostly similar across P rates and placement methods. The overall average yield increases with P fertilization were approximately 15%, 13%, and 23% at Indian Head (2016) and Outlook in 2016 and 2017, respectively. At both Indian Head and Outlook in 2016, the P response was similar across placement methods according to the contrast comparisons; however, at Outlook in 2017 the highest yields were achieved with broadcast placement. Despite the variation across environments, significant and interesting P responses were observed when the results were

averaged across all twelve sites. Yields increased linearly with increasing P rate from 2734 kg/ha to 2900+ kg/ha at 90 kg P_2O_5/ha with side-band and broadcast placement (~6% yield increase) the response was quadratic for seed-placed P with yields increasing in similar manner as the other placement methods up to 45 kg P_2O_5/ha but then declining back to a similar yield as the control when the rate was increased further to 90 kg P_2O_5/ha (Fig. 4).

To help with interpretation of results, the overall yield responses to P fertilizer were plotted along with the residual Olsen-P levels for each of the individual sites (Fig. 5). Looking at the results in this manner illustrates that the sites where positive responses occurred were always low in residual P (<15 ppm) but yield responses did not always occur in low P soils.
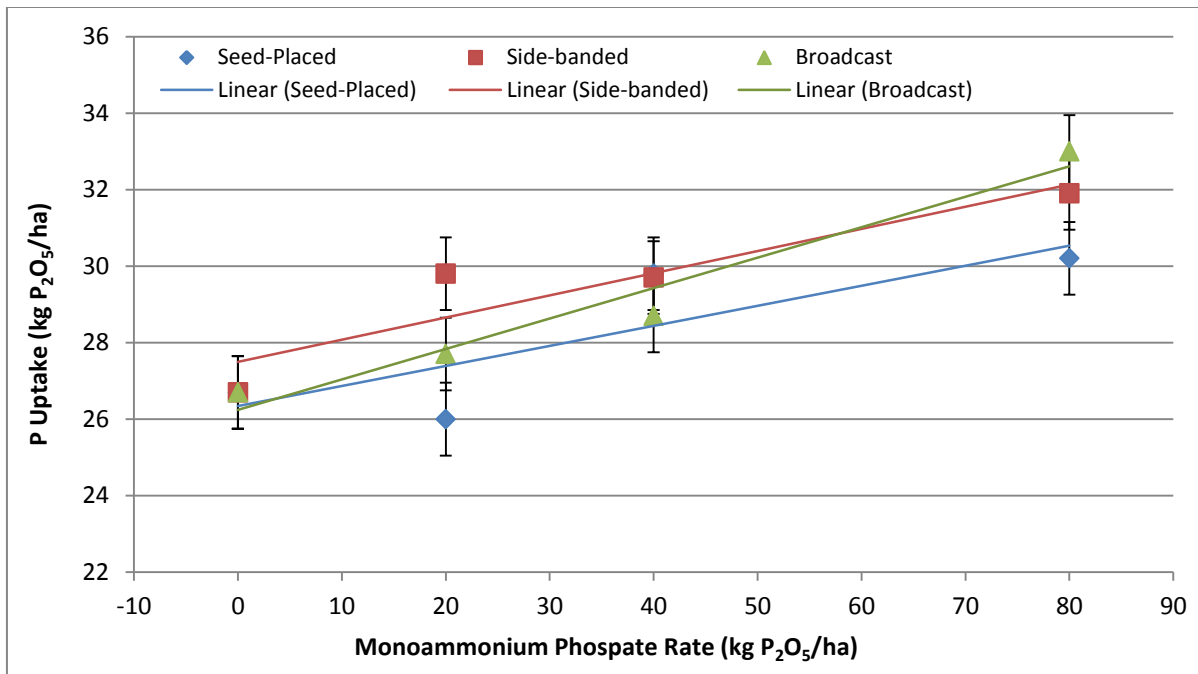

Figure 4. Phosphorus placement and rate effects on soybean seed yield averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.
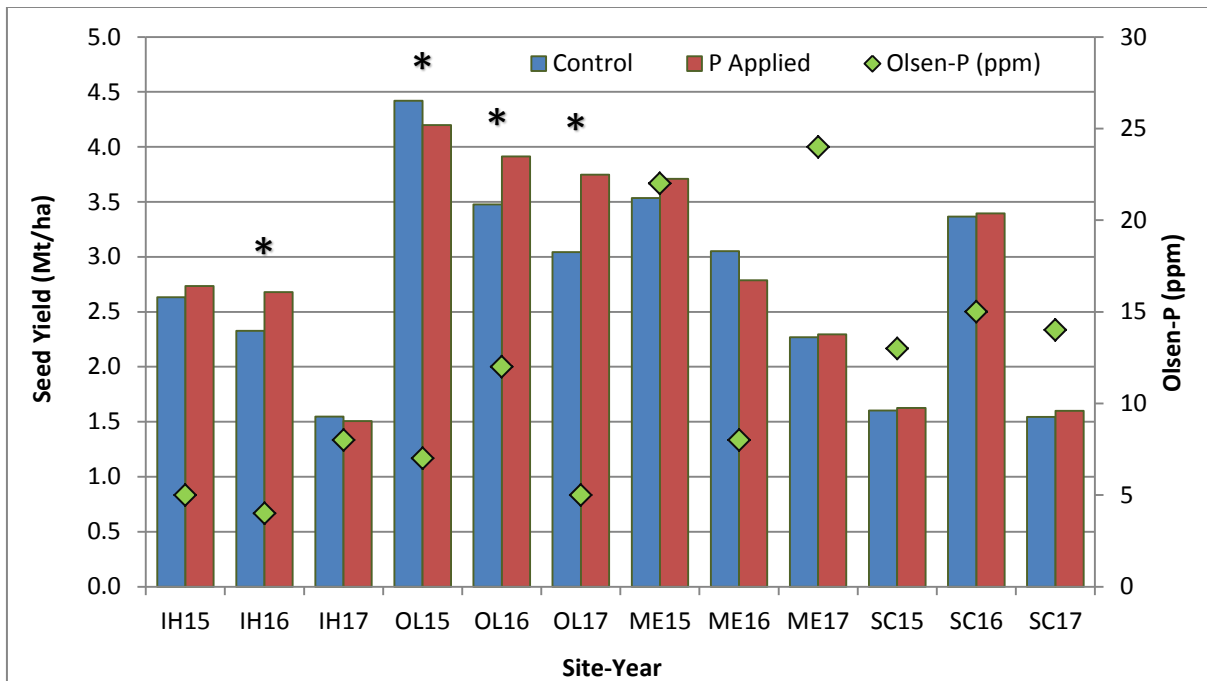
Figure 5. Overall soybean yield response to phosphorus fertilization relative to soil test residual P levels. Site-years with a significant (*P* ≤ 0.05) control versus fertilizer contrast comparison are denoted by an asterisk.

