

COMPARING IRRIGATION SCHEDULING TOOLS USED IN PRAIRIE CROP ROTATIONS

COMPARAISON DES OUTILS DE PROGRAMMATION DE L'IRRIGATION UTILISÉS DANS LES ROTATIONS CULTURALES DES PRAIRIES

Erin Karppinen¹, Evan Derdall², and Ashebir Godebo³

ABSTRACT

Irrigation schedules are designed to maintain plant available water (PAW; field capacity – permanent wilting point) so that soil moisture levels are between field capacity and the maximum allowed depletion, typically set at 50% of PAW. When irrigation scheduling methods and tools are used, producers can increase crop yield and improve water use efficiency (WUE) by maintaining adequate soil moisture for optimal crop production. There is limited information comparing different irrigation scheduling tools and the effects on crop yield, quality, and WUE in the prairies. To address this gap, a small-plot trial using a typical irrigated crop rotation (oilseed-pulse-cereal) was established to (i) compare the irrigation requirements and agronomic outcomes associated with irrigation scheduling tools and (ii) assess their return on investment. Treatments included weather- and soil-based scheduling tools that are commercially available to producers. Soil moisture was monitored throughout the growing season to match water application with the recommendations from provided by each tool, enabling evaluation of WUE and the agronomic and economic performance of each treatment. In this study, all of the scheduling tools effectively maintained soil moisture within the target range of 50-100% of PAW, and total irrigation applied by each tool was dependent on crop type, local environmental conditions, and sensor technology. Differences in moisture use and WUE did not affect yield or quality; however, reduced water use offers both economic and social benefits through lower pumping costs and more efficient use of available water resources. Initial economic assessments indicate that tools that enable more precise irrigation management can offer economic advantages. In years with adequate precipitation, all irrigation scheduling tools performed similarly in terms of yield and crop performance. Differences among tools were primarily related to irrigation amounts and soil moisture dynamics rather than agronomic outcomes, highlighting opportunities for improved water conservation without compromising yield.

Keywords: Irrigation scheduling tools; Prairie crop rotations; Soil moisture levels; Water application; Crop performance; Sensor technology.

RÉSUMÉ

Les calendriers d'irrigation sont conçus pour maintenir l'eau disponible pour les plantes (PAW ; capacité au champ – point de flétrissement permanent), de sorte que l'humidité du sol reste comprise entre la capacité au champ et le déficit maximal admissible, généralement fixé à 50 % de la PAW. L'utilisation de méthodes et d'outils de programmation de l'irrigation permet aux producteurs d'accroître le rendement des cultures et d'améliorer l'efficacité d'utilisation de l'eau (WUE), en maintenant une humidité du sol suffisante pour une production optimale. Il existe peu d'informations comparant les différents outils de programmation de l'irrigation et leurs effets sur le rendement, la

1 Agriculture and Agri-Food Canada, Canada-Saskatchewan Irrigation Diversification Centre, 901 McKenzie Street South, Outlook, SK S0L 2N0, Canada, erin.karppinen@agr.gc.ca

2 Agriculture and Agri-Food Canada, Saskatoon Research and Development Centre, Saskatoon, SK S7N 0X2, Canada, evan.derdall@agr.gc.ca

3 Irrigation Saskatchewan, Canada-Saskatchewan Irrigation Diversification Centre, 901 McKenzie Street South, Outlook, SK S0L 2N0, Canada, ashebir.godebo@irrigationsaskatchewan.com

