NRC Research Press

ARTICLE

Yield and uptake of nitrogen and phosphorus in soybean, pea, and lentil and effects on soil nutrient supply and crop yield in the succeeding year in Saskatchewan, Canada

J. Xie, J. Schoenau, and T.D. Warkentin

Abstract: There is little information on soybean [*Glycine max* (L.) Merr.] grown in western Canada despite its expanding acreage in this region. This study quantified the yield and uptake of nitrogen (N) and phosphorus (P) in three short-season soybean varieties (in 2014) and their impact on following wheat and canola crops, as well as soil nutrient supplies in 2015 in comparison to three pea and three lentil varieties at four sites in Saskatchewan. In 2014, soybean had comparable grain yield (929–3534 kg ha^{-1}) and higher grain N (39–48 g kg^{-1}) and P (5.1–6.8 g kg^{-1}) concentrations compared with pea and lentil. In 2015, although soil N and P supplies showed some responses to different stubbles during the growing season, cumulative soil nutrient supplies were similar in soybean, pea, and lentil stubbles at the end of the season. Overall, soybean, pea, and lentil stubbles had similar impact on the yield and uptake of N and P in the wheat or canola crop grown in the subsequent year. The findings suggest promising potential for soybean production to achieve rotational benefits similar to other grain legumes grown under western Canadian soil–climatic conditions.

Key words: soybean, pea, lentil, N and P uptake, soil N and P supplies, rotational effects.

Résumé : On sait relativement peu de choses sur la culture du soja [*Glycine max* (L.) Merr.] dans l'Ouest canadien, bien que la superficie qui lui est consacrée dans la région ne cesse de prendre de l'ampleur. La présente étude a permis d'établir le rendement ainsi que l'absorption d'azote (N) et de phosphore (P) de trois variétés de soja à saison courte (en 2014). Elle a aussi établi l'impact de cette culture sur celle, subséquente, de blé et de colza, en 2015, de même que sur les réserves d'éléments nutritifs dans le sol. Ces résultats sont comparés à ceux obtenus avec trois variétés de pois et autant de lentilles, à quatre endroits, en Saskatchewan. En 2014, le soja a donné un rendement grainier comparable (929 – 3534 kg par hectare) à celui du pois et de la lentille ainsi qu'une concentration de N (39 – 48 g par kg) et de P (5,1 – 6,8 g par kg) plus élevée dans le grain. L'année suivante, les stocks totaux d'oligoéléments dans le sol étaient similaires après la récolte du soja, du pois et de la lentille, en fin de saison, même si les réserves de N et de P avaient légèrement réagi aux différents types de chaume durant la période végétative. Dans l'ensemble, le chaume du soja, du pois et de la lentille a une incidence analogue sur le rendement et sur l'absorption du N et du P par le blé ou le colza cultivé l'année suivante. Ces constatations laissent croire que la culture du soja est prometteuse et qu'en assolement, elle pourrait conférer les mêmes avantages que les autres légumineuses grainières, dans les conditions climatiques et pédologiques particulières à l'ouest du Canada. [Traduit par la Rédaction]

Mots-clés : soja, pois, lentille, absorption de N et de P, réserves de P et de N du sol, effets de l'assolement.

Introduction

Including grain legumes in crop rotations provides both economic and environmental benefits such as mitigating inorganic nitrogen (N) fertilizer costs and greenhouse gas emissions related to excess use of inorganic N fertilizers due to their ability to fix N_2 from the atmosphere (Knight 2012). Through biological N_2 fixation (BNF), grain legumes are able to partially meet their N demands and thus lessen soil nutrient depletion (Ha et al. 2008). Other benefits of grain legumes include the exudation of N and other nutrients to the soil via the root system, enhancement of soil microbial activity,

Received 28 October 2016. Accepted 5 April 2017.

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and interruption of insect and disease cycles (Peoples et al. 2009; Lupwayi et al. 2011; Arcand et al. 2014). Therefore, grain legumes in cropping systems benefit not only the soil nutrient pool in the season when legumes are grown, but also succeeding crops. Non-N benefits from grain legumes include reducing root and leaf diseases and increasing availability of phosphorus, potassium, and sulfur (P, K, S) and growth substances released from legume residue (Stevenson and van Kessel 1996*a*). These non-N benefits are sometimes reported to exceed the N benefits. Stevenson and van Kessel (1996*a*) estimated that 92% of the yield advantage in a pea–wheat rotation was attributed to non-N rotation benefits in comparison to a wheat–wheat sequence in Saskatchewan. However, researchers have reported that using a cereal monoculture sequence as the reference usually caused overestimations of the non-N benefits of legumes in legume–cereal rotations, whereas using broadleaf crops as reference crops could avoid this overestimation (Beckie and Brandt 1997; Beckie et al. 1997).

The N and non-N rotational benefits of grain legumes vary with soi–climatic conditions, crop species and cultivars, and agronomic practice (Malhi et al. 2008). Agronomic practice affects the production and contribution of grain legumes through such factors as application of inoculants, method of harvesting, and fertilizer application (Ennin et al. 2004). Primarily, these factors affect the biomass accumulation, N fixation, and nutrient partitioning, which then determine the amount of nutrients returned to the soil via residue, provided that crop residue is not removed from the field at harvest (van Kessel 1994; Hungria et al. 2006; Zakeri et al. 2012). Therefore, nutrient partitioning between the grain and straw components of grain legumes is important in evaluating nutrient removal and rotational benefits of legumes. The availability of nutrients in legume residue to the soil nutrient pool and following crops is largely related to the biochemical characteristics of the residue [carbon (C) to N ratio, lignin content] and environmental factors influencing decomposition such as soil temperature, water content, and soil biota composition (Schoenau and Campbell 1996; Kumar and Goh 2003). As a result, the impact of the previous legume crop on the yield and nutrient content of succeeding crops normally varies with legume crop species, agronomic practices, and soil–climatic conditions (Przednowek et al. 2004; Peoples et al. 2009; Jani et al. 2015).

Production of soybean is expanding in western Canada due to the development of short-season herbicide-tolerant varieties. For instance, Manitoba became the second largest soybean producer in Canada in 2012 and in Saskatchewan, soybean acreage increased more than tenfold from 2011 to 2013 (Statistics Canada 2016). However, there is little information on the yield and nutrient assimilation in different plant components (grain vs. straw) of new short-season soybean varieties grown under western Canadian soil–climatic conditions. Little is known about the impact of soybean production on soil nutrient availability for crops in the following year under local growing conditions. Nutrient uptake can be related to immediate crop requirements for added fertilizer, as well as impact on soil fertility in future years when nutrient partitioning between the grain and the straw is determined. This information is needed for growers to make short- and long-term fertilization decisions when comparing soybean rotations with other pulse crop rotations.

