Towards climate-robust water management of potatoes

1. Introduction

The goals of this project are to identify (1) **where** in the landscape of Southern Alberta we can achieve the largest productivity and efficiency increases from new irrigation technology (e.g. variable rate irrigation) and (2) **how much** management effort that will require from irrigators. Our hypothesis is that in fields that are more complex, productivity differences can be minimized more by water management than fields that are less complex. We define **complexity** here as a combination of topographic features and physical and chemical properties of the soil in the landscape. Intuitively, it makes sense that a field containing hilltops, depressions, and a potpourri of soil textures would benefit more from precision irrigation or variable rate irrigation than a field that is completely flat and features a nice sandy loam rootzone throughout. However, we currently do not know how much yield variability can be reduced by precision irrigation or at which level of complexity variable rate irrigation will provide sufficient return on investment.

This project implements a multi-method approach combining measurements of physical characteristics and processes in fields, e.g. topography, soil type, weather, soil dynamics, with an investigation of the decision-making process of irrigators through questionnaires. We aim to find out how large moisture margins are and identify if these margins can be managed with current technology. This document provides a summary of the data collected in two years of the four-year project. The study is led by Lethbridge College and supported by the PGA and the Canadian Agricultural Partnership.

2. Site characteristics

In 2019 and 2020, we collaborated with five potato producers across Southern Alberta (Fig. 1). At this point, we have data from ten fields with varying levels of complexity. A major difficulty for this study is that the study takes place at new fields every year. We therefore look for measures to rank all fields in the study and perform regression analyses on the results.

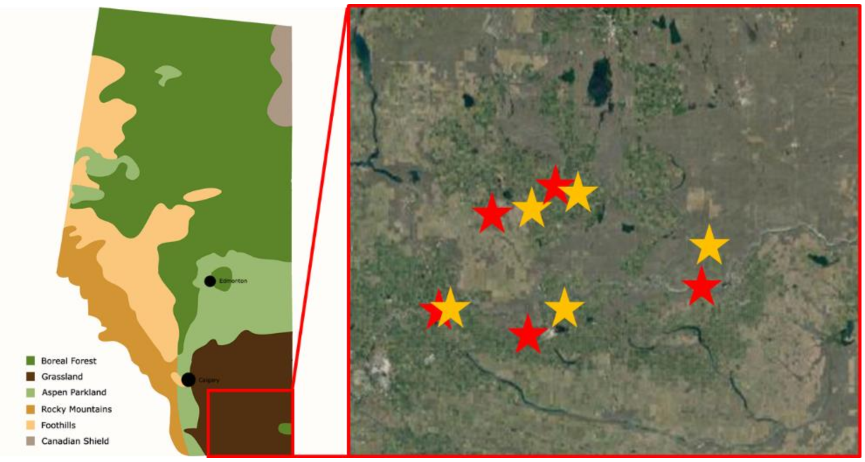


Figure 1. Approximate locations of field sites in Southern Alberta in 2019 (gold) and 2020 (red).

In terms of their topography, all ten fields are unique and statistically different. The topography of the fields varies from planar with 2.9 m elevation difference (Fig. 2a) to multiple hills and depressions with elevation differences up to 10.5 m (Fig. 2b). Between these two extremes, we analyzed the distributions of elevation (Fig. 2d), slope (Fig. 2e), and topographic position index (TPI, Fig. 2f) to determine a ranking of the fields in terms of topographic complexity (Fig. 2c).

