Optimizing Nitrogen and Phosphorus Management for Dry Bean in Southwestern Manitoba

Ramona Mohr[1], Yong Min Kim[1], Haider Abbas[2], Scott Chalmers[3], and Debra McLaren[1,4]

[1]Agriculture and Agri-Food Canada, Brandon Research and Development Centre, Brandon, MB
[2]Manitoba Agriculture, Manitoba Crop Diversification Centre (CMCDC), Carberry, MB;
[3]Manitoba Agriculture, Westman Agricultural Diversification Organization (WADO), Melita, MB; [4]Retired

Background:

In Manitoba, dry bean acreage has grown from 90,000 acres in 2015 to 168,300 acres in 2019, with total production ranging from 80,000 to 110,000 metric tonnes over this period (Statistics Canada 2020). Increasing interest in dry bean in southwestern Manitoba, which has not traditionally been a major bean-producing area, has generated questions as to optimum management practices for the growing conditions in this region. However, as a smaller acreage crop, comparatively little research has been done on dry bean production in Manitoba, particularly for the southwest region.

While dry bean is a pulse crop, one of the key inputs in dry bean production systems is nitrogen (N) fertilizer. Unlike crops like pea and soybean which derive their N through symbiotic N fixation, dry bean is generally considered to be a poor N-fixer. As such, N fertilizer application remains the most common N management practice on-farm even though commercial inoculants are available. While recent studies in the Carman and Portage areas of Manitoba have assessed the effect of broadcast, incorporated N on pinto and navy bean grown on 15" row spacings (MacMillan 2018), information is lacking regarding crop responses to sidebanded N in solid-seeded dry bean and regarding the relative effectiveness of inoculant under Manitoba conditions as an N management strategy. Further, little empirical information exists regarding the relationship between N management practices and the incidence and severity of white mould, a common disease in dry bean in Manitoba. If white mould is severe, bean yields may be reduced by 225-550 kg/ha (200-500 lbs/ac).

Information is also lacking regarding dry bean responses to fertilizer P under Manitoba conditions. While the importance of an adequate early-season P supply to achieve optimum yields is well-recognized, as is the potential for seedling damage to seed-placed P, limited research information is available for Manitoba.

Objectives:

The objective of the study is to identify fertilizer management practices to optimize the agronomic and economic performance of dry bean in southwestern Manitoba. By gaining a better understanding of the effect of N and P management on dry bean in current production systems in southwestern Manitoba, potential exists to improve nutrient use efficiency and reduce the potential for nutrient loss into the environment.

Specific objectives of this study are:
1) to determine the effect of rate of fertilizer N, applied with and without inoculant, on the growth, white mould incidence and severity, yield and quality of solid-seeded dry bean in southwestern Manitoba (Studies 1a and 1b).
2) to determine the effect of rate of fertilizer P, seed-placed versus side-banded, on the growth, yield and quality of solid-seeded dry bean in southwestern Manitoba (Study 2).

Materials and Methods:

A two-year field study was initiated in 2021 to determine the effect of nitrogen (N) and phosphorus (P) management on dry bean. The project consisted of three studies, each with separate experiments conducted for black and pinto bean.

- Study 1a (rainfed): Treatments consisted of a factorial combination of five N rates (0, 35, 70, 105, 140 kg N ha^{-1}, as sidebanded urea), applied with or without commercial inoculant (peat-based self-adhering). Inoculant was applied at the recommended rate and contained *Rhizobium leguminosarum* biovar *phaseoli* and *Pseudomonas sp*. (BOS self-adhering peat, NutriAg). Two treatments of 35 and 105 kg N ha^{-1} as sidebanded SuperU were included to assess impacts of N source on plant stand and yield.
- Study 1b (irrigated): Treatments consisted of five fertilizer N rates (0, 35, 70, 105, 140 kg N ha^{-1}, as sidebanded urea), all of which received commercial inoculant (self-adhering peat) as in Study 1. These trials were conducted under irrigation in order to create conditions conducive to disease development so that effects of N rate on white mould could be determined.
- Study 2 (rainfed): Treatments consisted of four P rates (0, 20, 40, 60 kg P_2O_5 ha^{-1} as monoammonium phosphate), seed-placed or sidebanded.

Studies 1a and 2 were conducted at Carberry and Melita in 2021, and at Carberry, Melita and Brandon in 2022. Study 1b was conducted under irrigation at Brandon and Carberry in 2022. Field trials had been established for Studies 1a and 2 at one additional site north of Brandon in 2021 and 2022. However, data from these sites is not included in this report as an equipment malfunction affected 2021 results, and excess spring moisture together with fall frost damaged the dry bean crop in 2022.

Field sites with low to moderate soil test N (Study 1) and P (Study 2) levels were selected for the study where possible in order to increase the likelihood of a crop response. In the fall prior to plot establishment, general soil sampling was conducted to identify suitable experimental sites. For Study 1a, soil test N averaged 34 kg N ha^{-1} to 60 cm at Melita in fall 2020, and 78 kg N ha^{-1} to 60 cm at Brandon and 37 kg N ha^{-1} to 60 cm at Melita in fall 2021. For Study 1b, soil test N averaged 62 kg N ha^{-1} to 60 cm at Brandon in fall 2021. Data for 2021 and 2022 trials at Carberry are pending. For Study 2, soil test P averaged 20 and 4 ppm Olsen P to 15 cm at Carberry and Melita in fall 2020, and 4, 17 and 6 ppm Olsen P to 15 cm at Brandon, Carberry and Melita in fall 2021.

Once experimental sites were identified, detailed soil sampling was conducted by replicate in the spring prior to plot establishment to characterize each experimental site and determine soil nutrient concentrations. Available site characterization data for 2021 sites are reported in Table 1. Analysis of the remaining 2021 samples and 2022 samples was underway at the time of report preparation.

Dry bean was direct-seeded into standing stubble on a narrow row spacing (9.25" to 10") in late May to early June (Table 1). Each trial was seeded to the same recommended varieties of black (cv Eclipse) and pinto (cv Windbreaker) bean, with seeding rate adjusted to achieve 26 live plants m^{-2}. Plot size was determined by the equipment available at each site.

Fertilizer N and P were applied at time of seeding as indicated by treatment. In Study 1a and 1b, a blanket application of 25 kg P_2O_5 ha^{-1} as side-banded monoammonium phosphate was applied in all treatments to ensure sufficiency. In Study 2, fertilizer N in the form of side-banded urea was applied at a rate adjusted to achieve a total N supply of 90 kg N ha^{-1} (i.e. total of fertilizer + soil test nitrate-N to 60 cm) to ensure sufficiency. Other nutrients were applied only as required based on soil testing to prevent deficiency. No inoculant was applied in Study 2.

Generally-accepted agronomic practices were employed at all sites. Beans were direct-harvested by plot combine in September (Table 1). Seed samples were dried, cleaned, and the cleaned yield calculated based on a standard moisture content. Seed was subsequently assessed for quality parameters. Seed weight was determined based on the weight of 1000 seeds counted on a mechanized seed counter. Percent protein and oil in seed was determined on whole seed samples by NIR using a grain quality analyzer equipped with a module for determination of test weight. Seed samples were subsequently ground and analyzed in a commercial laboratory for total N by combustion (Study 1) and total P by ICP (Study 2). The total N analysis conducted on dry bean seed in 2021 was used to generate a conversion factor which was used to convert % protein to %N for 2022 grain samples in order to estimate N removal in harvested seed.

Agronomic measurements: Crop emergence was recorded based on observations made every 2-3 days up to the point of 90% emergence. Plant emergence counts were conducted once all plants had emerged based on two 2-m lengths of row within each plot. Early season crop biomass was determined in Study 2 only approximately 5 weeks after emergence by harvesting 2-1 m lengths of row within each plot by cutting plants 1-2 cm above ground level. Biomass samples were dried, the dried weight recorded, and the sample ground and submitted to a commercial laboratory for determination of P concentration by ICP. In Study 1 at growth stage V3 and R1, chlorophyll meter readings were collected from 10 plants within the centre of each plot from the upper-most fully developed leaf. Concurrently, NDVI readings were collected from each plot using the Greenseeker. Nodulation score was determined in Study 1 at flowering by collecting 10 plants per plot and assessing nodulation on a scale of 0–4 (0=no nodules, 1 ≤ 5 nodules plant^{-1}, 2 ≤ 10 nodules plant^{-1}, 3 ≤ 20 nodules plant^{-1} and 4 ≥ 20 nodules plant^{-1}). Lodging was estimated based on the Belgian lodging scale (=area x intensity x 0.2), with area rated on a scale of 1 to 10 with 1=unaffected and intensity rated on a scale of 1 to 5 with 1=standing and 5=flat plants. Plant height was determined at maturity.

For the purpose of this report, data were analyzed by site-year using Proc Mixed in SAS (SAS® Studio v. 3.81, SAS Institute Inc., Cary, NC, USA). Treatments were considered fixed effects and replicates considered random effects. Contrast analysis was used to explore linear and quadratic responses to N and P fertilizer rates. A P-value ≤0.05 was considered statistically significant. Main factor effects are discussed except in those cases where significant interactions (P≤0.05) were evident.

Plant pathology assessments: To assess the interaction between N fertilizer rate and white mould, disease incidence and severity were determined on black and pinto beans for sclerotinia stem rot in 2022 at Brandon and Carberry. From each black and pinto bean plot, fifty plants were rated in August to determine the presence of sclerotinia stem rot. The disease incidence was rated as the percentage of diseased plants within the examined plants. The disease severity was rated based on a scale of 0 (no symptoms) to 4 (76-100% affected by lesions) across all examined plants and only infected plants with sclerotinia stem rot. The disease severity index (DSI) was calculated on a percentage basis, where DSI (%) = [sum (class frequency × score of rating class)]/[(total number of plants) × (maximal disease index)] × 100. Nodulation was recorded using 0 (no nodules) to 4 (≥ 20 nodules per plant) rating scales.

All statistical analyses were performed using SAS® Studio v. 3.81 (SAS Institute Inc., Cary, NC, USA). Disease incidence percentage data, disease severity rate and index data, and nodulation rating data were subjected to analysis of variance (ANOVA) for randomized complete block design by year and bean type using the general linear model procedure (PROC GLM), where least-squares means were separated using least significant difference (LSD) at $p < 0.05$, and using PROC MIXED, with treatment as a fixed effect and replication as a random effect, and least-squares means were compared using contrasts. The disease severity Index (%) and the disease incidence (%) were log-transformed to improve normality. Non-transformed data, however, were presented for ease of explanation. The relationship between disease severity and root nodulation ratings was also examined by correlation. The Type I error rate (α) was set at 0.05 for all statistical tests. Analysis of the Carberry site was ongoing at the time of report preparation.

