SASKATCHEWAN pulse Growers

# SPG Project Annual Progress Report

**1. SPG project details**

**Project File number: AGR1509**
**Project title: Developing phosphorus management recommendations for soybean production in Saskatchewan**
**Reporting period: April 1, 2016 – March 31, 2017**
**Approved Project Date: March, 2015**
**Report prepared by: Chris Holzapfel, Indian Head Agricultural Research Foundation (Email: cholzapfel@iharf.ca)**
**Date submitted to SPG: March 28**

**2. Specify project activities undertaken during this reporting period.** *Please note that changes from the original work plan will require consultation with, and written approval from SPG.*

**a.) Methodology:** *Include strategy, experimental design, tests, materials, sites, etc.*

In the spring of 2016, soybean field trials were established for second (of three) growing seasons at four locations in Saskatchewan: 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 evaluated were 3 phosphorus rates (22, 45 or 90 kg $P_2O_5$ $ha^{-1}$), three placement methods (seed-placed, side-banded or pre-seed broadcast) plus a control where no P fertilizer was applied. The 10 treatments were arranged in a Randomized Complete Block Design with four replicates. The protocol being followed was originally developed by Don Flaten and a team of researchers in Manitoba for a Pulse Science Cluster 2 project.

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. All other crop inputs (i.e. seeding rate, inoculant, and pest control products) were based on current recommendations and intended to be non-limiting. The variety was 2310 YR and the soybeans were always double inoculated (seed-applied plus 1-2x label rate of granular). Weeds were controlled using registered herbicide applications tailored to each site and the plots were combined when mature and dry. Pertinent site information and agronomic details are provided for each site in Tables 1 (2015) and 2 (2016).

The data collected included background residual soil nutrient testing, emergence measurements at approximately 2, 3 and 4 weeks after planting, above-ground biomass measurements during pod fill (target R5-R6), whole plant tissue P concentrations/total P uptake, seed yield, seed P concentrations/P exports. At Outlook, emergence counts were only completed at 4 weeks after planting and not all nutrient analyses are available at this time; however, all samples have been submitted and are currently being processed through AgVise laboratories (Northwood, ND).

All available response data available to date has been analysed separately for each site using the mixed procedure of SAS. The effects of P treatments were considered fixed while replicate effects were considered random. Individual treatment means were separated using Tukey's studentized range test and contrasts were used to compare specific groups of treatments (control vs. fertilized, seed-placed vs. side-banded, seed-placed vs. broadcast and side-banded vs. broadcast). Orthogonal contrasts were used to test whether responses to P rate were non-significant, linear or curvilinear separately. All treatment effects and differences between means were considered significant at $P \leq 0.05$.

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

| 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-11<br>Jun-18<br>Jun-25 | Jun-19 | Jun-4<br>Jun-11<br>Jun-18 | Jun-3<br>Jun-10<br>Jun-17 |
| In-crop herbicide 1 | 890 g glyphosate/ha + 50 g imazethapyr/ha<br>Jun-8 | 1334 g glyphosate/ha<br>June-22 | 1334 g glyphosate/ha<br>Jul-2 | 1780 g glyphosate/ha<br>Jun-12 |
| In-crop herbicide 2 | 890 g glyphosate/ha<br>Jul-4 | 1334 g glyphosate/ha<br>Jul-15 | 1334 g glyphosate/ha<br>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.**

| 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-7<br>Jun-13<br>Jun-20 | June 22 | Jun-1<br>Jun-7<br>Jun-14 | May-30<br>Jun-6<br>Jun-14 |
| In-crop herbicide 1 | 890 g glyphosate/ha + 50 g imazethapyr/ha<br>Jun-17 | 890 g glyphosate/ha<br>June 22 | 890 g glyphosate/ha<br>Jun-15 | 1134 g glyphosate/ha + 50 g imazethapyr/ha<br>Jun-17 |
| In-crop herbicide 2 | 890 g glyphosate/ha<br>Jul-5 | n/a | 890 g glyphosate/ha<br>Jul-5 | n/a |
| Biomass harvest | Aug-19 | Aug 27 | Aug-16 | Sep-6 |
| Seed harvest | Oct-1 | Oct 21 | Nov-8 | Oct-3 |

**b.) List and explain any deviations from the approved objectives:**

All activities are proceeding on schedule with no major deviations from the original research plan or proposed milestones.

**c.) Research results in the reporting period.** *(Describe progress towards meeting objectives. Please use revised objectives if approved revisions have been made to original objectives.*

| Objectives | Progress |
|---|---|
| To investigate soybean response to P fertilizer rates and placement methods in Saskatchewan. | Two of three years of field trials have been completed and all available response data has been summarized and analyzed. Any conclusions regarding the specific objectives of this project are still considered preliminary and subject to change. |

***add additional lines as required***

**d.) Discussion:** *Provide discussion and interpretation necessary to the full understanding (including on-farm use of information, if any) of progress made during this reporting period and the relevance of any findings. Detail any major concerns or project setbacks.*

All available response data to date has been analysed and is presented in the following section. Only limited discussion and interpretation of results are offered as the study will continue in 2017 and final data will be combined and re-analysed as appropriate. Soil test results are presented in Table 3. Residual P (Olsen) levels at the sites ranged from 4-22 ppm with less than 10 ppm at half of the test sites. In general, the sites at Indian Head have been extremely low in residual P (4-5 ppm), while those at Scott were more moderate (13-15 ppm) and the highest residual P levels were at Melfort in 2015 (22 ppm).

**Table 3. Soil test results for 2015 and 2016 soybean P fertility trials at Indian Head, Outlook, Melfort and Scott. Samples were collected in the early spring and submitted to AgVise laboratories for various analyses.**

| Soil Test | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| $NO_3$-N (0-60 cm) [z] | 15 kg/ha | 21 kg/ha | 53 kg/ha | 35 kg/ha | 84 kg/ha | 101 kg/ha | 53 kg/ha | 34 kg/ha |
| Olsen-P (0-15 cm) | 5 ppm | 4 ppm | 7 ppm | 12 ppm | 22 ppm | 8 ppm | 13 ppm | 15 ppm |
| K (0-15 cm) | 676 ppm | 545 ppm | 290 ppm | 231 ppm | 618 ppm | 486 ppm | 310 ppm | 320 ppm |
| S (0-60 cm) | 18 kg/ha | 70 kg/ha | 179 kg/ha | 47 kg/ha | 87 kg/ha | 36 kg/ha | 92 kg/ha | 44 kg/ha |
| OM % (0-15 cm) | 5.6 | 4.8 | — | 2.4 | 11.3 | 11.5 | 4.3 | 4.2 |
| pH (0-15) | 7.7 | 8.0 | 8.0 | 7.6 | 6.3 | 5.9 | 5.1 | 5.4 |

[z] Soil only sampled to 30 cm at Melfort

Mean monthly temperatures for each location are presented in Table 4 and total precipitation amounts are in Table 5. Temperatures have been average to slightly above-average for the respective locations over the past two

seasons, with particularly warm weather in June in all cases. Early frost was not considered a yield limiting factor in any cases. Cumulative growing season precipitation amounts were also above average except for Indian Head in 2015 where May-September rainfall amounts were about average and Scott in 2015 where total precipitation was only 79% of the long-term average. Hail occurred in both years at Indian Head with the damage occurring in late June (V1-V2) while in 2016 it occurred late July (R2). In both cases the damage was uniform and not believed to have affected data quality although yields were reduced substantially in 2016 as a result of the damage.

**Table 4. Mean monthly temperatures along with long-term (1981-2010) averages for the 2015-16 growing seasons at Indian Head, Outlook, Melfort and Scott, SK.**

| Year | May | June | July | August | September | Avg. / Total |
|---|---|---|---|---|---|---|
| | ---------- Mean Temperature (°C) ---------- | | | | | |
| Indian Head-16 | 14.0 | 17.5 | 18.5 | 17.2 | 12.8 | 16.0 |
| Indian Head-15 | 10.3 | 16.2 | 18.1 | 17.0 | 22.2 | 16.8 |
| Indian Head-LT | 10.8 | 15.8 | 18.2 | 17.4 | 11.5 | 14.7 |
| Outlook-16 | 13.5 | 17.5 | 18.6 | 16.9 | 12.1 | 15.7 |
| Outlook-15 | 10.4 | 17.3 | 19.2 | 17.4 | 12.6 | 15.4 |
| Outlook-LT | 11.5 | 16.1 | 18.9 | 18.0 | 12.3 | 15.4 |
| Melfort-16 | 13.6 | 17.1 | 18.1 | 16.3 | 12.0 | 15.4 |
| Melfort-15 | 9.9 | 16.4 | 17.9 | 17.0 | 11.9 | 14.6 |
| Melfort-LT | 10.7 | 15.9 | 17.5 | 16.8 | 10.8 | 14.3 |
| Scott-16 | 12.4 | 15.8 | 17.8 | 16.1 | 10.9 | 14.6 |
| Scott-15 | 9.4 | 16.0 | 18.1 | 16.8 | 11.0 | 14.3 |
| Scott-LT | 10.8 | 15.3 | 17.1 | 16.5 | 10.4 | 14.0 |