The overall F-tests from the combined analyses for seed P concentrations were significant for site-year, P treatment and the interaction (*P* < 0.001). Across P fertilizer treatments, the overall average P concentration ranged from 0.47-0.77% for individual site-years (Table 12). While differences across sites did not appear to correlate consistently with Olsen-P levels, seed P concentrations were generally lowest at Indian Head (0.47-0.53) where residual P was also lowest (5-8 ppm). The F-test for P treatment effects at individual site-years was significant in 8/12 possible cases; however, the check versus fertilized contrast comparison was only significant 25% of the time. The orthogonal contrasts detected linear increases in seed P (averaged across placement methods) 50% of the time and, when detected, differences between placement methods were inconsistent. At Indian Head in 2016, one of the responsive sites, seed P concentrations were highest with broadcast placement while, at Scott in both 2015 and 2017, seed P was highest with seed-placement. Averaged across sites, seed P concentrations were equal across placement methods (0.59%; *P* = 0.547-0.898), higher overall with P fertilization (0.56% versus 0.59%), and increased quadratically with P rate when averaged across placement methods (*P* = 0.029). For individual placement options, the quadratic response was significant for seed-placed and side-banded P (*P* = 0.011-0.040) while, for broadcast P, the response was strictly linear was (*P* < 0.001). Despite the different orthogonal contrast results, seed P concentrations were statistically similar for all three placement options at any given P rate (Fig. 6).
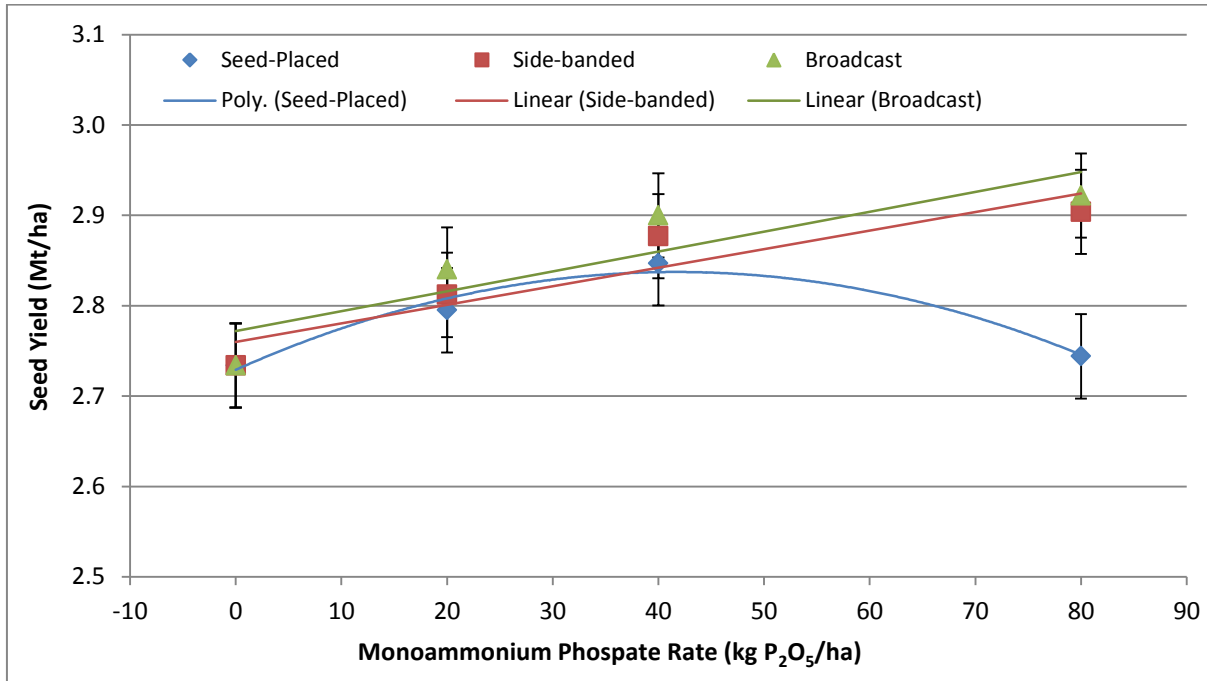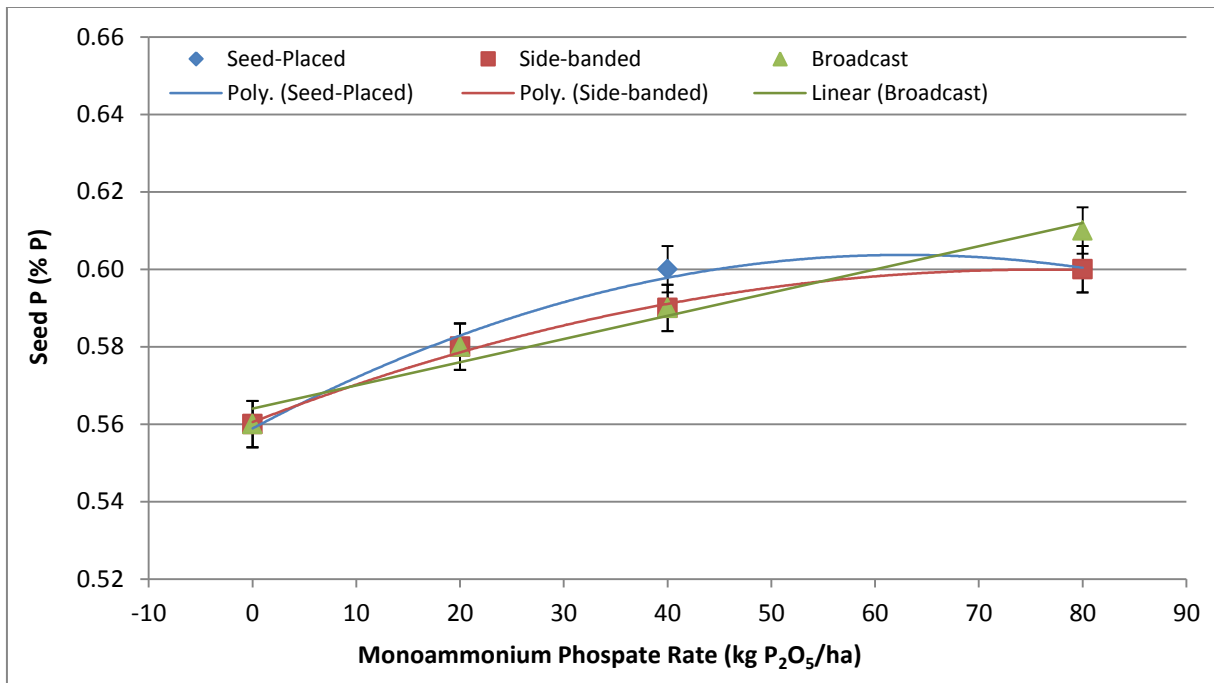
Figure 6. Phosphorus placement and rate effects on soybean seed P concentrations averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.

Estimated P_2O_5 exports (i.e. the P removed in the harvested grain) are a function of both seed yield and seed P concentrations and such, responded to the P treatments in a manner that was related but not identical to the two previously discussed variables. Phosphate exports in the seed were affected by site, P treatment, and their interaction ($P < 0.001$) with a range of 16-55 kg P_2O_5/ha amongst individual site-years and significant F-tests in 7/12 possible cases (Table 13). Much of the site-to-site variation was attributed to differences in seed yields as opposed to variation in seed P concentrations. Although the control and fertilized treatments were significantly different only 25% of the time, the overall linear and/or quadratic responses were significant 50% of the time. Differences amongst P placement methods (averaged across rates) were significant only at Outlook in 2017, where P exports were lowest with seed-placed P (similar for side-banded and broadcast P) and Melfort in 2017, where P_2O_5 exports were highest with side-banded P (similar for seed-placed and broadcast P). When responses were averaged across fertilizer rates and all twelve site-years, total P exports were higher with fertilizer than in the control (39 versus 36 kg P_2O_5/ha) and slightly but significantly ($P = 0.006$-0.034) higher with side-banded and broadcast P (39.1-39.6 kg P_2O_5/ha) than with seed-placement (38 kg P_2O_5/ha). For both seed-placed and broadcast P, the responses were linear ($P < 0.001$-0.005) but not quadratic ($P = 0.104$-0.188); however, the increase was much stronger with broadcast P as a result of the reduced yields at the highest rate of seed-placed P. For side-banded P, the response was quadratic ($P = 0.046$) with a strong increase going from 0-40 kg P_2O_5/ha but no further effect when the fertilizer rate was increased to 80 kg P_2O_5/ha (Fig. 7).
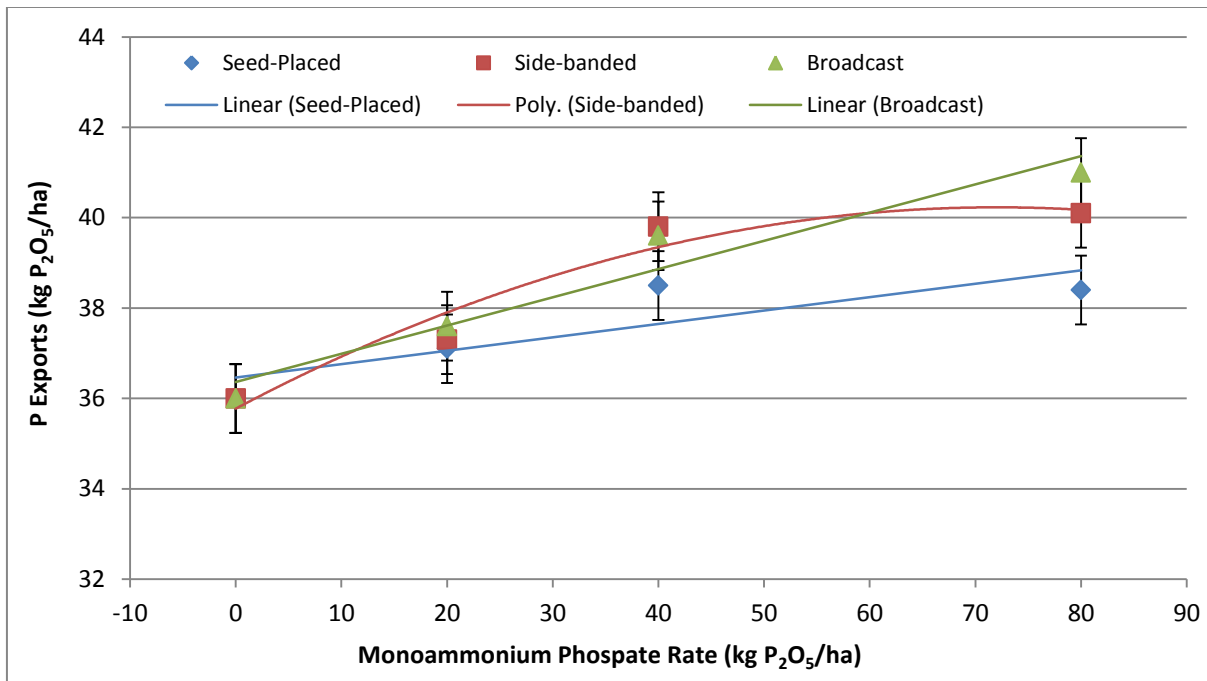
Figure 7. Phosphorus placement and rate effects on soybean P$_2$O$_5$ exports in harvested soybean seed averaged across 12 site-years in Saskatchewan. This average response should be interpreted cautiously as the specific effects varied from site-to-site.

