Impact of targeted management practices on nutrient export in runoff water on drained agricultural land (UnivRS #353133)

Year 1 (March 2021-March 2022) Progress Report

To: Saskatchewan Soil Conservation Association

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INTRODUCTION

Since the implementation of the Agricultural Water Management Strategy (AWMS) in 2015, the Water Security Agency (WSA) has provided funding to various organizations to demonstrate the process of achieving drainage approvals that meet regulatory requirements in balancing economic and environmental considerations. Further, WSA is interested in evaluating the cumulative impact that a properly designed drainage project in conjunction with the implementation of agricultural Beneficial Management Practices (BMPs) has on reducing nutrient export in runoff water. To this end, a multi-year project was initiated at the Glacier FarmMedia (GFM) Discovery Farm, including the process of achieving regulatory approval and the construction of a drainage project in fall of 2020 followed by a subsequent two-year field study initiated in 2021 to assess the impact that a particular BMP has on influencing nutrient losses in run-off water. The BMP's evaluated with relevance to soil conservation and regeneration are emphasized in this report.

SCIENTIFIC TEAM

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PROJECT OBJECTIVES

An outline of the project objectives is provided below:

- Achieve successful approval to construct a drainage work at the site;
- Complete construction of drainage work according to approval and host extension event;

- Evaluate the impact that regenerative agriculture practices (i.e. annual forage polycropping) have on influencing nutrient export in runoff water;
- Evaluate the impact that precision fertility management practices have on influencing nutrient export in runoff water.
- Evaluate the impact that crop residue management practices have on influencing nutrient export in runoff water.
- Transfer knowledge obtained from above project objectives to agricultural public through an extension event and GFM channels to magnify the impact of the completed project.

FIELD SITE DESCRIPTION

The field site is located at the Glacier FarmMedia (GFM) Discovery Farm Langham, located west of Langham, Saskatchewan (E ½ 15-39-8 W3M). The soil is classified as an Orthic Dark Brown Chernozem of the Elstow-Bradwell association. Typical soils here exhibit a loam to clay loam texture and have been formed on a glacio-lacustrine parent material. Very gentle slopes ranging from 0.5-2% are evident (Acton and Ellis, 1978). Working in consultation with technical and regulatory experts from the Saskatchewan Water Security Agency who conducted an intensive site survey in 2020, eight independent watersheds, henceforth referred to as basins, consisting of temporary, seasonal wetlands and covering a cumulative area of approximately 16 hectares (ha) were identified in a single field having a common management history (Figure 1).

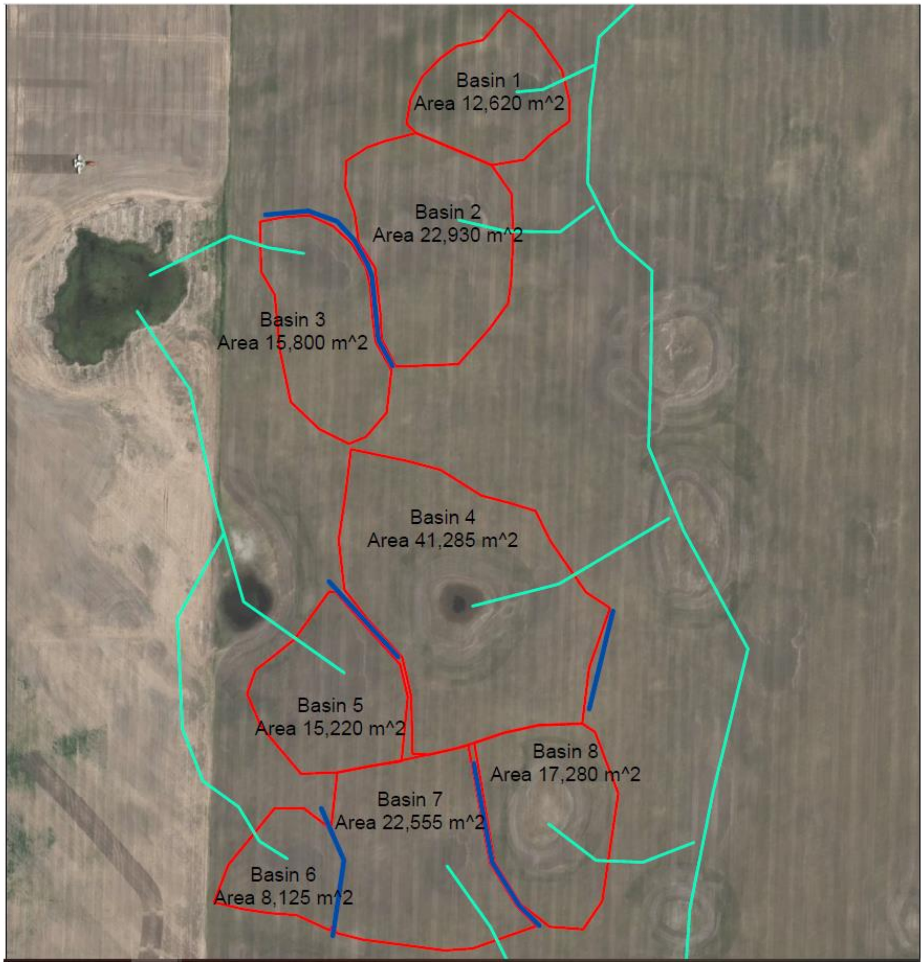


Figure 1. Field site overview showing basins (red polygons) and surface ditches (teal lines).