Results and Discussion:

Growing season conditions varied considerably between the two years of the study. The 2021 growing season was characterized by dry conditions and high summer temperatures which, together with weed pressure at Carberry, affected crop growth and yield potential and contributed to variability in the data of select trials. In contrast, 2022 was characterized by comparatively wetter conditions especially in the early part of the growing season which contributed to higher yield potential at all sites.

Study 1a. Effect of fertilizer N and inoculant on dry bean

Days to emergence: In select site-years, days to emergence (DTE) was determined by periodic visual assessments of each plot. Relatively few effects of fertilizer N rate and/or inoculation were observed.

In 2021, inoculation delayed emergence of black bean at Carberry (Table 2). In the case of pinto bean at Carberry, where no inoculant had been applied, DTE was 15 for rates of 0 to 105 kg N ha^{-1} then declined to 13 for 140 kg N ha^{-1}. By comparison, where inoculant had been applied, DTE was 15 for 0 to 35 kg N ha^{-1}, 13.5 for 70 kg N ha^{-1}, and 13 for 105-140 kg N ha^{-1}. The reason for the differential response to fertilizer N rate was unclear. In contrast to 2021, increasing N rate resulted in a small linear increase in DTE for pinto bean at Melita (Table 2). Although statistically significant, the difference between the 0N control and highest N rate was <1 day and therefore unlikely to be of agronomic significance.

Because fertilizer N was side-banded, the potential for fertilizer damage to dry bean seedlings was reduced, minimizing the chance of fertilizer effects on crop emergence.

Plant stand: Fertilizer N rate and inoculation similarly had few effects on plant stand (Table 3). Inoculation had no effect on plant stand except for pinto bean at Melita in 2022 where higher plant stands were associated with inoculation. Fertilizer N rate resulted in a significant quadratic response for black bean at Carberry and pinto bean at Melita in 2021, with plant stand increasing with increasing N rate then levelling off or declining with higher N rates. While a significant N rate x interaction was evident for pinto bean at Carberry in 2021, no main effects of either N rate or inoculation were noted.

To determine the effect of fertilizer N source on plant stand, treatments of 35 and 105 kg N ha^{-1} as urea and SuperU were compared. Urea and SuperU typically resulted in similar plant stands. Because all fertilizer N was side-banded, the risk of fertilizer-related seedling damage to plant stand was reduced.

Plant height and lodging: Plant height increased with increasing fertilizer N rate in 4 of 5 site-years for black bean and in 1 of 5 site-years for pinto bean (Table 4). Linear responses were evident in all cases except for black bean at Melita in 2021 where a significant quadratic response was evident. Inoculation increased plant height in 1 of 10 site-years only, for black bean at Melita in 2022.

Lodging was negligible in 2021 and at Carberry in 2022 (data not presented). In 2022, lodging score increased with increasing N rate for both black and pinto bean at Brandon and Melita. Lodging was generally low to moderate based on the Belgian lodging scale which has a maximum value of 10. Lodging scores for black bean ranged from 0.5 to 5.5 at Brandon and from 0.5 to 1.4 at Melita as N rate was increased from 0 to 140 kg N ha^{-1}. In the case of pinto bean, lodging score ranged from 2.0 to 5.8 at Brandon and from 0.5 to 1.0 at Melita as N rate was increased from 0 to 140 kg N ha^{-1}. Inoculation resulted in a small increase in lodging score for black bean at Melita in 2022, from 0.5 in non-inoculated treatments to 0.9 in inoculated treatments; however, the overall lodging score was low regardless.

Plant N status: Fertilizer N application consistently increased in-crop N status of the dry bean crop. In 2021, in-season chlorophyll meter readings taken at the 3rd trifoliate (V3) and at the beginning bloom stage (R1) showed numerical or statistical increases with increasing N rate for one or both crop stages indicating that both black bean and pinto bean were able to effectively access and take up N (Table 5). Similar results were observed in 2022 (Table 6). Increasing fertilizer N rate resulted in significant increases or similar trends (i.e. $0.05>P\leq0.10$) for both black and pinto bean at all sites, with the only exception being black bean at Melita at the V3 stage where N rate had no effect. By comparison, inoculation had fewer effects on in-crop N status than fertilizer rate. Inoculation reduced chlorophyll meter reading for black bean at V3 at Carberry in 2021, but had no effect at R1. In the case of pinto bean, inoculant increased chlorophyll meter readings at V3 at Brandon in 2022 and at R1 at Carberry and Melita in 2022. In most cases, significant interactions between N rate and inoculation were not evident suggesting that effects of fertilizer N rate were often similar regardless of whether or not inoculant had been applied.

Nodulation score: Nodulation score varied considerably among sites and years, suggesting differences in the potential for biological nitrogen fixation among site-years (Table 7). While nodulation scores were often relatively low (<2 on a scale of 0 to 4) at Melita, for example, higher lodging scores were noted at Brandon. Factors such as growing season conditions and field history may have contributed to this.

Nodulation score typically declined with increasing rates of fertilizer N, with declines ($P \leq 0.06$) evident in 5 of 5 site-years for black bean and in 3 of 5 site-years for pinto bean (Table 7). In contrast, inoculation influenced nodulation score less often. Inoculation resulted in significant increases in nodulation score in 2 of 10 site-years, for black bean at Melita in 2022 (0.4 versus 1.5) and for pinto bean at Melita in 2022 (0.7 versus 2.5), and a small decrease in nodulation score in 1 of 10 site-years, for pinto bean at Carberry in 2021 (1.9 versus 1.6).

Yield: Fertilizer N application increased or tended ($P=0.06$) to increase the yield of black bean in 3 of 5 site-years, and increased the yield of pinto bean in 1 of 5 site-years (Table 8; Fig. 1). Contrast analysis revealed a significant linear increase in yield with increasing N rate for black bean at Brandon and Melita in 2022, with a similar trend ($P=0.06$) at Melita in 2021. Yield increases over the range of N rates applied (from 0 to 140 kg N ha^{-1}) ranged from 1260 to 1413 kg ha^{-1} at Melita in 2021, from 2523 to 2650 kg ha^{-1} at Brandon in 2022, and from 3115 to 3717 kg ha^{-1} at Melita in 2022. For pinto bean, increasing N rate resulted in a significant linear increase in yield at Carberry in 2021, with yield increasing from 832 to 1123 kg ha^{-1} as N rate increased from 0 to 140 kg N ha^{-1}. A combination of dry conditions and weed pressure at the Carberry site contributed to variability and reduced yield potential in 2021.

Inoculation influenced dry bean yield in only 2 of 10 site-years (Table 8; Fig. 1). Inoculation significantly increased the yield of black bean (from 3115 to 3512 kg ha^{-1}) and pinto bean (2982 to 3371 kg ha^{-1}) at Melita in 2022. In both cases, the application of inoculant resulted in a measurable increase in nodulation score, from 0.4 to 1.5 for black bean and from 0.7 to 2.5 for pinto bean, and increased % protein in seed as well as N removal in harvested seed. Further, for pinto bean at Melita in 2022, a significant N rate x inoculation interaction was evident which revealed a significant linear increase in yield with increasing N rate where no inoculant was applied ($P=0.01$), but no yield response to fertilizer N where inoculant had been applied suggesting that inoculation was able to compensate for fertilizer N applications in this case (Fig. 1).

Seed quality: Seed weight increased with increasing N rate for black bean in 5 of 5 site-years, and for pinto bean in 1 of 5 site-years (Tables 9 and 10). In the case of black bean, seed weight typically increased linearly with increasing fertilizer N rate. However, in 2022, a significant quadratic effect was observed for black bean at Brandon and also for pinto bean at Melita, with a trend in both cases towards an initial decline in seed weight with increasing N rate followed by a subsequent increase in seed weight as N rate increased further. In the case of black bean, inoculation decreased seed weight at Carberry and Melita in 2021, but increased seed weight at Melita in 2022 where a significant yield increase was also noted. Inoculation reduced the seed weight of pinto bean at Brandon in 2022.

Increasing N rate reduced the test weight of black bean in 3 of 5 site-years and pinto bean in 4 of 5 site-years (Tables 9 and 10). Effects of inoculant were less frequent (Tables 9 and 10). The only cases where inoculant influenced test weight were for black and pinto bean at Melita in 2022, where significant yield increases had been associated with inoculation.

Protein and N removal in seed: Percent protein in seed increased with increasing fertilizer N rate regardless of site, year or bean type (Table 11). Inoculation increased % protein for black bean at Melita in 2022, and for pinto bean at Brandon, Carberry and Melita in 2022; no effects were evident in 2021. No N rate x inoculant interactions were evident except for pinto bean at Melita where protein increased linearly with increasing fertilizer N rate where inoculant had been applied but declined slightly then increased with increasing fertilizer N where inoculant had not been applied, resulting in a significant quadratic response (data not presented).

Nitrogen removal in harvested seed increased with increasing fertilizer N rate for black bean in 3 of 5 site-years and for pinto bean in 4 of 5 site-years (Table 12). By comparison, inoculation had few effects. Inoculant increased N removal in harvested seed in only 2 of 10 site-years, for both black and pinto bean at Melita in 2022. In both cases, inoculant had increased nodulation score, yield, and % protein in seed. Under the conditions of this study, N removal in harvested black bean seed averaged ~58 to 63 kg N ha^{-1} in 2021 and ~69 to 104 kg N ha^{-1} in 2022, whereas N removal in harvested pinto bean averaged ~40 to 56 kg N ha^{-1} in 2021 and ~72 to 113 kg N ha^{-1} in 2022 depending on the site.

Study 1b. Effect of fertilizer N rate on white mould in dry bean under irrigation

Plant pathology: In 2022 at Brandon, the incidence of white mould in black bean ranged from 60.5 to 67.0% with an overall mean of 62.6%, while the severity across infected plants ranged from 1.9 to 2.2, with a mean of 2.0 (Table 13). Nodulation ranged from 3.5 to 3.8, with a mean of 3.7. The highest disease incidence of 67% was observed with an N rate of 140 kg N/ha. In addition, the highest disease severity (2.2) was rated in the N rate with 70 kg N/ha as well as the highest nodulation (3.8).

