IMPACT OF FERTILIZER PHOSPHORUS (P) SOURCE, RATE, AND PLACEMENT STRATEGY ON YIELD, NUTRIENT UPTAKE, AND P LOSSES IN SNOWMELT RUNOFF WATER ACROSS VARIABLE TOPOGRAPHIES IN SASKATCHEWAN, CANADA

B. Weiseth, J. Schoenau, and J. Elliott
University of Saskatchewan, Saskatoon, SK, Canada
bnw562@mail.usask.ca (306) 381-3220

ABSTRACT

The plant availability and mobility in soil of a fertilizer phosphorus (P) source is influenced by the solubility of the fertilizer product and the reaction products formed in soil over time. In 2021, 2022 and 2023, responses of wheat, pea and canola yield, P uptake and recovery were determined using eight fertilizer P sources applied in a broadcast and incorporate or side-band placement strategy at a low and high (20 vs 40 kg P_2O_5 ha^{-1}) rates in upper (knoll) and lower (depression) landscape positions in a farm field in southern Saskatchewan, Canada. The P sources containing sulfur generally produced higher yields, P uptake and recovery in both landscape positions, while those of low solubility such as rock phosphate resulted in lowest uptake and lowest residual soil available P. The controlling influence of slope in driving nutrient transport in runoff water was investigated in a simulated snowmelt experiment using intact slabs of surface soil removed from the field. Differences in mobility of the fertilizer P sources were reflected in measured concentrations of Soluble Reactive inorganic Phosphorus (SRP_i) in snowmelt water. Less soluble P forms like rock phosphate and struvite resulted in lower P export in water.

INTRODUCTION

The application of 4R Nutrient Stewardship to fertilizer P management practices seeks to optimize crop nutrient uptake and yield while limiting nutrient losses from their place of application. While a variety of fertilizer P sources are commercially available, few studies have compared their agronomic and environmental performance under Canadian Prairie conditions. As the mobility of fertilizer P and its reaction products in soil is a function of its solubility (Chien et al., 2011), the optimal combination of fertilizer P source, rate, and placement strategy to limit losses in runoff water is important to discern. Furthermore, P fertilizer performance may be influenced by varying soil moisture dynamics across the landscape. Given the controlling influence of topography and soil properties on soil water dynamics (Biswas et al., 2012; Crossman et al., 2014), consideration of the influence of landscape and soil properties on fate of added P can benefit development of site-specific prescriptions intended to maximize crop P recovery and limit losses in snowmelt runoff water. Spring snowmelt represents the primary runoff event across the Prairie Pothole Region (PPR) (Pomeroy et al., 2005).

MATERIALS AND METHODS

Field experiments were established at two sites in the Brown soil climatic zone located in SW Saskatchewan. Recognizing the collective impact that slope and soil characteristics have on water redistribution and associated nutrient transport across the landscape and to capture the range of soil-water dynamics across the hummocky landscape of the PPR, each of the two sites are situated on a unique topographic position within the landscape. The sites are intended to represent typical upper (knoll) and lower (depression) slope positions in cultivated landscapes dominated by chernozemic soils. The sites are situated in a farm field near Central Butte, SK (herein referred to as CB Upslope and CB Lowslope). This three-year crop rotation study was established in the spring of 2021 with wheat, followed by pea in 2022, and canola in 2023. For each site, 36 treatments including combinations of eight fertilizer P forms (Table 1) two P application rates (20 and 40 kg P_2O_5 ha^{-1}), and two placement methods of P fertilizer (side-band and broadcast immediately prior to seeding) along with an unfertilized control were established in the spring of 2021.

Table 1. Phosphorus fertilizer sources used in study, listed by name and chemical analysis.

	Fertilizer P Name	**Chemical Analysis (%N - %P_2O_5 - %K_2O - %S)**
1	Monoammonium Phosphate (MAP)	11-52-0-0
2	Polymer Coated MAP (CMAP)	11-52-0-0
3	Liquid Ammonium Polyphosphate (LAP)	10-34-0-0
4	Triple Superphosphate (TSP)	0-45-0-0
5	MAP + Elemental Sulfur (MAP + ES)	9-43-0-16
6	Ammonium Phosphate Sulfate (APS)	17-20-0-15
7	Struvite (S)	5-28-0-0
8	Rock Phosphate (RP)	0-3-0-0

A plot seeder having a 1m-wide tool bar with four openers on 25.4 cm spacing was used for each 4 m x 1 m plot. The seeder is equipped with a double-shoot opener configuration to allow independent placement of seed and fertilizer, where fertilizer was placed in a band approximately 1.9 cm below and 1.9 cm to the side of the seed row for the side-band treatments. For the broadcast treatments, fertilizer was broadcast by a hand spreader to ensure that all the fertilizer was contained within the individual plot immediately prior to seeding. Total nitrogen and sulfur application rates were held constant among all treatments through addition of urea or potassium sulfate to balance nutrients as needed. At harvest, two 1 m length rows were harvested by hand from each plot and then air dried until threshing. Grain yield was weighed and recorded on a kg per ha basis. Straw yield was determined by subtracting grain yield from total biomass.