qualité et la WUE des cultures dans les Prairies. Pour combler cette lacune, un essai sur petites parcelles, fondé sur une rotation irriguée typique (oléagineux-légumineuse-céréale), a été mis en place afin (i) de comparer les besoins d'irrigation et les résultats agronomiques associés aux outils de programmation de l'irrigation et (ii) d'évaluer leur retour sur investissement. Les traitements comprenaient des outils de programmation fondés sur les données météorologiques ou sur le sol et disponibles dans le commerce pour les producteurs. L'humidité du sol a été suivie pendant toute la saison de végétation afin d'adapter les apports d'eau aux recommandations fournies par chaque outil, ce qui a permis d'évaluer la WUE ainsi que les performances agronomiques et économiques de chaque traitement. Dans cette étude, tous les outils de programmation ont maintenu efficacement l'humidité du sol dans la plage cible de 50 à 100 % de la PAW, et le volume total d'irrigation appliqué par chaque outil dépendait du type de culture, des conditions environnementales locales et de la technologie des capteurs. Les différences d'utilisation de l'humidité du sol et de WUE n'ont pas influé sur le rendement ni sur la qualité ; toutefois, la réduction de l'utilisation d'eau procure des avantages économiques et sociaux grâce à la baisse des coûts de pompage et à une utilisation plus efficace des ressources en eau disponibles. Les premières évaluations économiques indiquent que les outils permettant une gestion plus précise de l'irrigation peuvent offrir des avantages financiers. Les années où les précipitations étaient suffisantes, tous les outils de programmation de l'irrigation ont donné des résultats similaires en matière de rendement et de performances culturales. Les différences entre les outils concernaient principalement les volumes d'irrigation et la dynamique de l'humidité du sol plutôt que les résultats agronomiques, ce qui met en évidence des possibilités d'améliorer les économies d'eau sans compromettre le rendement.

Mots-clés : Programmation de l'irrigation utilisés; Rotations culturales des prairies; Niveaux de l'humidité du sol; Application d'eau; Performance de culture; Technologie des capteurs.

INTRODUCTION

In Canada, agriculture is the largest consumer of freshwater with over 2.5 million acres of irrigated farmland accounting for 80% of national consumption. Although Saskatchewan is not currently limited by the availability of water, it is important to consider future needs (i.e., climate change, competing demand on water resources) and to implement practices that promote long-term water sustainability. In 2020, the province of Saskatchewan announced a \$4 billion irrigation expansion project which aims to add approximately 500,000 acres of irrigated production to the Lake Diefenbaker Development Area. Although this transformative project was met with support, experts have raised concerns regarding potential impacts on water use and downstream supply.

Irrigation scheduling is a key practice for improving water use efficiency by applying water at the right time and rate to maintain soil moisture within optimal limits. Irrigation schedules are designed to maintain soil moisture levels between field capacity and the maximum allowed depletion (MAD), which is typically set at 50% of plant-available water (PAW). Plant available water refers to soil water that plants can readily absorb and use for growth, which is the difference between the soil water at field capacity (the amount of water soil can hold against the forces of gravity) and permanent wilting point (the amount of water at which plants can no longer access water and permanently wilt).

Information-based irrigation management can reduce water use by 40–60% while maintaining yields, but existing research focuses mainly on horticultural crops in subhumid regions, with little evidence for field crops in semi-arid Canada. (Shahrokhnia and Jorenush 2022; Song et al. 2022). Despite industry claims of water savings and yield gains, adoption of irrigation scheduling tools remains limited due to several factors, including lack of knowledge surrounding the benefits of irrigation scheduling, high water tolerance of commonly grown low-value crops, and skepticism related to return on investment (Bauer 2021; Bryant et al. 2023).

Advances in wireless soil moisture sensors have made irrigation scheduling more accessible and affordable, but adoption remains limited due to insufficient demonstration of their economic benefits. Most producers still rely on simple methods such as the hand-feel method (Wang et al. 2015), by which soil is manipulated by hand to determine approximate soil moisture content, and there is limited

research comparing soil-based irrigation tools and their impacts on crop yield, quality, and water use efficiency on the Canadian prairies. To address this gap, we compared different tools to provide more information to producers by evaluating the timing and depth of irrigation applications scheduled using weather- and soil-based methods and evaluating the return on investment (ROI)

MATERIALS & METHODS

Irrigation Scheduling Tools

Experimental treatments include 4 different irrigation scheduling tools (Figure 1).

1) Alberta Irrigation Management Model

Alberta Irrigation Management Model (AIMM) is a weather-based model that uses local weather data and estimated evapotranspiration to calculate changes to soil moisture. Multiple parameters, including crop type, root depth, planting date, irrigation system type, soil texture, and measured soil moisture, were used to setup the model. The model uses a Modified Penman Evapotranspiration Equation. Weather data was collected from Environment and Climate Change Canada's weather station, and uploaded multiple times per week and irrigation data was entered as it occurred.