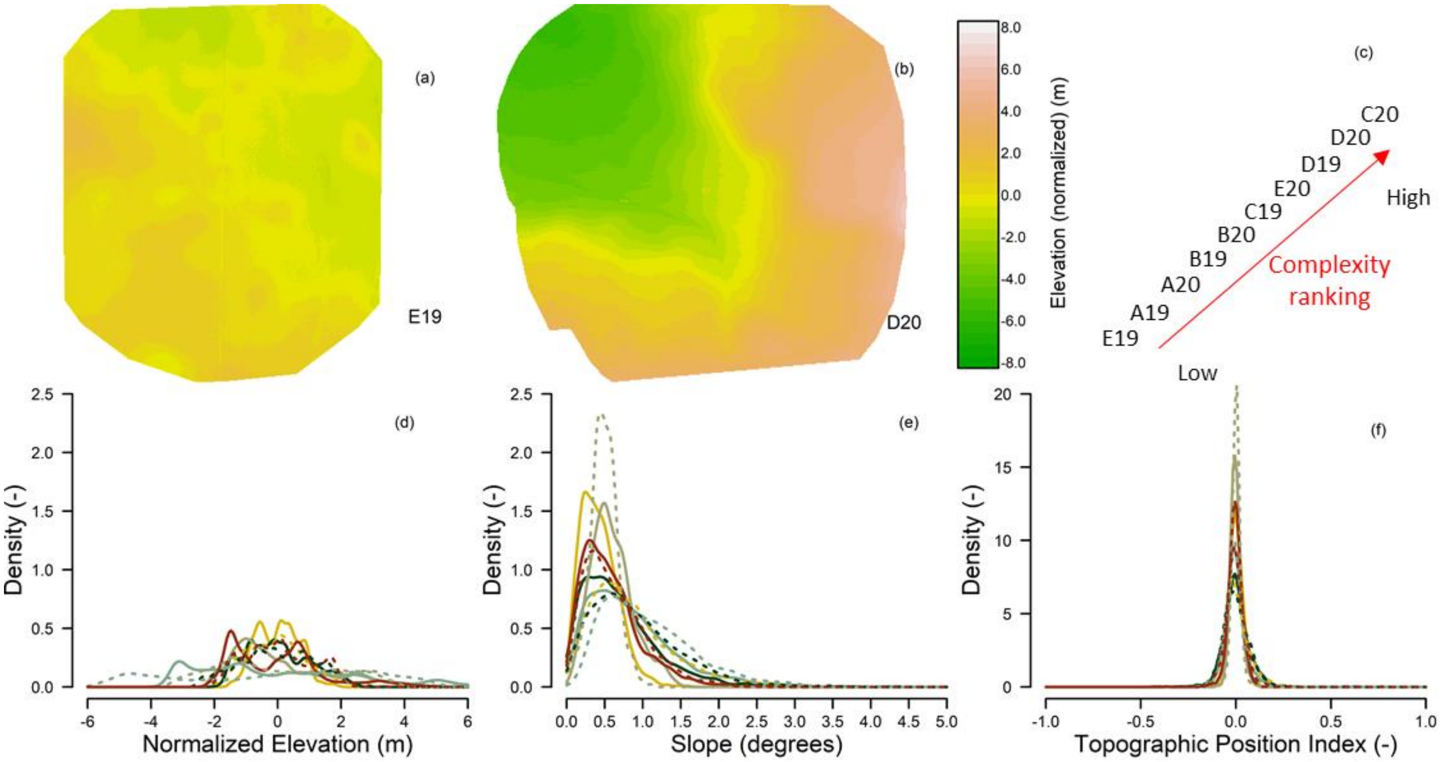
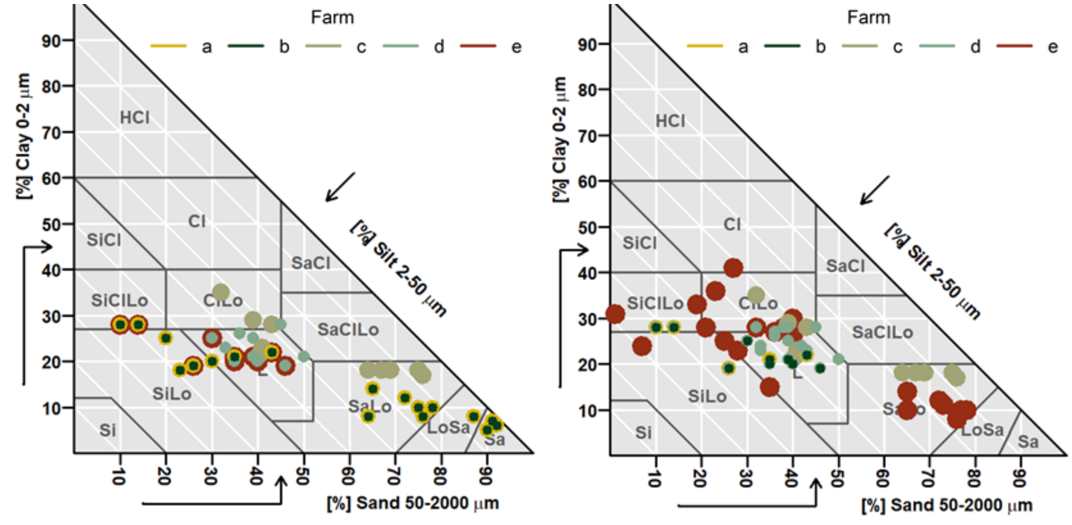