A simulated snowmelt runoff experiment using an intact slab of surface soil removed from the field plots after harvest was conducted following the method of Wiens et al. (2019) with slight modification as described below to meet the unique objectives of this study. As topographic factors are well known to influence nutrient transport mechanisms in runoff water an added factor of slope manipulation was added to the experiment, as described below. The simulation was conducted in a controlled environment room, where the temperature was kept at 10℃ to approximate the daytime high temperature during peak spring snowmelt. To account for the impact of topography and to allow for the lateral movement of snowmelt water, each slab was set at a predetermined angle. As each of the field sites represent a unique topographic position, a common slope was assigned to each site including 5% and 7% for the CB Lowslope and CB Upslope locations respectively to approximate the slopes as they exist in the field at the sites. Once the slope was set, an amount of snow representing 7.5 cm depth of snow on a per area basis (~ 600 g) was added to each slab and the snow was allowed to melt. Due to the low soil moisture content upon slab removal from the field, a second 600 g addition of snow was applied approximately 24 hrs after the first addition. Once the second addition had melted, the volume of run-off water was measured and a sub-sample of the runoff water collected for analysis.

RESULTS AND DISCUSSION

Yields

The yield results of the 2023 season canola (*Brassica napus*, var. PV681) are presented by site and experimental factor in Table 2. The 2023 growing season was drought affected, with lower-than-normal rainfall in June and July. In 2023, grain and straw yield were significantly influenced by site, with higher yields in the wetter Lowslope site. Fertilizer P source had a significant influence ($P < 0.10$) at the CB Lowslope site but not in the drier CB Upslope site. At the CB Lowslope site, grain yields were highest from application of MAP, followed closely by MAP+ES. These were the only treatments where a significant yield increase was observed relative to the control treatment. Overall, the limited yield response to P fertilization may be explained by dry conditions. Higher canola yield obtained using P sources containing S is consistent with similar responses observed in 2021 with spring wheat (data not shown), where yield and crop P uptake was greatest with APS and lower when less soluble P sources like rock P and struvite were used. Mobility and plant availability of fertilizer P is influenced by its solubility (Chien et al., 2011) and is reduced under dry conditions.

At both sites in 2023, neither fertilizer P rate nor placement method was shown to significantly influence canola grain or straw yield ($P > 0.10$) (Table 2). In 2021, a small but significant benefit of side-banding versus broadcasting was observed in spring wheat yield and P uptake. The lack of significant yield response in 2023 to placement or rate in P fertilized treatments also reflects three successive years of fertilizer P application in which there was reduced P uptake and crop removal due to dry conditions. Soil samples collected in fall of 2022 revealed each site to be more than sufficient in plant-available phosphate (data not shown). This observation agrees with Karamanos (2007), where out of 22 experiments conducted across Western Canada with canola, only 13% demonstrated a positive yield response to fertilizer P application where residual soil test Olsen P levels were greater than 30 lbs per acre. Differences in fertilizer P response observed in the two contrasting slope position sites in the current study supports the creation of site-specific Beneficial Management Practices that consider soil and landscape factors.

Table 2. Mean canola grain and straw yield by experimental factor and treatment for each field site.