In pinto bean, the incidence ranged from 50.0 to 57.5%, with an overall mean of 54.5% (Table 13). The severity had an overall mean of 2.4 ranging from 2.2 to 2.5. Nodulation ranged from 3.8 to 4.0, with a mean of 3.9. The highest disease incidence of 57.5% was observed in the treatments with an N rate of 0 and 105 kg N/ha, and the highest disease severity of 2.5 was observed in the treatment with N rate of 140 kg N/ha. In contrast, the highest nodulation of 4.0 was observed in the treatment with an N rate of 35 kg N/ha. In 2022, the overall disease incidence was higher in the black bean trial than in the pinto bean, whereas the disease severity and nodulation were higher in the pinto bean trial than in the black bean.

Overall, the N rate treatments had no significant effects on sclerotinia stem rot and nodulation in black and pinto beans at Brandon in 2022. Correlations among disease incidence, severity and nodulation for 2022 are shown in Table 14. A moderate negative relationship (r = -0.52259) between disease severity across infected plants and nodulation was observed only in 2022 pinto beans. Analysis of data from the Carberry site is ongoing.

Agronomy: Fertilizer N rate did not affect plant stand at Carberry, but resulted in a linear decline in plant stand for pinto bean at Brandon (Table 15). For black bean at Brandon, increasing N rate resulted in an initial decline in plant stand followed by an increase in plant stand with further increases in N rate. Increasing N rate increased chlorophyll meter readings for black bean at Brandon and Carberry with a similar trend (P=0.07) for pinto bean at Brandon at V3, and for pinto bean at Carberry at R1, indicating that the crop effectively accessed the fertilizer N applied (Table 15). Fertilizer N rate had no effect on the yield of either black or pinto bean at either of the 2022 sites, however, although % protein in seed increased linearly and test weight decreased linearly with increasing N rate for black bean at both sites (Tables 16 and 17). Fertilizer N rate had no effect on seed weight except for black bean at Carberry where a significant quadratic effect was evident with seed weight declining then increasing as fertilizer N rate increased. Days to maturity was determined at Brandon only, with increasing fertilizer N rate resulting in a linear increase in days to maturity from 99 to 103 days for black bean and from 100 to 103 days for pinto bean.

Study 2. Effect of fertilizer P rate and placement on dry bean

Plant stand: Plant stand was influenced by P rate in 3 of 5 site-years for black bean and in 1 of 4 site-years for pinto bean. Stand density for black bean declined linearly with increasing P rate at Carberry and Melita in 2021 (Table 18). Fertilizer P rate also had a significant effect on the stand of black bean at Brandon in 2022 and pinto bean at Melita in 2021, with plant stand declining as P rate increased from 0 to 40 kg P_2O_5 ha^{-1}, then increasing at the highest P rate. The reason for this non-linear response pattern is not clear. No P rate x placement interactions were evident suggesting that effects of P rate were similar regardless of whether fertilizer P had been seed-placed or side-banded. In general, a greater risk of fertilizer injury would be expected where fertilizer is seed-placed due to the close proximity of fertilizer to the seed. Dry conditions like those in 2021 may increase the risk of fertilizer injury overall, while other factors like a loss of separation between the fertilizer side-band and seedrow may also contribute to an increased risk of fertilizer injury.

The only cases where seed-placed P reduced plant stand overall compared to side-banded was for black bean at Melita in 2021 and at Brandon in 2022, where stands in seed-placed treatments were approximately 84% and 79% of that in side-banded treatments, respectively. The stand declines associated with seed-placed P are likely to be the result of fertilizer injury given that dry bean may be sensitive to seed-placed P. The Manitoba Soil Fertility Guide (2007) indicates that safe rates of seed-placed P are limited to 10 lb P_2O_5/ac (=12 kg P_2O_5/ha) with narrow row widths (<15”) for field bean, whereas significantly higher P rates were applied in the current study.

Early-season biomass production and P concentration: Early-season biomass production increased or tended ($0.05 \leq P \leq 0.10$) to increase linearly with increasing P rate in 2 of 5 site-years for black bean and 2 of 5 site-years for pinto bean (Table 19). Three of these four significant crop responses occurred in 2021, which might be due in part to reduced soil P availability under drier soil conditions in that year. P placement did not have a significant effect on early biomass yield for either bean type in any site-year, although side-banding tended (P=0.07) to increase early biomass yield compared to seed-placing P for black bean at Carberry in 2021; no effect of P placement had been evident on plant density at this site. No significant P rate x placement interactions were evident suggesting that effects of P rate were similar regardless of fertilizer placement.

The application of fertilizer P consistently increased P concentration in the crop early in the growing season. Phosphorus concentration in early-season biomass increased linearly with increasing P rate in 3 of 4 site-years for each of black bean and pinto bean. The 2022 Carberry site was not assessed. Effects of P placement on early season P status of dry bean were comparatively less frequent and consistent than P rate. For black bean, side-banding tended to increase %P at Carberry in 2021 (P=0.07) and to decrease % P at Melita in 2022 (P=0.10). Similarly, for pinto bean, side-banding increased %P at Carberry in 2021 and decreased %P at Brandon in 2022. No significant effects of P placement on biomass had been observed at these sites.

Plant vigour ratings: A visual assessment of plant vigour, with 1 being poor and 9 being healthy robust plants, was conducted to coincide with biomass measurements. Higher plant vigor scores were associated with increasing P rate in only 1 of 10 site-years, for pinto bean at Carberry in 2021 where vigour scores were 5.3, 6, 6.5 and 6 for fertilizer P rates of 0, 20, 40 and 60 kg P_2O_5 ha^{-1}, respectively. Effects of P placement were more frequently noted although effects varied among site-years.

Sidebanding increased plant vigour score compared to seed placement for black (6.3 vs 6.8) and pinto bean (6.5 vs 7.3) at Melita in 2021, and for black (6.9 vs 7.6) and pinto bean (7.3 vs 7.6) at Melita in 2022. In contrast, sidebanding decreased vigour score compared to seed placement for pinto bean at Carberry in 2021 (6.4 vs 5.5) and pinto bean at Brandon on 2022 (7.8 vs 6.9).

Yield: Effects of P management on dry bean yield were limited. Fertilizer P rate had a significant effect on yield in only one site-year. The yield of pinto bean increased linearly with increasing P rate at Melita in 2021 (Table 20). Increasing P rate had also increased plant P concentration early in the growing season, and tended (P=0.09) to increase early-season biomass yield at this site. Low soil test P levels at this site (4 ppm to 15 cm in fall 2020) likely contributed to the observed responses, along with dry conditions which may have reduced P availability. Although P application increased early-season biomass yield or P concentration in other site-years, these were not associated with increased yields.

Phosphorus placement had a statistically significant effect on dry bean yield in only two site-years. Seed-placed P increased the yield of pinto bean at Brandon in 2022, and had also been associated with a higher plant P concentration early in the growing season. For black bean at the Brandon site in 2022, significant effects of placement and P rate x placement were evident. Yield increased linearly (P=0.004) with P rate where P had been seed-placed, but followed a quadratic response (P=0.01) with yield increasing at lower P rates then declining with the highest P rate where P had been side-banded. The reason for the differing response to seed-placed versus side-banded P at Brandon in 2022 is unclear. No significant interactions between P rate and placement were evident early in the growing season for either plant stand or biomass yield (Tables 18 and 19) which suggested that P rate had a similar effect on crop establishment and early growth regardless of P placement and so was unlikely to have contributed to observed yield differences. Regardless, had seedling damage occurred that influenced yield, it would more likely have been a factor where higher P rates were placed near the seedrow rather than side-banded. Low soil test P (4 ppm to 15 cm in fall 2021) likely contributed to the P responses observed at this site.

Seed quality: Fertilizer P application increased or tended (P=0.09) to increase seed size for black bean in 3 of 5 site-years; a linear trend (P=0.10) was also evident for black bean at Melita in 2022 but effects were inconsistent across P rates (Table 22). Increasing P rate increased the seed size of pinto bean in only 1 of 5 site-years, at Brandon in 2022. A quadratic response was also noted for pinto bean at Carberry in 2022 where seed weight increased slightly with increasing P rate then declined. Effects of fertilizer placement were less consistent. For black bean, seed placement increased or tended to increase seed size at Melita in 2021 and 2022 compared to side-banding, but decreased seed size at Brandon in 2022. For pinto bean, seed-placement increased seed size only at Melita in 2021.

Fertilizer management had limited and inconsistent effects on test weight. In 2021, test weight increased linearly with increasing P rate in black bean, and varied with P rate in pinto bean at Melita in 2021 although no clear trend was evident (Table 22). In 2022, test weight declined linearly with increasing P rate for pinto bean at Brandon. In the case of black bean at Brandon, a significant quadratic response was evident with test weight increased with increasing P rate before declining slightly at the highest P rate. Effects of fertilizer placement were infrequent with seed-placement resulting in a higher test weight than side-banding for black bean at Brandon in 2022, and a trend toward a lower test weight for pinto bean at Carberry in 2022.

Phosphorus concentration and removal in seed: Phosphorus concentration in harvested seed increased linearly with increasing P rate for black bean in 2 of 4 site-years and for pinto bean in 2 of 4 site-years, with effects evident at Melita in 2021 and Brandon in 2022; the Carberry site was not assessed in 2022 (Table 23). Effects of fertilizer placement were limited. Side-banding slightly increased %P in seed for black bean at Melita in 2021, but had no effect on yield. In contrast, side-banding reduced %P for pinto bean at Brandon in 2022, and had also reduced yield at this site compared to seed-placement.

Phosphorus removal in harvested seed varied among bean types and site-years, averaging from ~6 to 13 kg P ha^{-1} (14 to 30 kg P_2O_5 ha^{-1}) in black bean and from ~4 to 15 kg P ha^{-1} (9 to 34 kg P_2O_5 ha^{-1}) depending upon site-year. Phosphorus removal in seed increased with increasing P rate for black bean in 2 of 4 site-years and for pinto bean in 2 of 4 site-years, reflecting the differences in seed P concentration noted above. Few effects of seed placement were observed. Side-banding reduced P removal in seed for pinto bean at Brandon in 2022 reflecting the lower %P and yield in the side-banded versus seed-placed treatments at this site. In black bean at Brandon, a significant P rate x placement interaction was evident, with P removal increasing from 10 to 14.4 kg P ha^{-1} across the range of P rates applied where P was seed-placed, but ranging from ~11 to 12 kg P ha^{-1} across P rates where P had been side-banded.