**Table 5. Total precipitation amounts along with long-term (1981-2010) averages for the 2015-16 growing seasons at Indian Head, Outlook, Melfort and Scott, SK.**

| Year | May | June | July | August | September | Avg. / Total |
|---|---|---|---|---|---|---|
| | ---------- Precipitation (mm) ---------- | | | | | |
| Indian Head-16 | 73 | 63 | 113 | 30 | 41 | 320 |
| Indian Head-15 | 16 | 38 | 95 | 59 | 68 | 275 |
| Indian Head-LT | 52 | 77 | 64 | 51 | 35 | 280 |
| Outlook-16 | 56 | 46 | 195 | 70 | 24 | 319 |
| Outlook-15 | 9 | 39 | 135 | 58 | 48 | 289 |
| Outlook-LT | 39 | 64 | 56 | 43 | 33 | 235 |
| Melfort-16 | 17 | 53 | 129 | 81 | 41 | 321 |
| Melfort-15 | 7 | 55 | 150 | 57 | 70 | 339 |
| Melfort-LT | 40 | 54 | 77 | 52 | 34 | 258 |
| Scott-16 | 65 | 21 | 88 | 98 | 22 | 294 |
| Scott-15 | 4 | 19 | 46 | 75 | 50 | 194 |
| Scott-LT | 35 | 62 | 72 | 46 | 33 | 247 |

Emergence measurements were targeted for approximately 2, 3 and 4 weeks after seeding; however the actual

dates varied across sites (i.e. measurements were delayed by approximately 1 week at Indian Head in 2015) and the plants were only counted once (approximately 4 weeks after planting) at Outlook. Emergence results for the first two measurement dates (targeted for 2 and 3 weeks after planting) are deferred to the Appendices (Tables A1-A4). At the first date, overall plant density varied widely across locations due differences in both environmental conditions and the actual measurement dates (i.e. Indian Head 2015 started one 1 week late); however, the overall F-tests for treatment effects on emergence were not significant at any sites. The contrasts, however, showed some evidence of reduced emergence at Scott in both 2015 and 2016 (Tables A1 and A2). At the second measurement date (targeted 3 weeks after planting), the overall F-test was only significant at 1/6 possible site-years but the orthogonal contrasts detected small but significant linear declines in plant density with seed-placement at Indian Head, Melfort and Scott in 2016 (Table A3). Because the effects were small and did not occur at all rates, plant populations with seed-placement only differed from side-band populations at one site (Melfort 2016) when averaged across rates (Table A4). Again, the early emergence measurements were not completed at Outlook.

Treatment effects on emergence for the final measurement date (4-5 weeks after planting) are presented in Tables 6 and 7 below. The overall F-test was only significant in 1/8 cases (Outlook 2016; $P < 0.01$); however, overall linear declines in plant populations were detected with seed-placement at 3/8 sites ($P < 0.01$-$0.02$; Melfort 2015, Melfort 2016 and Scott 2016). Melfort 2016 was the only site-year where, when averaged across rates, final emergence with seed-placed P (33 plants/$m^2$) differed from that of side-band or broadcast placement (46-47 plants/m2; $P < 0.01$). At Scott in 2015, the linear response was not quite significant ($P$ 0.06); however, there was a strong trend for lower plant densities with high rates of seed-placed monoammonium phosphate whereby 41% fewer plants were observed at the highest rate relative to the control. The overall decline from 0-90 kg $P_2O_5$/ha ranged from 23-50% at the sites where the linear response was significant at $P \leq 0.05$. In nearly all cases, Melfort 2016 being the exception, plant densities at the 45 kg $P_2O_5$ rate of seed-placed P were numerically similar to those observed in the control and there was never any indication of seedling injury at 22 kg $P_2O_5$/ha. While evidence of seedling injury was only observed at 38% of the sites, results to date show clear potential for soybean emergence to be negatively impacted by high rates of seed-placed monoammonium phosphate under certain conditions.

**Table 6. Treatment means, overall F-test and orthogonal contrast results for soybean emergence at T3 (~4 weeks after planting). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | T3 Emergence (plants/$m^2$) | | | | | | | |
| 0 P | 48.8 a | 49.3 a | 56.5 a | 46.8 a | 49.9 a | 48.2 | 39.6 a | 44.8 a |
| 22 P – Sp | 46.8 a | 54.6 a | 60.3 a | 44.9 ab | 44.3 ab | 45.5a a | 44.1 a | 42.3 a |
| 22 P – Sb | 49.0 a | 53.3 a | 71.3 a | 48.9 a | 36.9 ab | 47.4 a | 41.4 a | 42.8 a |
| 22 P – Bc | 50.3 a | 53.3 a | 61.3 a | 45.7 ab | 50.3 a | 47.0 a | 46.8 a | 41.5 a |
| 45 P – Sp | 48.6 a | 51.1 a | 82.3 a | 49.0 a | 42.2 ab | 32.0 a | 36.4 a | 45.0 a |
| 45 P – Sb | 44.7 a | 49.4 a | 64.8 a | 36.2 b | 36.2 ab | 47.2 a | 35.9 a | 43.5 a |
| 45 P – Bc | 44.9 a | 48.0 a | 66.3 a | 47.2 a | 46.1 ab | 45.1 a | 41.1 a | 44.5 a |
| 90 P – Sp | 43.9 a | 42.5 a | 42.3 a | 49.0 a | 23.6 b | 33.8 a | 23.4 a | 34.5 a |
| 90 P – Sb | 50.3 a | 47.2 a | 75.0 a | 50.9 a | 38.3 ab | 47.2 a | 43.1 a | 42.5 a |
| 90 P – Bc | 51.1 a | 51.7 a | 68.0 a | 49.4 a | 39.4 ab | 46.5 a | 45.8 a | 47.5 a |
| S.E.M. | 2.46 | 3.12 | 12.41 | 3.17 | 5.33 | 3.64 | 6.90 | 3.03 |
| | Pr > F (p-value) | | | | | | | |
| F-test (trt) | 0.396 | 0.235 | 0.641 | **0.004** | 0.058 | **0.025** | 0.490 | 0.279 |
| Sp – lin | 0.198 | **0.046** | 0.445 | 0.280 | **0.001** | **0.004** | 0.056 | **0.024** |
| Sp – quad | 0.629 | 0.075 | 0.069 | 0.952 | 0.478 | 0.142 | 0.399 | 0.254 |
| Sb – lin | 0.776 | 0.400 | 0.382 | 0.443 | 0.221 | 0.858 | 0.790 | 0.665 |
| Sb – quad | 0.212 | 0.463 | 0.834 | **0.001** | 0.129 | 0.889 | 0.646 | 0.857 |
| Bc – lin | 0.683 | 0.814 | 0.506 | 0.295 | 0.126 | 0.745 | 0.670 | 0.341 |
| Bc – quad | 0.243 | 0.872 | 0.800 | 0.601 | 0.727 | 0.641 | 0.911 | 0.445 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 7. Contrast comparisons for phosphorus fertilization and placement effects on soybean emergence at T3 (~4 weeks after planting).**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | T3 Emergence (plants/$m^2$) | | | | | | | |
| 0 P vs | 48.8 a | 49.3 a | 56.5 a | 46.8 a | 49.9 a | 48.2 a | 39.6 a | 44.8 a |
| Rest | 47.7 a | 50.1 a | 65.7 a | 46.8 a | 39.7 a | 43.3 a | 39.8 a | 42.7 a |
| Pr > *F* | 0.679 | 0.789 | 0.488 | 0.994 | 0.080 | 0.234 | 0.986 | 0.514 |
| Sp vs | 46.4 a | 49.4 a | 61.6 a | 47.6 a | 36.7 a | 32.9 b | 34.6 a | 40.6 a |
| Sb | 48.0 a | 50.0 a | 70.4 a | 45.3 a | 37.1 a | 47.3 a | 40.1 a | 42.9 a |
| Pr > *F* | 0.440 | 0.811 | 0.395 | 0.200 | 0.920 | **0.002** | 0.338 | 0.347 |
| Sp vs | 46.4 a | 49.4 a | 61.6 a | 47.6 a | 36.7 a | 32.9 b | 34.6 a | 40.6 a |
| Bc | 48.8 a | 51.0 a | 65.2 a | 47.4 a | 45.3 a | 46.2 a | 44.6 a | 44.5 a |
| Pr > *F* | 0.257 | 0.518 | 0.726 | 0.910 | 0.060 | **0.005** | 0.090 | 0.120 |
| Sb vs | 48.0 a | 50.0 a | 70.4 a | 45.3 a | 37.1 a | 47.3 a | 40.1 a | 42.9 a |
| Bc | 48.8 a | 51.0 a | 65.2 a | 47.4 a | 45.3 a | 46.2 a | 44.6 a | 44.5 a |
| Pr > *F* | 0.712 | 0.683 | 0.614 | 0.240 | 0.074 | 0.733 | 0.439 | 0.522 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Above-ground biomass yields were measured during the reproductive growth stages. While the ideal target stage was R5-R6, actual growth stages varied therefore the absolute above-ground biomass yields should not be compared across sites (Table 8). The overall F-test was significant at 2/8 sites, Outlook 2015 and Melfort 2016 (*P* = 0.03-0.05). At Outlook (2015), the highest above-ground biomass yields were observed with 22 kg $P_2O_5$ $ha^{-1}$ in the side-band and the lowest occurred with 90 kg $P_2O_5$ $ha^{-1}$ placed in the seed-row. The only significant contrasts were those comparing side-banded versus both seed-placed and broadcast P whereby side-banded P resulted in higher biomass yields (averaged across P rates) than the other placement options. None of the orthogonal contrasts were significant for any P placement methods which suggested that these effects may have been somewhat random and largely due to variability. At Melfort in 2016, there was a curvilinear reduction in above-ground biomass with seed-placed P (*P* = 0.03). Furthermore, while the overall difference between the control and the fertilized plots was not significant (*P* = 0.55), above-ground biomass with side-banded P was higher than for either seed-placed (*P* < 0.01) or broadcast P (*P* = 0.03; Table 9).