9. **Economic and Practical Implications For growers**

This research has provided Saskatchewan producers practical information on best management practices for P fertilization in soybeans. With crop responses to P fertilization being variable across locations and years it is difficult to specifically assess the full economic value to the work completed; however, some broad assumptions can be made. Furthermore, this information and the key lessons derived from the project can be utilized to help growers manage long-term P fertility goals while reducing risks and optimizing yields in soybean production.

1) Phosphorus exports in soybeans vary widely (with yield) with 16-58 kg P$_2$O$_5$/ha removed (in the harvested seed) amongst individual sites and an overall mean value of 39 kg P$_2$O$_5$/ha. To a large extent, long-term P fertility goals dictate what rate is appropriate on a site-specific basis; therefore, it is important to take into account the yield potential of crop. On a per bushel basis, P removal in the current study ranged from 0.6-1.1 lb/bu for individual sites and was 0.8 lb P$_2$O$_5$/bu) on average.

2) Negative effects of high rates of seed-placed P kg P$_2$O$_5$/ha (i.e. primarily reduced plant stands) were evident at 50% of the sites with the potential for harm being difficult to predict. At the highest rate (90 kg P$_2$O/ha) final plant populations were 18% lower with seed-placement as opposed to side-band or broadcast placement when averaged across all sites. Soybeans have capacity to compensate for lower populations through increased branching and, at seeding rates of 55 seeds/m^2 (220,000 seeds/ac), plant populations only fell below critical thresholds (25 plants/m^2) in one treatment at one site. Seed-placed rates of up to 40 kg P$_2$O$_5$/ha were safe across a wide range of conditions.

3) Positive yield responses to P fertilization were infrequent and modest but detected 25% of the time. Positive responses occurred only when soil test P values were below 15 ppm and there were no other major yield limiting factors. In the cases where positive responses occurred, they were similar across placement methods with the exception of one site where the response was negative with high rates of seed-placed P (Outlook 2015) and another where the strongest response was to broadcast P (Outlook 2017). The response to broadcast P was better than expected, suggesting that soybeans can access P close to the soil surface; however, this is still not a recommended practice due to higher potential for movement in runoff and, over time, conversion into less soluble P forms.

4) While the results varied amongst sites, when averaged all 12 site-years, seed yields were 6% higher when at least 40 kg P_2O_5/ha was applied; however, with 90 kg P_2O_5/ha placed in the seed row yields were reduced and did not significantly differ from the control. For the three responsive sites specifically, the benefit was 11-22% or 415-876 kg/ha (6-13 bu/ac).

5) Averaged across all site-years, yields were 167 kg/ha (approximately 2.5 bu/ac) higher with optimal P management and, in 2016, a new provincial record of approximately 850,000 acres of soybeans were seeded in Saskatchewan. Yield benefits associated with sound P management could be realized either through positive responses to fertilization or by mitigating potential yield loss due to unsafe (or inadequate) rates of seed-applied P. If we assume a seeded area of 500,000 ac, an average yield benefit of 2.5 bu and grain price of $10/bu, the potential economic impact of this research could be estimated at $12.5 million annually specifically for soybeans. At 1 million seeded acres, if production were to reach that level, the value would double to $25 million dollars annually. Further gains, which we did not attempt to quantify in this project, could be achieved through the effects of sound long-term P management on subsequent crops. For example, it has traditionally been recommended that growers do not seed-place more than 11 kg P_2O_5/ha to prevent potential injury. While there is undoubtedly still some risk to doing so, the results of this project along with those from the Manitoba study suggest that substantially higher rates are likely safe under most circumstances. This information may allow growers who are limited in their placement options to adopt higher application rates than they have previously done. Consequently, this could lead to reduced P deficits over the course of their crop rotations and improve the long-term fertility and productivity of their land for all crops.

10. Conclusions & Recommendations
Several key conclusions and recommendations can be drawn from this work.

1) Phosphorus rates: Appropriate rates depend on both the potential soybean yields that can be reasonably expected and the long-term fertility goals for the field in question. For example, if the objective is to maintain soil P over the long-term, rates should be approximately equal to crop removal. Removal ranged from 16-55 kg P_2O_5/ha (14-49 lb/ac) with an overall average of 39 kg P_2O_5/ha (35 lb/ac).

2) Safe rates of seed-applied phosphorus: While it was often minor, evidence of stand reduction with seed-placed P were detected approximately 50% of the time; however, the damage was generally only detected or large enough to be of concern at the highest rate. Furthermore, at the 55 seeds/m^2 (220,000 seeds/ac) seeding rate used, plant populations only fell below the critical threshold of 25 plants/m^2 in one treatment at one site. Reponses to seed-placed P were never better than side-banded or broadcast P for any of the variables and, when averaged across all sites, yields were reduced at the highest rate of seed-placed P. These results suggest the current recommendation of no more than 10-20 kg P_2O_5/ha may be more conservative than necessary but side-banding is a preferable method for applying P, especially at high rates. While soybeans responded well to broadcast P, this is still not considered an ideal option from either a fertilizer efficiency or environmental perspective.

3) Yield Response to applied phosphorus fertilizer: The results suggest that significant yield responses to P fertilization are rare on a field-to-field basis but can occur with the greatest potential for response when yield potential is high and soil residual P is low. On average, slightly higher (~6%) yields may be expected with adequate P fertilization and using adequate rates is important to maintain soil fertility over the long term.

11. Future research
Considered along with the results from the extensive, similar study in Manitoba, this research has answered many questions regarding the safety of seed-placed monoammonium phosphate, overall potential (and likelihood) of yield responses to P application, and expected P exports that might be expected with soybeans in Saskatchewan and western Canada in general. Future research might further consider the effects of overall residual P levels (i.e. previous fertilization practices) along with factors that may affect mycorrhizal populations such as crop rotation, tillage, and inoculant products on P uptake and yield of soybeans.

12. **Technology transfer activities**

In 2015, the research was introduced and field trials shown at two major field days at Indian Head, to approximately 70 retail agronomists on Jul-10 (Federated Coop Limited Tour) and 200 producers and agronomists on Jul-21 (Indian Head Crop Management Field Day). The first tour was hosted by Chris Holzapfel while, at the latter, John Heard (MAFRI) helped lead a discussion on soybean inoculation, starter N and options for rescuing crops in cases where nodulation is inadequate. The trial was also highlighted at a faba bean and soybean tour at Melfort on Jul-29 (2015) which was attended by 75 people.

In 2016, the trial was again shown and discussed by Chris Holzapfel (IHARF) and Corey Loessin (SPG) at the Indian Head Crop Management Field Day (Jul-19, 212 guests) and again on tours coordinated with Arysta Lifesciences (Jul-26, 45 guests) and Richardson Pioneer (Jul-27, 33 guests). At Outlook in 2016, the trial was shown to approximately 300 guests at the ICDC Field Day and again to approximately 50 guests on a smaller tour on Aug-16. At the 2016 Scott Field Day on Jul-13, Jeff Schoenau and WARC staff showed the trials and presented on the subject to approximately 200 people. Preliminary results were also presented by Chris Holzapfel at the Corn and Soybean Summit in Estevan (Dec-9 2016), approximately 40 guests), at the IHARF Winter Seminar and AGM in Weyburn (Feb-1 2016, approximately 100 guests), and at a Crop Command Agronomy meeting (March 16, ~50 guests) in Southey. Jessica Pratchler presented preliminary results at the SIA Ag Update in Melfort (February 2, approximately 150 guests).