Compared with soybean, field pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) are well-established pulse crops in western Canada. Previous studies showed that the rotational benefits and environmental impact of pea and lentil production were mainly attributed to the N fixation benefits, the low C to N ratios in the residue, and the contribution to available soil N (Stevenson and van Kessel 1996*b*; Adderley et al. 2006; Walley et al. 2007). Through a 2-yr (2014–2015) field experiment at four sites encompassing two Dark Brown and two Black Chernozemic soils (Typic Borolls, United States Department of Agriculture taxonomy system) in south-central Saskatchewan, this study assessed several aspects of soybean production in comparison to pea and lentil production under Saskatchewan conditions. Particularly, this study quantified the (*i*) yield and N and P uptake in the grain and straw of three short-season varieties of soybean, three varieties of pea, and three varieties of lentil grown in 2014; (*ii*) soil supply of available N and P during the 2015 growing season as affected by soybean, pea, or lentil stubble from the previous year; and (*iii*) yield and N and P uptake in the grain and straw of wheat (*Triticum aestivum* L.) or canola (*Brassica napus* L.) grown on soybean, pea, or lentil stubble in 2015.

Materials and Methods

Site description and experimental design

The experiment was conducted in 2014 and 2015 at four sites in south-central Saskatchewan, Canada, near Rosthern, Saskatoon, Scott, and Yorkton. The soil is classified as an Orthic Black Chernozemic soil at the Rosthern and Yorkton sites and an Orthic Dark Brown Chernozemic soil at the Saskatoon and Scott sites. At the four sites, the crop prior to the experiment was spring wheat and the tillage management was no-till. Monthly cumulative precipitation and mean temperature in the growing season of 2014 were close to or above the average level of the last 30 yr, whereas the growing season of 2015 was drier in early spring, according to data from Environment Canada weather stations near the sites (Table 1). To assess baseline soil nutrients before the experiment, preseeding soil composite samples from the 0–15 cm depth of the soil profile were obtained from each site in May 2014 by taking eight surface soil cores across the study area with a hand auger and combining the cores to produce a composite sample (Table 2).

Table 1. Monthly precipitation and mean monthly temperature during the growing season (May–August) in 2014 and 2015, as compared with the historical (1983–2013) data at the four sites.

		Precipitation (mm)			Temperature (°C)		
Site	Month	2014	2015	HM[a]	2014	2015	HM[a]
Rosthern	May	61	0	53	10.1	11.0	10.6
	June	95	14	107	14.1	17.7	15.4
	July	45	84	57	18.3	19.5	17.9
	August	19	45	41	17.9	17.7	17.1
	Sum/Mean[b]	220	144	258	15.1	16.4	15.3
Saskatoon	May	73	10	18	10.1	10.7	10.9
	June	102	21	82	14.4	17.6	15.5
	July	66	94	61	18.2	19.3	18.0
	August	17	81	41	18.0	17.4	17.4
	Sum/Mean	258	206	203	15.2	16.3	15.5
Scott	May	60	4	36	12.3	9.3	11.2
	June	95	19	62	17.8	16.0	16.6
	July	143	46	72	19.9	18.1	19.4
	August	82	75	46	18.9	16.8	18.3
	Sum/Mean	379	144	216	17.2	15.1	16.4
Yorkton	May	46	8	55	10.5	10.5	10.4
	June	235	28	82	15.4	16.7	15.7
	July	22	123	78	18.2	19.3	18.8
	August	87	46	51	17.6	17.5	17.2
	Sum/Mean	389	205	266	15.4	16.0	15.5

[a]HM, historical mean (1983–2013) from the nearest Environment Canada meteorological station to each of the four research sites.
[b]Precipitation data denotes cumulative precipitation from May to August and temperature data denotes mean monthly temperature during this period.

Table 2. Preseeding soil properties (nutrients measured in kg ha^{-1}) in the 0–15 cm soil profile at the four sites in May 2014.

Site	Texture	pH	EC (ds m^{-1})	NO_3^--N	P	K	SO_4^{2-}-S	Cu	Mn	Zn	B	Fe
Rosthern	Loam	6.2	0.1	6	28	322	5	1.1	37.1	3.3	1.7	174
Saskatoon	Loam	5.9	0.6	19	33	>600	>48	1.3	24.1	6.0	2.4	320
Scott	Loam	6.6	0.1	25	26	>545	9	1.5	27.9	2.0	2.4	118
Yorkton	Loam	7.9	0.1	8	47	463	5	0.9	12.9	5.5	2.4	29

Note: EC, electrical conductivity.

The experimental design was a randomized complete block design with four replicates at each site. In 2014, three modern short-season soybean varieties, three pea varieties, and three lentil varieties were selected to represent varieties and classes commonly grown by producers at the time of the study (Table 3). Before seeding, soybean seed was pretreated with ApronMaxx® RTA® (Syngenta Canada Inc., Guelph, ON) fungicide at the rate of 142 mL per 45 kg seeds. Granular TagTeam® inoculant (Novozymes BioAg Limited, Bagsværd, Denmark) for soybean [*Bradyrhizobium japonicum* (Kirch.) Jordan] and Nodulator® XL inoculant (BASF Canada Inc., Mississauga, ON; 2013) for pea and (or) lentil [*Rhizobium leguminosarum* (Frank) Frank emend. Ramírez-Bahena et al] were mixed together with the seed on site immediately before seeding at double the normal rate for soybean inoculant. Doubling the rate of soybean inoculant is a recommended practice where soybean has not been grown before, as the abundance of *B. japonicum* is typically very low in Saskatchewan soils. Seeding was carried out at the end of May to the first week of June 2014 by the Crop Development Centre, University of Saskatchewan and at each site all crops were seeded on the same day (Table 4). Plot size for each crop and site was 5 m^2 with 3 rows per plot, inter-row spacing of 35 cm, and row length of 3.65 m. Seeding rates were 65 seeds m^{-2} for soybean, 86 seeds m^{-2} for pea, and 129 seeds m^{-2} for lentil. No fertilizers were applied for any of the crops, as significant deficiencies were not identified by preseeding soil analysis (Table 2).

Table 3. Crop varieties used in the study.