2) CropX

CropX is a multi-depth, soil-based sensor that uses frequency domain reflectometry to estimate volumetric water content (VWC; %), temperature, and electrical conductivity at depths of 15 cm and 35 cm. This technology has built in wireless capability to transmit data to a cloud-based application. Probes were monitored multiple times per week using CropX's software (<https://myfarm.cropx.com/overview>) and refill and full setpoints were determined by the software which adjusts during the growing season to reflect an increase in rooting depth. Irrigation was triggered when average soil moisture reached the refill setpoint.

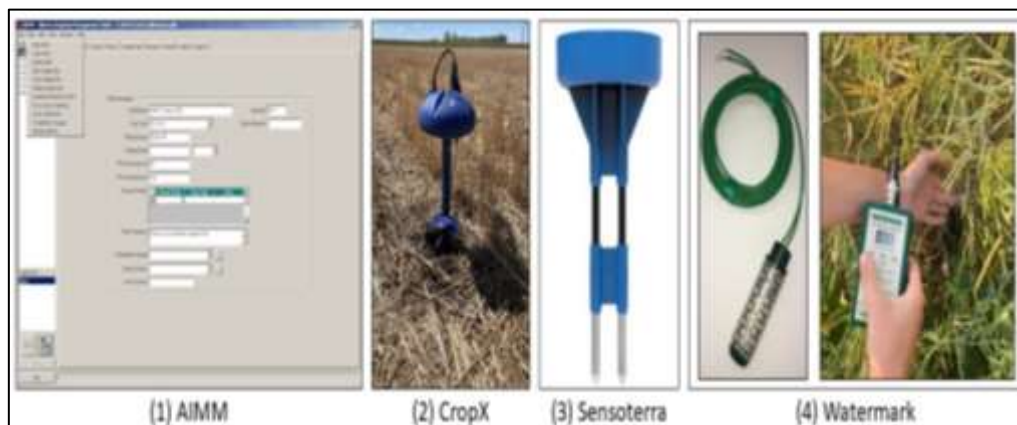


Figure 1. Irrigation scheduling tools used for experimental treatments: (1) Alberta Irrigation Management Model (AIMM), (2) CropX, (3) Sensoterra, and (4) Watermark

3) Sensoterra

Sensoterra is a soil-based sensor that uses time domain reflectometry to measure VWC. This technology has built in wireless capability to transmit data to a desktop or cellular application. Paired Sensoterra Moisture Sensors (15 cm and 30 cm depths) probes were monitored multiple times per week using Sensoterra's software (<https://monitor.sensoterra.com/main>). Irrigation was triggered when average soil moisture fell below the low setpoint.

4) Watermark

Watermark is a soil-based sensor that are comprised of electrodes that are embedded into a porous block (i.e., gypsum, granular matrix) and an electrical current is applied to the lead wires to measure electrical resistance, which is related to soil tension. Paired probes (15 cm and 30 cm depths) were manually read multiple times per week and irrigation was triggered at 50 centibars (cbars) which is 50% soil available water capacity of a silt loam soil. Irrigation was initially scheduled using the 15 cm Watermark, after which irrigation scheduling relied on the 30 cm Watermark sensor to account for increased root depth.

Experimental Setup

In 2025, the trial was established with 8 m x 8 m plots in a randomized complete block design (

Figure 2). Large plots were necessary to allow for a 5 m transition zone between scheduling treatments to prevent overspray of adjacent irrigation treatments into the harvest area. Each plot was irrigated with four individual sprinklers to allow for treatment-specific irrigation scheduling. Plots and associated scheduling treatments remained in the same place during the entire study period to capture soil moisture through an entire crop rotation.



Figure 2. Pea plots established in May 2025 at the Canada-Saskatchewan Irrigation Diversification Centre in Outlook, Saskatchewan.

Water Use and Water Use Efficiency

Water use efficiency (WUE) was calculated by combining plot yields with a simplified water balance to estimate total water use. Water use was determined as precipitation plus irrigation minus the change in soil moisture, with drainage and runoff assumed negligible. Precipitation and irrigation were measured throughout the season, while soil moisture was estimated from gravimetric samples taken before seeding and after harvest and converted to volumetric water content using bulk density.