SURFACE DITCH CONSTRUCTION

In fall of 2020, surface ditches were constructed as a part of a comprehensive water management strategy to channel water from each basin to an approved adequate outlet. Construction activities were completed by Jeff Penner of V-Wing in September 2020. A picture of the equipment utilized is shown in Figure 2 below. For the purpose of knowledge transfer and dissemination activities, an on-site extension event during construction activities was planned to provide members of the general public the opportunity to view the event. However, due to restrictions associated with the COVID-19 pandemic, a professional videographer company was hired to capture footage of the construction activities instead. This video is publicly available for viewing on the discoveryfarm.ca website. The entire project area was mapped on August 25, 2021 using a Quantum Trinity Remotely Piloted Aircraft System (RPAS) equipped with a Yellowscan Qube 240 LiDAR. Resultant data was used to create a high-resolution Digital Elevation Model (DEM) of the site, which serves as an “as-constructed” map of the site, and will be used to detect micro-variation in topography (Figure 3).

Figure 2. Field equipment used for construction of surface ditches.

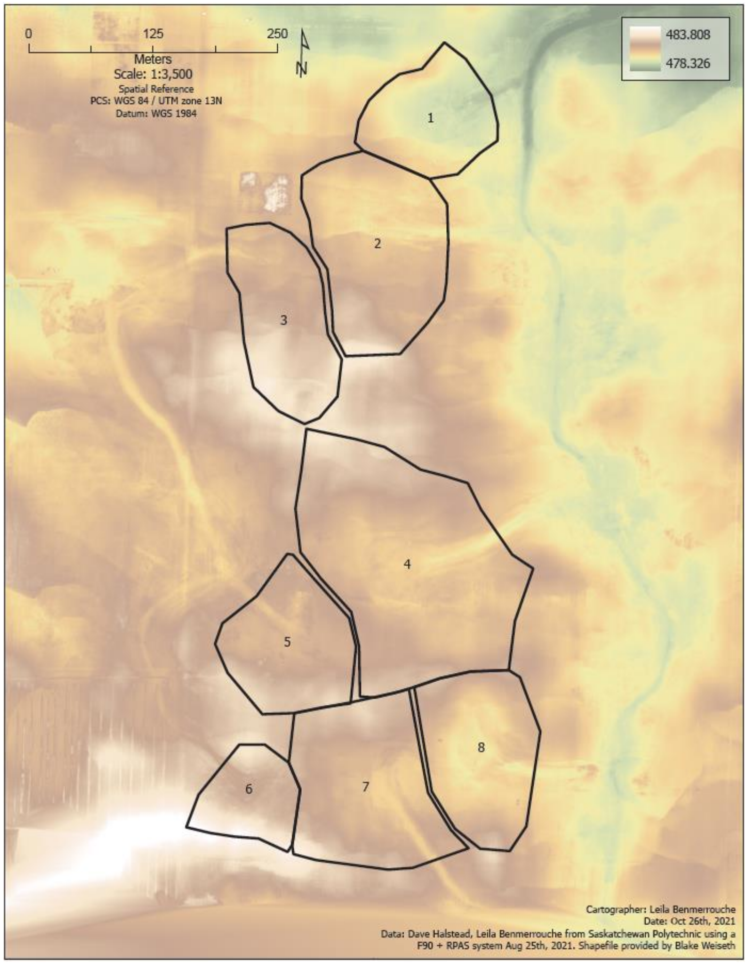


Figure 3. Digital Elevation Model of field site after construction of surface ditches.

EXPERIMENTAL DESIGN

In early spring of 2021, prior to instigation of management treatments on the watershed basins, snowmelt run-off water samples were collected by hand from each basin over a four-day period during peak run-off and were analyzed for Soluble Reactive P (SRP) concentrations to determine baseline water quality characteristics prior to treatment initiation. Additionally, in spring 2021, surface (0-10 cm) soil samples were collected from six locations in a transect across each basin and were analyzed for baseline physical and chemical properties. These same transect locations were sampled and analyzed again in fall of 2021, and will be sampled and analyzed again in fall of 2022. The transect locations were strategically chosen within each basin to represent three distinct landform complexes (i.e. unique topographical positions) across the landscape including 1) upslope, 2) midslope, and 3) lowslope. In this way, each landform complex is represented by two transect sampling locations in each basin. A graphical representation showing transect locations across the basin to include replicates of landform element complexes is shown in Figure 4 below.