**Table 8. Treatment means, overall F-test and orthogonal contrast results for soybean above-ground biomass production. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Above-ground Biomass (kg/ha) | | | | | | | |
| 0 P | 7849 a | 5328 a | 7708 ab | 2634 a | 6654 a | 4056 a | 1937 a | 9531 a |
| 22 P – Sp | 7538 a | 4889 a | 7648 ab | 2338 a | 4938 a | 3011 a | 2246 a | 8701 a |
| 22 P – Sb | 8768 a | 5709 a | 10965 a | 2343 a | 6864 a | 4185 a | 1874 a | 9107 a |
| 22 P – Bc | 8333 a | 4439 a | 7478 ab | 2746 a | 6727 a | 4101 a | 2220 a | 10039 a |
| 45 P – Sp | 8555 a | 5383 a | 8573 ab | 2581 a | 5445 a | 3319 a | 2217 a | 9401 a |
| 45 P – Sb | 7242 a | 6170 a | 7845 ab | 2292 a | 7488 a | 4571 a | 1810 a | 10476 a |
| 45 P – Bc | 8227 a | 5504 a | 7888 ab | 2699 a | 5263 a | 3209 a | 1614 a | 8831 a |
| 90 P – Sp | 8924 a | 5127 a | 6515 b | 2319 a | 6452 a | 3933 a | 1509 a | 9138 a |
| 90 P – Sb | 7800 a | 5189 a | 10640 ab | 2635 a | 7079 a | 4316 a | 2288 a | 9162 a |
| 90 P – Bc | 8333 a | 6188 a | 8443 ab | 2568 a | 6394 a | 3898 a | 1822 a | 10231 a |
| S.E.M. | 590.0 | 453.2 | 929.8 | 289.8 | 504.1 | 338.7 | 237.9 | 706.8 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.588 | 0.089 | **0.032** | 0.945 | 0.499 | **0.048** | 0.227 | 0.621 |
| Sp – lin | 0.117 | 0.925 | 0.365 | 0.565 | 0.802 | 0.750 | 0.114 | 0.884 |
| Sp – quad | 0.895 | 0.949 | 0.261 | 0.993 | 0.521 | **0.033** | 0.062 | 0.777 |
| Sb – lin | 0.590 | 0.736 | 0.122 | 0.877 | 0.772 | 0.545 | 0.253 | 0.891 |
| Sb – quad | 0.899 | 0.073 | 0.962 | 0.288 | 0.846 | 0.431 | 0.305 | 0.364 |
| Bc – lin | 0.642 | **0.028** | 0.482 | 0.804 | 0.636 | 0.553 | 0.431 | 0.613 |
| Bc – quad | 0.732 | 0.189 | 0.777 | 0.722 | 0.791 | 0.178 | 0.763 | 0.405 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 9. Contrast comparisons for phosphorus fertilization and placement effects on for soybean above-ground biomass yields.**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Above-ground Biomass (kg/ha) | | | | | | | |
| 0 P vs | 7849 a | 5328 a | 7708 a | 2634 a | 6654 a | 4056 a | 1937 a | 9531 a |
| Rest | 8191 a | 5400 a | 8444 a | 2502 a | 6294 a | 3838 a | 1956 a | 9454 a |
| Pr > *F* | 0.587 | 0.862 | 0.438 | 0.670 | 0.934 | 0.545 | 0.940 | 0.915 |
| Sp vs | 8339 a | 5133 a | 7579 b | 2413 a | 5612 a | 3421 b | 1991 a | 9080 a |
| Sb | 7937 a | 5689 a | 9817 a | 2423 a | 7144 a | 4357 a | 1991 a | 9582 a |
| Pr > *F* | 0.412 | 0.089 | **0.005** | 0.965 | 0.525 | **0.002** | 0.999 | 0.370 |
| Sp vs | 8339 a | 5133 a | 7579 a | 2413 a | 5612 a | 3421 a | 1991 a | 9080 a |
| Bc | 8298 a | 5377 a | 7936 a | 2671 a | 6128 a | 3736 a | 1885 a | 9700 a |
| Pr > *F* | 0.933 | 0.446 | 0.626 | 0.285 | 0.092 | 0.265 | 0.584 | 0.270 |
| Sb vs | 7937 a | 5689 a | 9817 a | 2423 a | 7144 a | 4357 a | 1991 a | 9582 a |
| Bc | 8298 a | 5377 a | 7936 b | 2671 a | 6128 a | 3736 b | 1885 a | 9700 a |
| Pr > *F* | 0.460 | 0.330 | **0.015** | 0.305 | 0.281 | **0.034** | 0.585 | 0.831 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Results for treatment effects on whole plant P concentration are presented in Tables 10 and 11. The overall F-tests were significant at 5/8 site-years (*P* < 0.01-0.03), the exceptions being Melfort in 2015 (*P* = 0.37) and Scott in both years (*P* = 0.16-0.32). While the multiple comparisons test did not identify any specific differences amongst treatment means at Indian Head in 2015, there was an overall linear increase in tissue P concentrations for all three placement methods (*P* < 0.01-0.03) with total P concentrations increasing from 0.24% in the control to 0.27-0.29%. At Indian Head in 2016, the response was even stronger with increases in P tissue concentration detected for all placement methods and values ranging from 0.18% in the control to as high as 0.29% with 90 kg $P_2O_5$/ha of broadcast P. Averaged across rates and placement methods, P fertilizer increased tissue P concentrations by 29% (*P* < 0.01) at Indian Head in 2016 and mean P concentrations were higher with broadcast placement (0.25%) than seed-row or side-band placement (0.22-0.23%; *P* < 0.01). At Outlook, tissue P concentrations were consistently higher with P fertilizer than in the control (*P* < 0.01-0.02); however, placement effects varied between years with seed-placement resulting in the highest concentrations in 2015 versus side-band placement in 2016. At Melfort in 2016, there was evidence of increasing tissue P concentrations with a significant overall F-test and linear responses for side-band and broadcast placement (*P* < 0.01-0.03). However, the check versus rest comparison was not significant at this site-year (*P* = 0.10) and there were no differences amongst placement methods when averaged across rates (*P* = 0.27-0.80). At Scott in 2015, while only the linear orthogonal contrast for seed placement was significant (*P* < 0.01); overall tissue P concentrations were higher with fertilizer than without (*P* 0.04) and there were no differences between placement methods when averaged across rates (*P* = 0.07-0.37).