Data Collection & Analysis

Plant emergence counts, plant height (lodged and stretched), lodging, and crop growth stages were recorded throughout the growing season. Seed from each plot was collected using a Wintersteiger plot combine to harvest a 8 m x 1.5 m area to determine yield. Seed moisture, oil content, test weight, and thousand kernel weight were measured to determine seed quality.

Economic Analysis

To support decision-making for Saskatchewan producers, we conducted a comparative analysis of irrigation scheduling tools that represent the two main scheduling approaches: weather-based and soil-based. Each tool differs in terms of technology, installation, automation, cost, data requirements, and usability. To evaluate the cost-effectiveness of each irrigation scheduling tool, we estimated the

total investment required for one full-sized pivot (140 acres) and compared it to projected income from pea yield. Return on investment (ROI) was calculated relative to AIMM, which served as the baseline due to its widespread use and zero capital cost, using yield-based income, annualized sensor costs, and irrigation energy costs while assuming other irrigation expenses remained constant.

RESULTS & DISCUSSION

Weather

During the growing season, there was a total of 209 mm of rainfall, with the majority of precipitation occurring in June (83 mm). Monthly precipitation was near-normal in April, well below average in May and September, and above average from June to August. Total precipitation from April to September (234 mm) was slightly below the 30-year average of 250 mm. Average daily maximum and minimum temperatures were above normal in early and late-season, and at or near-normal in mid-season. There were 12 days where daily maximum temperatures exceeded 30°C. Overall, cumulative corn heat units were near-normal in early and mid-season, but higher in September.

Yield, Seed Quality, and Physical Measurements

Scheduling tool had no significant effect on emergence, yield, seed quality, or physical crop characteristics (Table 1, ANOVA, $P \geq 0.05$). Plant emergence ranged from 78.7 to 90.7 plants m⁻², while grain yield varied modestly from 6,557 to 7,099 kg ha⁻¹ across tools. Seed quality parameters - including protein content (22.7 to 23.2%), test weight (75.9 to 76.0 kg hl⁻¹), and thousand-seed weight (263 to 269 g) - were similar among treatments. Crop height (86 to 93 cm) and lodging (0.27 to 0.36) also did not differ significantly. Overall, both weather-based and soil-based scheduling tools performed comparably across all measured outcomes.

Table 1. Effect of scheduling tool on emergence, yield, seed quality (oil, test weight, seed weight), and physical measurements (height, lodging). There were no differences between treatments (ANOVA, $P \geq 0.05$).

Scheduling Tool	Emergence (plants/m ²)	Yield (kg/ha)	Protein (%)	Test Weight (kg/hl)	Seed Weight (g/1000 seeds)	Height (cm)	Lodging (1=erect; 0=flat)
Weather-based							
AIMM	79.0 a	7,099 a	23.0 a	75.9 a	263 a	90 a	0.28 a
Soil-based							
CropX	90.7 a	6,991 a	22.7 a	76.0 a	269 a	86 a	0.35 a
Sensoterra	78.7 a	6,931 a	22.9 a	75.9 a	267 a	93 a	0.27 a
Watermark	78.7 a	6,557 a	23.2 a	76.0 a	265 a	92 a	0.36 a
P-value (0.05)	0.19	0.32	0.85	0.86	0.84	0.66	0.24

AIMM; Alberta Irrigation Management Model

Crop Growth Stages

There were no treatment differences in crop growth stage timing, including first flower, end of flower, and maturity ($P \leq 0.05$). On average, first flowering occurred 58 days after planting (DAP), flowering ended at 87 DAP, and maturity was reached at 100 DAP. This outcome was expected, as water application differed very little among treatments during the growing season.

Irrigation Scheduling

Sensor Output

All treatments were seeded on the same date; therefore, rainfall did not differ among treatments. In contrast, irrigation amounts varied, as scheduling was determined individually based on the output of each irrigation scheduling tool. Software outputs from AIMM (Figure 3), CropX