In 2017, the field trials at Indian Head could not be shown during IHARF/AAFC's main public field day; however, the site was visited and discussed with approximately 100 guests in total on two other tours hosted for Federated Co-Op (FCL) and Richardson-Pioneer agronomists on July 13 and July 21, respectively. At Scott, Jessica Weber highlighted the project during a Farm Writers of Saskatchewan tour hosted at the site on June 3. Chris Holzapfel also presented preliminary results to 382 attendants at the Pulse and Soybean Agronomy Workshop hosted by SPG in Saskatoon on November7-8.

In addition to the field tours and oral presentations, interim reports for the project have been available for download from the IHARF website (www.iharf.ca) and this final report will also be made publicly available in the near future.

13. **Funding contributions and Acknowledgements**

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14. Appendices

Table 1. Pertinent site and agronomic information for soybean phosphorus fertility study in 2015.

Agronomic Factor / Data Collection	Indian Head 2015	Outlook 2015	Melfort 2015	Scott 2015
Previous crop	Spring Wheat	Spring Wheat	Oat	Spring Wheat
Tillage System	no-till	cultivator/harrow	rototilled	no-till
Row spacing	30 cm	25 cm	19 cm	25 cm
Opener width	1.9 cm	disc	disc	2.5 cm
Seeding date	May 21	May-26	May-21	May-20
Seeding rate	55 seeds/m^2	53 seeds/m^2	55 seeds/m^2	55 seeds/m^2
Emergence counts	Jun-25	Jun-19	Jun-18	Jun-17
In-crop herbicide 1	890 g glyphosate/ha + 50 g imazethapyr/ha Jun-8	1334 g glyphosate/ha June-22	1334 g glyphosate/ha Jul-2	1780 g glyphosate/ha Jun-12
In-crop herbicide 2	890 g glyphosate/ha Jul-4	1334 g glyphosate/ha Jul-15	1334 g glyphosate/ha Jul-16	—
Biomass harvest	Aug-26	Aug-27	date not available	Jul-28
Seed harvest	Oct-10	Oct 13	Oct-16	Oct-1

Table 2. Pertinent site and agronomic information for soybean phosphorus fertility study in 2016.

Agronomic Factor / Data Collection	Indian Head 2016	Outlook 2016	Melfort 2016	Scott 2016
Previous crop	Spring Wheat	Spring Wheat	Spring Wheat	Spring Wheat
Tillage System	no-till	cultivator/harrow	no-till	no-till
Row spacing	25 cm	25 cm	30 cm	25 cm
Opener width	1.9 cm	disc	2.5 cm	2.5 cm
Seeding date	May 22	May 19	May 18	May 16
Seeding rate	63 seeds/m^2	53 seeds/m^2	56 seeds/m^2	55 seeds/m^2
Emergence counts	Jun-20	June 22	Jun-14	Jun-14
In-crop herbicide 1	890 g glyphosate/ha + 50 g imazethapyr/ha Jun-17	890 g glyphosate/ha June 22	890 g glyphosate/ha Jun-15	1134 g glyphosate/ha + 50 g imazethapyr/ha Jun-17
In-crop herbicide 2	890 g glyphosate/ha Jul-5	n/a	890 g glyphosate/ha Jul-5	n/a
Biomass harvest	Aug-19	Aug 27	Aug-16	Sep-6
Seed harvest	Oct-1	Oct 21	Nov-8	Oct-3

Table 3. Pertinent site and agronomic information for soybean phosphorus fertility study in 2017.

Agronomic Factor / Data Collection	Indian Head 2017	Outlook 2017	Melfort 2017	Scott 2017
Previous crop	Barley	Spring Wheat	Spring Wheat	Spring Wheat
Tillage System	no-till	cultivator/harrow	no-till	no-till
Row spacing	30 cm	25 cm	30 cm	25 cm
Opener width	1.9 cm	disc	2.5 cm	2.5 cm
Seeding date	May 16	May 24	May 29	May 24
Seeding rate	56 seeds/m^2	56 seeds/m^2	55 seeds/m^2	55 seeds/m^2
Emergence counts	Jun-19	June 28	Jun-26	Jun-21
In-crop herbicide 1	890 g glyphosate/ha + 50 g imazethapyr/ha Jun-16	890 g glyphosate/ha June 27	890 g glyphosate/ha Jun-20	890 g glyphosate/ha Jun-23
In-crop herbicide 2	890 g glyphosate/ha Jul-7	n/a	890 g glyphosate/ha Jul-5	890 g glyphosate/ha Jul-18
Biomass harvest	Aug-22	Aug 10	Aug-11	Sep-12
Seed harvest	Sep-29	Oct 12	Oct-6	Oct-5

Table 4. Mean monthly temperatures and total precipitation amounts for the 2015-17 growing seasons along with the long-term averages at four Saskatchewan locations: Indian Head, Outlook, Melfort, Scott.

Year	May	Jun	Jul	Aug	Avg	May	Jun	Jul	Aug	Sum
	---------------- Mean Temperature (°C) ----------------					------------------ Precipitation (mm) -------------				
Indian Head-15	10.3	16.2	18.1	17.0	15.4	16	38	95	59	208
Indian Head-16	14.0	17.5	18.5	17.2	16.8	73	63	113	30	279
Indian Head-17	11.6	15.5	18.4	16.7	15.6	10	66	15	25	117
Indian Head-LT	10.8	15.8	18.2	17.4	15.6	52	77	64	51	244
Outlook-15	10.4	17.3	19.2	17.4	16.1	9	39	135	58	241
Outlook-16	13.5	17.5	18.6	16.9	16.6	56	46	195	70	367
Outlook-17	12.2	16.2	19.8	17.9	16.5	33	28	68	7	136
Outlook-LT	11.5	16.1	18.9	18.0	16.1	39	64	56	43	202
Melfort-15	9.9	16.4	17.9	17.0	15.3	7	55	150	57	269
Melfort-16	13.6	17.1	18.1	16.3	16.3	17	53	129	81	280
Melfort-17	10.8	15.2	18.7	17.2	15.5	46	44	33	3	127
Melfort-LT	10.7	15.9	17.5	16.8	15.2	40	54	77	52	223
Scott-15	9.4	16.0	18.1	16.8	15.1	4	19	46	75	144
Scott-16	12.4	15.8	17.8	16.1	15.5	65	21	88	98	272
Scott-17	11.5	15.1	18.3	16.6	15.4	69	34	22	53	179
Scott-LT	10.8	15.3	17.1	16.5	14.9	35	62	72	46	215

Table 5. Soil test information for 12 site years (four locations over three years) in SPG soybean phosphorus rate/placement study.

Location	Year	pH (0-15 cm)	OM (0-15 cm)	Olsen-P (0-15 cm)	NO$_3$-N (0-60 cm)[z]	K (0-15 cm)	S (0-60 cm)[z]
		--------------	------- % -------	----- ppm -----	---- kg/ha ----	----- ppm -----	---- kg/ha ----
Indian Head	2015	7.7	5.6	5	15	676	18
	2016	8.0	4.8	4	21	545	70
	2017	7.3	6.0	8	24	635	114
Outlook	2015	8	—	7	53	290	179
	2016	7.6	2.4	12	35	231	47
	2017	7.3	1.9	5	44	165	98
Melfort	2015	6.3	11.3	22	84	618	87
	2016	5.9	11.5	8	101	486	36
	2017	6.2	11.7	24	39	798	74
Scott	2015	5.1	4.3	13	53	310	92
	2016	5.4	4.2	15	34	320	44
	2017	7.0	4.1	14	30	256	69

[z] Soil only sampled to 30 cm at Melfort

Table 6. Overall tests of fixed effects site (location x year), treatment (monoammonium phosphate rate/placement) and their interaction from a mixed model analyses of soybean phosphorus trials conducted at four Saskatchewan locations (Indian Head, Outlook, Melfort, and Scott) over a three-year period (2015-17).