Summary and conclusions:

Dry bean responded more frequently and consistently to fertilizer N application than to inoculation. The yield of black bean increased or tended (P=0.06) to increase with increasing N rate in 3 of 5 site-years, while the yield of pinto bean increased in only 1 of 5 site-years. Contrast analysis revealed linear responses across the range of N rates applied, which ranged from 0 to 140 kg N ha^{-1} as side-banded urea. Although the yield potential of black bean varied considerably among N-responsive site-years, yields in the highest N rate treatment ranged from 106 to 112% that of the 0N treatment depending upon site-year. For the N-responsive pinto bean site, the highest N rate yielded 120% of the 0N control; however, the yield potential at this site was quite low and data variable due to dry growing season conditions. Increasing N rate also resulted in a linear increase in the yield of pinto bean at Melita in 2022 but only where no inoculant had been applied; where inoculant had been applied fertilizer N did not increase yield. By comparison, inoculation resulted in an overall increase in yield in only 1 of 5 site-years for black bean and 1 of 5 site-years for pinto bean, which were both at Melita in 2022. At that site, inoculation significantly increased not only yield but also nodulation score and % protein and N removal in harvested seed for both black and pinto bean.

Fertilizer P application had limited effects on dry bean yield under the conditions of this study despite early-season increases in plant P concentration and, in select cases, in early-season biomass yield. Despite these early-season responses, P application resulted in an overall increase in yield only for pinto bean at Melita in 2021. Yield also increased linearly with P rate for black bean at Brandon in 2022; however, this effect occurred only where P had been seed-placed. Where P was side-banded, yield increased at lower P rates then declined with the highest P rate. At both the Melita and Brandon sites, soil test P measured in the fall before the trials were established was quite low (4 ppm Olsen P to 15 cm) which likely contributed to the responses observed. Aside from the black bean trial at Brandon in 2022, the only other case where P placement affected yield was for pinto bean at Brandon in 2022 where seed-placed P increased yield compared to side-banding.

While the current study provides data regarding the response of dry bean to fertilizer N and P management, and to inoculation, additional site-years of data would be helpful for the refinement of existing soil fertility recommendations for dry bean in Manitoba. Because the current study was conducted over only two field seasons, including 2021 which was unusually dry, there would be value in collecting data over a wider range of growing season conditions.

Additional information:

Project Public Information Materials:

- WADO (Scott Chalmers) was a guest on Manitoba Agriculture's Crop Talk Webinar (Zoom) on July 14th, 2021. (25 in attendance)
- Southwest Producer bus tour (in person) visited the dry bean field trials at WADO in Melita on July 22, 2021. (20 in attendance)
- Heard, J. Soil Fertility Research in Manitoba. 51st Annual North Central Extension-Industry Soil Fertility Conference. 17-18 November, 2021. Poster presentation included information on ongoing dry bean soil fertility research in Manitoba.
- Manitoba Soil Fertility Meeting (Zoom) March 17, 2022. (at least 22 in attendance) Overview of the planned research was provided.
- Mohr, R., Kim, Y.M., Chalmers, S. and Abbas, H. 2022. Optimizing nitrogen and phosphorus management for dry bean in southwestern Manitoba. CAP Interim Report. Jan 25, 2022. 6 pp.
- Mohr, R., Kim, Y.M., Chalmers, S. and Abbas, H. 2022. Optimizing nitrogen and phosphorus management for dry bean in southwestern Manitoba. MPSG Annual Extension Report. March 28, 2022. 4 pp.
- Chalmers, S., Mohr, R., Domitruk, D., Henderson, T., Khakbazan, M., and Abbas, H. 2021. Optimizing nitrogen and phosphorus management for dry bean in southwestern Manitoba. P. 131-133 *in* Westman Agricultural Diversification Organization 2021 Annual Report.
- Abbas, H., Mohr, R., Kim, Y.M., and Chalmers, S. 2021. Effect of fertilizer management on dry bean. P. 123-126 in 2021 Manitoba Crop Diversification Annual Report.
- MCDC (Haider Abbas, Scott Chalmers) Crop Talk webinar, July 6, 2022 (26 in attendance live. 84 views to date https://www.youtube.com/watch?v=3NYyFPt6dmU) Attendees made aware that the project was underway at WADO and CMCDC.
- Manitoba Watershed Districts, July 13, 2022 (27 in attendance)
- WADO Annual Field Day, July 20, 2022, presentation by Scott Chalmers and Gordon Finlay (66 in attendance)
- Primary Ag Branch Field Tour, August 3, 2022 (31 in attendance)
- CMCDC Annual Field Day, August 9, 2022 (86 in attendance)
- Assiniboine Community College Students' Tour, September 14, 2022 (73 in attendance)
- 4-H Manitoba Agri-Career Quest, October 03, 2022 (23 in attendance)
- MSSS Soil Fertility Course – Scheduled for February 8 & 9 (number of attendees tbd)
- MCDC is also participating with a booth at the following industry events and the dry bean project is expected to be part of the discussions as well: MB Ag Days, Crop Connect Conference, MB Potato Days, Canadian Spud Congress.

Publications: Due to the short duration of the current study (< 2 years), sufficient time was not available to prepare or publish a scientific manuscript prior to the preparation of this report.

Acknowledgements: The funders of this project were acknowledged in reports, and at extension events as outlined above.

Table 1. Site characteristics and planting and harvest dates at Carberry and Melita sites in 2021, and planting and harvest dates at Brandon, Carberry and Melita in 2022.

Soil characteristics	Carberry				Melita		
	Black N	Pinto N	Black P	Pinto P	Black & Pinto N	Black P	Pinto P
2021							
Soil texture	clay		clay		fine sandy loam	fine sandy loam	
Sand%:silt%:clay%	30:30:40		30:30:40		41:35:24	41:35:24	
Soil OM%	4.9		4.9		3.6	3.8	
Soil Organic Carbon (%)	3.23	3.53	3.08	3.30	2.33	2.30	2.65
Soil Total Nitrogen (%)	0.26	0.27	0.25	0.26	0.19	0.19	0.21
Soil pH	7.0	7.0	6.9	7.0	7.7	7.23	7.17
EC mS cm^{-1}	0.82	0.96	0.71	1.17	n.d.	4.12	2.37
Planting date	31-May-21	1-Jun-21	31-May-21	1-Jun-21	3-Jun-21	2-Jun-21	2-Jun-21
Harvest date	22-Sep-21	21-Sep-21	22-Sep-21	21-Sep-21	17-Sep-21	17-Sep-21	17-Sep-21
2022 [1]							
Planting date	7-Jun-22	7-Jun-22	7-Jun-22	7-Jun-22	25-May-22	25-May-22	25-May-22
Harvest date	29-Sep	29-Sep	29-Sep	29-Sep	12-Sep-22	12-Sep-22	12-Sep-22

[1]At Brandon in 2022, all trials were seeded on May 27, with rainfed trials harvested on September 12th and irrigated on September 21st. At Carberry in 2022, the irrigated study was planted on June 7 and harvested on September 28.

Table 2. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on days to emergence for black and pinto bean in 2021 and 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022			
		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
		Carberry	Melita	Carberry	Melita	Brandon	Melita	Brandon	Melita
Means		------------days-------------							
0		17.3	n.a	15.0	8.3	16.1	14.3	15.5	13.5
35		16.5	n.a	15.0	8.3	16.4	14.3	15.9	13.5
70		16.5	n.a	14.3	8.3	16.4	14.8	15.5	13.9
105		16.5	n.a	14.0	8.1	16.8	15.3	16.4	14.0
140		16.9	n.a	13.0	8.4	16.5	15.0	15.1	14.4
	no inoculant	15.6	n.a	14.6	8.3	16.5	14.7	15.7	13.9
	with inoculant	17.9	n.a	13.9	8.3	16.4	14.8	15.7	13.8
		Pr > F							
ANOVA									
Nitrogen fertilizer rate		0.46	n.a	**<0.001**	0.86	0.60	0.32	0.29	0.30
Inoculation		**<0.001**	n.a	**<0.001**	1.00	0.84	0.78	0.89	0.73
Rate x inoculation		0.35	n.a	**<0.001**	0.86	0.12	0.25	0.43	0.46
Contrasts									
N Linear		0.50	n.a	**<0.001**	0.80	0.20	0.06	0.85	**0.04**
N Quadratic		0.10	n.a	**0.001**	0.53	0.54	0.74	0.20	0.69

Table 3. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on plant density of black and pinto bean in 2021 and 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------plants m^{-2}------------									
0		21.9	24.9	26.2	17.2	23.6	29.0	25.5	18.1	n.a.	27.6
35		27.7	24.9	27.4	19.0	21.3	32.6	26.5	19.4	n.a.	26.3
70		26.7	26.0	26.6	22.5	22.4	28.9	22.4	20.3	n.a.	30.6
105		30.3	24.5	27.0	20.2	20.9	28.7	24.6	19.6	n.a.	24.1
140		27.7	22.4	25.5	18.3	23.3	29.0	26.2	18.1	n.a.	25.3
	no inoculant	27.4	23.9	26.2	19.7	21.5	28.9	25.2	18.8	n.a.	24.6
	with inoculant	26.3	25.2	26.9	19.2	23.1	30.4	24.9	19.3	n.a.	28.9
		Pr > F									
ANOVA											
Nitrogen fertilizer rate		**0.002**	0.81	0.47	0.27	0.64	0.37	0.48	0.83	---	0.21
Inoculation		0.33	0.51	0.31	0.72	0.24	0.28	0.87	0.73	---	**0.03**
Rate x inoculation		0.17	0.59	**0.02**	0.51	0.08	0.10	0.28	0.42	---	0.50
Contrasts											
N Linear		**0.001**	0.43	0.45	0.56	0.81	0.44	0.91	0.98	---	0.29
N Quadratic		**0.02**	0.39	0.15	**0.05**	0.23	0.60	0.27	0.24	---	0.44

n.a. Data not available at time of report preparation.

