IRRIGATION SCHEDULING MANUAL FOR SASKATCHEWAN

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Canada

IRRIGATION SCHEDULING MANUAL FOR SASKATCHEWAN

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FOREWORD

Fresh water is a public resource with many competing users including agriculture. With competition for water increasing from other sectors and with the threat of future droughts and water shortfalls, it is important for producers to be good stewards and make the most of what has been allocated to them.

One of the first and most cost effective steps to improving water use efficiency is to develop a practical irrigation schedule. The key to a successful strategy is to identify the methods and utilize the tools available that work best for each individual's operation from a cost and comfort standpoint to ensure long-term application and success.

This manual gives producers the tools for success to develop and implement irrigation scheduling practices into their daily operations. Topics such as soil-water-crop interactions, scheduling methods, available technologies and precision irrigation are covered, with the goal of providing the required knowledge and tools to implement irrigation scheduling practices from basic operations up to complex systems.

This manual builds upon past iterations of the Saskatchewan Irrigation Manual, adopting previously published information while providing important updates due to advances in scheduling technologies and the commercial availability of precision irrigation.

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INTRODUCTION

After temperature, water is the most limiting factor affecting crop productivity on the Prairies. Furthermore, to maximize crop productivity, water needs to be available at the right time and in the right amount to match crop demands. Nature is rarely so accommodating, especially on the Prairies where up to half the precipitation falls in the winter. Some of that is available for spring growth, but during the growing season, precipitation may be sporadic, can be light enough to evaporate before it reaches the crop, so intense over a short period causing flooding, or so localized that fields only a few kilometres apart will have vastly different rainfall patterns. In addition, the Canadian Prairie climate historically cycles through extended periods of warm and cool growing seasons and through extended periods of high moisture and drought. When a warm summer coincides with lower than average precipitation, agriculture production is further challenged (Figures 1, 2).

IRRIGATION IS:

The application of water to meet crop water demands that are not met through stored soil moisture and precipitation.

Irrigation, when applied at the right time and at the right volume, can help maximize crop yield and quality, protecting against seasonal water variability. Irrigation also opens up opportunities to grow higher value crops.