Crop	Variety	Market class	Breeder	Herbicide resistance
Soybean	P001T34R	Oilseed	Pioneer Dupont	Group 2
Soybean	TH3303R2Y	Oilseed	Thunder Seeds	Group 2
Soybean	NSC Moosomin	Oilseed	Northstar Genetics	Group 2
Pea	CDC Meadow	Yellow	CDC	Group 2
Pea	CDC Amarillo	Yellow	CDC	Group 2
Pea	CDC Limerick	Green	CDC	Group 2
Lentil	CDC Impower	Large green	CDC	Group 2
Lentil	CDC Imvincible	Small green	CDC	Group 2
Lentil	CDC Maxim	Small red	CDC	Group 2
Wheat	CDC Abound	Hard red	CDC	Group 2
Canola	Nexera 1016RR	Argentine hybrid	Dow AgroSciences	Glyphosate

Table 4. Dates of seeding, harvesting, residue return, and days to maturity at the four sites in 2014 and 2015.

			Harvesting		Days to maturity		
Year	Site	Seeding	Pea/Lentil	Soybean	Pea/Lentil	Soybean	Residue returning
2014[a]	Rosthern	31 May	9 Sep.	17 Sep.	101	109	16 Oct.
	Saskatoon	22 May	2 Sep.	23 Sep.	103	124	16 Oct.
	Scott	1 June	4 Sep.	17 Sep.	95	108	14 Oct.
	Yorkton	23 May	5 Sep.	22 Sep.	105	122	15 Oct.
2015	Rosthern	13 May	19 Aug.		98		30 Sep.
	Saskatoon	12 May	19 Aug.		99		30 Sep.
	Scott	6 May	20 Aug.		106		29 Sep.
	Yorkton	10 May	18 Aug.		100		15 Oct.

[a]In 2014, soybean was harvested later than pea and lentil due to its later maturity.

In 2015, Clearfield hard red spring wheat (‘CDC Abound’) was seeded in the second week of May on the stubble of soybean, pea, or lentil at Rosthern, Saskatoon, and Scott. The seeding rate was 248 seeds m^{-2} and no fertilizers were applied at the three sites. At the Yorkton site, canola (*B. napus* cv. ‘Nexera’) was seeded, as this site was managed by a producer who normally follows a grain legume–canola rotation. At Yorkton, 55 kg ha^{-1} of 11–52–0 fertilizer was applied in the seed-row at the time of seeding. Seeding dates are shown in Table 4. Odyssey® (BASF, imazamox–imazethapyr) was sprayed across the plots at each site in both study years for weed control with the exception of canola, which was treated with glyphosate.

Plant and soil sampling and analyses

In fall 2014 and 2015, crops were harvested at physiological maturity by hand cutting and completely removing aboveground crop materials including grain, straw, and leaves from the plot area. Harvesting dates for each site are shown in Table 4. In 2014, soybean was harvested later than pea and lentil due to its later maturity. Plant samples were dried at 30 °C and weighed to determine the grain and straw dry matter biomass. After threshing, the straw residue was returned to each plot from which it was harvested, followed by a light rotary tilling in order to anchor the residue in place. Residue was spread evenly over the plot area using a rake and a plastic frame was used to constrain the residue within the plot area.

Content of N and P in the grain and straw samples was determined using a hydrogen peroxide–sulphuric acid digestion at 360 °C as described by Thomas et al. (1967), followed by automated colorimetric measurements of N and P concentration in the digests (Technicon AutoAnalyzer; Technicon Industrial Systems, Tarrytown, NY). Carbon content in the straw samples was measured using a Leco TruMac CNS combustion analyzer (Leco Corporation, St. Joseph, MI). Soil composite samples collected were air-dried, sieved, and the <2 mm fraction was retained and analyzed for various extractable nutrient levels and chemical properties. Soil pH and electrical conductivity (EC) were measured in a 1:2 soil:water suspension (Nelson and Sommers 1982). Soil nitrate (NO_3^-) and sulphate (SO_4^{2-}) were extracted using 0.01 mol L^{-1} $CaCl_2$ extraction methodology described by Houba et al. (2000). Automated colorimetry was used to analyze the extracts for levels of NO_3^--N and SO_4^{2-}-S. Available P and K were measured on the soil depth sample of 0–15 cm using a modified Kelowna extraction procedure (Qian et al. 1994). Extracts were colorimetrically analyzed for P using a Technicon AutoAnalyzer II segmented flow automated system (Technicon Industrial Systems). Potassium concentration in the extracts was analyzed using flame atomic absorption (Varian Spectra 220 Atomic Absorption Spectrometer; Varian Inc., Palo Alto, CA). Plant available copper, manganese , zinc, and iron (Cu, Mn, Zn, and Fe) were extracted from samples using a 0.005 mol L^{-1} diethylenetriaminepentaacetic acid solution (Lindsay and Norvell 1978).

Soil N and P supply rates

Two sites (Rosthern and Saskatoon) were selected to follow soil available N (NO_3^--N + NH_4^+-N) and P (PO_4^{3-}-P) supply rates over the 2015 growing season. In May 2015 before seeding, soil samples were collected from the 0–15 cm depth of the soil profile in plots of one variety of each previous crop, including TH3303R2Y soybean, CDC Meadow pea, and CDC Maxim lentil. Preseeding soil supply rates of available N (NO_3^--N + NH_4^+-N) and P (PO_4^{3-}-P) were determined as the 24 h soil N and P supplies using the "sandwich" technique as described by Qian et al. (2008). Anion-exchange and cation-exchange membranes were soaked in a 0.5 M $NaHCO_3$ solution for 2 h and the membrane was then placed between two vial lids filled with soil subsamples with the water content at field capacity. These "sandwiches" were then stored at 20 °C for 24 h. After 24 h, membranes were rinsed using deionized water until they were free of residual soil and eluted with a 0.5 mol L^{-1} HCl solution. The eluate from anion-exchange membranes was analyzed for NO_3^--N and PO_4^{3-}-P and the eluate from cation-exchange membranes was analyzed for NH_4^+-N colorimetrically (Technicon AutoAnalyzer; Technicon Industrial Systems). The initial soil N and P supplies were used as the baseline soil nutrient supplies for the 2015 growing season.