Figure 2. Elevation maps of low complexity (a) and high complexity (b) fields obtained from UAV imagery. Complexity ranking of ten experimental fields in 2019 and 2020 (c). Density distributions of normalized elevation (d), slope (e), and TPI (f) for all ten fields. Color of the line indicates farm, line type indicates the year: 2019 solid, 2020 dotted.

The 2019 and 2020 fields of farms A, B, and D were neighbors in the complexity ranking, whereas farms C and E featured fields of varying topographic complexity in 2019 and 2020. Soil texture classifications of the ten field sites are presented in Fig. 3. Loam textures can be found in most fields, providing an opportunity to compare soil moisture behaviour under varying irrigation practices.



(a) (b)

Figure 3. Soil texture classification of samples at the five farms in 2019 (a) and 2020 (b).

Fields of farms C and D featured similar soil texture classes in both years. Fields of farms A, B, and E contained additional sandier spots in one of the two years. We are still processing soil samples for more detailed information of the distribution of textures and organic matter in the profiles of our monitoring points.

3. Weather and irrigation

A weather station is set up at each field site for the duration of the growing season, measuring air temperature, humidity, wind speed, incoming radiation at 5-minute intervals. A tipping bucket rain gauge is also present but set up under the pivot to capture irrigation as well as rainfall. The five farms span an area of 150 x 150 km. This is small enough for weather variables such as temperature, humidity, and wind speed to exhibit similar seasonal patterns during a growing season (Fig. 4). The resulting growing degree days at the five farms therefore track each other closely (Figs. 4e and 4f). Curves may be different due to variable start of the observation period (e.g. farm E in Fig. 4e and farm D in Fig. 4f). In the overlapping 3-month monitoring period (June, July, August), the sites received and average 1178 ± 14 GDD (2019) and an average 1186 ± 27 GDD (2020).