Table 4. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on plant height for black and pinto bean in 2021 and 2022.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means						------------cm------------					
0		38.1	47.3	32.1	50.5	48.2	41.1	49.9	41.9	39.2	42.9
35		39.7	51.5	34.3	56.0	52.4	40.6	50.4	41.9	38.6	42.9
70		41.6	54.3	33.8	55.4	54.0	42.4	55.1	43.0	40.1	46.1
105		40.6	56.8	36.8	57.0	55.6	42.1	55.1	43.1	37.9	48.9
140		43.2	51.4	34.6	54.9	57.7	41.4	56.1	41.1	39.1	45.6
	no inoculant	41.1	52.3	34.4	55.4	53.9	41.5	52.3	42.3	39.0	45.8
	with inoculant	40.1	52.2	34.2	54.2	53.3	41.6	54.4	42.1	38.9	44.8
						Pr > F					
ANOVA											
Nitrogen fertilizer rate		0.12	**0.002**	0.20	0.16	**<0.001**	0.35	**<0.001**	0.37	0.25	**0.03**
Inoculation		0.41	0.97	0.86	0.48	0.45	0.80	**0.04**	0.88	0.86	0.42
Rate x inoculation		0.48	0.26	0.53	0.96	0.39	0.91	0.13	0.54	0.81	0.61
Contrasts											
N Linear		**0.01**	**0.01**	0.09	0.11	**<0.001**	0.35	**<0.001**	0.91	0.65	**0.02**
N Quadratic		0.85	**0.001**	0.29	0.07	0.17	0.33	0.37	0.11	0.99	0.20

Table 5. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on in-crop N status of black and pinto bean at growth stages V3 and R1 in 2021.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Inoculant	Chlorophyll meter reading at growth stage V3				Chlorophyll meter reading at growth stage R1			
		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
		Carberry	Melita	Carberry	Melita	Carberry	Melita	Carberry	Melita
Means									
0		47.5	31.3	49.7	39.9	43.9	31.0	48.2	34.1
35		49.5	34.7	49.6	45.9	44.8	31.9	48.7	34.3
70		49.4	35.6	49.1	46.0	45.4	31.6	47.7	34.0
105		51.8	36.3	50.7	45.5	46.3	31.5	50.6	34.3
140		50.1	36.3	50.2	45.5	46.1	32.7	48.8	35.0
	no inoculant	51.0	35.0	50.1	45.2	45.5	32.0	49.4	34.3
	with inoculant	48.3	34.6	49.6	43.9	45.1	31.5	48.2	34.4
						Pr > F			
ANOVA									
Nitrogen fertilizer rate		0.30	**<0.001**	0.81	**0.004**	**<0.001**	0.42	0.64	0.75
Inoculation		**0.04**	0.41	0.57	0.25	0.27	0.36	0.37	0.88
Rate x inoculation		0.89	0.50	0.86	0.26	0.07	0.29	0.72	0.72
Contrasts									
N Linear		0.09	**<0.001**	0.51	**0.01**	**<0.001**	0.13	0.47	0.30
N Quadratic		0.35	**0.002**	0.73	**0.01**	0.11	0.74	0.91	0.46

[1] The SPAD Chlorophyll Meter provides a measure of leaf greenness by measuring the amount of chlorophyll in the leaf tissue (ratio of leaf transmittance in red light at 650 nm and near-infrared light at 940 nm).

Table 6. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on in-crop N status of black and pinto bean at growth stages V3 and R1 in 2022.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Inoculant	Chlorophyll meter reading at growth stage V3						Chlorophyll meter reading at growth stage R1					
		Black Bean			Pinto Bean			Black Bean			Pinto Bean		
		Brandon	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means													
0		39.8	34.7	34.5	38.5	36.2	36.1	33.8	37.3	32.0	40.8	43.6	40.3
35		40.2	39.0	32.6	40.0	37.3	36.6	33.4	36.8	32.0	38.9	43.2	40.4
70		41.4	39.8	32.7	41.8	39.4	36.9	34.2	37.5	32.1	41.6	43.8	42.5
105		40.6	41.2	33.6	41.8	39.8	37.2	35.3	38.2	32.7	41.1	45.4	42.4
140		42.2	41.5	32.5	42.1	39.4	40.0	36.8	38.2	35.0	43.5	44.5	44.4
	no inoculant	41.2	39.0	32.8	40.4	38.7	37.6	34.7	37.2	32.5	40.6	43.3	41.4
	with inoculant	40.5	39.4	33.5	41.2	38.2	37.1	34.7	38.0	33.0	41.8	44.8	42.7
								Pr > F					
ANOVA													
Nitrogen fertilizer rate		**0.04**	**<0.001**	0.56	**<0.001**	**0.01**	0.29	**<0.001**	0.33	**0.03**	**0.01**	0.10	**0.001**
Inoculation		0.22	0.55	0.44	**0.03**	0.45	0.69	0.93	0.16	0.49	0.11	**0.01**	
Rate x inoculation		0.34	0.84	0.65	**0.02**	0.21	0.35	**0.03**	0.76	0.98	0.69	0.49	0.13
Contrasts													
N Linear		**0.006**	**<0.001**	0.35	**<0.001**	**0.001**	**0.06**	**<0.001**	0.07	**0.01**	**0.01**	**0.04**	**<0.001**
N Quadratic		0.91	**0.02**	0.52	**0.01**	0.10	0.36	**0.01**	0.61	0.06	0.10	0.96	0.53

[1] The SPAD Chlorophyll Meter provides a measure of leaf greenness by measuring the amount of chlorophyll in the leaf tissue (ratio of leaf transmittance in red light at 650 nm and near-infrared light at 940 nm).

Table 7. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on nodulation score of black and pinto bean in 2021 and 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		--scale 0-4[1]--									
0		1.6	1.6	2.6	2.3	3.4	2.6	1.1	3.0	1.5	1.9
35		1.3	1.7	1.8	1.5	3.4	2.1	1.0	3.2	1.7	1.9
70		1.1	1.0	1.5	1.3	3.0	2.0	0.9	3.0	1.5	1.7
105		0.9	0.5	1.5	1.0	3.0	1.7	0.9	3.1	1.2	1.3
140		1.0	0.6	1.4	0.7	2.5	1.4	0.6	3.2	1.3	1.2
	no inoculant	1.3	1.1	1.9	1.3	3.1	2.0	0.4	3.1	1.3	0.7
	with inoculant	1.1	1.0	1.6	1.4	3.0	2.0	1.5	3.2	1.6	2.5
		Pr > F									
ANOVA											
Nitrogen fertilizer rate		**0.01**	**<0.001**	**<0.001**	**<0.001**	**0.03**	**<0.001**	0.37	0.61	0.39	**0.02**
Inoculation		0.14	0.33	**0.02**	0.85	0.67	0.92	**<0.001**	0.45	0.16	**<0.001**
Rate x inoculation		0.45	0.18	0.56	0.76	0.83	0.38	0.54	0.20	0.51	0.31
Contrasts											
N Linear		**0.002**	**<0.001**	**<0.001**	**<0.001**	**0.002**	**<0.001**	**0.06**	0.44	0.12	**0.001**
N Quadratic		0.10	0.38	**0.003**	0.13	0.61	0.64	0.64	0.63	0.88	0.52

[1] Nodulation is based on the number and size of nodules, 0 = no nodules to 4 ≥20 nodules per plant

Table 8. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on yield of black and pinto bean in 2021 and 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------kg ha^{-1}------------									
0		1717	1260	832	1346	2523	1900	3115	2521	1809	3060
35		1416	1333	924	1377	2567	2004	3091	2795	1960	3144
70		1717	1372	942	1364	2669	1983	3174	2631	1857	3132
105		1398	1408	1005	1367	2680	1890	3472	2754	1933	3248
140		1527	1413	1123	1368	2650	1863	3717	2574	1946	3299
	no inoculant	1712	1364	988	1378	2619	1951	3115	2643	1880	2982
	with inoculant	1398	1350	942	1351	2617	1905	3512	2666	1922	3371
		Pr > F									
ANOVA											
Nitrogen fertilizer rate		0.74	0.38	0.32	1.00	0.10	0.21	**0.002**	0.28	0.24	0.62
Inoculation		0.12	0.80	0.60	0.59	0.96	0.31	**<0.001**	0.80	0.40	**<0.001**
Rate x inoculation		0.18	0.27	0.18	0.81	0.17	0.65	0.64	0.24	0.70	**0.05**
Contrasts											
N Linear		0.57	0.06	**0.04**	0.84	**0.02**	0.24	**<0.001**	0.84	0.16	0.13
N Quadratic		0.77	0.55	0.79	0.83	0.19	0.08	0.09	0.11	0.63	0.89

Table 9. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on seed weight and test weight of black and pinto bean in 2021.

Fertilizer N rate (kg N ha^{-1})	Inoculant	Seed weight				Test weight			
		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
		Carberry	Melita	Carberry	Melita	Carberry	Melita	Carberry	Melita
Means		------------g per 1000 seeds------------				------------kg hL^{-1}------------			
0		186.8	163.4	370.9	287.4	81.5	82.2	73.7	73.8
35		190.1	165.4	375.8	291.2	80.8	81.7	73.0	73.6
70		189.0	168.7	374.5	286.2	81.0	81.0	73.2	73.5
105		194.3	170.6	372.6	295.7	80.7	80.7	72.7	73.1
140		193.4	174.2	375.4	296.5	80.8	80.3	73.0	72.8
	no inoculant	193.5	169.8	376.1	290.1	81.0	81.1	73.3	73.4
	with inoculant	188.0	167.1	371.5	292.7	80.9	81.3	72.9	73.3
		Pr > F							
ANOVA									
Nitrogen fertilizer rate		**0.05**	**<0.001**	0.75	0.13	0.25	**<0.001**	0.34	**0.03**
Inoculation		**0.003**	**0.01**	0.09	0.40	0.69	0.33	0.17	0.56
Rate x inoculation		0.93	0.19	0.51	0.99	0.27	0.46	0.55	0.22
Contrasts									
N Linear		**0.01**	**<0.001**	0.54	**0.04**	0.07	**<0.001**	0.14	**0.002**
N Quadratic		0.79	0.665	0.68	0.49	0.35	0.49	0.27	0.61