During the 2015 growing season, soil available N and P supply rates were measured using plant root simulator (PRS®) ion exchange resin membrane probes (Western Ag Innovations Inc., Saskatoon, SK) at the Rosthern and Saskatoon sites. Two anion-exchange and two cation-exchange PRS® probes were buried in each plot. The first burial was carried out one week following seeding by inserting PRS®-probes vertically into the 0–15 cm soil profile, with polyvinyl chloride cylinders surrounding the probes to prevent root competition. The area within the cylinders was kept free of plant growth. The probes were replaced biweekly throughout the growing season by inserting a set of newly-regenerated probes in the same soil slots as the previous probes. The concentrations of NO_3^--N, PO_4^{3-}-P, and NH_4^+-N on the probes were determined following the protocol of Hangs et al. (2013). Briefly, probes were washed until the probes were free of soil using deionized water and eluted with a 0.5 mol L^{-1} HCl solution, which was then analyzed for NO_3^--N, PO_4^{3-}-P, and NH_4^+-N colorimetrically (Technicon AutoAnalyzer; Technicon Industrial Systems). The N and P concentrations represented the biweekly supply rates of soil NO_3^--N, PO_4^{3-}-P, and NH_4^+-N. PRS®-probes were regenerated by being shaken three times in a 0.5 mol L^{-1} $NaHCO_3$ solution for 4 h and rinsed thoroughly using deionized water between each shaking. Cumulative supply rates of these nutrients were calculated according to the PRS handbook manual (Western Ag Inc. 2006).

Statistical analysis

Data were analyzed using SAS 9.4 for Windows (SAS Institute Inc., Cary, NC). Data distribution normality was tested using the Kolmogorov–Smirnov test using PROC UNIVARIATE in SAS and homogeneity of variance was tested using the Levene's test. Yield and nutrient uptake data were analyzed by site due to interactions between site–years and comparison of means at each site was conducted using PROC Mixed in SAS, with crop variety as the fixed effect and block as the random effect (Yang 2010). The Tukey HSD method was used to conduct multiple comparisons among group means at an alpha level of 0.05. Comparing means of soil nutrient supplies at each sampling time was analyzed with repeated measures at an α level of 0.10 according to Hangs et al. (2013).

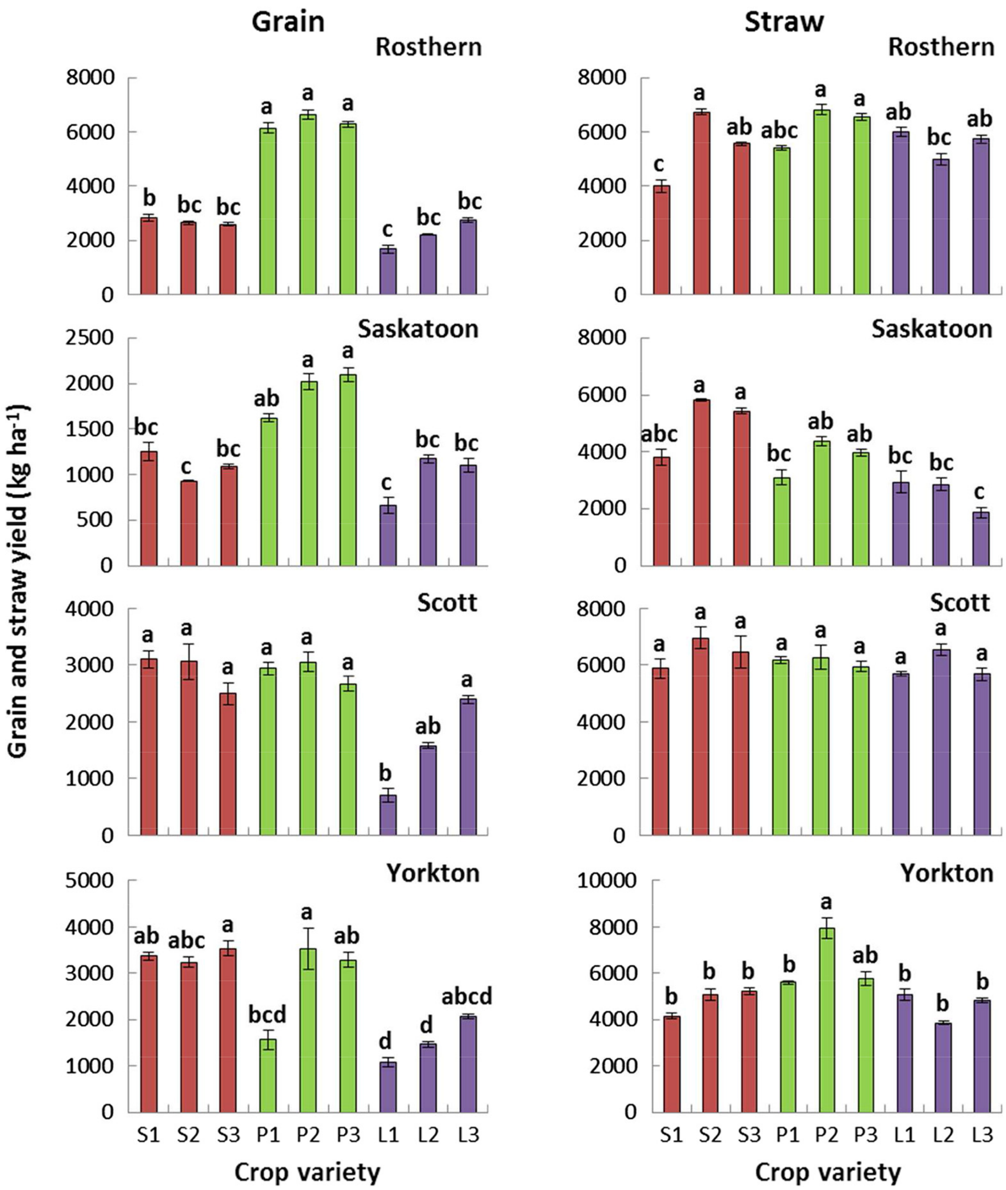
Results

Yield and uptake of N and P in soybean, pea, and lentil

In general, grain yield of soybean, pea, and lentil at the four sites (Fig. 1) was at or above the provincial average yield levels for each crop in Saskatchewan in 2014, which were 1278, 2287, and 1537 kg ha^{-1} for soybean, pea, and lentil, respectively (Government of Saskatchewan 2014). The three selected short-season soybean varieties were able to achieve yield similar to the selected pea and lentil varieties at three of the four sites, with pea having superior yield at Rosthern. Crops generally had a similar straw yield at each site, with CDC Impower (large green market class) lentil having low grain yield but relatively high straw yield due to its tall growth habit compared with the other lentil varieties. Overall, soybean varieties had similar grain yield (929–3534 kg ha^{-1}) and straw yield (3799–6956 kg ha^{-1}) to the grain yield (1565–6644 kg ha^{-1}) and straw yield (3101–7946 kg ha^{-1}) of pea varieties. Lentil generally had slightly lower grain yield (664–2755 kg ha^{-1}), especially at Yorkton, and similar straw yield (1870.5–6551 kg ha^{-1}) compared with soybean and pea. Crop harvest indexes were 13%–46% in soybean, 9%–55% in pea, and 5%–43% in lentil.