P$_2$O$_5$ Rate / Placement	Fixed Effect		
	Site	Trt	Site × Trt
	--- Pr > F ---		
Emergence (plants/m^2)	< 0.001	< 0.001	0.001
Above-ground Biomass (kg/ha)	< 0.001	0.006	0.011
Whole Plant Tissue P (% P)	< 0.001	< 0.001	< 0.001
In-season P uptake (kg P$_2$O$_5$/ha)	< 0.001	< 0.001	< 0.001
Seed Yield (kg/ha)	< 0.001	0.005	< 0.001
Seed P (% P)	< 0.001	< 0.001	< 0.001
Seed P Exports (kg P$_2$O$_5$/ha)	< 0.001	< 0.001	< 0.001

Table 7. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean emergence over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
	--- Emergence (plants/m^2) ---												
0 P	48.8 a	49.3 a	41.4 ab	56.5 a	46.8 a	44.7 cd	49.9 a	48.2 a	37.3 a	39.6 a	44.8 a	51.7 a	46.6 a
22 P – Sp	46.8 a	54.6 a	35.3 abc	60.3 a	44.9 a	46.1 bcd	44.3 a	45.5 a	40.6 a	44.1 a	42.3 a	57.1 a	46.8 a
45 P – Sp	48.6 a	51.1 a	31.6 bc	82.3 a	49.0 a	51.0 ab	42.2 a	32.0 b	35.7 a	36.4 a	45.0 a	43.8 a	45.7 a
90 P – Sp	43.9 a	42.5 a	27.7 c	42.3 a	49.0 a	49.4 abc	23.6 b	33.8 b	38.6 a	23.4 a	34.5 a	50.2 a	38.2 b
22 P – Sb	49.0 a	53.3 a	41.8 ab	71.3 a	48.9 a	49.6 abc	36.9 ab	47.4 a	38.6 a	41.4 a	42.8 a	49.5 a	47.5 a
45 P – Sb	44.7 a	49.4 a	44.1 a	64.8 a	36.2 b	43.2 d	36.2 ab	47.2 a	44.3 a	35.9 a	43.5 a	50.9 a	45.0 a
90 P – Sb	50.3 a	47.2 a	28.7 c	75.0 a	50.9 a	46.6 bcd	38.3 a	47.2 a	36.5 a	43.1 a	42.5 a	53.9 a	46.7 a
22 P – Bc	50.3 a	53.3 a	39.0 abc	61.3 a	45.7 a	45.7 bcd	50.3 a	47.0 a	44.3 a	46.8 a	41.5 a	56.3 a	48.4 a
45 P – Bc	44.9 a	48.0 a	28.9 c	66.3 a	47.2 a	53.0 a	46.1 a	45.1 a	39.4 a	41.1 a	44.5 a	50.2 a	46.2 a
90 P – Bc	51.1 a	51.7 a	31.6 bc	68.0 a	49.4 a	50.7 ab	39.4 a	46.6 a	33.2 a	45.8 a	47.5 a	48.0 a	46.9 a
S.E.M.	2.84	3.28	4.26	12.49	2.55	2.37	5.44	3.88	5.26	7.05	3.23	3.32	1.56
Pr > F	0.404	0.174	**0.016**	0.642	**< 0.001**	**0.007**	**0.021**	**0.006**	0.886	0.478	0.218	0.099	**< 0.001**
All	47.8 b-c	50.0 b	35.0 f	64.8 a	46.8 b-d	48.0 bc	40.7 e	44.0 cde	38.8 ef	39.7 ef	42.9 de	51.2 b	45.8
(S.E.M.)	(1.53)	(1.62)	(1.83)	(4.14)	(1.48)	(1.45)	(2.12)	(1.74)	(2.08)	(2.55)	(2.55)	(1.63)	–
	--- Pr > F (p-value) ---												
0 P vs Rest	0.684	0.785	0.096	0.483	0.994	0.079	0.068	0.225	0.751	0.986	0.504	0.864	0.594
Sp vs Sb	0.445	0.807	**0.044**	0.389	0.199	0.149	0.919	**0.001**	0.717	0.333	0.335	0.674	**0.022**
Sp vs Bc	0.260	0.509	0.622	0.724	0.911	0.539	**0.049**	**0.002**	0.870	0.081	0.106	0.655	**0.004**
Sb vs Bc	0.716	0.677	0.126	0.611	0.241	**0.040**	0.061	0.731	0.843	0.435	0.512	0.979	0.531
All - lin	0.789	0.228	**0.003**	0.728	0.202	**0.047**	**0.004**	0.103	0.660	0.569	0.406	0.465	**0.040**
All - quad	0.383	0.269	0.936	0.287	0.062	0.194	0.822	0.340	0.377	0.821	0.924	0.685	0.474
Sp – lin	0.198	**0.036**	**0.017**	0.440	0.281	0.058	**< 0.001**	**0.002**	0.996	**0.048**	**0.016**	0.306	**<.0001**
Sp – quad	0.634	0.063	0.490	0.059	0.952	0.190	0.468	0.132	0.924	0.394	0.239	0.372	0.057
Sb – lin	0.779	0.389	**0.019**	0.375	0.446	0.968	0.207	0.857	0.948	0.789	0.658	0.470	0.844
Sb – quad	0.213	0.453	0.086	0.833	**< 0.001**	0.951	0.115	0.888	0.305	0.644	0.854	0.496	0.632
Bc – lin	0.687	0.811	**0.051**	0.501	0.297	**0.011**	0.112	0.742	0.355	0.668	0.328	0.178	0.865
Bc – quad	0.245	0.869	0.228	0.798	0.605	0.103	0.722	0.639	0.304	0.911	0.434	0.500	0.874

Heterogeneous variance estimates permitted for individual site-years

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 8. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean biomass production (mid-late reproductive stages) over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
--- Above-Ground Biomass (kg/ha) ---													
0 P	7849 a	5328 a	3618	7708 b	2634 a	1810 a	4087 a	6654 a-c	6307 a	1937 a	9531 a	4028 c	5124 b-e
22 P – Sp	7538 a	4889 a	3855	7648 b	2338 a	2040 a	4478 a	4938 d	5372 a	2246 a	8701 a	3467 d	4793 e
45 P – Sp	8555 a	5383 a	4223	8573 ab	2581 a	2420 a	4539 a	5445 b-d	4839 a	2217 a	9401 a	4533 a-c	5226 a-d
90 P – Sp	8924 a	5127 a	4075	6515 b	2319 a	2093 a	4331 a	6452 a-d	4979 a	1509 a	9138 a	4651 ab	5009 cde
22 P – Sb	8768 a	5709 a	4711	10965 a	2343 a	2250 a	3997 a	6864 ab	5782 a	1874 a	9107 a	4105 c	5540 a
45 P – Sb	7242 a	6170 a	4203	7845 b	2292 a	2493 a	4362 a	7488 a	5167 a	1810 a	10476 a	4130 bc	5306 a-d
90 P – Sb	7800 a	5189 a	3538	10640 a	2635 a	2018 a	4215 a	7079 a	5840 a	2288 a	9162 a	4390 bc	5399 abc
22 P – Bc	8333 a	4439 a	3928	7478 b	2746 a	2478 a	2887 a	6727 a-c	3748 a	2220 a	10039 a	4355 bc	4948 de
45 P – Bc	8227 a	5504 a	3669	7888 b	2699 a	2323 a	4405 a	5263 cd	5610 a	1614 a	8831 a	4671 ab	5058 b-e
90 P – Bc	8333 a	6188 a	4080	8443 ab	2568 a	2410 a	3961 a	6394 a-d	5996 a	1822 a	10231 a	5030 a	5455 ab
S.E.M.	592.6	424.2	438.2	923.9	309.8	307.5	501.9	561.4	586.3	248.6	699.9	221.5	150.9
Pr > F	0.568	0.087	0.738	**0.015**	0.959	0.775	0.490	**0.017**	0.114	0.165	0.661	**< 0.001**	**0.006**
All	8157 b	5393 d	3990 e	8370 b	2515 f	2233 fg	4126 e	6330 c	5364 d	1954 g	9462 a	4336 e	5186
(S.E.M.)	(207.1)	(160.6)	(164.3)	(305.2)	(131.9)	(131.4)	(181.6)	(198.3)	(205.4)	(118.2)	(238.3)	(112.7)	–
--- Pr > F (p-value) ---													
0 P vs Rest	0.580	0.870	0.361	0.448	0.673	0.129	0.934	0.539	0.087	0.939	0.917	0.108	0.662
Sp vs Sb	0.401	0.101	0.776	**0.003**	0.965	0.773	0.523	**0.001**	0.260	0.999	0.376	0.957	**0.001**
Sp vs Bc	0.932	0.472	0.650	0.634	0.285	0.360	0.084	0.254	0.908	0.576	0.274	**0.005**	0.234
Sb vs Bc	0.451	0.356	0.461	**0.013**	0.305	0.531	0.275	**0.025**	0.312	0.577	0.835	**0.004**	**0.032**
All - lin	0.491	0.438	0.735	0.554	0.769	0.332	0.652	0.882	0.509	0.573	0.923	**<0.001**	0.217
All - quad	0.969	0.847	0.297	0.723	0.745	0.076	0.795	0.197	**0.045**	0.787	0.927	0.918	0.792
Sp – lin	0.103	0.929	0.429	0.374	0.568	0.478	0.802	0.746	0.122	0.100	0.886	**0.001**	0.972
Sp – quad	0.893	0.952	0.511	0.269	0.993	0.229	0.518	**0.025**	0.219	**0.051**	0.782	0.598	0.974
Sb – lin	0.583	0.751	0.500	0.124	0.878	0.723	0.772	0.539	0.582	0.239	0.893	0.189	0.422
Sb – quad	0.898	0.082	0.076	0.963	0.288	0.090	0.846	0.434	0.217	0.292	0.371	0.782	0.345
Bc – lin	0.636	**0.032**	0.518	0.492	0.806	0.260	0.634	0.547	0.543	0.420	0.620	**<0.001**	**0.051**
Bc – quad	0.727	0.210	0.901	0.782	0.724	0.301	0.790	0.167	**0.048**	0.759	0.412	0.565	0.119