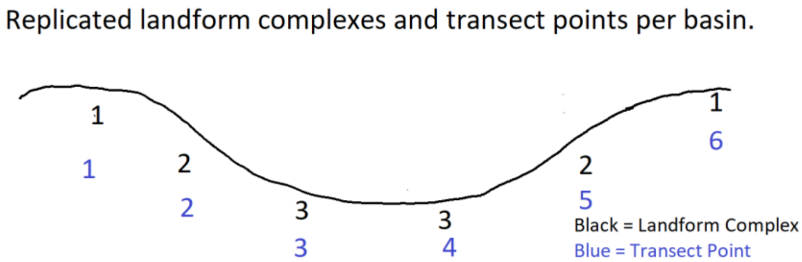


Figure 4. Diagrammatic representation of replicated landform complex locations (black numbers 1, 2 and 3 represent upslope, midslope and lowslope landform element complexes) and respective transect sampling points (blue numbers) per basin.

FIELD STUDY

Following construction of the comprehensive water management strategy, a two-year field study was initiated beginning in spring of 2021 as part of the PhD research work conducted in Blake Weiseth's PhD program. The field study is intended to determine the impact that a given BMP implemented on land subjected to surface drainage has on influencing crop productivity including 1) yield and nutrient uptake and removal in harvest and 2) nitrogen (N) and phosphorus (P) concentrations and losses in run-off water. In total, three BMPs were evaluated, along with a control treatment. Each of the treatments is randomly assigned to the two of the eight basins to provide replication. The four treatments each applied to two of the basins are outlined below:

1) Variable-rate precision fertilizer application (F): Rates of N and P varied according to prescription developed for each unique management zone delineated within the basins. The VR prescription seeks to achieve acceptable crop yield goals while reducing nutrient application rates compared to standard practices by accounting for residual plant-available nutrients often found accumulated in low-lying areas within the field as assessed through spring soil sampling and analysis. Crop uptake and removal of residual nutrients in harvested material, with adjusted fertilizer rates to match soil fertility differences is anticipated to result in reduced nutrient export in run-off water compared to the control treatment.

2) Crop residue management (R): An industry-accepted residue management practice (e.g.shallow tillage) conducted following crop harvest to lightly incorporate crop residue into the soil profile. As previous research has shown surface crop residue to be a significant source of soluble reactive P (SRP), incorporation of crop residue into the surface soil seeks to reduce interaction of surface crop residue with snowmelt run-off water, thereby reducing the removal of SRP from the residue in run-off.

3) Poly-cropping of annual forages (P): A blend of annual forage species including N-fixing legumes. Species in the annual forage mix along with the percentage each species comprised of the mix is as follows: hps Hairy Vetch (30%), hps Crimson Clover (25%), hps Tillage Radish (25%), and hps Turnips (20%).As salt-affected soils tend to manifest in low-lying areas of the landscape due to water tables periodically near the soil surface, cropping of annual forage species which are relatively more salt-tolerant than annual grain species, is increasing in popularity as a targeted BMP. Annual forage species of

diverse composition and with specific traits such as salt tolerance are anticipated to have increased uptake of residual soil nutrients and soil water use compared to annual grain species. Further, with the inclusion of legumes within the forage species blend, reduced fertilizer N application at the time of seeding is needed compared to annual cereal or oilseed crops to achieve acceptable crop yields.

4) Control (C): A control treatment of standard farming practices including fixed fertilizer application rates and no post-harvest residue management.

For treatments 1, 2, and 4, the crop of interest was flax in 2021. A multi-species annual forage blend was seeded in treatment 3 as described below.

METHODS

Seeding

All seeding operations were conducted using a 24.4 m wide SeedHawk toolbar with a SeedHawk 980 air cart. The toolbar has independently-controlled openers on 30.5 cm spacing, with seed and fertilizer delivered in a double-shoot side-band configuration. The annual forage polycropping treatment (P Treatment) was planted on May 28, 2021, with a seed rate of 13 kg ha^{-1} along with fertilizer applied in the side-band at rates of 56 and 28 kg N and P_2O_5 per ha respectively. A fixed rate of seed and fertilizer was applied for the control treatment. Application rates of seed and fertilizer are shown in Table 1.

Seeding operations for all basins seeded to flax (Treatments C, F and R) were completed on May 31, 2021. A fixed rate of seed and fertilizer was applied for the control treatment while for the variable-rate fertilizer treatment, a unique rate was applied to each of ten soil management zones delineated within the relevant basins. Application rates of seed and fertilizer prescribed for each management zone are shown in Table 2 below. Rates of seed and fertilizer prescribed for soil management zone 5 (mid range) were applied to the entire basins assigned to the control treatment. Accounting for the percent area each soil management zone occupies within the basin (see Table 3), weighted average rates of N, P_2O_5, and seed for basins 3 and 4 are shown in Table 4 below.

Table 1: Application rates of seed and fertilizer nutrients applied for annual forage polycropping treatment.

Seed (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (kg ha^{-1})
45	93	52	11	11

Table 2: Application rates of seed and fertilizer nutrients by soil management zone in variable-rate fertilizer application treatment (F Treatment).