Soybean had higher grain N (39.3–47.6 g kg^{-1}) than pea (19.9–37.4 g kg^{-1}) and lentil (28.8–37.6 g kg^{-1}) at 3 of the 4 site–years (Table 5). Soybean grain P concentration (5.1–6.8 g kg^{-1}) was generally greater than pea (3.2–4.5 g kg^{-1}) and lentil (3.3–4.4 g kg^{-1}) at all 4 site–years.

Fig. 1. Grain and straw yield (n = 4) of soybean (red), pea (green), and lentil (purple) at four sites in 2014. S1, S2, and S3 denote P001T34R, TH3303R2Y, and NSC Moosomin soybean varieties, respectively; P1, P2, and P3 denote CDC Meadow, CDC Amarillo, and CDC Limerick pea varieties, respectively; L1, L2, and L3 denote CDC Impower, CDC Imvincible, and CDC Maxim lentil varieties, respectively. Error bars represent one standard error. Within a site, bars with the same letters are not significantly different ($P \geq 0.05$) according to Tukey's HSD test. [Colour online.]



Straw N and P concentrations were higher in some lentil varieties but the trend was not consistent across the sites. Overall, among the three crops, soybean had high concentration of N and P in the grain, while lentil had relatively high N and P concentration in the straw.

Generally, soybean and pea had a similar amount of grain N and P uptake at Saskatoon, Scott, and Yorkton while lentil had relatively lower grain N and P uptake (Table 6). Straw N and P uptake by soybean was similar to pea across the sites. At Yorkton, all three soybean varieties had significantly lower straw N yield than pea and lentil and lower straw P yield than CDC Amarillo pea and all three lentil varieties. Harvest N indexes (HNI) and harvest P indexes (HPI) appeared to be higher for soybean and pea while lentil had relatively lower HNI and HPI.

Stubble impact on soil nutrient supplies and wheat in the subsequent year

In May 2015, plots with lentil grown in the previous rotational year (2014) had higher preseeding supply rates of NO_3^--N than plots with soybean grown in the previous year at Rosthern (Table 7). At Saskatoon, preseeding soil NO_3^--N rates were similar in different crop stubbles from

Table 5. N and P concentration (n = 4) in the grain and straw of soybean, pea, and lentil in 2014.

			N concentration (g N kg^{-1})		P concentration (g P kg^{-1})	
Site	Crop	Variety	Grain	Straw	Grain	Straw
Rosthern	Soybean	P001T34R	43.1a	8.6a	5.5a	0.8c
		TH3303R2Y	43.0a	7.4a	5.7a	1.0bc
		NSC Moosomin	44.5a	8.2a	5.7a	0.9bc
	Pea	CDC Meadow	26.7d	8.7a	3.2c	0.6c
		CDC Amarillo	26.7d	9.1a	3.3c	0.6c
		CDC Limerick	29.7cd	8.9a	3.7bc	0.6c
	Lentil	CDC Impower	30.4c	12.9a	4.1b	1.5ab
		CDC Imvincible	34.4b	14.1a	4.1b	1.8a
		CDC Maxim	31.4bc	9.1a	3.9b	1.1abc
Saskatoon	Soybean	P001T34R	41.2a	7.5b	5.1abc	1.2a
		TH3303R2Y	43.5a	8.4b	6.3ab	1.5a
		NSC Moosomin	45.9a	10.1b	6.8a	1.6a
	Pea	CDC Meadow	19.9c	13.8ab	3.7c	1.1a
		CDC Amarillo	26.8bc	14.6ab	4.2bc	1.1a
		CDC Limerick	28.9bc	18.0a	4.4bc	1.5a
	Lentil	CDC Impower	28.8bc	13.0ab	4.2bc	1.3a
		CDC Imvincible	30.3b	10.8b	3.9bc	1.2a
		CDC Maxim	28.8bc	10.7b	3.7c	1.0a
Scott	Soybean	P001T34R	47.3a	9.5abc	5.6a	0.8bc
		TH3303R2Y	39.3a	3.4c	5.5a	0.6c
		NSC Moosomin	45.7a	6.5bc	5.4ab	0.7bc
	Pea	CDC Meadow	37.4a	14.9a	4.0c	1.2abc
		CDC Amarillo	36.9a	12.8ab	4.0c	0.9bc
		CDC Limerick	36.7a	16.0a	4.3bc	1.1abc
	Lentil	CDC Impower	37.6a	16.9a	3.7c	1.9a
		CDC Imvincible	35.7a	14.9a	3.7c	1.7ab
		CDC Maxim	37.2a	14.6ab	3.3c	1.4abc
Yorkton	Soybean	P001T34R	44.5b	4.2d	5.9a	0.8d
		TH3303R2Y	43.6b	3.8d	5.6a	1.0cd
		NSC Moosomin	47.6a	4.4d	6.0a	0.9cd
	Pea	CDC Meadow	31.1d	12.2c	4.3b	1.4bcd
		CDC Amarillo	30.6d	13.2bc	4.3b	1.3bcd
		CDC Limerick	33.2cd	14.7bc	4.5b	1.5bc
	Lentil	CDC Impower	32.6cd	14.3bc	4.3b	1.9ab
		CDC Imvincible	35.0c	16.4ab	4.4b	2.3a
		CDC Maxim	35.5c	19.3a	4.3b	2.4a

Note: Within a column, means of a site followed by the same lowercased letter are not significantly different from each other ($P \geq 0.05$) according to a Tukey's honest significant difference (HSD) test.

2014. Soybean, pea, and lentil stubbles had similar soil NH_4^+-N and PO_4^{3-}-P supply rates at both site sites before seeding, respectively.

At Rosthern, soybean and pea stubbles had similar soil N supplies at the beginning of the growing season (Fig. 2) while lentil stubble had a higher initial soil N supply, agreeing with the preseeding soil N supply as shown in Table 7. Cumulative soil N supply in soybean stubbles was lower than in lentil stubble in the first month following seeding but by harvest, cumulative N supply was similar in the three stubbles. At Saskatoon, the three pulse stubbles had similar soil N supplies throughout the season. Soil available P supplies were similar in different stubbles at both the Rosthern and Saskatoon sites at the end of the growing season, although at the Rosthern site, soil available P supply was higher in soybean stubble than in lentil stubble for most of the growing season (Fig. 3). Despite the superior pea grain yield at Rosthern in the previous year, soybean, pea, and lentil stubbles produced similar cumulative soil N or P supplies at either of the two sites by the end of the 2015 growing season.