Table 10. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on seed weight and test weight of black and pinto bean in 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	Seed weight						Test wieght					
		Black Bean			Pinto Bean			Black Bean			Pinto Bean		
		Brandon	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------g per 1000 seeds------------						------------kg hL^{-1}------------					
0		157.0	175.8	165.2	359.4	377.8	339.4	83.7	86.6	85.9	79.1	78.8	80.2
35		153.5	178.4	165.4	351.8	368.9	339.5	83.8	86.4	85.5	78.8	78.5	80.3
70		152.1	180.8	165.0	354.3	373.7	333.1	83.6	86.5	85.6	78.7	78.5	80.2
105		156.3	179.0	166.9	357.2	371.5	332.9	82.9	86.3	85.0	78.4	78.3	80.1
140		162.3	180.2	171.7	356.8	373.6	341.7	82.2	86.3	84.6	78.2	78.1	79.4
	no inoculant	156.2	177.9	165.6	358.6	372.1	335.7	83.1	86.5	85.5	78.6	78.6	80.4
	with inoculant	156.3	179.8	168.1	353.1	374.1	338.9	83.3	86.4	85.1	78.6	78.3	79.7
		Pr > F											
ANOVA													
Nitrogen fertilizer rate		**<0.001**	0.08	**0.001**	0.13	0.25	0.16	**<0.001**	0.593	**<0.001**	**0.02**	0.20	**0.004**
Inoculation		0.93	0.10	**0.02**	**0.01**	0.42	0.25	0.26	0.45	**0.009**	0.87	0.13	**<0.001**
Rate x inoculation		0.13	0.68	0.64	0.67	0.52	0.75	0.64	0.32	0.66	0.90	0.66	0.35
Contrasts													
N Linear		**0.001**	**0.03**	**<0.001**	0.97	0.51	0.83	**<0.001**	0.142	**<0.001**	**0.001**	**0.02**	**0.001**
N Quadratic		**<0.001**	0.15	**0.01**	0.07	0.16	**0.05**	**0.01**	0.93	0.14	0.90	0.86	**0.02**

Table 11. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on percent protein in seed of black and pinto bean in 2021 and 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------%------------									
0		28.8	28.6	27.5	26.8	24.5	26.1	23.0	26.0	26.3	23.9
35		30.5	29.4	28.8	28.5	25.1	27.0	22.9	26.1	26.1	23.9
70		31.4	32.2	28.9	29.5	25.9	27.1	23.3	26.6	26.3	24.5
105		32.3	33.9	29.7	31.1	27.2	27.1	24.8	27.2	26.9	24.9
140		32.5	34.9	29.8	32.3	30.3	27.8	26.5	28.1	27.0	25.8
	no inoculant	31.0	31.6	28.8	29.9	26.5	26.9	23.5	26.7	26.3	23.3
	with inoculant	31.3	32.1	29.0	29.4	26.7	27.1	24.7	27.0	26.8	25.9
		Pr > F									
ANOVA											
Nitrogen fertilizer rate		**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.03**	**0.002**
Inoculation		0.48	0.29	0.59	0.25	0.47	0.47	**0.002**	**0.05**	**0.02**	**<0.001**
Rate x inoculation		0.17	0.54	0.24	0.20	0.89	0.31	0.11	0.35	0.16	**0.40**
Contrasts											
N Linear		**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.01**	**<0.001**
N Quadratic		0.10	0.68	0.20	0.82	**<0.001**	0.56	**0.002**	**0.02**	0.18	0.17

Table 12. Effect of fertilizer N rate (applied as side-banded urea) and inoculant application on estimated nitrogen removal in harvested seed of black and pinto bean in 2022.

Fertilizer N rate (kg N ha^{-1})	Inoculant	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------kg ha^{-1}------------									
0		63.7	47.8	32.6	50.9	80.9	65.1	93.3	94.0	68.1	106.4
35		56.1	52.4	37.7	54.4	84.4	71.2	91.8	104.7	73.3	109.5
70		69.7	59.0	38.8	55.5	90.6	70.9	96.0	100.1	69.8	111.5
105		58.4	64.9	41.9	59.8	96.3	67.6	111.4	106.5	74.0	116.8
140		65.4	66.5	47.6	60.8	107.1	68.5	128.1	102.3	74.8	122.0
	no inoculant	68.5	57.7	40.0	56.7	91.4	69.3	95.4	100.6	70.7	101.5
	with inoculant	56.9	58.6	39.5	55.9	92.3	68.1	112.8	102.4	73.3	125.0
		Pr > F									
ANOVA											
Nitrogen fertilizer rate		0.740	**<0.001**	0.07	**0.03**	**<0.001**	0.20	**<0.001**	0.235	0.08	0.16
Inoculation		0.11	0.67	0.88	0.69	0.62	0.51	**<0.001**	0.62	0.14	**<0.001**
Rate x inoculation		0.14	0.28	0.18	0.93	0.25	0.59	0.25	0.23	0.45	0.07
Contrasts											
N Linear		0.819	**<0.001**	**0.005**	**0.002**	**<0.001**	0.60	**<0.001**	0.15	**0.03**	**0.014**
N Quadratic		0.88	0.46	0.81	0.83	**0.057**	0.08	**0.003**	0.22	0.89	0.67

Table 13. Effect of nitrogen rate fertilization on disease incidence and severity of sclerotinia stem rot and nodulation of black and pinto bean grown under irrigation at Brandon in 2022.

Fertilizer N rate (kg N ha^{-1})	Black bean					Pinto bean				
	DI[a] (%)	Sev.[b] (Scale 0-4)	Sev.[c] (Scale 0-4)	DSI[d] (%)	Nod.[e] (Scale 0-4)	DI[a] (%)	Sev.[b] (Scale 0-4)	Sev.[c] (Scale 0-4)	DSI[d] (%)	Nod.[e] (Scale 0-4)
0	60.5	1.18	1.85	29.5	3.7	57.5	1.32	2.42	33	3.9
35	61.5	1.35	2.14	33.6	3.7	50	1.05	2.19	26.3	4
70	62	1.34	2.15	33.5	3.8	54.5	1.29	2.4	32.1	3.9
105	62	1.17	1.89	29.3	3.7	57.5	1.31	2.33	32.8	3.9
140	67	1.32	1.95	33	3.5	53	1.37	2.51	34.3	3.8
Mean	**62.6**	**1.27**	**2**	**31.78**	**3.7**	**54.5**	**1.27**	**2.37**	**31.68**	**3.9**
F Value	*0.35*	*0.24*	*0.81*	*0.27*	*0.69*	*0.8*	*1.75*	*0.56*	*1.59*	*0.72*
Pr>F	*0.8368*	*0.9121*	*0.5426*	*0.8913*	*0.6108*	*0.5494*	*0.2029*	*0.696*	*0.24*	*0.5935*
N Rate Significant Contrasts α = 0.05	none	none	none	none	none	none	**35 vs 140**	none	none	none
Overall Mean	**25.5**	**0.6**	**1.3**	**13**	**3.1**	**28.4**	**0.8**	**1.8**	**16.6**	**3.2**

[a]Disease incidence (DI) across all examined plants.

[b]Disease severity (Sev.) across all examined plants.

[c]Disease severity across only infected plants.

[d]Disease severity index (DSI) percentage across all examined plants.

[e]Root nodulation (Nod.) per 10 plant examined.

Table 14. Correlation coefficients among mean variables (least-squares entry means) of disease incidence and severity of sclerotinia stem rot and nodulation of black and pinto beans at Brandon in 2022.

Bean type		**DI[a]**	**Sev.[b]**	**Sev.[c]**	**Nod.[d]**
Black beans	**DI**	1	0.95226	0.9233	0.00591
			<.0001	***<.0001***	*0.9803*
	Sev.[b]		1	0.98368	-0.07664
				<.0001	*0.7481*
	Sev.[c]			1	-0.06858
					0.7739
	Nod.				1
Pinto beans	**DI**	1	0.96322	0.94953	-0.35595
			<.0001	***<.0001***	*0.1235*
	Sev.[b]		1	0.97961	-0.49544
				<.0001	***0.0263***
	Sev.[c]			1	-0.52259
					0.0181
	Nod.				1

[a]Disease incidence (DI) across all examined plants.

[b]Disease severity (Sev.) across all examined plants.

[c]Disease severity across only infected plants.

[d]Root nodulation (Nod.) per 10 plant examined.

Table 15. Effect of fertilizer N rate (applied as side-banded urea on plant density and chlorophyll meter readings at growth stage V3 and R1 for black and pinto bean grown under irrigation at Brandon and Carberry in 2022.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Plant Density				Chlorophyll meter reading at growth stage V3[1]				Chlorophyll meter reading at growth stage R1			
	Black Bean		Pinto Bean		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry
Means	--------plants m^{-2}--------											
0	32.0	20.6	29.5	37.8	36.8	36.0	39.3	39.9	34.8	35.7	43.5	42.6
35	27.8	18.8	24.6	33.1	38.6	37.4	41.1	40.3	34.7	35.1	43.3	42.3
70	22.4	17.6	21.9	37.2	38.6	37.3	41.0	39.8	34.4	36.7	41.3	43.3
105	32.5	20.2	22.9	34.3	39.9	38.1	40.5	41.9	33.9	35.9	42.6	43.5
140	35.9	21.8	20.7	37.7	38.7	38.1	43.1	41.5	34.9	35.4	42.6	44.7
							Pr > F					
ANOVA												
Nitrogen fertilizer rate	**0.005**	0.83	0.07	0.30	**0.03**	0.07	0.24	0.45	0.88	0.57	0.18	0.14
Contrasts												
N Linear	0.09	0.67	**0.01**	0.87	**0.02**	**0.01**	0.07	0.14	0.84	0.98	0.24	**0.02**
N Quadratic	**0.002**	0.31	0.26	0.22	**0.04**	0.33	0.81	0.78	0.51	0.42	0.15	0.37

[1] The SPAD Chlorophyll Meter provided a measure of leaf greenness by measuring the amount of chlorophyll in the leaf tissue (ratio of leaf transmittance in red light at 650 nm and near-infrared light at 940 nm) at growth stage V3 (third unrolled trifoliate leaf) and R1 (beginning of flowering).

Table 16. Effect of fertilizer N rate (applied as side-banded urea) on yield and percent protein in harvested seed for black and pinto bean grown under irrigation at Brandon and Carberry in 2022.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Yield				Protein in seed			
	Black Bean		Pinto Bean		Black Bean		Pinto Bean	
	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry
Means	--------$kg\ ha^{-1}$--------				--------%--------			
0	4297	1961	3031	1921	25.2	24.3	26.8	25.4
35	3985	2024	3274	2039	26.0	25.1	27.1	25.0
70	3771	2025	2889	1981	26.7	25.0	26.5	24.5
105	4414	1975	3145	1740	26.8	25.2	26.5	25.1
140	4146	1798	3510	1852	27.3	25.4	26.4	25.3
					Pr > F			
ANOVA								
Nitrogen fertilizer rate	0.19	0.34	0.13	0.18	**0.004**	**0.01**	0.90	0.23
Contrasts								
N Linear	0.84	0.18	0.12	0.13	**<0.001**	**0.002**	0.43	0.83
N Quadratic	0.21	0.12	0.16	0.55	0.27	0.210	0.92	**0.04**

Table 17. Effect of fertilizer N rate (applied as side-banded urea) on seed weight and test weight of black and pinto bean grown under irrigation at Brandon and Carberry in 2022.