**Table 10. Treatment means, overall F-test and orthogonal contrast results for soybean whole plant tissue P concentrations. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Tissue Phosphorus Concentration (% P) | | | | | | | |
| 0 P | 0.238 a | 0.180 c | 0.170 c | 0.283 b | 0.238 a | 0.278 b | 0.185 a | 0.220 a |
| 22 P – Sp | 0.250 a | 0.210 bc | 0.183 bc | 0.303 ab | 0.230 a | 0.285 ab | 0.208 a | 0.235 a |
| 22 P – Sb | 0.225 a | 0.215 b | 0.178 bc | 0.353 ab | 0.228 a | 0.278 b | 0.208 a | 0.240 a |
| 22 P – Bc | 0.238 a | 0.218 b | 0.193 bc | 0.343 ab | 0.228 a | 0.290 b | 0.195 a | 0.235 a |
| 45 P – Sp | 0.250 a | 0.220 b | 0.245 ab | 0.295 ab | 0.235 a | 0.300 ab | 0.208 a | 0.228 a |
| 45 P – Sb | 0.258 a | 0.223 b | 0.193 bc | 0.353 ab | 0.253 a | 0.290 ab | 0.213 a | 0.225 a |
| 45 P – Bc | 0.250 a | 0.238 b | 0.188 bc | 0.360 a | 0.250 a | 0.280 b | 0.208 a | 0.240 a |
| 90 P – Sp | 0.280 a | 0.240 b | 0.285 a | 0.328 ab | 0.258 a | 0.288 ab | 0.235 a | 0.243 a |
| 90 P – Sb | 0.273 a | 0.238 b | 0.223 abc | 0.345 ab | 0.260 a | 0.300 ab | 0.205 a | 0.235 a |
| 90 P – Bc | 0.285 a | 0.288 a | 0.215 abc | 0.353 ab | 0.253 a | 0.320 a | 0.200 a | 0.250 a |
| S.E.M. | 0.0129 | 0.0162 | 0.0190 | 0.0174 | 0.0132 | 0.0081 | 0.0102 | 0.0103 |
| | Pr > F (p-value) | | | | | | | |
| F-test | **0.046** | **< 0.001** | **< 0.001** | **0.004** | 0.370 | **0.027** | 0.164 | 0.324 |
| Sp – lin | **0.027** | **< 0.001** | **< 0.001** | **0.049** | 0.170 | 0.358 | **0.002** | 0.095 |
| Sp – quad | 0.699 | 0.115 | 0.693 | 0.806 | 0.322 | 0.124 | 0.875 | 0.941 |
| Sb – lin | **0.021** | **< 0.001** | **0.014** | **0.022** | 0.092 | **0.034** | 0.254 | 0.409 |
| Sb – quad | 0.687 | **0.034** | 0.782 | **0.007** | 0.829 | 0.902 | 0.107 | 0.656 |
| Bc – lin | **0.008** | **< 0.001** | 0.058 | **0.005** | 0.221 | **0.001** | 0.298 | **0.016** |
| Bc – quad | 0.397 | 0.407 | 0.979 | **0.009** | 0.920 | 0.169 | 0.260 | 0.490 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 11. Contrast comparisons for phosphorus fertilization and placement effects on soybean whole plant tissue P concentrations.**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | ---------- Tissue Phosphorus Concentration (% P) ---------- | | | | | | | |
| 0 P vs | 0.238 a | 0.180 b | 0.170 b | 0.283 b | 0.238 a | 0.278 a | 0.185 b | 0.220 a |
| Rest | 0.257 a | 0.232 a | 0.211 a | 0.337 a | 0.243 a | 0.289 a | 0.210 a | 0.235 a |
| Pr > *F* | 0.175 | **< 0.001** | **0.016** | **0.002** | 0.632 | 0.097 | **0.036** | 0.060 |
| Sp vs | 0.260 a | 0.223 a | 0.238 a | 0.309 b | 0.241 a | 0.291 a | 0.217 a | 0.235 a |
| Sb | 0.252 a | 0.225 a | 0.198 b | 0.350 a | 0.247 a | 0.289 a | 0.209 a | 0.233 a |
| Pr > *F* | 0.435 | 0.771 | **0.003** | **0.002** | 0.556 | 0.804 | 0.324 | 0.802 |
| Sp vs | 0.260 a | 0.223 b | 0.238 a | 0.309 b | 0.241 a | 0.291 a | 0.217 a | 0.235 a |
| Bc | 0.258 a | 0.248 a | 0.199 b | 0.352 a | 0.239 a | 0.285 a | 0.202 a | 0.238 a |
| Pr > *F* | 0.814 | **< 0.001** | **0.004** | **0.001** | 0.800 | 0.387 | 0.067 | 0.320 |
| Sb vs | 0.252 a | 0.225 b | 0.198 a | 0.350 a | 0.247 a | 0.289 a | 0.209 a | 0.233 a |
| Bc | 0.258 a | 0.248 a | 0.199 a | 0.352 a | 0.239 a | 0.285 a | 0.202 a | 0.238 a |
| Pr > *F* | 0.584 | **0.001** | 0.947 | 0.890 | 0.736 | 0.268 | 0.374 | 0.216 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Phosphorus uptake during pod-filling was calculated from the above-ground biomass yields and tissue P concentrations and results from all sites are presented in Tables 12 and 13. For this variable, P was converted to $P_2O_5$ equivalent so that the units would be the same as those of the P fertilizer rates. The overall F-test for P uptake was significant at 3/8 sites; Indian Head 2016, Outlook 2015 and Melfort 2016 ($P < 0.01$-$0.04$); however, there was also evidence of a linear increase in P uptake with fertilization at Indian Head in 2015, particularly for seed-row and broadcast placement ($P < 0.01$-$0.03$). At Indian Head in 2016, total P uptake increased from 23 to 29 kg $P_2O_5$ with monoammonium phosphate when averaged across rates and placement options ($P = 0.01$). At Outlook in 2015 total P uptake was increased from 30 to 40 kg $P_2O_5$/ha with P fertilizer ($P = 0.03$) and $P_2O_5$ uptake tended to be lowest with broadcast placement and highest with side-banding. At Melfort in 2016, while the F-test was significant, there was no evidence of increased P uptake with fertilization but rather reduced P uptake with seed-placed fertilizer. This effect was largely attributable to the reduced biomass yields observed with seed-placed $P_2O_5$. At Scott in 2015, the measurements were completed earlier than the other site-years therefore absolute values lower; however, there was evidence of a quadratic response to seed-placed P in the orthogonal contrasts despite the lack of a significant overall F-test.

**Table 12. Treatment means, overall F-test and orthogonal contrast results for soybean P uptake (based on above-ground biomass yields and P concentrations). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, *P* ≤ 0.05).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Phosphorus Uptake (kg $P_2O_5$/ha) | | | | | | | |
| 0 P | 42.5 a | 22.5 b | 29.8 b | 17.2 a | 22.5 a | 42.3 a | 8.2 a | 48.0 a |
| 22 P – Sp | 42.9 a | 24.2 b | 31.3 b | 16.2 a | 23.8 a | 32.4 a | 10.7 a | 46.7 a |
| 22 P – Sb | 45.2 a | 28.2 b | 45.0 ab | 19.0 a | 20.8 a | 43.8 a | 8.9 a | 50.6 a |
| 22 P – Bc | 45.6 a | 22.0 b | 32.2 b | 21.8 a | 15.2 a | 44.5 a | 9.9 a | 54.1 a |
| 45 P – Sp | 48.5 a | 27.5 b | 47.6 ab | 17.3 a | 24.4 a | 37.3 a | 10.4 a | 48.7 a |
| 45 P – Sb | 42.5 a | 31.5 ab | 34.5 ab | 18.5 a | 25.3 a | 49.8 a | 8.6 a | 54.1 a |
| 45 P – Bc | 47.2 a | 30.3 ab | 34.0 ab | 22.1 a | 25.2 a | 33.4 a | 7.7 a | 48.5 a |
| 90 P – Sp | 56.8 a | 28.0 b | 42.0 ab | 17.3 a | 25.2 a | 42.7 a | 7.9 a | 50.8 a |
| 90 P – Sb | 48.9 a | 28.5 b | 54.3 a | 20.8 a | 25.0 a | 48.7 a | 10.7 a | 49.2 a |
| 90 P – Bc | 54.3 a | 41.1 a | 41.9 ab | 20.7 a | 22.8 a | 46.9 a | 8.3 a | 58.2 a |
| S.E.M. | 3.64 | 3.68 | 5.46 | 2.31 | 3.11 | 2.37 | 1.02 | 4.18 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.065 | **< 0.001** | **0.004** | 0.588 | 0.408 | **0.037** | 0.320 | 0.401 |
| Sp – lin | **0.003** | 0.083 | **0.020** | 0.894 | 0.538 | 0.547 | 0.516 | 0.474 |
| Sp – quad | 0.609 | 0.511 | 0.109 | 0.900 | 0.854 | 0.100 | **0.023** | 0.746 |
| Sb – lin | 0.226 | 0.105 | **0.001** | 0.314 | 0.406 | 0.199 | 0.076 | 0.834 |
| Sb – quad | 0.616 | **0.034** | 0.650 | 0.998 | 0.940 | 0.488 | 0.583 | 0.220 |
| Bc – lin | **0.017** | **< 0.001** | **0.044** | 0.427 | 0.451 | 0.578 | 0.722 | 0.076 |
| Bc – quad | 0.825 | 0.261 | 0.743 | 0.171 | 0.799 | 0.086 | 0.848 | 0.593 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 13. Contrast comparisons for phosphorus fertilization and placement effects on soybean phosphorus uptake (based on above-ground biomass yields and P concentrations).**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | ---------- Phosphorus Uptake (kg $P_2O_5$/ha) ---------- | | | | | | | |
| 0 P vs | 42.5 a | 22.5 b | 29.8 b | 17.2 a | 22.5 a | 42.3 a | 8.2 a | 48.0 a |
| Rest | 48.0 a | 29.0 a | 40.3 a | 19.3 a | 23.1 a | 42.2 a | 9.2 a | 51.2 a |
| Pr > *F* | 0.135 | **0.013** | **0.026** | 0.399 | 0.865 | 0.967 | 0.312 | 0.383 |
| Sp vs | 49.4 a | 26.6 a | 40.3 a | 16.9 a | 24.5 a | 37.5 b | 9.7 a | 48.7 a |
| Sb | 45.5 a | 29.4 a | 44.6 a | 19.4 a | 23.7 a | 47.4 a | 9.4 a | 51.3 a |
| Pr > *F* | 0.170 | 0.148 | 0.224 | 0.199 | 0.749 | **0.004** | 0.737 | 0.363 |
| Sp vs | 49.4 a | 26.6 b | 40.3 a | 16.9 a | 24.5 a | 37.5 a | 9.7 a | 48.7 a |
| Bc | 49.0 a | 31.1 a | 36.0 a | 21.5 b | 21.1 a | 41.6 a | 8.6 a | 53.6 a |
| Pr > *F* | 0.898 | **0.022** | 0.226 | **0.022** | 0.174 | 0.203 | 0.210 | 0.089 |
| Sb vs | 45.5 a | 29.4 a | 44.6 a | 19.4 a | 23.7 a | 47.4 a | 9.4 a | 51.3 a |
| Bc | 49.0 a | 31.1 a | 36.0 b | 21.5 a | 21.1 a | 41.6 a | 8.6 a | 53.6 a |
| Pr > *F* | 0.212 | 0.358 | **0.020** | 0.273 | 0.292 | 0.075 | 0.354 | 0.407 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Treatment means and test results for soybean seed yield are presented in Tables 14 and 15. Averaged across treatments, mean yields ranged from 2526-4222 kg/ha and the overall F-tests for treatment effects on soybean yield were significant at 3/8 site-years (Indian Head 2016, Outlook 2015 and Melfort 2016). Of these sites, Indian Head 2016 was the only one where there was a clear positive yield response to P fertilizer. At this site yields increased quadratically with P, regardless of placement method, from 2225 kg/ha in the control to over 2600 kg/ha when 45 kg P2O5/ha or more was applied. This was an increase of approximately 18% and the effects on seed yield were similar for all placement options. While the overall F-test was not significant (*P* = 0.08), there was evidence of a positive response to P fertilizer at Outlook in 2016 with significant orthogonal linear contrasts for all three placement methods (*P* = < 0.01-0.02) and a 13% yield advantage in the fertilized plots relative to the control. Like Indian Head in 2016, there were no differences amongst placement methods detected. For the other sites where significant treatment effects on yield were detected they were negative. At Outlook in 2015, while the control did not yield lower than any of the fertilized treatments, there was a significant yield reduction at the highest rate (90 kg $P_2O_5$) was applied in the seed-row. Consequently, relative to the control, yields were slightly lower in the fertilized plots when averaged across rates and placement methods (*P* = 0.05). Further evidence of this existed in the contrasts which indicated lower overall yields with seed-placement relative to side-banding or broadcasting (*P* < 0.01); however, the reduction was only observed at the highest fertilizer rate. Inexplicably, at Melfort in 2016 the significant F-test appeared to be due to a tendency for lower yields with P fertilization; however, the negative effects appeared strongest for side-band and broadcast placement which contradicts the negative impact seed-placement had on emergence and biomass yields.