Zone	Seed (kg ha^{-1})	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	S (kg ha^{-1})
1	50.4	72.19	32.71	9.52	9.52
2	44.8	74.59	36.07	9.80	9.80

3	44.8	79.51	39.43	10.08	10.08
4	44.8	85.79	45.25	10.08	10.08
5	44.8	93.13	51.96	10.64	10.64
6	44.8	95.81	56.90	10.08	10.08
7	50.4	85.06	54.21	8.40	8.40
8	56.0	63.70	43.91	5.60	5.60
9	67.2	48.89	35.39	3.92	3.92
10	78.4	35.45	27.78	2.80	2.80

Table 3. Breakdown of area occupied by each soil management zone across Basin 3 and 4.

Zone	Basin 3		Basin 4	
	Area (ha)	(% Area of Basin)	Area (ha)	(% Area of Basin)
1	0.092	5.7	0.152	3.6
2	0.135	8.3	0.531	12.6
3	0.195	12.0	0.434	10.3
4	0.303	18.7	0.442	10.5
5	0.255	15.7	0.539	12.8
6	0.260	16.0	0.722	17.1
7	0.198	12.2	0.698	16.6
8	0.159	9.8	0.522	12.4
9	0.024	1.5	0.178	4.2
10	0.000	0.0	0	0
Total	4.007	100	4.219	100

Table 4. Application rates of seed, N, and P for variable rate (Treatment F) presented as weighted averages and relative to control treatment.

Basin	Weighted Average Application Rate (kg ha^{-1})					
	Flax Seed	% of Zone 5	N	% of Zone 5	P_2O_5	% of Zone 5
3	47.2	105.4 %	83.3	89.4 %	46.8	90.1 %
4	48.3	107.8 %	81.5	87.5 %	46.8	90.1 %

Data Collection Hardware Installation

On June 2, 2021, an H-flume was installed at the point where the surface ditch exits each basin, as shown in Figure 5 below. Additionally, a soil moisture probe (Sentek Technologies, Drill & Drop model) was installed in basins 1, 2, 5, and 6. These probes measure volumetric soil moisture content in 10 cm depth increments from the surface to a 120cm depth. Each soil moisture probe is coupled to an above-ground precipitation gauge.

Figure 5. Example of H-flume installed at the exit point of the surface ditch from each basin.

Weed Control

Weed control at the study area was achieved by chemical means through the application of approved herbicides at label rates. For the annual forage polycropping treatment, pre-seed herbicide application consisted of glyphosate, carfentrazone-ethyl, and bromoxynil. For treatments seeded to flax, pre-seed herbicide application consisted of sulfentrazone, carfentrazone-ethyl, and glyphosate. In-crop herbicide application for the flax treatments consisted of bromoxynil, MCPA, and clethodim. No herbicides were applied in-season for the annual forage polycropping treatment due to lack of products registered for application on all the species included in the poly-cropping mixture.

Crop Harvest

For the annual forage polycropping treatment, forage harvest samples were collected on two dates, including on July 15, 2021 when the forage would normally be harvested, and September 30, 2021 to account for biomass regrowth following the first cutting. During each cutting event, a single m^2 biomass sample was collected from each of the six transect locations per basin and dry biomass yield was recorded following air drying. Square metre flax samples were collected by hand on August 24, 2021 and air dried until threshing for grain and straw yield determination on October 19, 2021. For flax treatments, straw yield was calculated by subtracting grain yield from the total mass of the m^2 sample. For the annual forage polycropping treatment, yield consisted of the mass of the entire above-ground sample. An image showing the productivity of the annual forage poly-cropping treatment taken on September 29, 2021 just prior to second cut harvest is shown in Figure 6 below.

Post Harvest Tillage

On September 23 of 2021 the flax stubble in basins 2 and 5 (crop residue management treatment) received a light tillage operation with a 6 foot wide chisel plow with 12 inch spacing and sweeps. This treatment is evaluated for its effect on infiltration, nutrient export in simulated snowmelt run-off and in spring 2022 field snowmelt run-off.

Figure 6. Photo showing basin receiving annual forage polycropping treatment taken on September 29, 2021.

Post-harvest Soil Sampling

Following the 2021 crop harvest, surface (0-15 cm) soil samples were collected from each of the six transect locations per basin and analyzed for residual plant-available nitrate and phosphate. Additionally, from each transect location, intact soil slabs were extracted from the field (Figure 7) and frozen upon return to the laboratory. A simulated snowmelt run-off event will be conducted under climate-controlled conditions in Spring 2022 as outlined below. Finally, water infiltration assessment was conducted following crop harvest at each transect location per basin using a double-ring infiltrometer (see Figure 8). Upon assessment of water infiltration rates, the double-ring infiltrometer was removed and reinstalled prior to soil freeze up to facilitate measurement of water infiltration rates in spring of 2022 during peak snowmelt.

Figure 7. Apparatus used for intact soil slab removal.

Figure 8. Double-ring infiltrometer used for water infiltration assessment.