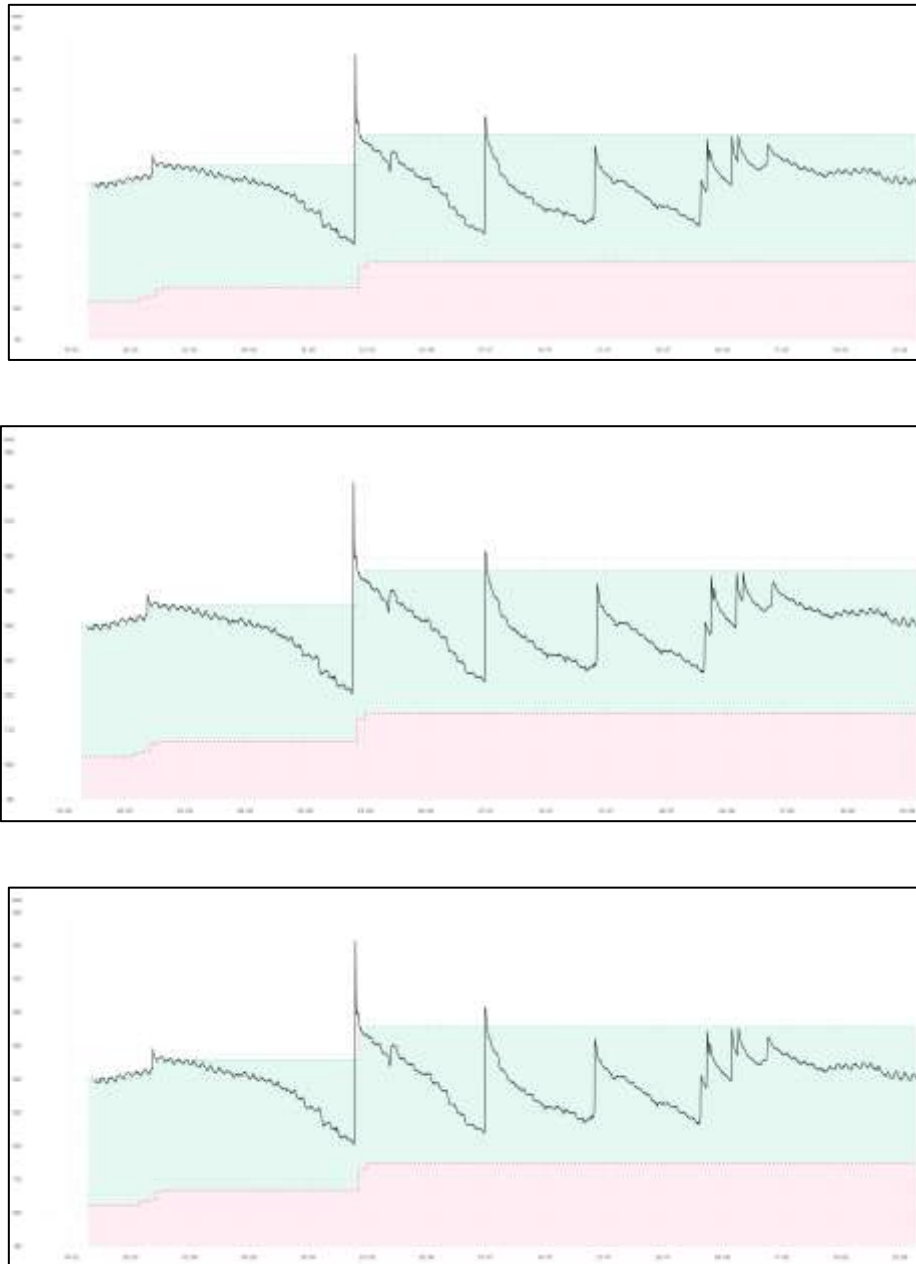


Figure 4), and Sensoterra (Figure 5) are presented, while Watermark readings are shown graphically in Figure 6. The goal was to maintain soil moisture between field capacity and MAD throughout the growing season. However, soil moisture exceeded field capacity early in the season due to above-normal precipitation in June.