Heterogeneous variance estimates permitted for individual site-years

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 9. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean whole plant tissue P concentrations (mid-late reproductive stages) over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, *P* ≤ 0.05).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
--- Whole Plant Tissue P (% P) ---													
0 P	0.24 bc	0.18 e	0.24 a	0.17 e	0.28 d	0.28 c	0.24 a	0.28 b	0.24 a	0.19 a	0.22 a	0.23 c	0.232 e
22 P – Sp	0.25 a-c	0.21 d	0.21 a	0.18 c-e	0.30 b-d	0.29 c	0.23 a	0.29 b	0.24 a	0.21 a	0.24 a	0.29 a	0.244 d
45 P – Sp	0.25 a-c	0.22 cd	0.23 a	0.25 ab	0.30 cd	0.30 bc	0.24 a	0.28 b	0.24 a	0.21 a	0.23 a	0.29 a	0.253 cd
90 P – Sp	0.28 a	0.24 b	0.25 a	0.29 a	0.33 a-c	0.29 c	0.26 a	0.29 b	0.26 a	0.24 a	0.24 a	0.28 ab	0.265 ab
22 P – Sb	0.23 c	0.22 d	0.23 a	0.18 de	0.35 a	0.28 c	0.23 a	0.30 ab	0.24 a	0.21 a	0.24 a	0.27 ab	0.245 d
45 P – Sb	0.26 abc	0.22 b-d	0.22 a	0.19 c-e	0.35 a	0.30 c	0.25 a	0.29 b	0.25 a	0.21 a	0.23 a	0.25 bc	0.252 cd
90 P – Sb	0.27 ab	0.24 bc	0.22 a	0.22 bc	0.35 a	0.30 bc	0.26 a	0.28 b	0.25 a	0.21 a	0.24 a	0.29 a	0.264 ab
22 P – Bc	0.24 bc	0.22 d	0.20 a	0.19 c-e	0.34 ab	0.31 a-c	0.23 a	0.29 b	0.24 a	0.20 a	0.24 a	0.27 ab	0.250 cd
45 P – Bc	0.25 a-c	0.24 bc	0.25 a	0.19 c-e	0.36 a	0.34 a	0.25 a	0.30 ab	0.24 a	0.21 a	0.24 a	0.27 ab	0.256 bc
90 P – Bc	0.29 a	0.29 a	0.21 a	0.22 b-d	0.35 a	0.33 ab	0.25 a	0.32 a	0.24 a	0.20 a	0.25 a	0.27 ab	0.268 a
S.E.M.	0.015	0.011	0.017	0.017	0.017	0.014	0.014	0.012	0.013	0.013	0.011	0.014	0.0041
Pr > F	**0.016**	**<0.001**	0.273	**<0.001**	**<0.001**	**0.011**	0.327	**0.009**	0.970	0.132	0.279	**0.011**	**<0.001**
All	0.26 de	0.23 fg	0.23 fg	0.21 g	0.33 a	0.30 b	0.24 d-f	0.29 bc	0.24 ef	0.21 g	0.24 ef	0.27 cd	0.25
(S.E.M.)	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)	(0.008)	(0.009)	(0.008)	(0.009)	(0.009)	(0.009)	(0.009)	–
--- Pr > F (p-value) ---													
0 P vs Rest	0.164	**<0.001**	0.559	**0.011**	**0.001**	0.082	0.627	0.093	0.540	**0.031**	**0.050**	**0.001**	**<0.001**
Sp vs Sb	0.427	0.771	0.100	**0.002**	**0.001**	1.000	0.550	0.806	1.000	0.325	0.800	0.112	0.860
Sp vs Bc	0.812	**<0.001**	0.303	**0.002**	**0.000**	**0.001**	0.798	0.389	0.679	0.062	0.311	**0.052**	0.151
Sb vs Bc	0.578	**<0.001**	0.537	0.947	0.890	**0.001**	0.732	0.269	0.679	0.376	0.205	0.723	0.107
All - lin	**0.001**	**<0.001**	0.417	**<.0001**	**0.001**	**0.046**	**0.051**	**0.004**	0.293	**0.016**	**0.023**	**0.003**	**<0.001**
All - quad	0.453	0.036	0.783	0.948	**0.015**	0.162	0.547	0.983	0.854	0.189	0.580	**0.042**	**0.025**
Sp – lin	**0.019**	**<0.001**	0.212	**<.0001**	**0.041**	0.650	0.157	0.360	0.165	**0.001**	0.084	0.055	**<0.001**
Sp – quad	0.695	0.108	0.818	0.693	0.805	0.359	0.312	0.121	0.698	0.877	0.940	**0.002**	0.158
Sb – lin	**0.015**	**<0.001**	0.363	**0.010**	**0.016**	0.163	0.080	**0.029**	0.535	0.254	0.401	**0.002**	**<0.001**
Sb – quad	0.683	**0.027**	0.261	0.782	**0.004**	1.000	0.826	0.903	0.554	0.103	0.652	0.903	0.189
Bc – lin	**0.004**	**<0.001**	0.136	**0.051**	**0.003**	**0.008**	0.209	**0.001**	0.716	0.299	**0.011**	0.096	**<0.001**
Bc – quad	0.389	0.404	0.776	0.979	**0.006**	**0.030**	0.919	0.167	0.838	0.260	0.484	0.113	**0.025**

Heterogeneous variance estimates permitted for individual site-years

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 10. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean in-season P uptake (mid-late reproductive stages) over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
-- In-season P-Uptake (kg P_2O_5/ha) --													
0 P	42.5 c	22.6 d	19.5 a	29.9 c	17.2 a	11.7 a	22.5 a	42.4 a-d	34.3 a	8.2 a	48.0 a	21.4 d	26.7 ef
22 P – Sp	42.9 c	24.2 cd	18.2 a	31.3 c	16.3 a	13.2 a	23.8 a	32.4 d	28.9 a	10.7 a	46.7 a	23.2 d	26.0 f
45 P – Sp	48.5 a-c	27.5 b-d	25.0 a	47.6 a	17.3 a	16.6 a	20.8 a	37.3 b-d	26.8 a	10.4 a	48.7 a	29.5 a	29.8 b-d
90 P – Sp	56.8 a	28.0 b-d	22.6 a	42.1 a-c	17.3 a	14.0 a	15.2 a	42.7 a-d	29.2 a	7.9 a	50.8 a	29.3 ab	30.2 bc
22 P – Sb	45.2 bc	28.2 b-d	22.9 a	45.0 ab	19.0 a	14.3 a	24.4 a	43.8 a-c	31.7 a	8.9 a	50.6 a	24.8 b-d	29.8 b-d
45 P – Sb	42.5 c	31.5 b	21.4 a	34.6 bc	18.5 a	16.9 a	25.3 a	49.8 a	29.4 a	8.6 a	54.1 a	23.7 cd	29.7 b-d
90 P – Sb	48.9 a-c	28.5 b-d	18.6 a	54.3 a	20.8 a	14.0 a	25.2 a	48.8 a	32.7 a	10.8 a	49.2 a	29.1 ab	31.9 ab
22 P – Bc	45.6 bc	22.1 d	18.9 a	32.3 c	21.8 a	17.4 a	25.2 a	44.4 ab	20.6 a	9.9 a	54.1 a	26.5 a-c	27.7 d-f
45 P – Bc	47.2 bc	30.3 bc	21.6 a	34.0 bc	22.1 a	17.8 a	25.0 a	33.4 cd	30.8 a	7.7 a	48.6 a	28.5 ab	28.7 c-e
90 P – Bc	54.3 ab	41.1 a	20.1 a	41.9 a-c	20.7 a	18.1 a	22.8 a	46.9 ab	33.3 a	8.3 a	58.2 a	30.5 a	33.0 a
S.E.M.	3.67	2.78	3.25	4.74	2.74	2.34	3.32	4.17	3.42	1.76	3.77	2.21	0.95
Pr > F	**0.028**	**<0.001**	0.812	**0.001**	0.588	0.161	0.364	**0.012**	0.104	0.149	0.405	**<0.001**	**<0.001**
All	47.4 ab	28.4 d	20.8 f	39.3 c	19.1 fg	15.4 g	23.0 ef	42.2 bc	29.8 d	9.1 h	50.9 a	26.6 de	29.3
(S.E.M.)	(1.81)	(1.64)	(1.72)	(2.04)	(1.63)	(1.57)	(1.74)	(1.91)	(1.76)	(1.49)	(1.83)	(1.55)	–
-- Pr > F (p-value) --													
0 P vs Rest	0.124	**0.010**	0.612	**0.028**	0.398	**0.035**	0.863	0.963	0.121	0.294	0.386	**0.001**	**0.001**
Sp vs Sb	0.159	0.151	0.259	0.245	0.192	0.746	0.745	**0.002**	0.248	0.732	0.368	0.281	**0.009**
Sp vs Bc	0.897	**0.019**	0.849	0.247	0.016	0.034	0.160	0.195	0.974	0.194	0.085	0.395	0.099
Sb vs Bc	0.201	0.362	0.348	**0.021**	0.266	0.072	0.280	0.066	0.235	0.339	0.409	**0.054**	0.337
All - lin	**0.002**	**<0.001**	0.984	**0.001**	0.389	0.083	0.320	0.272	0.804	0.712	0.229	**<0.001**	**<0.001**
All - quad	0.573	0.441	0.498	0.717	0.570	**0.025**	0.998	0.209	**0.039**	0.343	0.863	0.198	0.896
Sp – lin	**0.001**	0.081	0.951	**0.022**	0.900	0.347	0.530	0.544	0.309	0.512	0.477	**<0.001**	**<0.001**
Sp – quad	0.605	0.513	0.490	0.122	0.902	0.139	0.852	0.090	0.145	**0.015**	0.746	0.111	0.656
Sb – lin	0.216	0.104	0.904	**0.001**	0.307	0.403	0.396	0.190	0.748	0.063	0.837	**0.002**	**<0.001**
Sb – quad	0.611	**0.031**	0.455	0.668	0.988	0.079	0.939	0.490	0.275	0.582	0.219	0.767	0.345
Bc – lin	0.011	**<0.001**	0.891	**0.049**	0.425	**0.032**	0.441	0.574	0.436	0.708	0.072	**<0.001**	**<0.001**
Bc – quad	0.824	0.265	0.950	0.753	0.162	0.084	0.796	0.076	**0.043**	0.828	0.600	0.120	0.271