Residue Leachate Experiment:

A residue leachate experiment was added to the study and conducted to determine Soluble Reactive Phosphorus (SRP) released from crop residue as influenced by fertilizer source and placement method, to better determine the sources of P that may be released to run-off water. For the selected treatment combination as described in “Post-harvest Soil Sampling” section above, a crop residue sub-sample was collected representing a pre-defined proportion of the total surface crop residue and harvested plot area. The residue subsample was placed in a plastic bag, and a known volume of distilled water was added to represent 3 cm of run-off water on a per area basis. The bags were then sealed and care was taken to ensure that air was excluded from the system. The bags were allowed to sit at room temperature for 24 hrs and then were placed outside to freeze. During the freezing period, the diurnal temperature ranged from -10 to 0℃ and was intentionally chosen to reflect environmental conditions during spring snowmelt. Once frozen, the samples were allowed to thaw at room temperature and a leachate sub-sample was collected for analysis.

Simulated Snowmelt Run-off Experiment:

The simulated snowmelt run-off experiment is conducted to assess the impact of the management treatments on soluble reactive P and nitrogen released in snowmelt run-off water under controlled conditions. Further, as topographic factors are well known to influence nutrient transport mechanisms in run-off water an added factor of slope manipulation was added to the experiment, as described below. The simulation is conducted in a controlled environment room, with a temperature of 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 to replicate the average slope from where it was extracted from the field. Once the slope is set, ~600 grams of uncontaminated snow (representing 7.5 cm depth of snow on a per area basis) is added to each slab and the snow allowed to melt within the controlled environment (Figure 3). If required due to the low soil moisture content upon slab removal from the field, a second 600 g addition of snow is applied approximately 24 hrs after the first addition. Once the second addition has melted, a sub-sample of the run-off water is collected for analysis.

Figure 9. Snow addition to soil slab with container to catch run-off water (foreground) and wooden shim used to manipulate slope angle (background).

RESULTS

Climate data

Monthly mean temperature and precipitation data are presented by month over the 2021 growing season in Table 5 below.

Table 5. Comparison of mean monthly precipitation (mm) and temperature (°C) during the 2021 growing season at Discovery Farm, Langham SK.

	Discovery Farm Langham	
Month	Mean Temperature (°C)	Mean Precipitation (mm)
May	10.8	42.0
June	19.2	27.6
July	21.5	11.4
August	17.6	44.6
Total	--	125.6

Baseline soil and run-off water properties

Selected surface (0-10 cm) soil properties from samples collected in spring 2021 prior to treatment initiation are reported by treatment and landform complex in Table 6 below. Snowmelt run-off water samples collected during peak run-off in spring 2021 are reported for each basin in Figure 10. No statistically significant difference was observed in Soluble Reactive P concentrations measured between the eight basins in the study ($p>0.10$).

Table 6. Selected surface (0-10 cm) soil properties by treatment and complex collected in spring 2021 prior to treatment initiation.

		Soil Properties (0-10 cm)					
Treatment	**Complex**	PO_4^- µg/g	NO_3^- µg/g	NH_4^+ µg/g	OC %	pH	EC dS/m
C	1	5.65	21.48	5.34	2.2	7.6	0.3
	2	8.18	47.99	4.31	2.7	7.2	3.9
	3	14.40	20.39	5.36	4.0	7.8	0.3
R	1	4.50	20.44	4.73	2.5	7.0	2.5
	2	7.74	20.85	3.99	3.1	7.4	0.6
	3	14.54	33.92	3.68	3.1	7.5	1.9
F	1	8.39	36.92	3.95	2.5	6.9	0.3
	2	11.93	35.19	4.48	2.7	6.6	1.7
	3	8.08	30.43	4.05	2.5	7.3	0.4
P	1	9.95	25.83	5.46	2.4	6.7	0.2
	2	8.45	57.62	6.85	2.5	6.7	3.3
	3	9.01	19.53	7.32	2.8	6.6	0.5

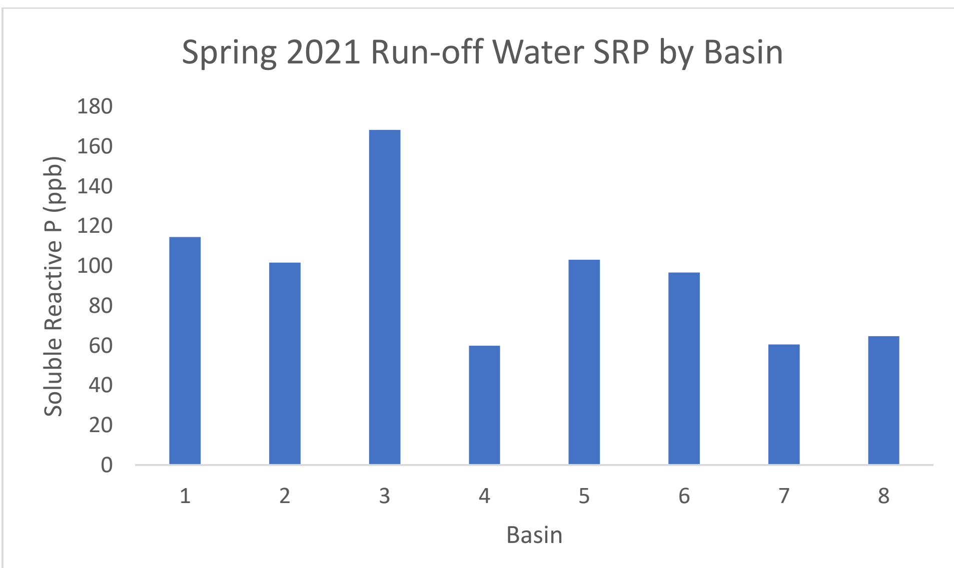


Figure 10. Soluble Reactive P concentration (parts per billion) by basin measured during spring 2021 snowmelt run-off prior to treatment initiation.