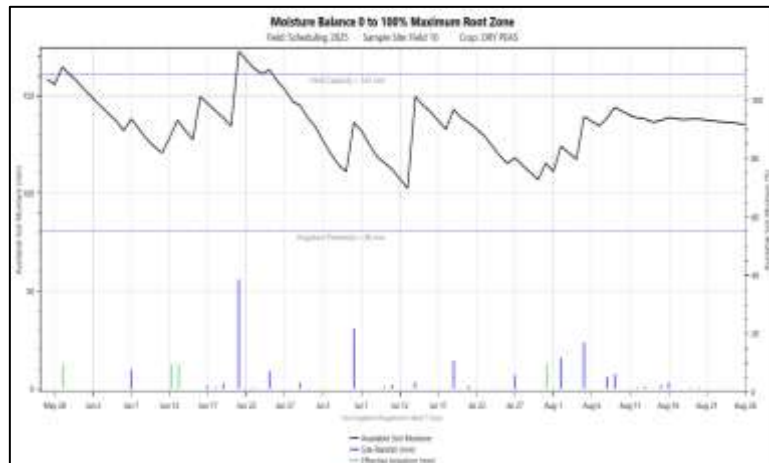


Figure 3. Software output from the Alberta Irrigation Management Model. The area between the blue horizontal dashed lines represents soil moisture between field capacity and maximum allowed depletion. Green bars along the x-axis represent irrigation applications of 12.5 mm, while blue bars represent rainfall events.

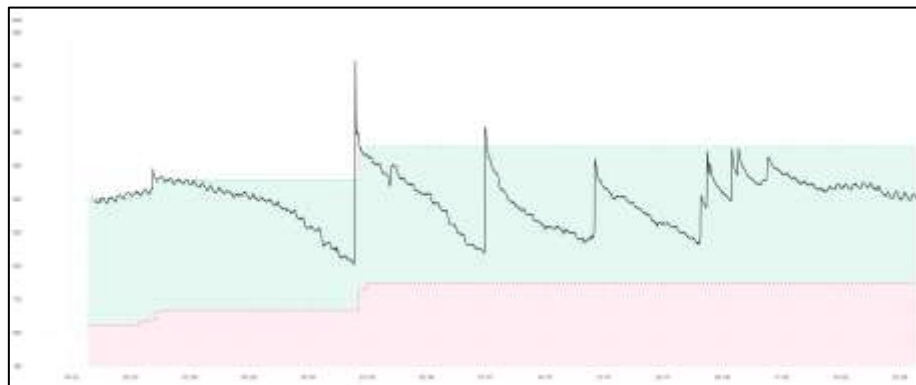


Figure 4. Software output from a CropX sensor. The green shaded area on the graph represents soil moisture between field capacity and maximum allowed depletion. Green bars along the x-axis represent irrigation applications of 12.5 mm.



Figure 5. Volumetric water content recorded by Sensoterra probes at 15 cm (orange) and 30 cm (green) depths. The white shaded area represents the target soil moisture range between field capacity and maximum allowable depletion; green bars along the x-axis indicate 12.5 mm irrigation applications.

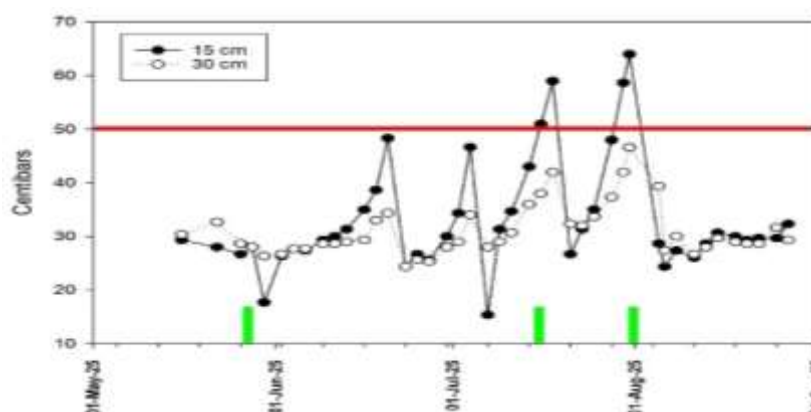


Figure 6. Average Watermark readings at 15 and 30 cm depths. The horizontal red line represents 50% plant-available water for a silt loam soil, corresponding to approximately 50 centibars of soil water tension. Green bars along the x-axis represent irrigation applications of 12.5 mm.

Outputs from all scheduling tools were generally similar, with total irrigation amounts of 50 mm applied under AIMM and Sensoterra treatments and 37.5 mm applied under CropX and Watermark treatments. Watermarks provide clear threshold values for triggering irrigation (i.e., 50 cbars), whereas the other scheduling tools rely on a target range between field capacity and MAD. This range-based approach introduced greater subjectivity in irrigation timing and application decisions, particularly with AIMM. For example, AIMM operated over a broad range of 80 mm to 181 mm, compared to CropX, which had a narrower range of 115 mm to 156 mm for most of the growing season. After two years of testing sensor-based and model-based irrigation scheduling, Sui and Vories (2020) found that the number and time of irrigation events differed, particularly at the early and late growth stages which aligns with the results observed in this study.