**Table 14. Treatment means, overall F-test and orthogonal contrast results for soybean seed yields. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Seed Yield (kg/ha) | | | | | | | |
| 0 P | 2632 a | 2225 d | 4419 a | 3476 a | 3536 a | 3052 a | 1601 a | 3366 a |
| 22 P – Sp | 2689 a | 2421 cd | 4380 a | 4011 a | 3636 a | 2481 a | 1842 a | 3217 a |
| 22 P – Sb | 2818 a | 2468 bc | 4317 a | 3888 a | 3574 a | 2947 a | 1657 a | 3270 a |
| 22 P – Bc | 2707 a | 2443 c | 4295 a | 3728 a | 3908 a | 2768 a | 1621 a | 3491 a |
| 45 P – Sp | 2669 a | 2553 abc | 4120 a | 3886 a | 3895 a | 2841 a | 1649 a | 3382 a |
| 45 P – Sb | 2736 a | 2560 abc | 4277 a | 3825 a | 3721 a | 3162 a | 1511 a | 3445 a |
| 45 P – Bc | 2766 a | 2621 abc | 4227 a | 3903 a | 3611 a | 3035 a | 1533 a | 3471 a |
| 90 P – Sp | 2762 a | 2666 ab | 3619 b | 4002 a | 3521 a | 2950 a | 1254 a | 3291 a |
| 90 P – Sb | 2715 a | 2607 abc | 4240 a | 3977 a | 3765 a | 2461 a | 1799 a | 3538 a |
| 90 P – Bc | 2741 a | 2696 a | 4324 a | 4005 a | 3745 a | 2430 a | 1770 a | 3446 a |
| S.E.M. | 59.3 | 87.7 | 105.8 | 119.2 | 245.7 | 150.0 | 170.0 | 238.8 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.599 | **< 0.001** | **< 0.001** | 0.076 | 0.720 | **0.009** | 0.421 | 0.907 |
| Sp – lin | 0.146 | **< 0.001** | **< 0.001** | **0.016** | 0.970 | 0.743 | 0.062 | 0.909 |
| Sp – quad | 0.859 | **0.037** | 0.246 | 0.064 | 0.121 | 0.074 | 0.143 | 0.961 |
| Sb – lin | 0.680 | **< 0.001** | 0.228 | **0.014** | 0.295 | **0.010** | 0.443 | 0.322 |
| Sb – quad | 0.123 | **0.004** | 0.599 | 0.192 | 0.816 | 0.077 | 0.475 | 0.760 |
| Bc – lin | 0.214 | **< 0.001** | 0.567 | **0.003** | 0.678 | **0.012** | 0.481 | 0.816 |
| Bc – quad | 0.263 | **0.005** | 0.215 | 0.229 | 0.623 | 0.331 | 0.529 | 0.640 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 15. Contrast comparisons for phosphorus fertilization and placement effects on soybean seed yield.**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Seed Yield (kg/ha) | | | | | | | |
| 0 P vs | 2632 a | 2225 b | 4419 a | 3476 b | 3536 a | 3052 a | 1601 a | 3366 a |
| Rest | 2734 a | 2559 a | 4200 b | 3914 a | 3708 a | 2786 a | 1626 a | 3395 a |
| Pr > *F* | 0.113 | **< 0.001** | **0.045** | **0.001** | 0.340 | 0.105 | 0.885 | 0.869 |
| Sp vs | 2707 a | 2547 a | 4040 b | 3966 a | 3684 a | 2757 a | 1582 a | 3297 a |
| Sb | 2756 a | 2545 a | 4278 a | 3897 a | 3687 a | 2857 a | 1656 a | 3418 a |
| Pr > *F* | 0.311 | 0.952 | **0.006** | 0.468 | 0.985 | 0.426 | 0.589 | 0.361 |
| Sp vs | 2707 a | 2547 a | 4040 b | 3966 a | 3684 a | 2757 a | 1582 a | 3297 a |
| Bc | 2738 a | 2587 a | 4282 a | 3879 a | 3755 a | 2744 a | 1641 a | 3469 a |
| Pr > *F* | 0.519 | 0.284 | **0.006** | 0.364 | 0.614 | 0.913 | 0.661 | 0.198 |
| Sb vs | 2756 a | 2545 a | 4278 a | 3897 a | 3687 a | 2857 a | 1656 a | 3418 a |
| Bc | 2738 a | 2587 a | 4282 a | 3879 a | 3755 a | 2744 a | 1641 a | 3469 a |
| Pr > *F* | 0.707 | 0.258 | 0.963 | 0.853 | 0.627 | 0.366 | 0.918 | 0.698 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Treatment means and test results for seed P concentrations are presented in Tables 16 and 17. Averaged across treatments, seed P concentrations ranged from 0.47-70% depending on the site-year. The overall F-test for seed P concentrations was significant at 6/8 site-years and the response has generally either been linear/quadratic increases in seed P concentration with increasing P rates and/or overall higher seed P concentrations with P fertilization. The most consistent responses were observed at Indian Head in both years and Outlook in 2015 and differences in placement options were generally not significant in these cases. The major exception was at Indian Head in 2016 where broadcast P resulted in higher P concentrations than either seed-placed or side banded P.