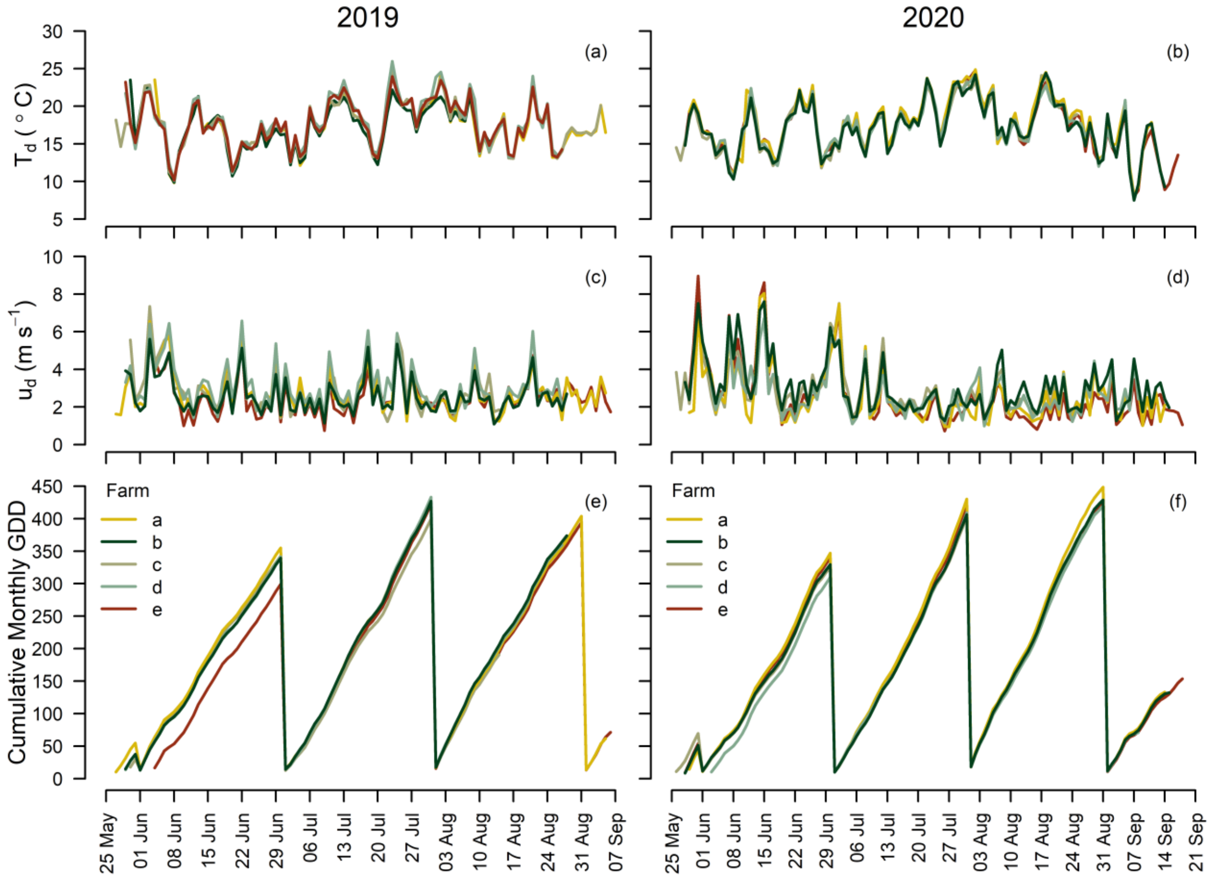


Figure 4. Hourly air temperature at five sites in 2019 (a) and 2020 (b). Hourly wind speed at five sites in 2019 (c) and 2020 (d). Growing Degree Days cumulated by month at five sites in 2019 (e) and 2020 (f).

Alike weather conditions generate alike plant water use requirements between farms (transpiration T in Table 1). Soil evaporation (E, Table 1) numbers may vary more, because these depend on the occurrence of rainfall or irrigation as well as on the shared weather conditions. Rainfall is of course highly variable between sites. The ratio between rainfall (R, Table 1) and irrigation (I, Table 1) therefore varies as well between sites within a given year. June 2020 saw twice as much rainfall than June 2019.

Table 1. Water balance based on weather observations from the five farms in 2019 and 2020. Rainfall (R), irrigation (I), plant transpiration (T), and soil evaporation (E) result in an expected change of moisture in the rootzone over the monitoring period (ΔS_{EX}): $R + I - T - E = \Delta S_{EX}$. The average and standard deviation of the observed change in moisture (ΔS_{OB}) was determined from soil moisture observations at five monitoring locations in each field. All values in mm.

	2019						2020				
Farm	R	I	T	E	ΔS_{EX}	ΔS_{OB}	$R + I$	T	E	ΔS_{EX}	ΔS_{OB}
A	63	296	335	9	16	17.5 ± 5.8	393	365	44	-16	-17.8 ± 14.2
B	106	273	301	12	66	-2.6 ± 26.0	396	343	42	11	-4.5 ± 25.9
C	127	193	242	30	48	16.2 ± 14.4	360	300	52	8	-2.0 ± 28
D	122	247	305	25	36	27.7 ± 15.4	464	350	31	83	37.6 ± 16.8
E	77	286	326	26	11	10.3 ± 13.5	382	383	32	-33	-11.3 ± 16.5

Note 1. Monitoring periods were not the same at all sites. This was the biggest factor in the different values for T between the farms. This is also a reason for differences between inputs as presented in this table and seasonal totals recorded on farm.
Note 2. Where a VRI schedule was applied, the irrigation amount presented in the table represents the 100% setting.
Note 3. R and I have not been completely separated yet for 2020 and are presented as one input.

In 2019, the combined irrigation and rainfall inputs at the four farms that featured three months of observations were almost the same: an average of 368 ± 9 mm. At farms A and E, the expected moisture change was the closest to the observed moisture change. These were the farms with the lowest complexity of the year, but also received the least amount of rainfall. At farm B, the difference between expected and observed was the largest.

In 2020, the combined inputs featured one outlier, resulting in an average of 399 ± 39 mm. The expected and observed moisture change were closest at farm A and in an acceptable range at farms B and C. The difference at farm D could have been the result of drainage of water from the rootzone.