Heterogeneous variance estimates permitted for individual site-years

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 11. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean seed yield over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
--- Seed Yield (kg /ha) ---													
0 P	2632 a	2328 e	1548 a	4419 a	3476 b	3042 c	3536 a	3052 a	2268 a	1601 a	3366 a	1544 a	2734 d
22 P – Sp	2689 a	2534 d	1499 a	4380 ab	4011 a	3705 ab	3636 a	2481 b	2120 a	1842 a	3217 a	1426 a	2795 b-d
45 P – Sp	2669 a	2672 bc	1526 a	4120 b	3886 a	3747 ab	3895 a	2841 ab	2182 a	1649 a	3382 a	1595 a	2847 a-c
90 P – Sp	2762 a	2790 ab	1428 a	3619 c	4002 a	3439 bc	3521 a	2950 a	2312 a	1254 a	3291 a	1560 a	2744 cd
22 P – Sb	2818 a	2583 cd	1496 a	4317 ab	3888 a	3367 bc	3574 a	2947 a	2109 a	1657 a	3270 a	1725 a	2812 a-d
45 P – Sb	2736 a	2679 bc	1529 a	4277 ab	3825 a	3871 ab	3721 a	3162 a	2554 a	1511 a	3445 a	1216 a	2877 ab
90 P – Sb	2715 a	2728 ab	1579 a	4240 ab	3977 a	3677 ab	3765 a	2461 b	2604 a	1799 a	3538 a	1763 a	2904 ab
22 P – Bc	2707 a	2556 cd	1511 a	4295 ab	3728 ab	3788 ab	3908 a	2768 ab	2078 a	1621 a	3491 a	1632 a	2840 a-d
45 P – Bc	2766 a	2743 ab	1437 a	4227 ab	3903 a	4010 a	3611 a	3035 a	2313 a	1533 a	3471 a	1746 a	2900 ab
90 P – Bc	2741 a	2822 a	1544 a	4324 ab	4005 a	4115 a	3745 a	2430 b	2390 a	1770 a	3446 a	1731 a	2922 a
S.E.M.	101.4	95.0	94.9	128.5	142.2	214.7	194.8	174.7	188.9	183.4	186.7	171.8	46.6
Pr > F	0.590	**<0.001**	0.398	**<0.001**	**0.034**	**0.007**	0.779	**0.002**	0.327	0.378	0.937	0.239	**<0.001**
All	2724 d	2643 d	1510 f	4222 a	3870 b	3676 bc	3691 b	2813 d	2293 e	1624 f	3392 c	1594 f	2838
(S.E.M.)	(84.9)	(84.1)	(84.1)	(88.5)	(90.5)	(103.9)	(99.9)	(96.1)	(98.7)	(97.7)	(98.3)	(95.5)	–
--- Pr > F (p-value) ---													
0 P vs Rest	0.101	**<0.001**	0.379	**0.035**	**<0.001**	**0.001**	0.354	0.103	0.875	0.883	0.873	0.727	**0.007**
Sp vs Sb	0.301	0.951	0.184	**0.003**	0.459	0.960	0.985	0.431	0.118	0.582	0.374	0.739	**0.035**
Sp vs Bc	0.513	0.275	0.731	**0.003**	0.353	**0.036**	0.626	0.914	0.688	0.655	0.206	0.154	**0.005**
Sb vs Bc	0.704	0.248	0.323	0.963	0.850	**0.040**	0.639	0.371	0.244	0.917	0.707	0.274	0.488
All - lin	0.158	**<0.001**	0.642	**<0.001**	**<0.001**	**0.002**	0.540	0.028	0.168	0.840	0.632	0.416	**0.006**
All - quad	0.249	**<0.001**	0.300	0.780	**0.042**	**0.003**	0.315	0.670	0.588	0.948	0.960	0.610	**0.023**
Sp – lin	0.134	**<0.001**	0.083	**<0.001**	**0.010**	0.330	0.971	0.747	0.706	0.051	0.912	0.758	0.968
Sp – quad	0.858	**0.029**	0.703	0.234	**0.053**	**0.011**	0.127	0.071	0.478	0.129	0.963	0.938	**0.028**
Sb – lin	0.676	**<0.001**	0.446	0.216	**0.008**	**0.018**	0.308	0.008	0.060	0.433	0.334	0.537	**0.003**
Sb – quad	0.112	**0.002**	0.362	0.594	0.179	**0.054**	0.822	0.074	0.990	0.465	0.768	0.110	0.223
Bc – lin	0.203	**<0.001**	0.940	0.561	**0.001**	**<0.001**	0.688	0.009	0.392	0.472	0.822	0.363	**0.001**
Bc – quad	0.253	**0.002**	0.078	0.203	0.216	**0.030**	0.634	0.335	0.632	0.520	0.651	0.581	0.105