At 2015 harvest, wheat grain and straw yield generally showed no large or consistent response to different stubbles at Rosthern, Saskatoon, and Scott (Table 8). Uptake of N and P in wheat grain and straw was similar on the three stubbles at Scott, whereas at Rosthern and Saskatoon the wheat grain N and P uptake tended to be slightly higher

Table 6. N and P uptake ($n = 4$) in the grain and straw of soybean, pea, and lentil in 2014.

			N yield (kg N ha^{-1})		P uptake (kg P ha^{-1})			
Site	Crop	Variety	Grain	Straw	Grain	Straw	HNI (%)	HPI (%)
Rosthern	Soybean	P001T34R	121.4b	34.0a	15.5bc	3.1b	78a	84ab
		TH3303R2Y	113.9bc	50.1a	15.1bc	6.8ab	69ab	69abc
		NSC Moosomin	116.0bc	45.5a	14.8bc	5.3ab	72ab	74ab
	Pea	CDC Meadow	163.4a	47.6a	19.8ab	3.1b	77a	86a
		CDC Amarillo	177.6a	61.1a	21.8a	4.1b	74ab	84ab
		CDC Limerick	186.9a	58.4a	23.1a	4.0b	76a	85a
	Lentil	CDC Impower	51.2e	78.3a	6.8d	9.3a	40c	42d
		CDC Imvincible	76.6de	72.0a	9.1d	9.1a	52bc	50cd
		CDC Maxim	86.4dc	54.1a	10.8cd	6.6ab	61ab	62bc
Saskatoon	Soybean	P001T34R	51.3ab	25.8b	7.0abc	4.0c	67a	64a
		TH3303R2Y	40.4abc	48.6ab	5.8abc	8.5ab	45abc	41a
		NSC Moosomin	50.1ab	55.3ab	7.4ab	8.8a	48ac	46a
	Pea	CDC Meadow	33.7bc	43.0ab	6.1abc	3.4c	44bc	64a
		CDC Amarillo	54.0ab	63.9ab	8.4ab	4.6bc	46abc	64a
		CDC Limerick	60.8a	71.9a	9.2a	5.8abc	46abc	61a
	Lentil	CDC Impower	19.1c	38.6ab	2.8c	4.0c	33c	41a
		CDC Imvincible	35.6abc	31.7ab	4.6bc	3.5c	53abc	57a
		CDC Maxim	31.6bc	20.5b	4.1bc	2.0c	61ab	67a
Scott	Soybean	P001T34R	150.1a	57.9abc	17.0a	4.9ab	72ab	77a
		TH3303R2Y	124.3ab	24.8c	16.4a	4.1b	83a	80a
		NSC Moosomin	117.2ab	39.6bc	13.5ab	4.8ab	75ab	74ab
	Pea	CDC Meadow	109.5abc	91.8ab	11.8abc	7.1ab	54bc	62abc
		CDC Amarillo	112.3abc	77.8abc	12.1abc	5.3ab	59abc	70ab
		CDC Limerick	98.9abc	94.8ab	11.3abc	6.8ab	51bcd	62abc
	Lentil	CDC Impower	26.8c	97.0ab	2.5d	10.8a	22d	19d
		CDC Imvincible	57.0bc	98.1a	5.9cd	11.0a	37cd	35cd
		CDC Maxim	90.1abc	83.6ab	7.8bcd	8.1ab	52bc	49bcd
Yorkton	Soybean	P001T34R	149.9ab	18.0c	19.9a	3.2e	89a	86a
		TH3303R2Y	141.6ab	19.5c	18.1a	4.6de	88a	80ab
		NSC Moosomin	168.0a	22.6c	21.2a	4.7cde	88a	82a
	Pea	CDC Meadow	48.4de	68.4b	6.6c	7.9bcd	41bc	46cd
		CDC Amarillo	106.1bcd	104.1a	14.9ab	10.2ab	50bc	59bcd
		CDC Limerick	109.1abc	85.0ab	14.5ab	8.4abc	56b	63abc
	Lentil	CDC Impower	35.2e	73.2ab	4.5c	9.6ab	32c	32d
		CDC Imvincible	50.4cde	63.1b	6.4c	9.0ab	44bc	42cd
		CDC Maxim	76.3cde	93.0ab	9.2bc	11.8a	45bc	44cd

Note: Within a column, means of a site followed by the same lowercased letter are not significantly different from each other ($P \geq 0.05$) according to a Tukey's HSD test. HNI, harvest nitrogen index; HPI, harvest phosphorus index.

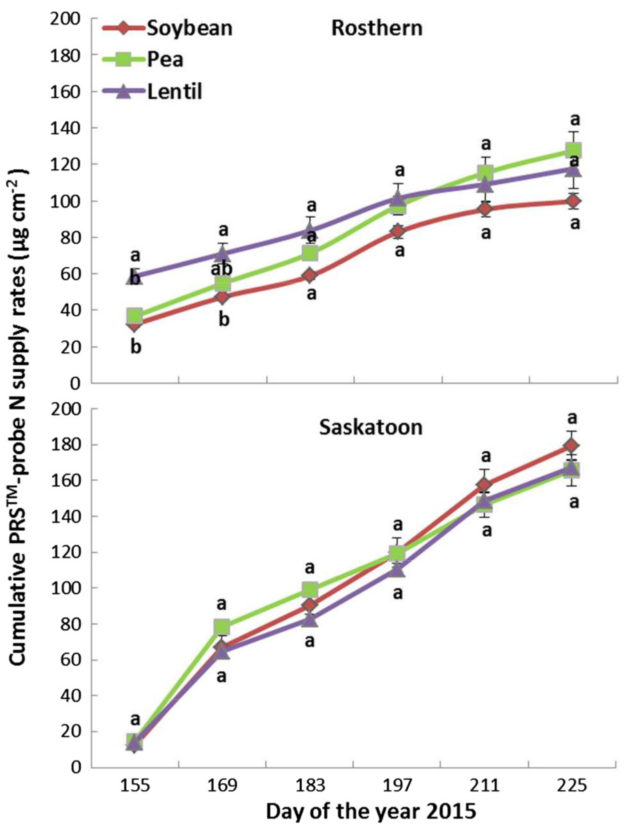
Table 7. Preseeding soil N and P supply ($n = 4$) at Rosthern and Saskatoon in May 2015.