Water balance analysis is a fundamental step in quantifying the potential impact of precision irrigation management: if we can identify field locations that fill or drain consistently faster than others, we can pinpoint fields as better candidates for targeted water management. We are currently exploring the water balance properties and sensitivity of the field locations with agrohydrological models.

Irrigation inputs to the fields are determined from thee sources: a rain gauge placed under the pivot at one of the monitoring locations, a flow meter that is placed on the mainline feeding the pivot, and from producer logs. These sources do not always agree. This can be due to actual water losses between scheduling, pumping, and sprinkling or due to errors (human/mechanical). In cases where the three sources line up well (Fig. 5), the differences in water volume can still be equivalent to 6 mm (~1/4 in) of irrigation depth over the course of four irrigation applications.

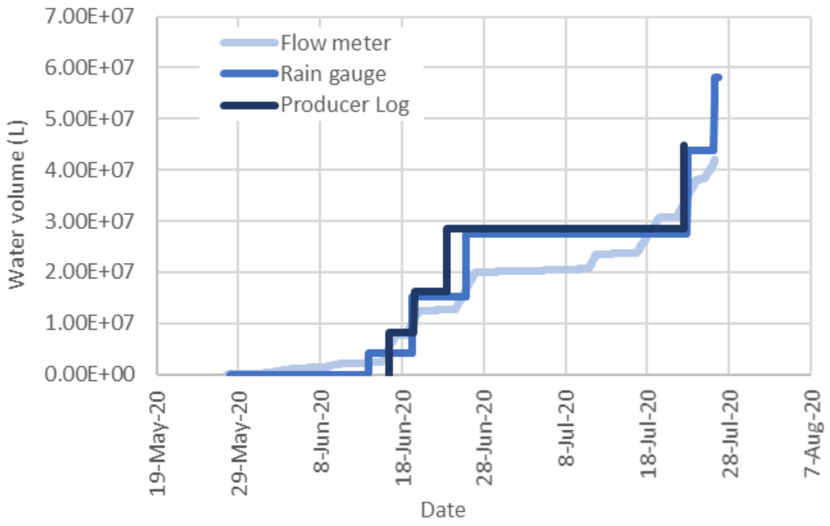


Figure 5. Comparison of cumulative water volume irrigated determined from three sources on one farm in June/July 2020.

Uncertainty around current irrigation water inputs is of course a major inhibition for the successful implementation of precision irrigation or operation of VRI. In the coming two field seasons we will take a closer look at the margin of error around irrigation amounts.

4. Soil moisture dynamics and variability

In this study, soil moisture is monitored at five locations in each field. An elevation map of the field is analyzed to identify topographic features. Locations are selected to represent outstanding features (hills, depressions) and areas of soil variability for more widely distributed topographic conditions (e.g. gentle slopes). Four sensors are installed in and under the potato hill at each location, to track soil moisture dynamics in the entire rootzone. A comparison between moisture dynamics within four fields is presented in Fig. 6. For each point, the observations at four depths were converted to total volumetric water content (VWC) in the 70 cm rootzone.