**Table 16. Treatment means, overall F-test and orthogonal contrast results for soybean seed P concentrations. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Seed Phosphorus Concentration (% P) | | | | | | | |
| 0 P | 0.488 b | 0.393 e | 0.528 b | 0.593 a | 0.548 b | 0.693 a | 0.558 ab | 0.550 a |
| 22 P – Sp | 0.510 ab | 0.435 d | 0.535 b | 0.595 a | 0.553 b | 0.680 a | 0.630 a | 0.573 a |
| 22 P – Sb | 0.518 ab | 0.425 de | 0.550 b | 0.648 a | 0.533 b | 0.685 a | 0.590 ab | 0.585 a |
| 22 P – Bc | 0.520 ab | 0.458 cd | 0.540 b | 0.620 a | 0.493 b | 0.675 a | 0.563 ab | 0.555 a |
| 45 P – Sp | 0.530 ab | 0.460 cd | 0.588 ab | 0.605 a | 0.525 b | 0.698 a | 0.605 ab | 0.583 a |
| 45 P – Sb | 0.538 ab | 0.455 cd | 0.570 ab | 0.640 a | 0.520 b | 0.730 a | 0.528 b | 0.575 a |
| 45 P – Bc | 0.518 ab | 0.493 bc | 0.565 ab | 0.628 a | 0.540 b | 0.705 a | 0.593 ab | 0.573 a |
| 90 P – Sp | 0.568 ab | 0.503 ab | 0.625 a | 0.613 a | 0.558 ab | 0.710 a | 0.575 ab | 0.573 a |
| 90 P – Sb | 0.578 a | 0.505 ab | 0.620 a | 0.608 a | 0.530 b | 0.723 a | 0.540 b | 0.570 a |
| 90 P – Bc | 0.565 ab | 0.535 a | 0.588 ab | 0.633 a | 0.640 a | 0.730 a | 0.563 ab | 0.593 a |
| S.E.M. | 0.0257 | 0.0180 | 0.0130 | 0.0150 | 0.0229 | 0.0147 | 0.0172 | 0.0158 |
| | Pr > F (p-value) | | | | | | | |
| F-test | **0.020** | **< 0.001** | **< 0.001** | 0.117 | **< 0.001** | **0.036** | **0.009** | 0.669 |
| Sp – lin | **0.002** | **< 0.001** | **< 0.001** | 0.273 | 0.806 | 0.202 | 0.952 | 0.350 |
| Sp – quad | 0.890 | 0.111 | 0.890 | 0.954 | 0.352 | 0.549 | **0.011** | 0.210 |
| Sb – lin | **0.001** | **< 0.001** | **< 0.001** | 0.917 | 0.513 | **0.040** | 0.173 | 0.575 |
| Sb – quad | 0.748 | 0.493 | 0.842 | **0.005** | 0.393 | 0.461 | 0.917 | 0.205 |
| Bc – lin | **0.005** | **< 0.001** | **0.002** | 0.070 | **< 0.001** | **0.014** | 0.752 | 0.036 |
| Bc – quad | 0.936 | **0.001** | 0.759 | 0.283 | **0.002** | 0.335 | 0.209 | 0.947 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 17. Contrast comparisons for phosphorus fertilization and placement effects on soybean seed phosphorus concentrations.**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | ---------- Seed Phosphorus Concentration (% P) ---------- | | | | | | | |
| 0 P vs | 0.488 b | 0.393 b | 0.528 b | 0.593 a | 0.548 a | 0.693 a | 0.558 a | 0.550 a |
| Rest | 0.538 a | 0.474 a | 0.576 | 0.621 a | 0.544 a | 0.704 a | 0.576 a | 0.576 a |
| Pr > *F* | **0.010** | **< 0.001** | **0.002** | 0.065 | 0.827 | 0.411 | 0.314 | 0.119 |
| Sp vs | 0.536 a | 0.466 a | 0.583 | 0.604 b | 0.545 a | 0.696 a | 0.603 a | 0.576 a |
| Sb | 0.545 a | 0.462 a | 0.580 | 0.632 a | 0.528 a | 0.713 a | 0.553 b | 0.577 a |
| Pr > *F* | 0.561 | 0.519 | 0.816 | **0.023** | 0.241 | 0.126 | **0.001** | 0.946 |
| Sp vs | 0.536 a | 0.466 b | 0.583 | 0.604 a | 0.545 a | 0.696 a | 0.603 a | 0.576 a |
| Bc | 0.534 a | 0.495 a | 0.564 | 0.627 a | 0.558 a | 0.703 a | 0.573 b | 0.574 a |
| Pr > *F* | 0.907 | **< 0.001** | 0.100 | 0.059 | 0.399 | 0.484 | **0.037** | 0.839 |
| Sb vs | 0.545 a | 0.462 b | 0.580 | 0.632 a | 0.528 b | 0.713 a | 0.553 a | 0.577 a |
| Bc | 0.534 a | 0.495 a | 0.564 | 0.627 a | 0.558 a | 0.703 a | 0.573 a | 0.574 a |
| Pr > *F* | 0.486 | **< 0.001** | 0.148 | 0.665 | **0.050** | 0.393 | 0.166 | 0.786 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

Treatment means and test results for P exports in the harvested seed are presented for all sites where data is available in Tables 18 and 19. Similar to the values for P uptake, P was also converted to $P_2O_5$ for this parameter. Overall mean $P_2O_5$ exports ranged from 21-55 kg $P_2O_5$/ha, largely depending on the seed yields that were achieved. In general, the treatments had less of an impact on P2O5 exports than they did on seed P concentrations alone with significant F-tests at only 3/8 site-years. The strongest and most consistent response was at Indian Head in 2016 where both seed yields and P concentrations were increased with fertilizer application. Reasonably consistent responses were also detected at Indian Head in 2015 and Outlook in both years where the orthogonal contrasts and/or control versus rest comparisons were significant.

**Table 18. Treatment means, overall F-test and orthogonal contrast results for soybean seed $P_2O_5$ exports. Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[z] / Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | Phosphorus Exports (kg $P_2O_5$/ha) | | | | | | | |
| 0 P | 30.8 a | 20.0 e | 53.5 a | 47.3 a | 43.9 a | 48.5 ab | 22.8 ab | 46.0 a |
| 22 P – Sp | 31.3 a | 24.2 d | 53.8 a | 54.8 a | 46.3 a | 38.7 b | 28.1 a | 45.5 a |
| 22 P – Sb | 32.4 a | 24.1 d | 54.4 a | 57.7 a | 43.3 a | 46.2 ab | 18.9 ab | 47.4 a |
| 22 P – Bc | 32.7 a | 25.7 cd | 53.2 a | 53.1 a | 44.4 a | 42.8 ab | 20.6 ab | 48.1 a |
| 45 P – Sp | 32.7 a | 26.9 c | 55.4 a | 54.0 a | 46.8 a | 45.5 ab | 17.1 b | 48.8 a |
| 45 P – Sb | 33.9 a | 26.8 c | 55.9 a | 56.2 a | 44.4 a | 52.8 a | 21.8 ab | 49.3 a |
| 45 P – Bc | 33.2 a | 29.7 b | 54.7 a | 56.0 a | 44.6 a | 49.0 ab | 22.2 ab | 49.4 a |
| 90 P – Sp | 35.8 a | 30.8 b | 51.8 a | 56.2 a | 45.1 a | 48.1 ab | 19.4 ab | 46.5 a |
| 90 P – Sb | 36.2 a | 30.2 b | 60.2 a | 55.3 a | 45.6 a | 40.8 ab | 22.4 ab | 50.0 a |
| 90 P – Bc | 33.7 a | 33.1 a | 58.4 a | 58.0 a | 54.9 a | 40.6 ab | 19.5 ab | 50.5 a |
| S.E.M. | 1.78 | 1.75 | 2.03 | 2.45 | 3.46 | 2.57 | 1.94 | 3.02 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.083 | **< 0.001** | 0.132 | 0.107 | 0.325 | **0.012** | **0.038** | 0.612 |
| Sp – lin | **0.004** | **< 0.001** | 0.545 | **0.023** | 0.865 | 0.451 | **0.031** | 0.706 |
| Sp – quad | 0.642 | **0.004** | 0.294 | 0.175 | 0.488 | 0.065 | 0.752 | 0.442 |
| Sb – lin | **0.004** | **< 0.001** | **0.013** | 0.074 | 0.628 | 0.068 | 0.756 | 0.137 |
| Sb – quad | 0.764 | **0.003** | 0.670 | **0.015** | 0.841 | **0.054** | 0.368 | 0.610 |
| Bc – lin | 0.123 | **< 0.001** | **0.051** | **0.003** | 0.011 | 0.092 | 0.301 | 0.107 |
| Bc – quad | 0.430 | **< 0.001** | 0.512 | 0.168 | 0.216 | 0.515 | 0.894 | 0.591 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table 19. Contrast comparisons for phosphorus fertilization and placement effects on soybean seed $P_2O_5$ exports.**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | ---------- Phosphorus Exports (kg $P_2O_5$/ha) ---------- | | | | | | | |
| 0 P vs | 30.8 b | 20.0 b | 53.5 a | 47.3 b | 43.9 a | 48.5 a | 22.8 a | 46.0 a |
| Rest | 33.5 a | 27.9 a | 55.3 a | 55.7 a | 46.2 a | 44.9 a | 21.1 a | 48.4 a |
| Pr > *F* | **0.042** | **< 0.001** | 0.365 | **0.002** | 0.492 | 0.205 | 0.414 | 0.245 |
| Sp vs | 33.3 a | 27.3 a | 53.7 b | 55.0 a | 46.1 a | 44.1 a | 21.5 a | 46.9 a |
| Sb | 34.2 a | 27.0 a | 56.4 a | 56.4 a | 44.4 a | 46.6 a | 21.0 a | 48.9 a |
| Pr > *F* | 0.382 | 0.460 | **0.053** | 0.450 | 0.514 | 0.240 | 0.763 | 0.228 |
| Sp vs | 33.3 a | 27.3 b | 53.7 a | 55.0 a | 46.1 a | 44.1 a | 21.5 a | 46.9 a |
| Bc | 33.2 a | 29.5 a | 55.4 a | 55.7 a | 48.0 a | 44.1 a | 20.8 a | 49.3 a |
| Pr > *F* | 0.955 | **< 0.001** | 0.276 | 0.687 | 0.440 | 0.978 | 0.636 | 0.144 |
| Sb vs | 34.2 a | 27.0 b | 56.4 a | 56.4 a | 44.4 a | 46.6 a | 21.0 a | 48.9 a |
| Bc | 33.2 a | 29.5 a | 55.4 a | 55.7 a | 48.0 a | 44.1 a | 20.8 a | 49.3 a |
| Pr > *F* | 0.352 | **< 0.001** | 0.371 | 0.723 | 0.160 | 0.251 | 0.863 | 0.788 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**e.) List summary of findings, implications, and briefly discuss any conclusions.**