Fertilizer N rate ($kg\ N\ ha^{-1}$)	Seed weight				Test weight			
	Black Bean		Pinto Bean		Black Bean		Pinto Bean	
	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry	Brandon	Carberry
Means	--------g per 1000 seeds--------				--------$kg\ hL^{-1}$--------			
0	174.5	190.6	368.9	386.1	84.1	87.0	79.0	77.8
35	174.7	191.1	368.8	375.4	83.9	86.8	79.2	77.9
70	174.7	181.7	363.2	385.5	83.5	86.2	78.8	77.9
105	180.2	188.5	369.5	377.3	83.7	86.7	78.8	77.4
140	179.0	190.5	371.0	378.9	83.6	86.2	78.7	77.9
					Pr > F			
ANOVA								
Nitrogen fertilizer rate	0.48	0.06	0.96	0.14	0.11	**0.003**	0.60	0.52
Contrasts								
N Linear	0.13	0.71	0.79	0.26	**0.02**	**0.002**	0.18	0.69
N Quadratic	0.81	**0.04**	0.55	0.64	0.28	0.54	0.83	0.78

Table 18. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on plant density of black and pinto bean in 2021 and 2022.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------plants m^{-2}------------									
0		27.4	28.1	24.1	24.2	27.1	30.1	27.5	20.2	n.a	26.2
20		27.8	24.5	23.9	21.4	26.9	29.8	25.8	20.5	n.a	24.6
40		25.2	25.1	26.1	20.6	21.4	30.9	25.1	20.6	n.a	22.4
60		22.0	22.5	24.5	23.6	25.7	30.8	23.7	23.8	n.a	25.4
	Seed-placed	26.9	22.9	25.6	21.9	22.3	31.5	24.2	22.2	n.a	24.5
	Side-banded	24.3	27.2	23.7	23.0	28.2	29.3	26.8	20.3	n.a	24.7
		Pr > F									
ANOVA											
Phosphorus fertilizer rate		0.14	0.11	0.42	0.13	**0.04**	0.93	0.55	0.35	n.a	0.37
Placement		0.18	**0.01**	0.07	0.37	**0.001**	0.15	0.17	0.23	n.a	0.90
Rate x placement		0.32	0.79	0.60	0.33	0.19	0.46	0.77	0.44	n.a	0.79
Contrasts											
P Linear		**0.03**	**0.03**	0.46	0.62	0.16	0.61	0.16	0.14	n.a	0.53
P Quadratic		0.35	0.74	0.47	**0.02**	0.15	0.96	0.95	0.37	n.a	0.16

n.a. Data were not available at time of report

Table 19. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on early-season biomass yield of black and pinto bean in 2021 and 2022.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		------------g m^{-2}------------									
0		101	192	108	265	78	303	94	111	349	306
20		167	208	113	312	82	307	85	116	324	305
40		156	211	138	378	71	324	96	109	363	297
60		178	228	138	339	79	335	104	117	389	283
	Seed-placed	139	212	128	310	77	318	93	113	358	295
	Side-banded	162	208	121	337	77	317	96	113	355	301
		Pr > F									
ANOVA											
Phosphorus fertilizer rate		**0.001**	0.46	**0.04**	0.20	0.48	0.59	0.14	0.89	0.28	0.62
Placement		0.07	0.77	0.45	0.47	0.97	0.94	0.56	0.96	0.91	0.64
Rate x placement		0.14	0.88	0.25	0.16	0.80	0.72	0.24	0.64	0.51	0.24
Contrasts											
P Linear		**0.001**	0.12	**0.01**	0.09	0.69	0.18	0.10	0.75	0.14	0.22
P Quadratic		0.09	0.96	0.78	0.25	0.74	0.84	0.16	0.85	0.28	0.64

Table 20. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on P concentration in early-season biomass of black and pinto bean in 2021 and 2022.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022			
		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
		Carberry	Melita	Carberry	Melita	Brandon	Melita	Brandon	Melita
Means		----------% P----------							
0		0.21	0.19	0.19	0.18	0.30	0.32	0.29	0.31
20		0.19	0.22	0.20	0.20	0.31	0.34	0.31	0.31
40		0.19	0.24	0.20	0.23	0.31	0.35	0.32	0.30
60		0.20	0.26	0.22	0.24	0.33	0.36	0.33	0.32
	Seed-placed	0.19	0.23	0.19	0.21	0.31	0.35	0.32	0.31
	Side-banded	0.20	0.23	0.21	0.21	0.32	0.34	0.30	0.31
		Pr > F							
ANOVA									
Phosphorus fertilizer rate		0.28	**<0.001**	0.13	**<0.001**	**0.01**	**0.01**	**0.001**	0.74
Placement		0.07	0.35	**0.01**	0.91	0.41	0.10	**0.006**	0.39
Rate x placement		0.50	0.98	0.75	0.59	0.73	0.45	0.13	0.36
Contrasts									
P Linear		0.31	**<0.001**	**0.04**	**<0.001**	**0.001**	**0.001**	**<0.001**	0.70
P Quadratic		0.14	0.44	0.41	0.57	0.41	0.25	0.60	0.49

Table 21. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on yield of black and pinto bean in 2021 and 2022.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		----------kg ha^{-1}----------									
0		2150	1268	1075	1716	2818	2483	2445	2465	2032	3022
20		2294	1354	1153	1682	3120	2359	2661	2523	1983	3023
40		2081	1352	1352	1841	3107	2473	2508	2542	1916	3115
60		2168	1426	1249	1864	3046	2444	2619	2591	1991	3048
	Seed-placed	2243	1369	1293	1765	3112	2470	2603	2706	1937	3043
	Side-banded	2103	1331	1121	1786	2934	2410	2514	2354	2023	3061
		Pr > F									
ANOVA											
Phosphorus fertilizer rate		0.79	0.52	0.50	**0.02**	0.06	0.73	0.31	0.87	0.46	0.44
Placement		0.36	0.61	0.21	0.64	**0.04**	0.49	0.34	**0.004**	0.10	0.69
Rate x placement		0.79	0.29	0.81	0.63	**0.002**	0.55	0.58	0.50	0.60	**0.02**
Contrasts											
P Linear		0.82	0.16	0.24	**0.01**	0.08	0.99	0.36	0.42	0.41	0.41
P Quadratic		0.85	0.93	0.50	0.53	**0.04**	0.58	0.56	0.96	0.23	0.46

Table 22. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on seed weight and test weight of black and pinto bean in 2021 and 2022.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022						2021				2022					
		Black Bean		Pinto Bean		Black Bean			Pinto Bean			Black Bean		Pinto Bean		Black Bean			Pinto Bean		
		Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita	Carberry	Melita	Carberry	Melita	Brandon	Carberry	Melita	Brandon	Carberry	Melita
Means		----------g per 1000 seeds----------										----------kg hL^{-1}----------									
0		196.8	164.7	383.3	302.3	161.7	177.5	156.1	346.7	354.0	336.0	81.4	81.9	72.2	75.5	84.0	85.2	86.5	79.3	78.3	80.1
20		197.7	164.9	380.5	300.5	162.5	178.9	157.0	350.5	357.8	335.9	81.4	82.1	72.6	74.7	84.2	85.4	86.1	79.0	78.1	80.1
40		195.2	166.9	373.9	306.1	166.3	181.7	152.1	354.8	356.0	336.9	81.3	82.4	72.4	75.4	84.7	85.3	86.6	78.9	77.9	80.1
60		196.0	167.8	378.0	301.4	166.7	180.8	154.1	357.5	352.3	334.8	81.5	82.6	72.3	75.0	84.1	85.3	86.5	78.7	78.1	80.2
	Seed-placed	196.7	168.5	379.9	306.6	161.8	180.3	156.0	352.9	355.4	336.0	81.4	82.5	72.4	75.1	84.4	85.4	86.3	79.1	78.0	80.3
	Side-banded	196.2	163.7	377.9	298.6	166.7	179.1	153.6	351.8	354.6	335.8	81.4	82.1	72.4	75.1	84.0	85.2	86.5	79.0	78.2	80.0
												Pr > F									
ANOVA																					
Phosphorus fertilizer rate		0.81	0.35	0.26	0.40	0.11	0.11	0.09	**0.06**	0.13	0.98	0.88	0.26	0.44	**0.01**	**0.06**	0.84	0.34	**0.02**	0.08	0.83
Placement		0.79	**0.003**	0.56	**0.004**	**0.01**	0.36	0.10	0.71	0.62	0.93	0.62	0.17	0.88	0.89	**0.03**	0.46	0.48	0.46	0.08	0.11
Rate x placement		0.57	0.16	0.10	0.06	0.74	0.83	0.22	0.93	**0.01**	0.66	0.77	0.55	0.80	0.44	0.12	0.29	0.08	**0.02**	0.26	0.55
Contrasts																					
P Linear		0.55	0.09	0.15	0.78	**0.02**	**0.03**	0.10	**0.01**	0.36	0.85	0.77	**0.05**	0.98	0.39	0.29	0.67	0.52	**0.003**	0.07	0.66
P Quadratic		0.99	0.79	0.31	0.55	0.92	0.38	0.69	0.84	**0.03**	0.76	0.56	0.91	0.15	0.26	**0.04**	0.58	0.61	0.74	0.08	0.44

Table 23. Effect of fertilizer P rate (applied as monoammonium phosphate) and placement on the P concentration in seed of black and pinto bean in 2021 and 2022, and P removal in harvested seed.