Heterogeneous variance estimates permitted for individual site-years

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 12. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean seed P concentrations over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD test, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–
						------- Seed P Concentration (% P) -------							
0 P	0.49	0.39 e	0.47 a-c	0.53 c	0.59 a	0.59 a-c	0.55 b	0.69 a	0.76 a	0.56 cde	0.55 a	0.62 d	0.56 f
22 P – Sp	0.51	0.44 de	0.43 c	0.54 c	0.60 a	0.56 bc	0.55 b	0.68 a	0.75 a	0.63 a	0.57 a	0.68 abc	0.58 de
45 P – Sp	0.53	0.46 b-d	0.50 a	0.59 ab	0.61 a	0.60 a-c	0.53 bc	0.70 a	0.79 a	0.61 ab	0.58 a	0.72 a	0.60 b
90 P – Sp	0.57	0.50 ab	0.44 c	0.63 a	0.61 a	0.57 bc	0.56 b	0.71 a	0.79 a	0.58 b-d	0.57 a	0.70 ab	0.60 ab
22 P – Sb	0.52	0.43 de	0.46 a-c	0.55 bc	0.65 a	0.56 c	0.53 bc	0.69 a	0.79 a	0.59 a-c	0.59 a	0.67 bc	0.58 c-e
45 P – Sb	0.54	0.46 cd	0.47 a-c	0.57 bc	0.64 a	0.63 a	0.52 bc	0.73 a	0.76 a	0.53 e	0.58 a	0.69 ab	0.59 bc
90 P – Sb	0.58	0.51 a	0.50 a	0.62 a	0.61 a	0.55 c	0.53 bc	0.72 a	0.80 a	0.54 de	0.57 a	0.66 bcd	0.60 b
22 P – Bc	0.52	0.46 cd	0.49 ab	0.54 c	0.62 a	0.60 ab	0.49 c	0.68 a	0.76 a	0.56 b-e	0.56 a	0.64 cd	0.58 ef
45 P – Bc	0.52	0.49 a-c	0.45 bc	0.57 bc	0.63 a	0.58 bc	0.54 b	0.71 a	0.76 a	0.59 a-c	0.57 a	0.68 abc	0.59 b-d
90 P – Bc	0.57	0.54 a	0.45 bc	0.59 ab	0.63 a	0.61 ab	0.64 a	0.73 a	0.78 a	0.56 b-e	0.59 a	0.67 bc	0.61 a
S.E.M.	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.006
Pr > F	**0.001**	**<0.001**	**0.018**	**<0.001**	0.212	**0.021**	**<0.001**	0.123	0.399	**<0.001**	0.768	**0.002**	**< 0.001**
All	0.53 e	0.47 f	0.47 f	0.57 de	0.62 c	0.58 cd	0.54 de	0.70 b	0.77 a	0.57 de	0.57 de	0.67 b	0.59
(S.E.M.)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	(0.015)	–
						------- Pr > F (p-value) -------							
0 P vs Rest	**0.003**	**<0.001**	0.794	**0.005**	0.096	0.896	0.806	0.503	0.260	0.274	0.138	**0.001**	**<.0001**
Sp vs Sb	0.527	0.752	0.130	0.849	**0.037**	0.849	0.184	0.206	0.569	**<0.001**	0.950	**0.023**	0.635
Sp vs Bc	0.899	**0.027**	0.613	0.164	0.088	0.114	0.343	0.569	0.704	**0.020**	0.849	**0.008**	0.898
Sb vs Bc	0.448	**0.012**	0.312	0.230	0.704	0.164	**0.023**	0.487	0.343	0.130	0.800	0.704	0.547
All - lin	**<0.001**	**<0.001**	0.835	**<0.001**	0.233	0.781	**0.037**	0.031	0.060	0.590	0.128	**0.002**	**<.0001**
All - quad	0.852	0.195	0.817	0.928	0.103	0.404	**0.010**	0.761	0.951	0.060	0.295	**0.001**	**0.029**
Sp – lin	**<0.001**	**<0.001**	0.432	**<0.001**	0.333	0.675	0.783	0.295	0.100	0.948	0.380	**0.002**	**<.0001**
Sp – quad	0.881	0.424	0.208	0.911	0.960	0.699	0.294	0.626	0.727	**0.004**	0.236	**0.001**	**0.011**
Sb – lin	**<0.001**	**<0.001**	0.105	**<0.001**	0.927	0.395	0.463	0.084	0.133	0.136	0.600	0.214	**<.0001**
Sb – quad	0.727	0.736	0.369	0.871	**0.009**	0.071	0.336	0.549	0.755	0.911	0.231	**0.008**	**0.040**
Bc – lin	**0.001**	**<0.001**	0.191	**0.005**	0.102	0.521	**<0.001**	0.036	0.272	0.733	0.042	**0.014**	**<.0001**
Bc – quad	0.930	0.083	0.881	0.803	0.343	0.727	**<0.001**	0.432	0.861	0.170	0.950	0.138	0.823

^{Z} P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Table 13. Treatment means, overall F-test and contrast results for phosphorus rate and placement effects on soybean seed P_2O_5 exports over 12 site-years. Means within a column followed by the same letter do not significantly differ (Fisher's protected LSD, $P \leq 0.05$).

P_2O_5 Rate / Placement	Indian Head			Outlook			Melfort			Scott			Average
	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	–

-- Seed P_2O_5 Exports (kg P_2O_5/ha) --

P_2O_5 Rate / Placement	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	Avg
0 P	30.8 a	21.0 e	16.7 a	53.5 bc	47.3 b	40.8 e	43.9 b	48.5 a-c	39.3 cd	22.8 ab	46.0 a	22.0	36.0 d
22 P – Sp	31.3 a	25.4 c-e	14.9 a	53.8 bc	54.8 a	47.6 b-d	46.3 b	38.7 e	36.3 d	28.1 a	45.6 a	22.3	37.1 cd
45 P – Sp	32.7 a	28.2 b-d	17.4 a	55.4 a-c	54.0 ab	51.3 a-c	46.8 b	45.5 b-e	39.0 cd	17.1 b	48.9 a	26.2	38.5 bc
90 P – Sp	35.8 a	32.2 ab	14.3 a	51.8 c	56.2 a	44.9 de	45.1 b	48.1 a-c	41.6 a-d	19.4 b	46.5 a	25.0	38.4 bc
22 P – Sb	32.4 a	24.9 de	15.7 a	54.4 a-c	57.7 a	42.4 de	43.3 b	46.1 b-d	38.0 cd	18.9 b	47.4 a	26.4	37.3 cd
45 P – Sb	33.9 a	28.0 b-d	16.5 a	55.9 a-c	56.2 a	55.6 a	44.4 b	52.9 a	44.4 ab	21.8 b	49.3 a	19.2	39.8 ab
90 P – Sb	36.2 a	31.6 ab	18.1 a	60.2 a	55.3 a	47.0 cd	45.6 b	40.8 d-e	47.5 a	22.4 ab	50.0 a	26.5	40.1 ab
22 P – Bc	32.7 a	26.9 b-e	16.9 a	53.2 bc	53.2 ab	51.7 a-c	44.4 b	42.8 c-d	36.3 d	20.6 b	48.1 a	24.0	37.6 cd
45 P – Bc	33.2 a	31.1 a-c	14.9 a	54.7 a-c	56.0 a	53.1 ab	44.6 b	49.0 ab	40.2 b-d	22.2 ab	49.4 a	27.3	39.6 ab
90 P – Bc	33.7 a	34.6 a	15.9 a	58.4 ab	58.0 a	56.8 a	54.9 a	40.6 de	42.6 a-c	19.5 b	50.5 a	26.7	41.0 a
S.E.M.	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	2.65	0.76
Pr > F	0.744	**0.000**	0.966	0.189	**0.033**	**<.0001**	**0.011**	**<.0001**	**0.004**	**0.040**	0.741	0.143	**< 0.001**
All	33.3 d	28.4 de	16.1 g	55.1 a	54.9 a	49.1 b	45.9 b	45.3 bc	40.5 c	21.3 f	48.2 b	24.6 ef	38.5
(S.E.M.)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	(1.71)	–

-- Pr > F (p-value) --

	2015	2016	2017	2015	2016	2017	2015	2016	2017	2015	2016	2017	Avg
0 P vs Rest	0.216	**<0. 001**	0.774	0.408	**<0. 001**	**0.049**	0.327	0.117	0.533	0.451	0.282	0.212	**<0. 001**
Sp vs Sb	0.606	0.815	0.485	0.070	0.425	**0.006**	0.351	0.152	**0.013**	0.781	0.265	0.789	**0.034**
Sp vs Bc	0.973	0.189	0.833	0.318	0.670	**0.001**	0.270	0.970	0.674	0.663	0.173	0.397	**0.006**
Sb vs Bc	0.582	0.122	0.626	0.414	0.709	0.133	**0.042**	0.163	**0.039**	0.875	0.804	0.265	0.514
All - lin	**0.043**	**<0. 001**	0.851	0.105	**<0. 001**	**<0. 001**	**0.034**	0.124	**0.008**	0.226	0.153	0.096	**<0. 001**
All - quad	0.868	0.207	0.850	0.992	**0.010**	**<0. 001**	0.625	0.686	0.385	0.652	0.451	0.744	**0.026**
Sp – lin	0.071	**<0. 001**	0.528	0.581	**0.011**	0.279	0.808	0.362	0.243	**0.040**	0.732	0.238	**0.005**
Sp – quad	0.785	0.471	0.682	0.337	0.138	**0.001**	0.322	**0.021**	0.337	0.771	0.478	0.454	0.104
Sb – lin	0.063	**<0. 001**	0.549	**0.017**	**0.049**	**0.010**	0.490	**0.022**	**0.001**	0.776	0.167	0.340	**<0. 001**
Sb – quad	0.860	0.476	0.641	0.699	**0.006**	**<0. 001**	0.775	**0.016**	0.861	0.406	0.640	0.306	**0.046**
Bc – lin	0.355	**<0. 001**	0.694	0.067	**0.001**	**<0. 001**	**<0. 001**	**0.036**	0.117	0.338	0.132	0.104	**<0. 001**
Bc – quad	0.642	0.174	0.718	0.550	0.133	**0.019**	0.074	0.429	0.430	0.902	0.622	0.318	0.188

[z] P = kg P_2O_5 ha^{-1} as monoammonium phosphate (11-52-0); Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

15. Reference papers or articles

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