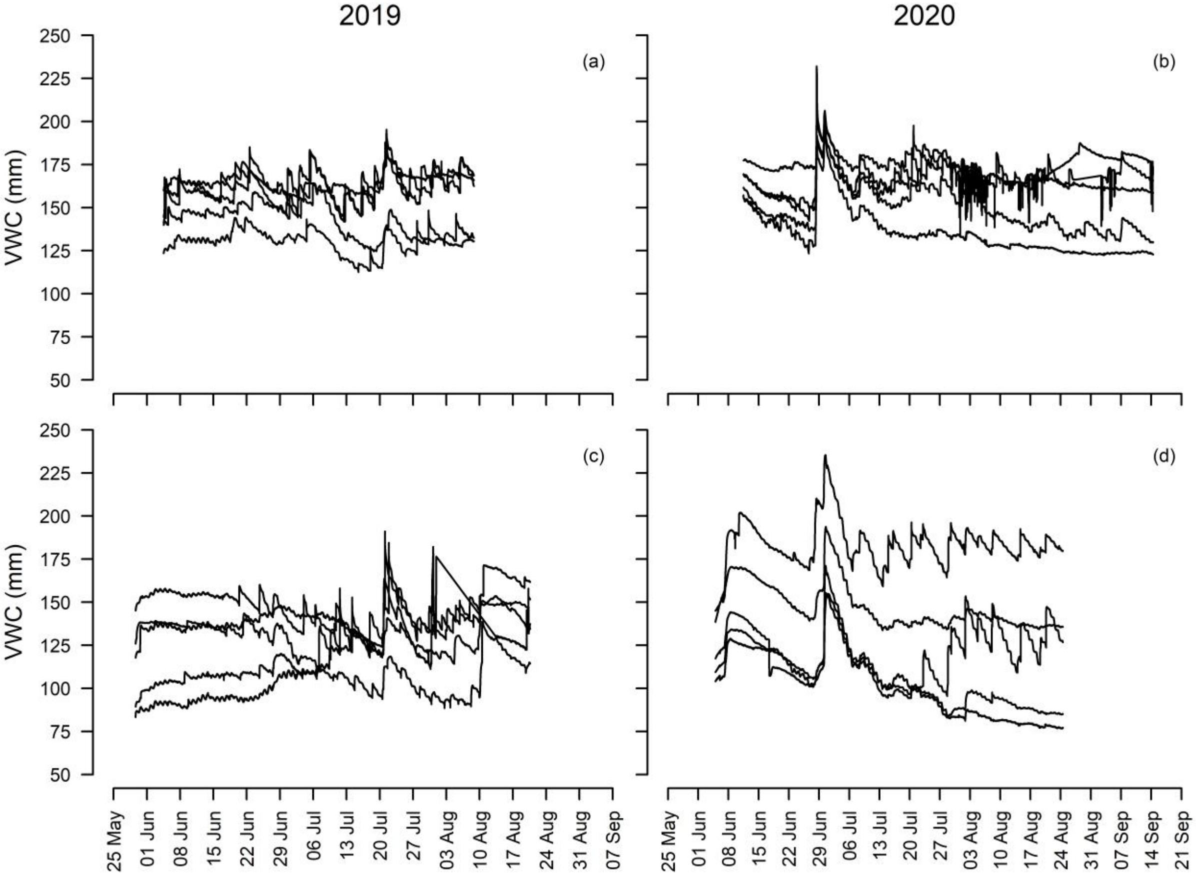


Figure 6. Total amount of soil moisture in the rootzone for low complexity fields E in 2019 (a), A in 2020 (b), and high complexity fields D in 2019 (c), and C in 2020. Each line represents one location in the field. The timeseries of the fields have different start and end dates because instrument installation and removal occur after power hilling and before harvest, respectively.

Regardless of soil type and position in the field, moisture dynamics fluctuate rapidly in response to rainfall and irrigation events. Rainfall events tend to have longer lasting effects than irrigation applications of the same size. This is mostly a result of the difference in intensity and duration of such events. At all sites, 2020 moisture patterns were characterized by long wetting due to high rainfall in early and late June. These wet periods also caused drainage of water from the rootzone. We do not measure that in the field but use computer models to get an estimate. The VWC at the beginning of the growing season is more uniform in low complexity fields (Figs. 6a and 6b) than in high complexity fields (Figs. 6c and 6d). Regardless of field complexity, some convergence may occur during the season with two or three points clustering around similar values by the end of the growing season. However, these clusters are more different in high complexity fields (Fig. 6d) than in low complexity fields (Figs. 6a and 6b).

While the fluctuations at each point are quite dramatic, VWC changes over the growing season are much smaller. In Fig. 7, the VWC at the end of the season is plotted against VWC at the beginning of the season for the five locations in the 2019 and 2020 fields.

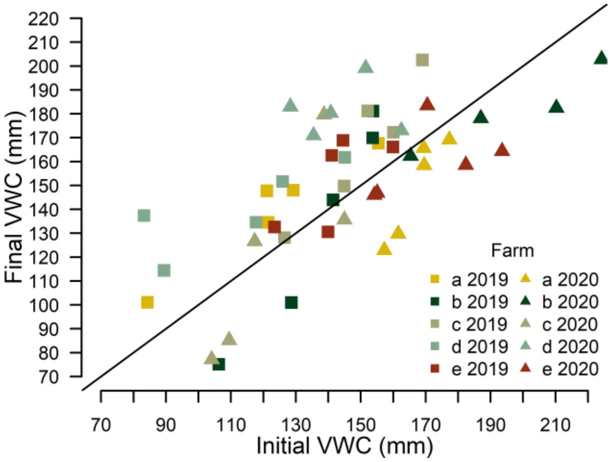


Figure 7. Final moisture content of each monitoring point in 2019 and 2020 plotted against initial moisture content of each monitoring point in 2019 and 2020. The straight line is the 1 to 1 line.