Water Application

Generally, the four different scheduling tools all successfully maintained soil moisture between 50-100% of PAW with irrigation application ranging from 37.5 mm (1.5") to 50.0 mm (2.0") (Table 2). There was a 12.5 mm (0.5") difference in irrigation application between the CropX/Watermark and AIMM/Sensoterra treatments. Differences between the irrigation required by the tools were minimal and could be attributed to sensor technology (i.e., time domain reflectometry vs. electrical resistance block) and assumptions built into proprietary software that models crop water use (i.e., CropX vs. Sensoterra). Other researchers have reported that evapotranspiration and water-balance (ET-WB) scheduling methods used less irrigation water than soil moisture-based methods (Asefa and Tadesse 2024). In contrast, results from the first year of this study showed that the weather-based model applied more water than the soil-based sensors

Table 2. Cumulative precipitation and irrigation amounts received by each treatment during the growing season

Scheduling Tool	Precipitation	Irrigation	Precipitation + Irrigation
	mm		
AIMM	209.1	50.0	259.1
CropX		37.5	246.6
Sensoterra		50.0	259.1
Watermark		37.5	246.6

AIMM = Alberta Irrigation Management Model

In Saskatchewan, each irrigated field is allocated 300 mm of water, however, based on the 1980-2024 average seasonal rainfall (230 mm) and average seasonal crop water use (300 mm) for the Outlook area, estimated irrigation requirements for dry pea production are approximately 127 mm (Irrigation Saskatchewan 2025). Relative to this assumption, we applied significantly less water.

Water Use & Water Use Efficiency

Water use efficiency did not differ significantly between treatments (ANOVA, $P \geq 0.05$), with mean values ranging from 25.7 to 30.5 kg/ha-mm. Watermark had the highest numerical value, whereas AIMM had the lowest (Figure 7).

In contrast, moisture use differed among treatments (ANOVA, $P \leq 0.05$). AIMM had the highest moisture use (276.9 mm) and was significantly greater than Watermark (218.1 mm; Figure 7). CropX and Sensoterra showed intermediate moisture use (240.5 and 247.9 mm, respectively) and did not differ significantly from either AIMM or Watermark. In this study, total moisture use - analogous to average seasonal crop water use - ranged from 190 mm to 300 mm (Figure 7), compared to 250 mm to 350 mm published by Irrigation Saskatchewan. Under dryland crop production, average water use of pea has been reported as 266 mm (Angadi et al. 2008), which is comparable to the higher end of moisture use observed in this study.

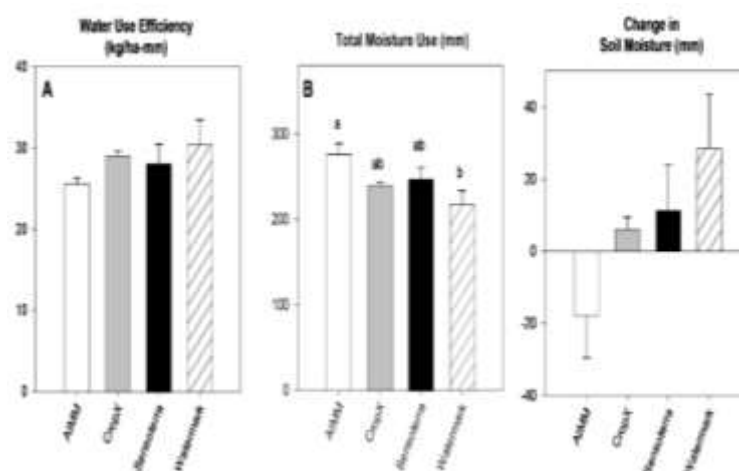


Figure 7. (A) Water use efficiency (kg/ha-mm), (B) total moisture use (mm), and (C) change in soil moisture (mm) under Alberta Irrigation Management Model (AIMM), CropX, Sensoterra, and Watermark treatments. For total moisture use, different letters indicate significant differences between seeding dates (ANOVA, $P \leq 0.05$).