Grain and straw yield

Grain and straw yield are reported by treatment (Figure 11) and landform complex (Figure 12). Straw yield was significantly influenced by treatment ($p<0.05$) and landform complex ($p<0.001$). The treatment effect did not have a significant impact on flax grain yield ($p>0.10$), but flax grain yield did vary significantly according to landform complex ($p<0.10$).

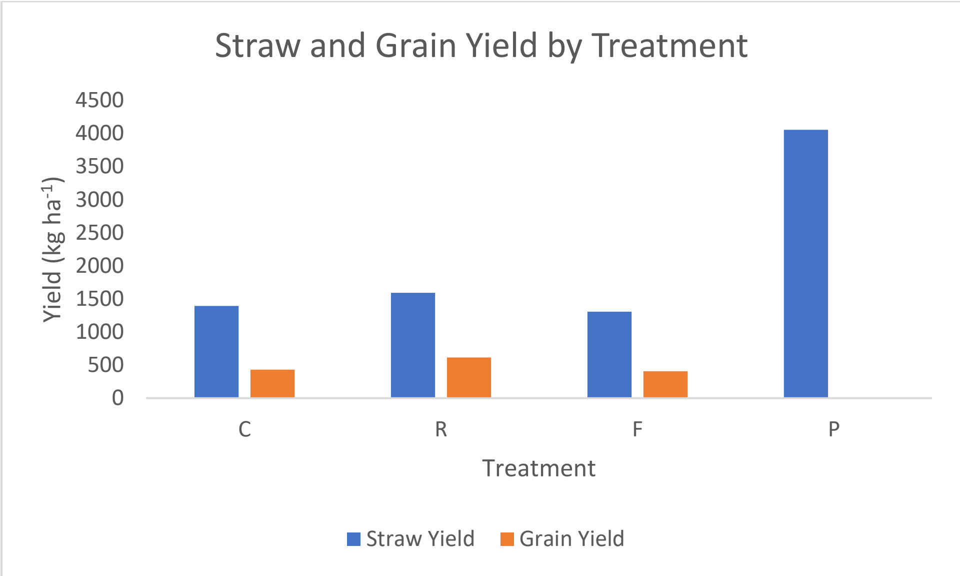


Figure 11. 2021 yield according to treatment. C, R and F are flax grain and straw and P is the polycrop forage yield.

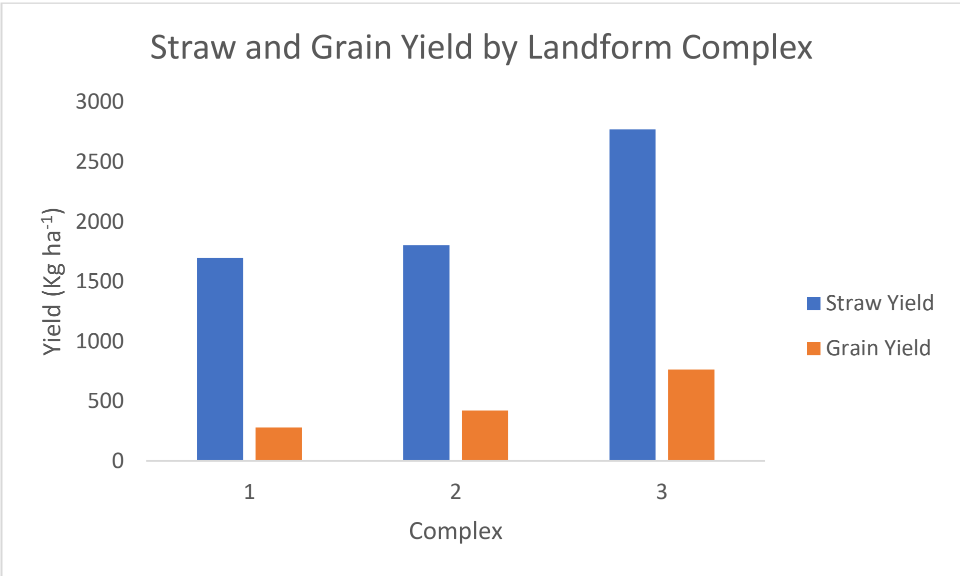


Figure 12. 2021 straw and grain flax yield according to landform complex.