Overall, the first two years of this project have been considered successful with a wide range in overall soybean yields and soil test P levels / environmental conditions and all work proceeding on schedule. Focussing on emergence, negative effects of high rates of seed-placed P were detected at 3/8 site-years but only observed at the highest rates. Occasionally this led to reduced biomass yields and, subsequently, P update. While biomass was generally unaffected, higher overall tissue P concentrations were detected at half (4/8) of the site-years and an overall increase in P uptake (based on biomass yields and tissue P concentrations at 2/8 site-years. There was evidence of yield increases with P fertilization at 2/8 site-years (Indian Head 2016 and Outlook 2016) but, due primarily to the loss at the highest rate of seed place P, lower overall yields at Outlook in 2015. Seed P concentrations are not yet available for all sites but preliminary analyses showed clear increases with fertilization in both years at Indian Head. In 2015 there were no differences amongst placement options while in 2016 seed P concentrations were highest with broadcast placement. Total P export data are not available for all sites either; however, significant increases with P fertilizer were detected both years at Indian Head. Notably, total P exports ranged from 22-48 kg P2O5 (of the data which is available) depending on the overall yields indicating that applied rates should be in this range to maintain soil fertility over the long-term. Despite the fact the reductions in emergence have been relatively uncommon and, in most cases modest, growers are advised to be extremely cautious or avoid seed-row placement for rates beyond 22 kg $P_2O_5$/ha.

**3. Non-confidential abstract/summary:** *This must include overall project objectives, a brief mention of methodology and research design, and a summary of findings for use in publications and on the SPG website. Maximum 500 words in lay language. Please note that this summary will be used as such and no additional permission will be sought from the project applicant to publish the summary.*

A project was initiated in 2015 to investigate soybean response to phosphorus (P) fertilizer rates and placement options under field conditions in Saskatchewan. The second year of field trials has been completed with locations

at Indian Head, Outlook, Melfort and Scott. The treatments are a combination of 3 P fertilizer rates (22, 45 and 90 kg $P_2O_5$ $ha^{-1}$) and 3 placement options (seed-placed, side-banded and pre-seed broadcast) along with a control. The specific field protocols being followed were originally developed at the University of Manitoba and have also been implemented at various locations throughout that province. Preliminary results showed evidence of reduced plant populations with 45-90 kg $ha^{-1}$ of seed-placed P at 3/8 site-years (Melfort 2015 and 2016 and Scott 2016) while, at Outlook in 2015, effects on emergence were not significant but yields were reduced with 90 kg $P_2O_5$ $ha^{-1}$ of seed-placed P. While negative impacts on emergence were not always detected and were frequently subtle, these results support the recommendation that rates of seed-placed P exceeding 22 kg $P_2O_5$/ha should be avoided to minimize the potential for seedling injury. While whole plant tissue P concentrations were increased with fertilization to some extent at the majority of sites, seed yield increases with P were only evident at 2/8 sites with the strongest response at Indian Head 2016 and smaller but significant linear yield increases with P fertilizer at Outlook in 2016. The magnitudes of the responses were approximately 18% and 13% at Indian Head (2016) and Outlook (2016), respectively. In contrast, at Outlook in 2015 the only significant P fertilizer effects on yield were negative and specific to the highest rate of seed placed P. This work is continuing at all four locations in 2017 with funding provided by the Saskatchewan Pulse Crop Development Board.

**4. List any technology transfer activities undertaken in relation to this project:** *Include conference presentations, posters, papers published, etc.*

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) and at the IHARF Winter Seminar and AGM in Weyburn (Feb-1 2016, approximately 100 guests). Jessica Pratchler presented preliminary results at the SIA Ag Update in Melfort (February 2, approximately 150 guests).

**5. List any changes expected to industry contributions, in-kind support, collaborations or other resources.**

There are no confirmed or anticipated changes to industry contributions, in-kind support, collaborations or other resources specifically attributable to this project.

**6. Appendices:** *Include any additional materials supporting the previous sections, e.g. detailed data tables, maps, graphs, photos, specifications, literature cited, acknowledgments.*

**<u>Project Rationale and Review of the Literature</u>**

The current research was initiated to determine the best phosphorus fertilizer rate and placement options for soybean production in Saskatchewan to help growers produce this crop in the most economically, agronomically and environmentally sound manner possible. While still a relatively minor crop provincially, southeast Saskatchewan saw rapid adoption of this crop and, since then, producers throughout the province have expressed interest in this crop and have been experimenting with it. In Manitoba, farmers have adopted soybeans as a major component of their crop rotation, with more than 1 million acres planted in 2013 up to a reported 1.6 million acres in 2016. In Saskatchewan, 2016 soybean acres were estimated at approximately 240,000 acres compared to 170,000 in 2013. Soybeans are 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 high yields of soybeans in addition to other crops in our rotations.

Research in Illinois showed that soybean root distribution was not affected by P fertilizer rate or placement when the fertilizer was 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. However, it has been shown that soybeans do yield more in soils with high P fertility than low P fertility (eg. 10-15 more bushels per acre in southern Minnesota, Randall 2012) and that this crop makes excellent use of the soil's P reserves (Kalra & Soper 1967). This may be 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. Currently, there is conflicting evidence as to whether soybeans respond better to banded or broadcast P fertilizer or to P fertilizer 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 to ensure availability early in the season and to slow down conversion to less available forms. However, soybeans are considered sensitive to seed-placed fertilizer so applying the required amounts of P fertilizer in or near the seed may reduce 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 variables but did not affect seed yield. Preliminary studies in Manitoba in 2013 and 2014 showed substantial plant stand reductions from seed-placed P in coarse textured soils, but only at 80 lb $P_2O_5$ per acre with no significant impact on plant stands in clay soils (Bardella et al. 2014). This suggests that soybeans may be less sensitive to seed-placed P in western Canadian soils than anticipated, but caution is still advised particularly in coarse textured soils. Given concerns about seedling sensitivity and the fact that soybeans are 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. Research in Iowa has shown 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, again, fertilizer placement did not affect yield (Borges and Mallarino 2000). Due to concerns of seedling toxicity and soybean's inconsistent response to banded P, broadcast P has occasionally been recommended for soybeans 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 and doing so may leave the P fertilizer vulnerable to runoff losses to 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.

**Literature Cited**

**Bardella, G., Heard, J., Lange, D., Lawley, Y., Grant, C. and Flaten, D. 2014.** 4R P Management for soybeans in the northern frontier: Rate and placement effects on plant stand and seed yield. Proc. Manitoba Agronomists Conference. University of Manitoba. Winnipeg, Manitoba. [Online] Available: http://umanitoba.ca/faculties/afs/agronomists_conf/posters.html [18 Dec. 2014].

**Borges, R. and Mallarino, A.P. 2000.** Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. Agron. J. 92: 380-388.

**Farmaha, B., Fernandez, F. and Nafziger, E.D. 2012.** Distribution of soybean roots, soil water, phosphorus and potassium concentrations with broadcast and subsurface-band fertilization. Soil Sci. Soc. Am. J. 76: 1079-1089.

**Heard, J. 2006.** Nutrient uptake and partitioning by soybeans in Manitoba. Proc. Manitoba Agronomists Conference. University of Manitoba. Winnipeg, Manitoba. [Online] Available: http://www.umanitoba.ca/faculties/afs/MAC_proceedings/2006/proceedings.html [27 Nov. 2014].

**Kalra, Y.P. and Soper, R.J. 1967.** Efficiency of rape, oats, soybeans, and flax in absorbing soil and fertilizer phosphorus at seven stages of growth. Agron. J. 60: 209-212.

**Randal, G. 2012.** Fertility Management of Soybeans. Proc. Manitoba Agronomists Conference. University of Manitoba. Winnipeg, Manitoba. [Online] Available: http://umanitoba.ca/faculties/afs/agronomists_conf/MAC%20Proceedings%202012.html [27 Nov. 2014].