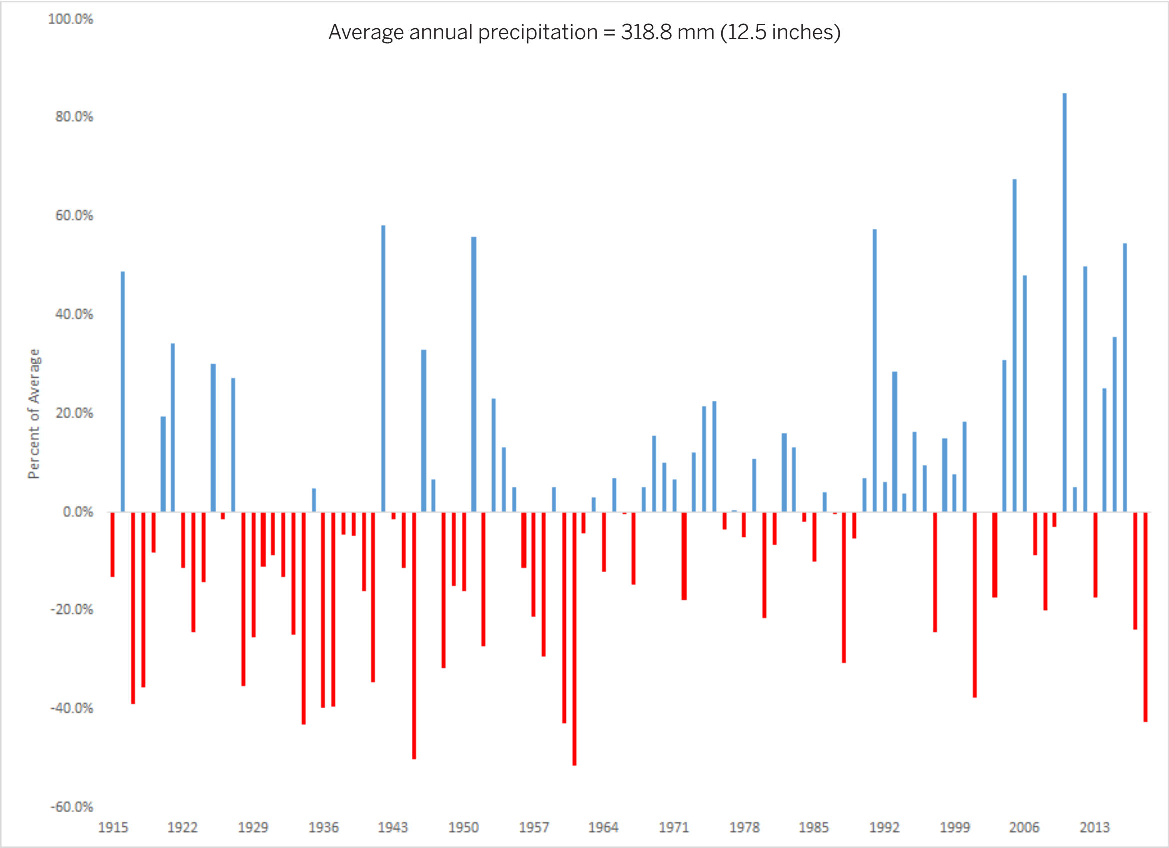


Figure 1: Deviation from average annual precipitation (318.8 mm = 12.5 inches), Outlook, Saskatchewan (1915–2018) (bars above zero (blue) are years of above average precipitation; bars below zero (red) are years of below average precipitation).

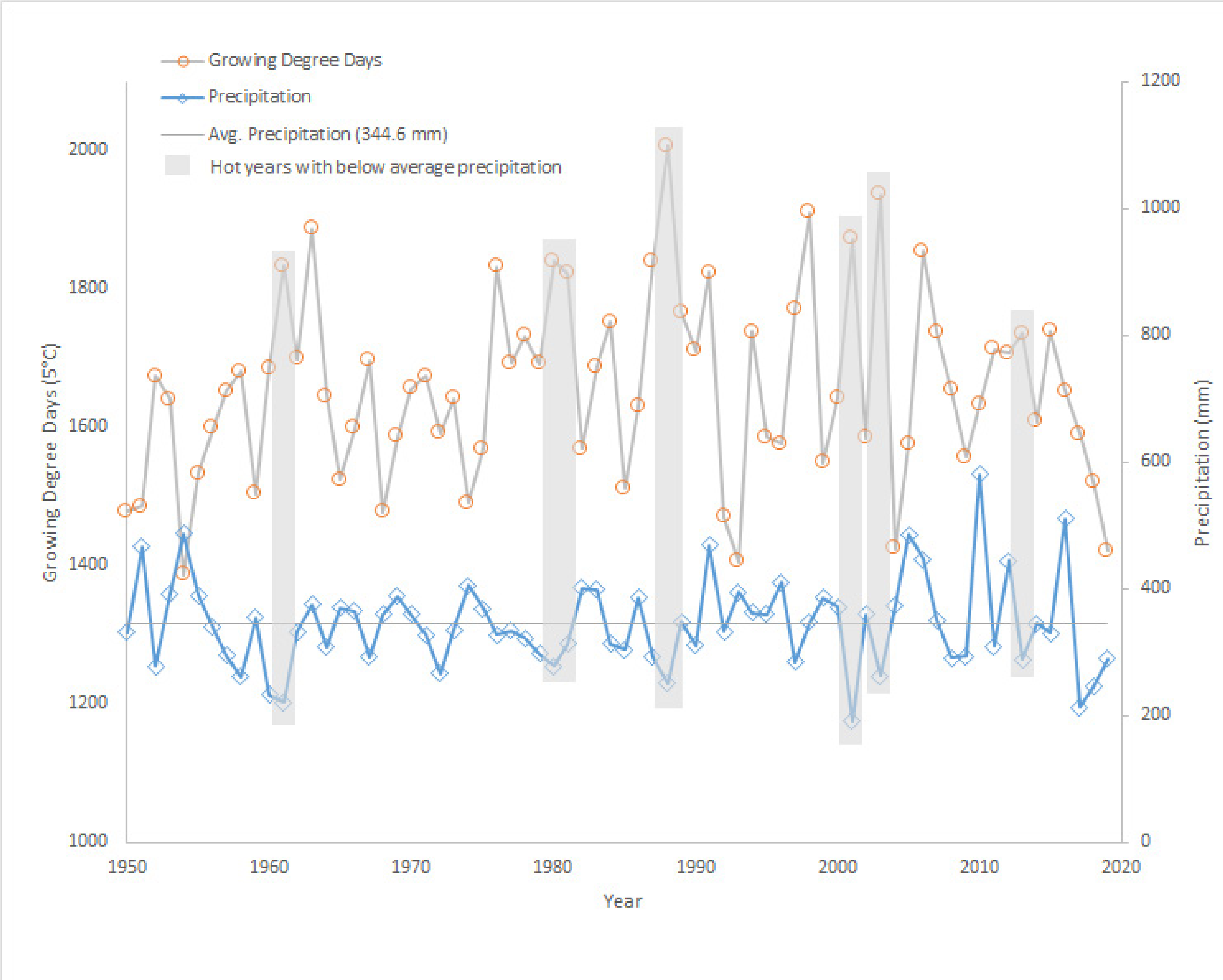


Figure 2. Annual growing degree days (base 5°C) and precipitation for Rosetown, Saskatchewan (1950–2019). Grey bars highlight years when relatively warm growing conditions coincided with below-average annual precipitation (NRCan, ECCC).