Straw P and N uptake

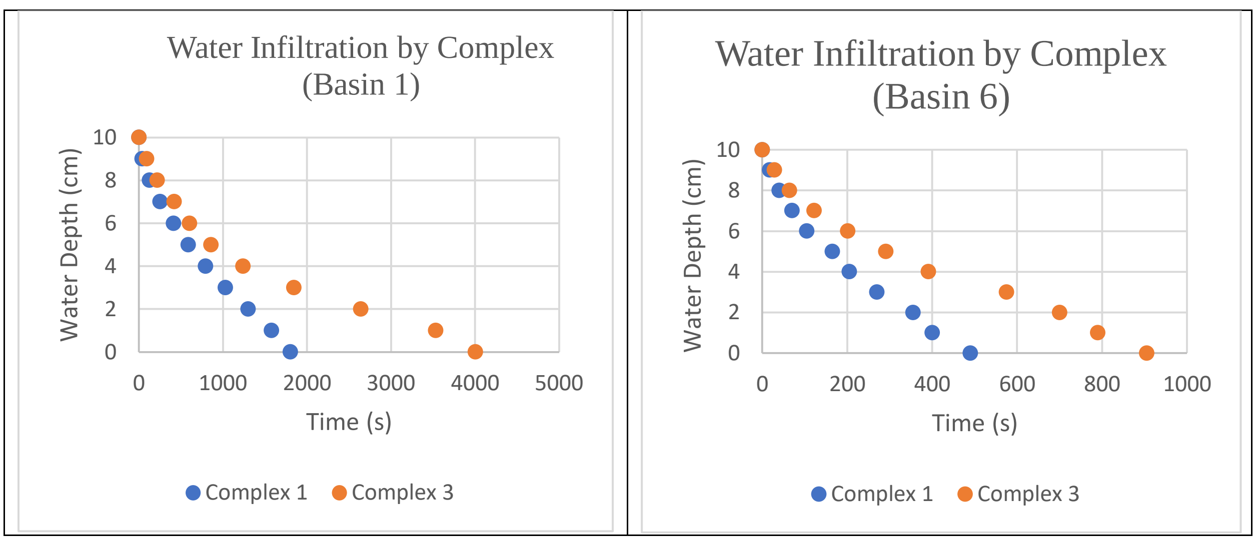
Uptake of P and N in straw by treatment and landform complex are shown below in Table 7. Straw P uptake was significantly impacted by both treatment ($p<0.001$) and complex ($p<0.05$). Treatment was also shown to have a significant impact on nitrogen uptake in straw ($p<0.01$).

Table 7. P and N uptake in straw according to treatment and landform complex.

Factor		Phosphorus Uptake (kg P ha-1)	Nitrogen Uptake (kg N ha-1)
Treatment	C	0.56	12.03
	F	0.40	8.95
	R	0.45	9.93
	P	8.26	119.75
Complex	1	2.13	41.62
	2	1.98	30.05
	3	3.14	41.32

Fall 2021 water infiltration

Water infiltration was measured at two landform complex locations for each basin following harvest in 2021. Water infiltration is plotted over time for each of the basins in Figure 13 below. At the time of writing, no attempt has been made to determine infiltration rate among treatments and landform complexes. This information will be presented in the 2022 report. Water infiltration was slower in the low slope than up slope complexes likely due to higher clay content.