Site	Previous crop[a]	NO_3^--N [μg cm^{-2} (24 h)$^{-1}$]	PO_4^{3-}-P [μg cm^{-2} (24 h)$^{-1}$]	NH_4^+-N [μg cm^{-2} (24 h)$^{-1}$]
Rosthern	Soybean	11.4b	1.5a	0.1a
	Pea	16.6ab	1.1a	0.1a
	Lentil	19.6a	1.0a	0.1a
Saskatoon	Soybean	6.0a	0.3a	0.2a
	Pea	6.5a	0.0a	0.1a
	Lentil	9.2a	0.1a	0.2a

Note: Within a column, means of a site followed by the same lowercased letter are not significantly different from each other ($P \geq 0.05$) according to a Tukey's HSD test.

[a]The crop that was grown in the same plot in 2014.

Fig. 2. Cumulative soil N (NO_3^--N and NH_4^+-N) supply ($n = 4$) at the Rosthern and Saskatoon sites during the 2015 growing season. Values are the mean cumulative soil N supply rates through the 2015 growing season with soybean, pea, or lentil grown in the previous crop year (2014). Error bars represent one standard error. For each sampling date, cumulative soil N supplies with the same letter are not significantly different ($P \geq 0.10$) according to Tukey's HSD test. [Colour online.]



on lentil stubble. Likewise, at Yorkton, canola yield and uptake of N and P was similar on different legume stubbles from the previous rotational year.

Discussion

As Bullock and Nadler (2013) noted, although a lack of heat units and insufficient soil moisture may be considered major challenges for soybean production in western Canada, the future of soybean production appears positive due to the increasing average air temperature across southern Canada. In the present study, the grain yield of selected modern short-season varieties of soybean [929–3534 kg ha^{-1}, harvest index (HI) of 14%–45%], pea (1565–6644 kg ha^{-1}, HI of 22%–53%), and lentil (664–2755 kg ha^{-1}, HI of 11%–37%) are comparable to previous studies conducted in western Canada. Przednowek et al. (2004) reported the grain yield of soybean as 1098–3415 kg ha^{-1} and of pea as 1194–3563 kg ha^{-1} in a 3-yr (1998–2000) field trial carried out at four sites in southern Manitoba. They found that compared with soybean, pea yielded better and provided more N benefits to wheat grown in the subsequent year. In another rotation experiment conducted nearly two decades ago at three sites in Saskatchewan, pea grain yield ranged from 1656–2227 kg ha^{-1} and the grain yield of wheat grown on pea stubble was 43% higher than that grown on wheat stubble (Stevenson and van Kessel 1996*b*), reflecting the rotational benefits of grain legumes to succeeding crops as opposed to non-legumes. Generally, soybean yields in the present study are lower than those reported in eastern Canada and the mid-western United States (Wilcox 2001; Egli 2008; Cober and Voldeng 2012; Messiga et al. 2012; Dagel et al. 2014). Differences in the soybean grain yield between Saskatchewan, eastern Canada, and the United States can be largely attributed to the relatively drier and colder environment in Saskatchewan.

There is little recently reported information on the nutrient uptake of soybean grown in Canada. Parsons (2005) reported the N uptake of soybeans as 62–136 kg ha^{-1} and P uptake as 6.3–12.5 kg ha^{-1} from a 2-yr rotation experiment with different manure treatments conducted in Truro, NS. This study had comparable aboveground N uptake (grain + straw) but lower P compared with the present study. In other regions, there has been a considerable amount of research on nutrient uptake but with variable values reported. In a meta-analysis, data from 480 experiments conducted worldwide suggested the mean of N uptake of soybean as 219 kg ha^{-1}, ranging from 44 to 480 kg ha^{-1}, with 50% of the data falling between 154 and 280 kg ha^{-1} (Salvagiotti et al. 2008). Variation of soybean yield and nutrient uptake is presumably attributed to different growing conditions, fertility treatments applied in each experiment, and differences in how plots were harvested and in processing of plant samples.

In 2014, near-normal precipitation and temperatures were recorded during the growing season, which contributed to good soybean production in this region. Overall, selected soybean varieties had similar yield and uptake of N and P in comparison to pea and lentil at Saskatoon, Scott, and Yorkton. At Rosthern, pea had significantly higher grain yield than soybean and lentil. However, in the following year, soybean, pea, and lentil stubbles did not show large or consistent impact on soil nutrient supplies or the yield and nutrient uptake of wheat and canola. This lack of response implied similar short-term rotational impact of soybean, pea, and lentil under Saskatchewan conditions, suggesting that N and P fertilizer management for crops immediately following soybean may not need large adjustment as opposed to crops following pea and lentil in this region.

However, higher N and P concentrations in soybean grain across the sites indicated greater potential for depletion by crop removal over the long term. Therefore, soil N and P removals need to be considered when rotations with soybean are used for several cycles

Table 8. Yield, N, and P uptake ($n = 4$) in the grain and straw of wheat at Rosthern, Saskatoon, and Scott and of canola at Yorkton in 2015.