		Site			
		CB Upslope		CB Lowslope	
Factor	Treatment	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})
Source	C	1027^{a}	2199^{a}	2357^{b}	4964^{b}
	APS	1069^{a}	2666^{a}	2759^{ab}	5849^{ab}
	LAP	990^{a}	2454^{a}	2582^{ab}	5547^{ab}
	MAP	1081^{a}	2392^{a}	2978^{a}	6405^{a}
	MAPC	1051^{a}	2678^{a}	2882^{ab}	5967^{ab}
	MAP+ES	1090^{a}	2637^{a}	2974^{a}	6278^{a}
	RP	1034^{a}	2506^{a}	2593^{ab}	5406^{ab}
	S	1099^{a}	2542^{a}	2606^{ab}	5573^{ab}
	TSP	1174^{a}	2702^{a}	2629^{ab}	5614^{ab}
	P Value	0.88	0.84	0.09	0.09
	SEM	116	178	600	955
Rate	Low (20 kg P_2O_5 ha^{-1})	1074^{a}	2488^{a}	2682^{a}	5638^{a}
	High (40 kg P_2O_5 ha^{-1})	1063^{a}	2574^{a}	2731^{a}	5829^{a}
	P Value	0.86	0.34	0.61	0.27
	SEM	62	90	96	174
Placement	Side-band	1025^{a}	2566^{a}	2717^{a}	5705^{a}
	Broadcast	1112^{a}	2495^{a}	2696^{a}	5762^{a}
	P Value	0.17	0.43	0.83	0.75
	SEM	87	90	96	174

P Concentration in Run-Off

Soluble Reactive inorganic P (SRP_i) concentrations in simulated snowmelt runoff from intact soil slabs collected after harvest of spring wheat in fall of 2021 are shown in Figure 1. In general, addition of fertilizer P resulted in higher SRP_i concentrations in snowmelt runoff water relative to the control treatment where no fertilizer P was applied. In the case of rock phosphate (RP) however, SRP_i losses were not significantly different than the control treatment. This is consistent with the lower solubility of P forms (apatite) in rock phosphate fertilizer sources and the low measured extractable and exchangeable P in the soil following application of this source (Table 3). Trends in SRP_i losses from fertilizer P sources were not consistent between the two different landscape position sites. This may reflect differences in P fertilizer reaction products formed in the different soils from the P forms and agrees with soil and landscape properties as driving factors in nutrient transport (Crossman et al., 2014).

Overall, SRP_i losses in the simulated snowmelt run-off were not found to be significantly influenced by fertilizer P placement method (P >0.10) (Data not shown). Side-band at seeding had slightly higher post-harvest extractable and exchangeable P in the surface soil than the pre-seeding broadcast (Table 3), which may reflect reduced fixation from banding of the P. This could offset the benefit of deeper placement with banding compared to broadcasting on reducing run-off P. In this study, the timing of the surface broadcast application immediately prior to seeding, with incorporation accomplished during seeding with the seeding tool, could also be an important factor to limit P losses in runoff water, and agrees with previously conducted work (Weiseth, 2015; Wiens et al., 2019).

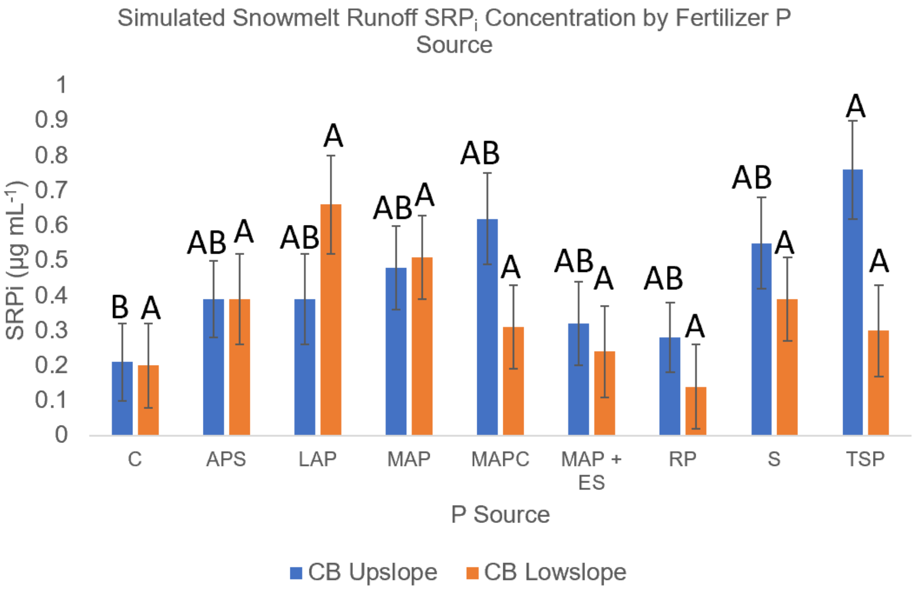

Figure 1. Mean SRP_i concentration in simulated snowmelt runoff water by fertilizer source conducted on intact surface soil slabs removed in fall of 2021 from the two field sites. Error bars represent the standard error of the mean of each treatment. For a site, bars followed by different letters indicate a significant (p<0.10) difference.