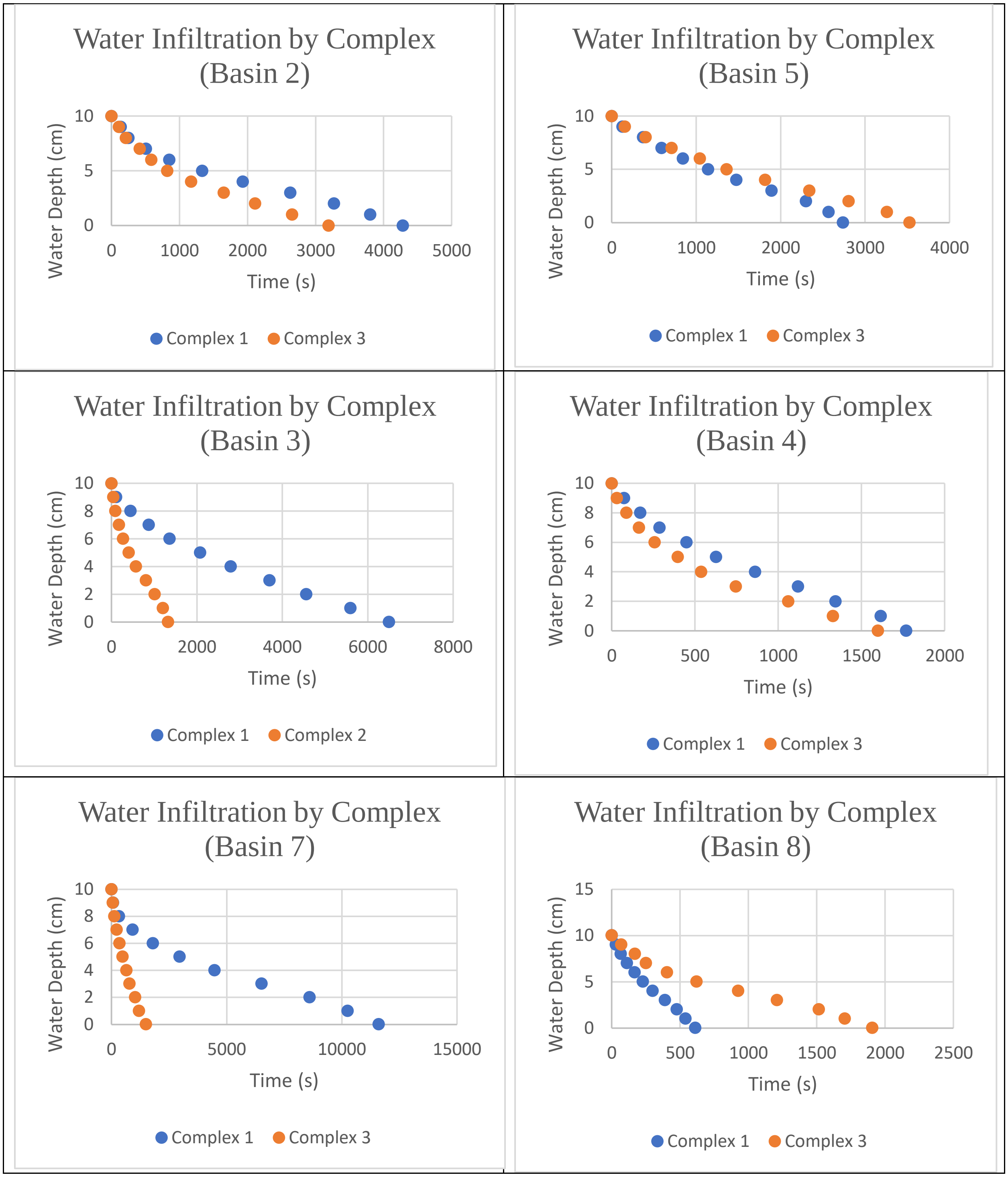


Figure 13. Water infiltration over time by landform complex for each basin. Figures within the same row are replicates of each treatment.

DISCUSSION

Results from soil and snowmelt run-off samples collected in Spring 2021 reveal no significant difference in plant-available soil P or SRP in snowmelt run-off water among basins. With no significant differences in the baseline condition prior to treatment application, it can be assumed that differences in crop response or nutrient export that are revealed over the study period are due to the treatment effect. Straw yield was significantly impacted by treatment, with the highest yield observed from the forage polycropping treatment. This is not surprising as forage crop varieties are selected largely for their superior biomass production, whereas flax varieties are selected for high grain yield and other traits which facilitate ease of harvest and post-residue management such as short standing height. The forage also exhibited significant second growth in response to late season rains which contributed to harvested biomass yields.

Grain yield among flax treatments did not differ significantly according to treatment. Importantly, the variable-rate fertilizer application treatment yield similarly to the control treatment despite fertilizer application rates of approximately 90% of total N and P_20_5 relative to the control treatment. In this way, no yield penalty was observed from reducing the total nutrient application rates in the variable-rate fertilizer application treatment. The impact that this treatment and others had on influencing residual (i.e. Fall 2021) soil nutrient levels and nutrient concentration in snowmelt run-off water is yet to be determined as analysis of fall 2021 soil samples is currently underway.

Mean grain yield was significantly influenced by landform complex, with yields increasing in the order 1 (upslope) < 2 (midslope) < 3 (lowslope). This yield response is likely due to differences in soil-water dynamics across the landform complexes and its ability to influence yield despite low rainfall over the growing season. For example, topography and slope are well known to control the lateral distribution of water and soil properties to influence surface water infiltration and storage (Castillo, 2010; Biswas et al., 2012) with greater accumulated moisture in the low slopes and basins of landscapes. Straw P uptake was also significantly influenced by landform complex, with highest uptake observed in lowslope areas of the basin where extractable soil available P was generally higher.

FUTURE WORK

Project activities are progressing as planned and all project milestones achieved within the project period. Snowmelt run-off water will be collected in spring of 2022 and the volume and nutrient concentrations will be determined. Additionally, the simulated snowmelt run-off experiment is planned for March 2022. Analysis of fall 2021 collected soil samples will be completed during the spring of 2022. Field activities for the 2022 growing season will be conducted as outlined in the Methods section above, with wheat being the crop of interest for the variable-rate fertilizer, crop residue management, and control treatments.

KNOWLEDGE TRANSFER ACTIVITIES

This project was highlighted during several knowledge transfer events conducted both in-person on the Discovery Farm Langham site, as well as virtually. A listing of these events is presented below.

- Water Management Project introduction video, highlighting construction of surface ditches;
- Discovery Farm VIP Experience: June 23 & 24, 2021 and July 20-23, 2021;
- Stakeholder Day: August 17, 2021;
- University and Industry Consortium: October 5, 2021; and
- Farm Forum Event virtual conference presentation “Managing soil moisture variability”.

B. Weiseth, J. Schoenau, and J. Elliott 2022. Impact of fertilizer and cropping management practices on phosphorus and nitrogen use efficiency and losses in run-off water in variable topographies of Saskatchewan. 2022 Soils and Crops Workshop, March 9, Prairieland Park, Saskatoon, SK (Oral Presentation Title Accepted).

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