			Yield (kg ha^{-1})		N uptake (kg N ha^{-1})		P uptake (kg P ha^{-1})	
Site	Stubble	Variety	Grain	Straw	Grain	Straw	Grain	Straw
Rosthern	Soybean	P001T34R	3052bc	3639a	65.9bc	16.8a	13.8abc	1.3ab
		TH3303R2Y	2905c	3396a	64.2bc	18.0a	13.3abc	1.7ab
		NSC Moosomin	3093abc	3749a	67.9bc	18.2a	13.8abc	1.4ab
	Pea	CDC Meadow	3183abc	3744a	72.2ab	19.4a	14.4abc	1.0ab
		CDC Amarillo	2742c	4236a	60.4bc	25.0a	12.5bc	2.3a
		CDC Limerick	3193abc	3846a	73.3ab	22.3a	14.0abc	1.8ab
	Lentil	CDC Impower	3191abc	3924a	72.1ab	18.3a	13.6abc	0.6b
		CDC Imvincible	3642ab	4056a	83.4a	21.0a	15.2ab	0.9ab
		CDC Maxim	3746a	4016a	85.7a	20.1a	16.2a	1.0ab
	Wheat	CDC Abound	2649c	3108a	57.8c	17.2a	11.6c	1.2ab
Saskatoon	Soybean	P001T34R	2097bc	2208ab	45.1bc	7.3c	9.4bc	1.9a
		TH3303R2Y	2629ab	2705ab	59.9ab	13.4abc	13.0ab	2.9a
		NSC Moosomin	2706ab	2907ab	64.0ab	13.3abc	13.5ab	2.8a
	Pea	CDC Meadow	2925ab	2972ab	66.4ab	15.4ab	14.2a	2.5a
		CDC Amarillo	2850ab	3236a	64.4ab	14.7ab	13.9ab	2.1a
		CDC Limerick	3044ab	3323a	71.5a	16.5a	14.8a	2.5a
	Lentil	CDC Impower	2886ab	3016a	65.8ab	13.4abc	13.7ab	2.3a
		CDC Imvincible	3098a	3184a	73.7a	15.3ab	14.8a	2.2a
		CDC Maxim	2889ab	2880ab	66.6ab	13.9abc	14.0a	2.3a
	Wheat	CDC Abound	1484c	1710b	34.2c	9.1bc	7.5c	2.2a
Scott	Soybean	P001T34R	4775a	3703a	111.8a	19.9a	16.3a	1.3a
		TH3303R2Y	3830a	3009a	86.3a	17.5a	14.3a	1.3a
		NSC Moosomin	4636a	3574a	107.4a	18.0a	16.3a	1.1a
	Pea	CDC Meadow	4331a	3277a	103.3a	17.2a	14.9a	0.9a
		CDC Amarillo	3998a	2992a	93.7a	16.3a	13.8a	0.9a
		CDC Limerick	3909a	2870a	93.9a	15.8a	14.1a	0.9a
	Lentil	CDC Impower	4354a	3257a	105.0a	15.9a	14.4a	0.8a
		CDC Imvincible	4944a	3582a	118.1a	18.2a	16.5a	0.9a
		CDC Maxim	4465a	3418a	105.5a	18.3a	14.9a	1.0a
Yorkton	Soybean	P001T34R	1851a	5306a	50.5a	23.7a	13.0a	1.9a
		TH3303R2Y	1750a	5219a	50.6a	21.7a	13.3a	2.8a
		NSC Moosomin	1911a	5167a	53.7a	18.2a	13.6a	2.1a
	Pea	CDC Meadow	1786a	5012a	50.9a	23.0a	12.9a	1.7a
		CDC Amarillo	1983a	6010a	55.8a	20.5a	14.8a	1.6a
		CDC Limerick	2278a	5952a	68.2a	24.3a	16.3a	2.0a
	Lentil	CDC Impower	2054a	5861a	62.9a	24.6a	15.9a	2.3a
		CDC Imvincible	2017a	5214a	55.8a	24.1a	14.5a	2.7a
		CDC Maxim	2349a	6338a	62.1a	19.7a	16.1a	1.8a

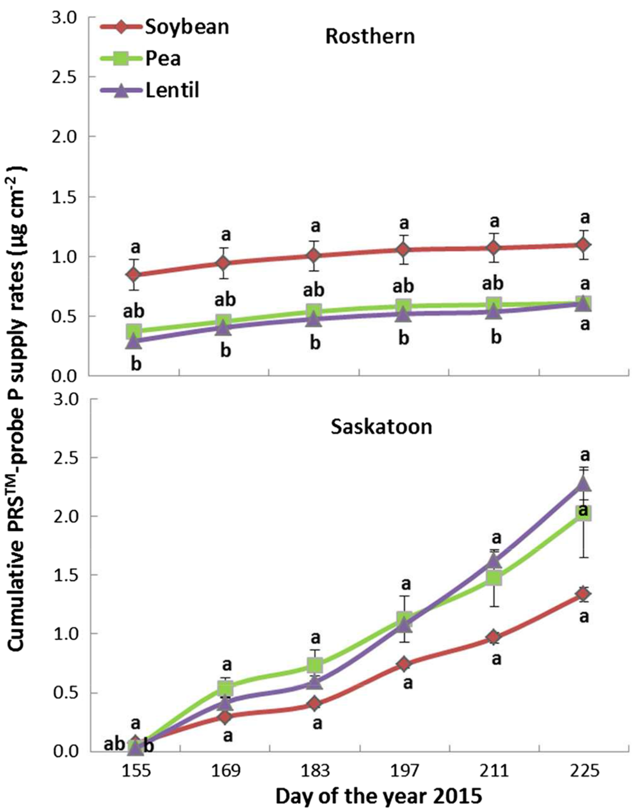
Note: Within a column, means of a site followed by the same lowercased letter are not significantly different from each other ($P \geq 0.05$) according to a Tukey's HSD test.

compared with pea and lentil rotations. Given the dry conditions in May and June of 2015, it is possible that mineralization did not reach the maximum, muting the effects of the previous crops on soil nutrient supplies, crop yield, and nutrient uptake. Although pulse grain yield has been suggested as a parameter for providing N credits in fertilizer recommendations for following crops in rotation (Beckie and Brandt 1997), aboveground straw yield and composition or HI is likely a better indicator for the contribution. However, it is difficult to practically obtain straw yield values for grower fields and below-ground contributions would be very challenging to predict.

Conclusion

Selected short-season varieties of soybean had similar or higher grain yield compared with pea and lentil varieties at three of the four sites under Saskatchewan conditions. Soybean had higher grain N and P concentrations but lower or similar straw N and P concentrations compared with pea and lentil. As a result, soybean had relatively high HNI and HPI, whereas lentil generally had lower HNI and HPI across the sites. Soybean, pea, and lentil as previous crops did not result in large or consistent difference in soil N and P supplies, crop yield, and nutrient uptake in the following year.

Fig. 3. Cumulative soil available PO_4^{3-}-P supply ($n = 4$) at the Rosthern and Saskatoon sites during the 2015 growing season. Values are the mean cumulative soil P supplies through the 2015 growing season with soybean, pea, or lentil grown in the previous crop year. Error bars represent one standard error. For each sampling date, cumulative soil N supplies with the same letter are not significantly different ($P \geq 0.10$) according to Tukey's HSD test. [Colour online.]



Our findings therefore imply that under the growing conditions experienced at the four sites in 2014 and 2015, soybean was able to achieve a similar level regarding yield, uptake of N and P, and benefits to subsequent wheat and canola crops compared with pea and lentil grown under similar conditions in western Canada without extreme weather conditions or other stresses.

Acknowledgements

This work was financially supported by the Agriculture Development Fund, Saskatchewan Pulse Growers, Western Grains Research Foundation, China Scholarship Council, and the University of Saskatchewan. We would like to acknowledge members of Team Schoenau for their assistance with soil sampling, crop harvesting, and sample processing. Help from B. Barlow, S. Ife, and S. Wagenhoffer on seeding and site preparation is also acknowledged.

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