Table 3. Post-harvest 2021 soil (0-15cm) extractable (modified Kelowna) and exchangeable (anion exchange resin membrane) P by field site and treatment.

		Site		Site	
Factor	Treatment	CB Upslope	CB Lowslope	CB Upslope	CB Lowslope
		MK-P (mg kg^{-1})		Anion Exchange Membrane P (µg 10cm^{-2})	
	C	8.2^{ab}	10.1^{b}	2.4^{c}	2.9^{a}
	APS	14.2^{a}	13.1^{ab}	5.3^{ab}	2.7^{a}
	LAP	12.0^{ab}	11.2^{ab}	4.1^{abc}	3.0^{a}
	MAP	13.0^{ab}	13.1^{ab}	4.9^{a}	3.5^{a}
	MAPC	12.2^{ab}	16.2^{a}	4.4^{ab}	5.0^{a}
Source	MAP+ES	11.4^{ab}	15.1^{ab}	3.6^{abc}	3.9^{a}
	RP	8.3^{b}	11.6^{ab}	2.6^{bc}	3.0^{a}
	S	12.1^{ab}	13.3^{ab}	4.5^{ab}	4.8^{a}
	TSP	11.3^{ab}	11.71^{ab}	3.3^{abc}	3.6^{a}

	P Value	<0.05	0.01	0.001	0.24
	SEM	3.5	2.4	1.7	1.1
Rate	Low (20 kg P_2O_5 ha^{-1})	10.3^{b}	12.4^{a}	3.4^{b}	3.5^{a}
	High (40 kg P_2O_5 ha^{-1})	12.5^{a}	13.3^{a}	4.4^{a}	3.6^{a}
	P Value	<0.01	0.46	0.03	0.19
	SEM	0.8	2.4	1.7	1.1
Placement	Side-band	12.1^{a}	13.7^{a}	4.4^{a}	3.9^{a}
	Broadcast	10.6^{a}	12.0^{a}	3.4^{b}	3.2^{a}
	P Value	<0.01	0.10	0.04	0.98
	SEM	0.8	2.4	1.7	1.1

CONCLUSION

Lower solubility P fertilizer forms demonstrated lower plant availability and yield response but also lower losses in snowmelt run-off from prairie soils. Drought conditions were a factor limiting the overall crop response to rate and placement of added P fertilizer in this study. Differences in performance and fate of P forms observed in the up versus low slope sites point towards a need for site-specific P management in prairie pothole landscapes.

REFERENCES

Biswas, A., H.W. Chau, A.K. Bedard-Haughn, and B.C. Si. (2012). Factors controlling soil water storage in the hummocky landscape of the Prairie Pothole Region of North America. *Can. J. Soil Sci* .https://doi:10.4141/CJSS2011-045

Chien, S.H., L.I. Prochnow, S. Tu, and C.S. Snyder. (2011). Agronomic and environmental aspects of phosphate fertilizers varying in source and solubility: An update review. *Nutr. Cycling Agroecosyst*. https://doi:10.1007/s10705-010-9390-4

Crossman, J., M.N. Futter, P.G. Whitehead, E. Stainsby, H.M. Baulch, L. Jin, S.K. Oni, R.L. Wilby, and P.J. Dillon. (2014). Flow pathways and nutrient transport mechanisms drive hydrochemical sensitivity to climate change across catchments with different geology and topography. *Hydrol. Earth Syst. Sci.*, https://doi.org/10.5194/hess-18-5125-2014

Karamanos, R. (2007). Agroeconomics of phosphate fertilizer in Manitoba. In: Proceedings of the 8th Annual Manitoba Agronomists Conference. 11-12 Dec. 2007. University of Manitoba, Winnipeg, MB, Canada.

Pomeroy, J.W., D. de Boer, and L.W. Matz. 2005. Hydrology and water resources of Saskatchewan. Ctr. Hydrol. Rep. 1. Univ. Saskatchewan, Saskatoon, SK, Canada.

Weiseth, B. (2015). *Impact of fertilizer placement on phosphorus in crop, soil, and runoff water in a brown chernozem in south-central Saskatchewan* [Master's thesis, University of Saskatchewan]. USASK library. https://harvest.usask.ca/handle/10388/ETD-2015-11-2287.

Wiens, J.T., B.J. Cade-Menun, B. Weiseth, and J.J. Schoenau. (2019). Potential phosphorus export in snowmelt as influenced by fertilizer placement method in the Canadian Prairies. *J. Environ. Qual*. https://doi.org/10.2134/jeq2018.07.0276.