Fertilizer P rate (kg P_2O_5 ha^{-1} as MAP)	Placement	2021				2022				2021				2022			
		Black Bean		Pinto Bean		Black Bean		Pinto Bean		Black Bean		Pinto Bean		Black Bean		Pinto Bean	
		Carberry	Melita	Carberry	Melita	Brandon	Melita	Brandon	Melita	Carberry	Melita	Carberry	Melita	Brandon	Melita	Brandon	Melita
Means		----------% P in seed----------								----------kg P ha^{-1} removed in harvested seed----------							
0		0.34	0.39	0.36	0.39	0.38	0.53	0.36	0.49	7.25	4.98	3.90	6.62	10.7	12.9	8.9	14.7
20		0.33	0.44	0.36	0.39	0.40	0.52	0.40	0.48	7.68	5.98	4.18	6.63	12.5	13.7	10.1	14.6
40		0.34	0.47	0.35	0.43	0.41	0.52	0.40	0.48	7.11	6.30	4.64	7.87	12.6	13.1	10.3	15.0
60		0.35	0.47	0.36	0.46	0.42	0.53	0.41	0.49	7.60	6.77	4.51	8.63	12.8	13.8	10.8	15.0
	Seed-placed	0.34	0.44	0.35	0.42	0.40	0.53	0.41	0.49	7.66	6.00	4.51	7.37	12.5	13.7	11.0	14.9
	Side-banded	0.34	0.45	0.36	0.42	0.40	0.52	0.38	0.48	7.16	6.01	4.11	7.51	11.7	13.1	9.0	14.7
										Pr > F							
ANOVA																	
Phosphorus fertilizer rate		0.47	**<0.001**	0.75	**<0.001**	**0.02**	0.55	**0.001**	0.83	0.88	**0.01**	0.74	**<0.001**	**0.003**	0.47	0.09	0.83
Placement		0.88	**0.04**	0.18	0.63	0.82	0.78	**0.003**	0.32	0.39	0.99	0.44	0.48	**0.04**	0.29	**0.001**	0.64
Rate x placement		**0.05**	0.52	0.26	0.15	0.13	0.07	0.11	0.16	0.81	0.26	0.90	0.44	**0.003**	0.52	0.25	0.21
Contrasts																	
P Linear		0.22	**<0.001**	0.65	**<0.001**	**0.003**	0.90	**<0.001**	0.75	0.85	**0.001**	0.33	**<0.001**	**0.001**	0.35	**0.02**	0.52
P Quadratic		0.38	**0.005**	0.59	0.08	0.42	0.23	0.09	0.39	0.96	0.44	0.70	0.08	**0.04**	0.91	0.54	0.90

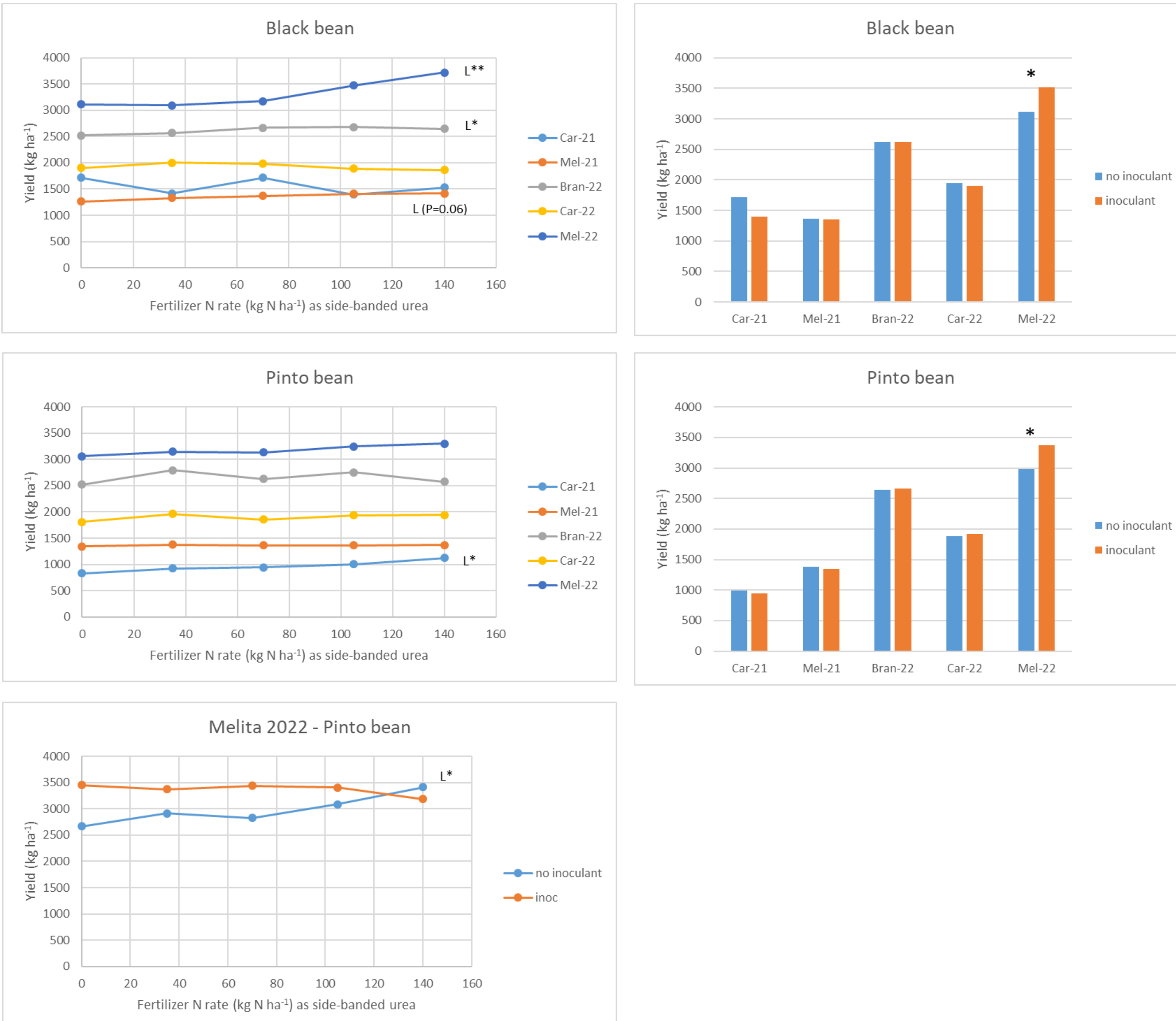

Figure 1. Effect of fertilizer N rate and inoculant on yield of black and pinto bean at Brandon, Carberry and Melita in 2021 and 2022, and interactive effect of fertilizer N rate x inoculant on yield for pinto bean at Melita in 2022. (L*, L** indicate a significant linear response to increasing fertilizer N rate at P≤0.05 and P≤0.01, respectively. * indicates a significant difference (P≤0.05) between inoculated and non-inoculated treatments, averaged across fertilizer N rates).

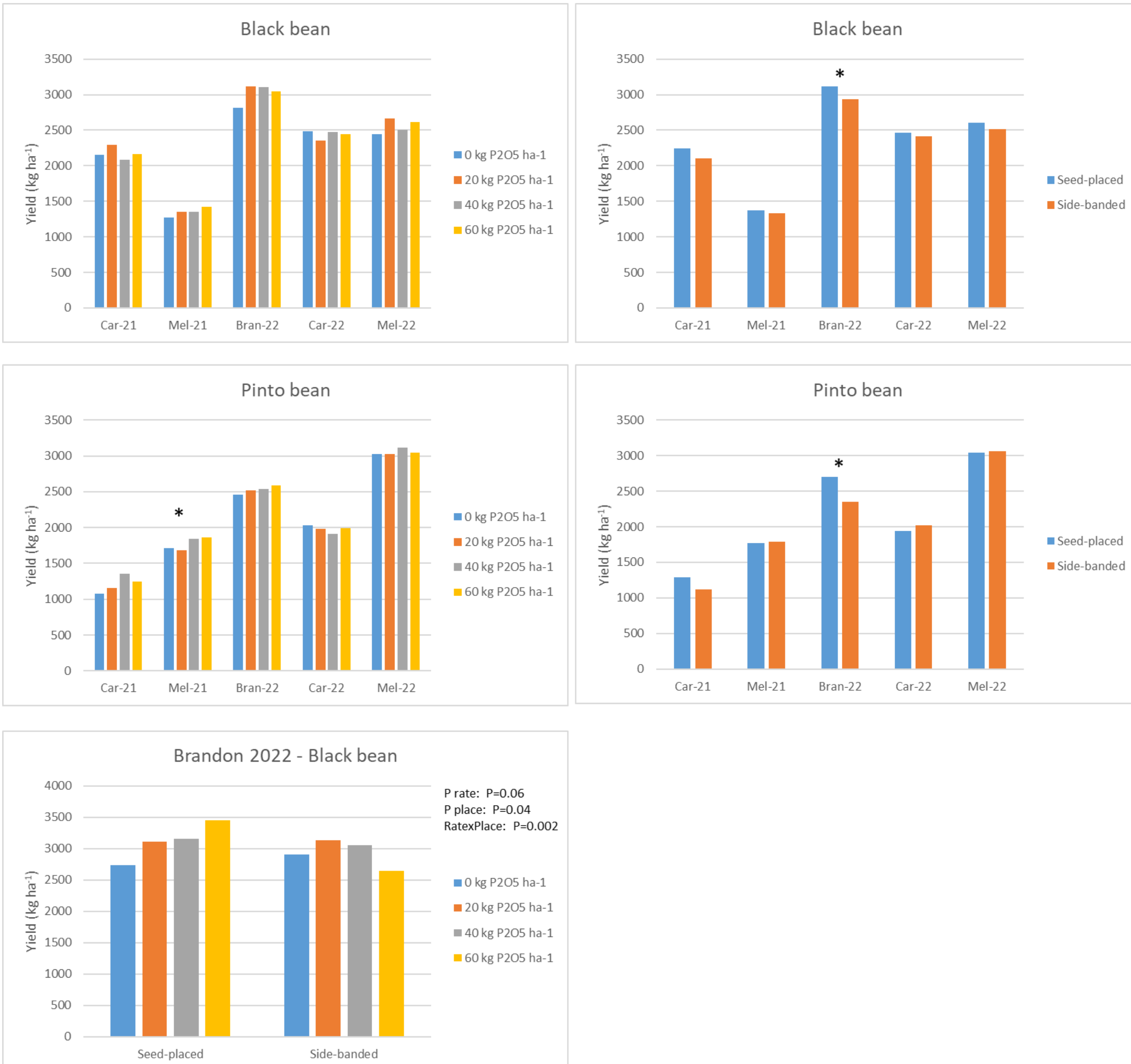

Figure 2. Effect of fertilizer P rate and placement on yield of black and pinto bean at Brandon, Carberry and Melita in 2021 and 2022, and interactive effect of fertilizer P rate x placement on yield for black bean at Brandon in 2022. (* indicate a significant treatment effect at P≤0.05).