Although WUE was similar across treatments, differences in total moisture use suggest variation from water management strategies, with Watermark achieving lower water use without compromising efficiency. Despite these differences, neither yield or pea quality was significantly affected. Nevertheless, higher WUE offers potential economic benefits, such as reduced pumping costs, as well as social benefits related to public perceptions of water conservation. Water use efficiency was negatively correlated with total moisture ($P \leq 0.05$), as expected, and differences in WUE were likely driven by irrigation not precipitation.

Reported WUE values for pea under dryland production in Saskatchewan range from 9.98 kg/ha-mm (Angadi et al. 2008) to 8.68 to 11.0 kg/ha-mm (Paquette et al. 2024). As expected, WUE values observed under irrigated production in the present study were substantially higher. Consistent with previous irrigation studies, treatment effects on WUE can be minimal in years with adequate moisture availability (Liyanage et al. 2022). Due to the above-normal amount of precipitation that occurred in June and near normal growing season average, there was little supplemental irrigation required to maximize yield. Similar to last years results using canola, the AIMM treatment resulted in higher moisture use which indicates increased reliance on existing soil water. If the soil is not replenished in the offseason with snowmelt and rainfall, additional irrigation water will be needed in future growing seasons.

Economic Analysis

Sensor investment costs and ROI are presented in Table 3 and Table 4, respectively.

Table 3. Sensor investment costs, per 140 acres.

Sensor Information	Irrigation Scheduling Tool			
	AIMM	CropX	Sensoterra	Watermark
Sensors per field	n/a	2	4	4
Sensor cost (\$/unit)	0	2,100	400	150
Initial subscription (\$)	0	0	2,000	400
Annual subscription (\$)	0	560	0	0
Average sensor lifetime (years)	n/a	5	3	3
Cost for one full system over sensor lifetime (\$)	0	8,600	1,000	3,600
Annualized cost (\$/year)	0	1,736	333	1,200

Table 4. Return on investment, per 140 acres.

ROI Information	Irrigation Scheduling Tool			
	AIMM	CropX	Sensoterra	Watermark
Yield (bu/ac)	106	104	103	97
Total yield (bu)	14,773	14,550	14,424	13,646
Gross income (\$)	148,179	145,932	144,673	136,865
Irrigation energy cost (\$)	552	414	552	414
Sensor cost (\$/year)	0	1,736	1,200	333
Total cost (\$)	552	2,150	1,752	747
ROI (%)	-	-205	-300	-1,615

All sensor-based tools produced negative ROI relative to AIMM in 2025.

- CropX had the least negative ROI (-205%), reflecting moderate yield and reduced irrigation, but sensor costs outweighed the economic gains.
- Sensoterra and Watermark recorded larger negative ROI values (-300% and -1,615%, respectively), driven primarily by lower yields and fixed sensor costs.
- AIMM remained the most economically favorable option for peas under the 2025 conditions due to zero capital cost and high yield.

CONCLUSIONS

Key findings from this study include:

- Growing season precipitation (209 mm) was slightly below the 30-year average, with above-normal rainfall in June and near-normal conditions overall. This reduced the need for supplemental irrigation.
- Irrigation scheduling tool had no significant effect on crop emergence, yield, seed quality, crop growth stage timing, or physical characteristics.
- All scheduling tools effectively maintained soil moisture within the target range (50–100% PAW). Total irrigation applied ranged from 37.5 to 50.0 mm, with CropX and Watermark requiring less irrigation than AIMM and Sensoterra. Differences in irrigation amounts were small and attributable to sensor technology and modeling approaches.
- Water use efficiency did not differ significantly among treatments and was substantially higher than reported dryland pea values. However, total moisture use differed, with AIMM using the most water and Watermark the least. Watermark achieved lower moisture use without compromising yield or efficiency.

- These results highlight that economic performance is crop- and season-specific, and that improved WUE does not automatically translate into positive ROI when yield gains are limited.
- Under a year with adequate precipitation, all irrigation scheduling tools performed similarly in terms of yield and crop performance. Differences among tools were primarily related to irrigation amounts and soil moisture dynamics rather than agronomic outcomes, highlighting opportunities for improved water conservation without yield penalties.

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