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**Additional Results Tables**

**Table A1. Treatment means, overall F-test and orthogonal contrast results for soybean emergence at approximately 2 weeks after planting (T1). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[Z] | Indian Head | | Outlook [Y] | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| / Contrast | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | T1 Emergence (plants/$m^2$) | | | | | | | |
| 0 P | 45.9 a | 38.8 ab | — | — | 3.2 a | 28.5 a | 23.9 a | 23.3 a |
| 22 P – Sp | 46.3 a | 43.3 ab | — | — | 3.9 a | 30.8 a | 21.2 a | 22.3 a |
| 22 P – Sb | 47.0 a | 46.0 a | — | — | 1.1 a | 28.9 a | 30.5 a | 23.5 a |
| 22 P – Bc | 47.4 a | 44.1 ab | — | — | 3.2 a | 35.9 a | 25.8 a | 20.5 a |
| 45 P – Sp | 45.3 a | 38.6 ab | — | — | 2.1 a | 25.8 a | 18.2 a | 20.0 a |
| 45 P – Sb | 44.7 a | 41.0 ab | — | — | 0.0 a | 33.7 a | 22.4 a | 22.5 a |
| 45 P – Bc | 43.3 a | 40.0 ab | — | — | 0.4 a | 26.7 a | 26.6 a | 21.0 a |
| 90 P – Sp | 39.6 a | 28.5 b | — | — | 0.7 a | 25.4 a | 14.3 a | 11.5 a |
| 90 P – Sb | 48.8 a | 36.1 ab | — | — | 1.1 a | 29.7 a | 26.8 a | 24.8 a |
| 90 P – Bc | 49.6 a | 40.2 ab | — | — | 1.8 a | 30.6 a | 26.6 a | 21.0 a |
| S.E.M. | 3.09 | 3.66 | — | — | 1.23 | 3.76 | 4.46 | 3.89 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.565 | 0.068 | — | — | 0.208 | 0.617 | 0.369 | 0.166 |
| Sp – lin | 0.119 | 0.013 | — | — | 0.060 | 0.403 | 0.122 | **0.005** |
| Sp – quad | 0.463 | 0.118 | — | — | 0.625 | 0.947 | 0.881 | 0.431 |
| Sb – lin | 0.559 | 0.289 | — | — | 0.230 | 0.738 | 0.925 | 0.729 |
| Sb – quad | 0.604 | 0.162 | — | — | 0.097 | 0.453 | 0.994 | 0.731 |
| Bc – lin | 0.477 | 0.966 | — | — | 0.240 | 0.900 | 0.697 | 0.681 |
| Bc – quad | 0.383 | 0.574 | — | — | 0.262 | 0.922 | 0.777 | 0.625 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast [Y] Data not available

**Table A2. Contrast comparisons for phosphorus fertilization and placement effects on soybean emergence at T1 (~2 weeks after planting).**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | ---------- T1 Emergence (plants/$m^2$) ---------- | | | | | | | |
| 0 P vs | 45.9 a | 38.8 a | — | — | 3.2 a | 28.5 a | 23.9 a | 23.3 a |
| Rest | 45.8 a | 39.8 a | — | — | 1.6 a | 29.7 a | 23.6 a | 20.8 a |
| Pr > *F* | 0.964 | 0.784 | — | — | 0.174 | 0.763 | 0.948 | 0.425 |
| Sp vs | 43.7 a | 36.8 a | — | — | 2.2 a | 27.3 a | 17.9 b | 17.9 b |
| Sb | 46.8 a | 41.0 a | — | — | 0.7 a | 30.8 a | 26.6 a | 23.6 a |
| Pr > *F* | 0.233 | 0.134 | — | — | 0.098 | 0.276 | **0.024** | **0.024** |
| Sp vs | 43.7 a | 36.8 a | — | — | 2.2 a | 27.3 a | 17.9 b | 17.9 a |
| Bc | 46.8 a | 41.4 a | — | — | 1.8 a | 31.1 a | 26.3 a | 20.8 a |
| Pr > *F* | 0.242 | 0.103 | — | — | 0.602 | 0.231 | **0.028** | 0.228 |
| Sb vs | 46.8 a | 41.0 a | — | — | 0.7 a | 30.8 a | 26.6 a | 23.6 a |
| Bc | 46.8 a | 41.4 a | — | — | 1.8 a | 31.1 a | 26.3 a | 20.8 a |
| Pr > *F* | 0.982 | 0.888 | — | — | 0.245 | 0.910 | 0.946 | 0.255 |

[z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast

**Table A3. Treatment means, overall F-test and orthogonal contrast results for soybean emergence at approximately 3 weeks after planting (T2). Means within a column followed by the same letter do not significantly differ (Tukey's studentized range test, $P \leq 0.05$).**

| Treatment[Z] / Contrast | Indian Head | | Outlook [Y] | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | T2 Emergence (plants/$m^2$) | | | | | | | |
| 0 P | 49.2 a | 49.9 a | — | — | 41.2 a | 39.8 a | 39.7 a | 43.0 a |
| 22 P – Sp | 49.0 a | 53.5 a | — | — | 36.6 a | 43.3 a | 41.1 a | 38.8 a |
| 22 P – Sb | 50.7 a | 52.9 a | — | — | 26.0 a | 37.3 a | 39.4 a | 38.5 a |
| 22 P – Bc | 51.1 a | 53.3 a | — | — | 41.9 a | 44.3 a | 48.5 a | 39.3 a |
| 45 P – Sp | 50.7 a | 50.3 a | — | — | 33.4 a | 30.6 a | 35.9 a | 41.3 a |
| 45 P – Sb | 48.4 a | 49.2 a | — | — | 28.8 a | 44.1 a | 34.2 a | 41.0 a |
| 45 P – Bc | 47.2 a | 50.3 a | — | — | 35.9 a | 44.3 a | 40.1 a | 41.3 a |
| 90 P – Sp | 45.3 a | 42.3 a | — | — | 18.3 a | 29.3 a | 23.4 a | 32.0 a |
| 90 P – Sb | 52.1 a | 47.8 a | — | — | 28.5 a | 45.1 a | 42.3 a | 39.5 a |
| 90 P – Bc | 52.9 a | 50.7 a | — | — | 30.3 a | 43.7 a | 43.3 a | 44.0 a |
| S.E.M. | 2.86 | 2.89 | — | — | 5.53 | 3.88 | 6.53 | 2.76 |
| | Pr > F (p-value) | | | | | | | |
| F-test | 0.749 | 0.211 | — | — | 0.095 | **0.044** | 0.432 | 0.106 |
| Sp – lin | 0.339 | **0.021** | — | — | 0.624 | **0.020** | 0.056 | **0.005** |
| Sp – quad | 0.403 | 0.111 | — | — | 0.228 | 0.876 | 0.485 | 0.432 |
| Sb – lin | 0.545 | 0.385 | — | — | 0.173 | 0.204 | 0.805 | 0.492 |
| Sb – quad | 0.671 | 0.608 | — | — | 0.118 | 0.966 | 0.481 | 0.588 |
| Bc – lin | 0.457 | 0.936 | — | — | 0.830 | 0.575 | 0.929 | 0.525 |
| Bc – quad | 0.446 | 0.704 | — | — | 0.820 | 0.478 | 0.800 | 0.269 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast [Y] Data not available

**Table A4. Contrast comparisons for phosphorus fertilization and placement effects on soybean emergence at T2 (~3 weeks after planting).**

| Contrast | Indian Head | | Outlook | | Melfort | | Scott | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 | 2015 | 2016 |
| | T2 Emergence (plants/$m^2$) | | | | | | | |
| 0 P vs | 49.2 a | 49.9 a | — | — | 41.2 a | 39.8 a | 39.7 a | 43.0 a |
| Rest | 49.7 a | 50.0 a | — | — | 31.1 a | 40.2 a | 38.7 a | 39.5 a |
| Pr > *F* | 0.877 | 0.954 | — | — | 0.720 | 0.916 | 0.889 | 0.182 |
| Sp vs | 48.3 a | 48.7 a | — | — | 29.4 a | 34.4 b | 33.5 a | 37.4 a |
| Sb | 50.4 a | 50.0 a | — | — | 27.8 a | 42.2 a | 38.6 a | 39.7 a |
| Pr > *F* | 0.388 | 0.564 | — | — | 0.157 | **0.021** | 0.342 | 0.249 |
| Sp vs | 48.3 a | 48.7 a | — | — | 29.4 a | 34.4 b | 33.5 a | 37.4 b |
| Bc | 50.4 a | 51.4 a | — | — | 36.0 a | 44.1 a | 44.0 a | 41.5 a |
| Pr > *F* | 0.390 | 0.227 | — | — | 0.080 | **0.005** | 0.059 | **0.045** |
| Sb vs | 50.4 a | 50.0 a | — | — | 27.8 b | 42.2 a | 38.6 a | 39.7 a |
| Bc | 50.4 a | 51.4 a | — | — | 36.0 a | 44.1 a | 44.0 a | 41.5 a |
| Pr > *F* | 0.997 | 0.520 | — | — | **0.005** | 0.551 | 0.326 | 0.363 |

[Z] P = kg $P_2O_5$ $ha^{-1}$; Sp – seed-row placement; Sb – side-band; Bc – pre-seed broadcast