In 2019, 22 out of 25 monitoring points were wetter at the end of the monitoring period than at the beginning (most square symbols in Fig. 7 plot above the line). All 2019 points of farm E group together in the middle of Fig. 7, similar to how the temporal dynamics group together closely in Fig. 6a. In other fields, the divergence of moisture curves causes points to spread out more in Fig. 7, but still at limited distance from the 1 to 1 line. This indicates that while average conditions within the field are different, the changes in the field are similar. It also indicates that in most cases irrigation (and rainfall) inputs balanced well with plant transpiration and soil evaporation. We are currently analyzing these timeseries to identify periods of water stress (if any) and to relate average conditions back to landscape features.

5. Crop development and yield

Crop development was monitored during weekly field visits and by analyzing satellite imagery. We used the IRRISAT web application which generates maps of NDVI (normalized vegetation difference index) and crop coefficient K_C from Landsat and Sentinel satellite imagery. The maps generated with this app have 15 to 30 m pixels, which is sufficiently small to detect spatial patterns in crop development. The field median of K_C and its interquartile range (IQR) are presented in Fig. 8 for all five farms in 2019 and 2020. The satellite imagery is acquired every eight days, but gaps in the timeseries occur easily if a cloud layer is present on the day of pass.

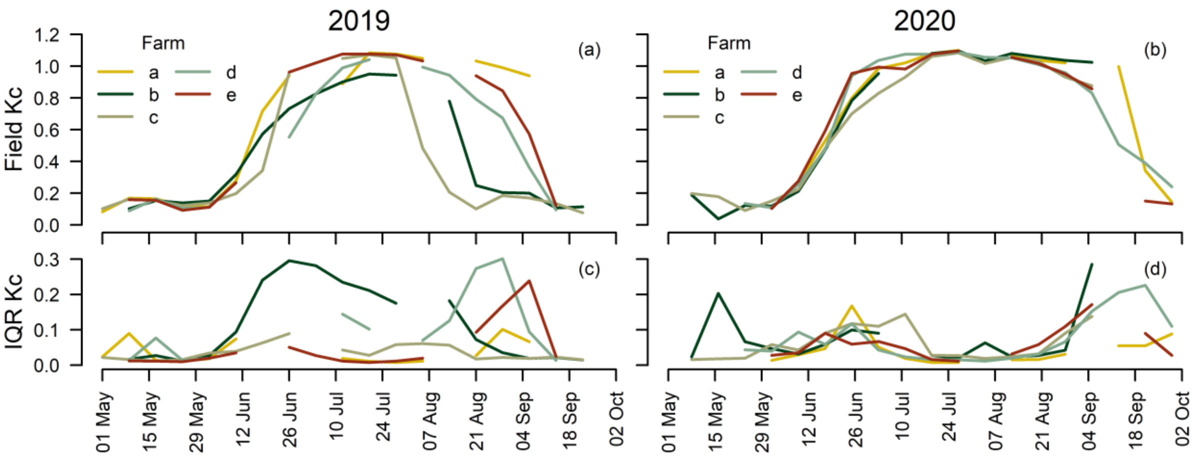


Figure 8. Spatial median value of crop coefficient K_C of the five field sites in 2019 (a) and 2020 (b). Variability of crop development expressed as the interquartile range (IQR) of all K_C values found in the fields in 2019 (c) and 2020 (d).

While planting dates varied between farms, crops developed along a steady trajectory in 2020 (Fig. 8b). The largest within-field variations occur at the beginning and end of the growing season (Fig. 8d). In July and August K_C maxed out at a value of 1.07 in all fields. In 2019, differences between fields and within fields were larger (Figs. 8a and 8b). Fields A and E exhibited similar trajectories as the 2020 fields, but fields B and D contained K_C variability that was visible on the satellite.

We determined yield at the end of each season, two to ten days before actual harvest by digging up all tubers from a stretch of hill near each soil moisture monitoring point for a total of fifteen yield samples per field. We graded the tubers by size class, checked a subsample for internal and external defects, and determined specific gravity, glucose content, and dry weight. These variables can be analyzed per farm and per monitoring point. Yield -expressed as the total fresh tuber weight in kg per sampling plot- is shown in Fig. 9 in order of low to high field complexity.

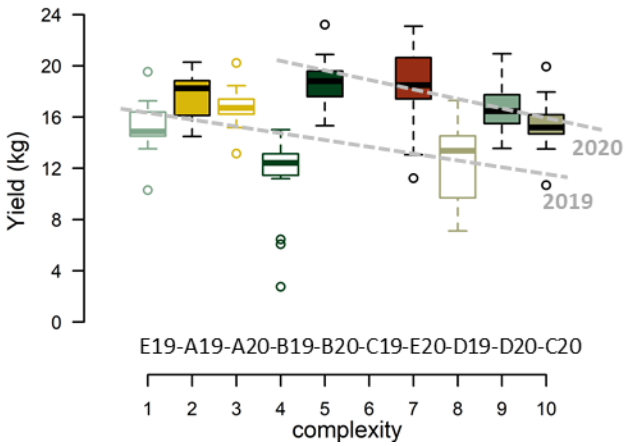


Figure 9. Statistical properties of yield at nine farms, ordered from low to high complexity. The thick line in each box represents the median value, the vertical size of the boxes the interquartile range and the whiskers and open circles the extreme values of yield.

Our initial hypothesis was that yields will be more uniform in fields with low complexity. In 2019, the observations seemed to support that idea, while also showing a decrease of total yield (samples were not weighted for their areal representation) with an increase of field complexity. On one farm, a representative yield could not be determined. Of the remaining four, three farms featured statistically significant differences. In 2020, the decreasing trend featured more outliers and within field variability did not show a clear increase or decrease. Four of the five farms had a significantly higher yield in 2020 than in 2019. In 2020, the yields between farms were not significantly different, with the exception of the pair B and C. In both years, one field featured uniform yields along all monitoring points, whereas in other fields 2, 3, or 4 yield groups could be distinguished at a significance level of $p = 0.05$ or lower. In 2019, the number of groups increased with increasing field complexity. In 2020, no such trend was detected.

It should be noted that these patterns are very preliminary. We cannot draw any firm conclusions about the effect of landscape variability on yield variability until we have a larger dataset to perform a regression on. A second note is that the complexity ranking as presented in Fig. 9 places all fields at identical steps of complexity. That is a simplification. The appearance of the regressions may change when fields group closer together or further away.

6. Ongoing and future work

With two years of data under our belt, we can start to tease apart the effects of weather and landscape on water-related productivity of potatoes. Until now, our analyses have been focused mostly on the field level. We are currently working on analyses at the point level and identifying patterns of behavior. These analyses lean on the dataset, but also require computer simulation with geostatistical, hydrological, and crop models.

Field work along the lines presented in this report will continue for two more growing seasons. We will dive deeper into the investigation of irrigation management practices. Our first surveys were sent out this summer, but the return rate was not quite sufficient to present the findings in this report.

The COVID-19 pandemic prevented us from hosting a field day this summer. We recorded short videos that demonstrate the data collection in this project. These videos can be found on the Youtube channel of Lethbridge College: https://www.youtube.com/user/lethbridgecollege.

As of September 2020, two MSc students have started their programs at the University of Saskatchewan under the flag of this project. One student focuses on further analysis of the field data and modeling of the relationship between water processes and crop growth, while the other one focuses on the opportunities and limitations for adoption of precision irrigation practices. T

For any further questions or comments regarding this project, please contact: willemijn.appels@lethbridgecollege.ca

THANK YOU

Bennen Farms
Perry Farm
Stiekema-Kolhorn Farm
Torlang Farms
Windiana Farms

Lethbridge College

PGA
POTATO GROWERS OF ALBERTA

CANADIAN
AGRICULTURAL
PARTNERSHIP
Innovate. Grow. Prosper.

Alberta

Canada