In Canada, irrigation on over 1 million hectares (2.5 million acres) of farmland accounts for 80% of national fresh water consumption. Little to none of the irrigation water is returned to the fresh water supply (lakes, reservoirs, rivers). And while fresh water is often seen as abundant (Canadian rivers account for 7% of the world's renewable freshwater flow), the critical issue is geography: 60% of Canada's freshwater drains north away from where the majority of the population (85%), industry and agriculture occur (i.e. within 300 km of the Canada-USA border. Therefore, Canadian fresh water resources must be carefully managed to ensure there is a sustainable supply of good quality water available for all sectors including satisfying environmental system needs (e.g. aquatic and terrestrial wildlife habitats) as well as fulfilling transboundary (inter-provincial and international) water agreements.

SCHEDULE IRRIGATION TO MAXIMIZE RETURNS

An irrigation system has substantial associated capital (piping, pumps, sprinkler system [e.g. centre pivot]) and operational (power, maintenance, repair, labour, administration) costs. In order to get the most out of your investment, you will need to maximize efficiencies (i.e. reduce water and power consumption without sacrificing crop yield or quality). This can be accomplished with scheduling irrigation.

With irrigation scheduling, irrigation is timed to avoid crop water stress. This means that water should be applied (1) before it is needed (**RIGHT TIME**), (2) only where it is needed (**RIGHT PLACE**), and (3) only as much as is required to top up soil moisture to field capacity (**RIGHT AMOUNT**). This approach can improve profitability:

- Higher crop yield, quality and uniformity
- Lower nutrient loss through reduced leaching
- Better water-use efficiency (less unnecessary water applied)
- Lower operating costs (lower pumping costs)

Effective irrigation scheduling can be challenging as fields are variable in terms of topography, soil type and fertility. These factors interact with weather conditions leading to differences in crop stage and water needs across a field.

Four key pieces of information are required to schedule irrigation effectively:

- Soil water holding capacity
- Soil moisture status
- Plant water stress indicator(s)
- Crop- and growth stage-specific water usage

A fifth factor, rainfall, is usually accounted for by measuring soil moisture, or by using a local rain gauge or regional weather station data. In scheduling systems that use complex models, rainfall is included to estimate soil moisture.

The simplest irrigation scheduling scheme is to irrigate the entire field according to the area in the field with the greatest water need. Water need may be determined by visual cues (e.g. wilting, poor vigor) or by checking root zone moisture with a spade. This approach assures that little to none of the crop is under drought stress but there may be areas that are kept too wet. At the other end of the spectrum, sophisticated systems may employ a fleet of soil moisture sensors, use remote imagery (e.g. satellite, drones) and controllable irrigation zones (i.e. irrigate only the parts of the field where the crop needs water). This approach requires more management but, if done correctly, all plants receive the right amount of water leading to optimized crop yield, quality and uniformity as well as reduced energy (pumping) costs and lower water-use.

THE RELATIONSHIP BETWEEN WATER AND YIELD

A primary reason to schedule irrigation according to crop needs is to optimize yield for the irrigation water you have available (i.e. you may not always have all the water you require to maximize yield). This is usually defined by terms such as Water Use Efficiency or Water Productivity. In agriculture, these two terms are often used interchangeably. Historically, Water Use Efficiency is used by engineers to describe the efficiency of the overall system (conveyance, irrigation, management, crop), whereas Water Productivity is used by agrologists to define the efficiency of the cropping system. In general, both describe the amount of water required per unit of crop produced. As an irrigator, you strive to maximize productivity and profitability.

When a crop is under stress (nutrient deficiency, insect pests, weed, heat, disease pressure, water stress), the ultimate impact is reduced yield (biomass, grain, fruit). In the case of water stress, plants can suffer from too much (flood) or too little (drought) water. Water-Yield curves show how crop yield is affected by seasonal water availability. These curves do not account for timing, but they show the impact that insufficient or excess water (total seasonal) has on crop yield (Figure 3; Appendix D: Examples 1, 2, page 62).

Water-Yield curves show the relationship for an ideal system, where reduced yield is due to insufficient water applied to meet crop demands (= crop stress). In the real world, not all water applied through the irrigation system reaches the crop because of water lost to inefficient system design, components or management (e.g. sprinkler evaporation, drift, runoff, deep drainage, crop stress; Appendix A: Table A2, page 47). These inefficiencies along with poor scheduling can have a compounding effect on crop yield. To account for system inefficiencies, additional irrigation water is required to achieve the desired yield response (Figure 4).

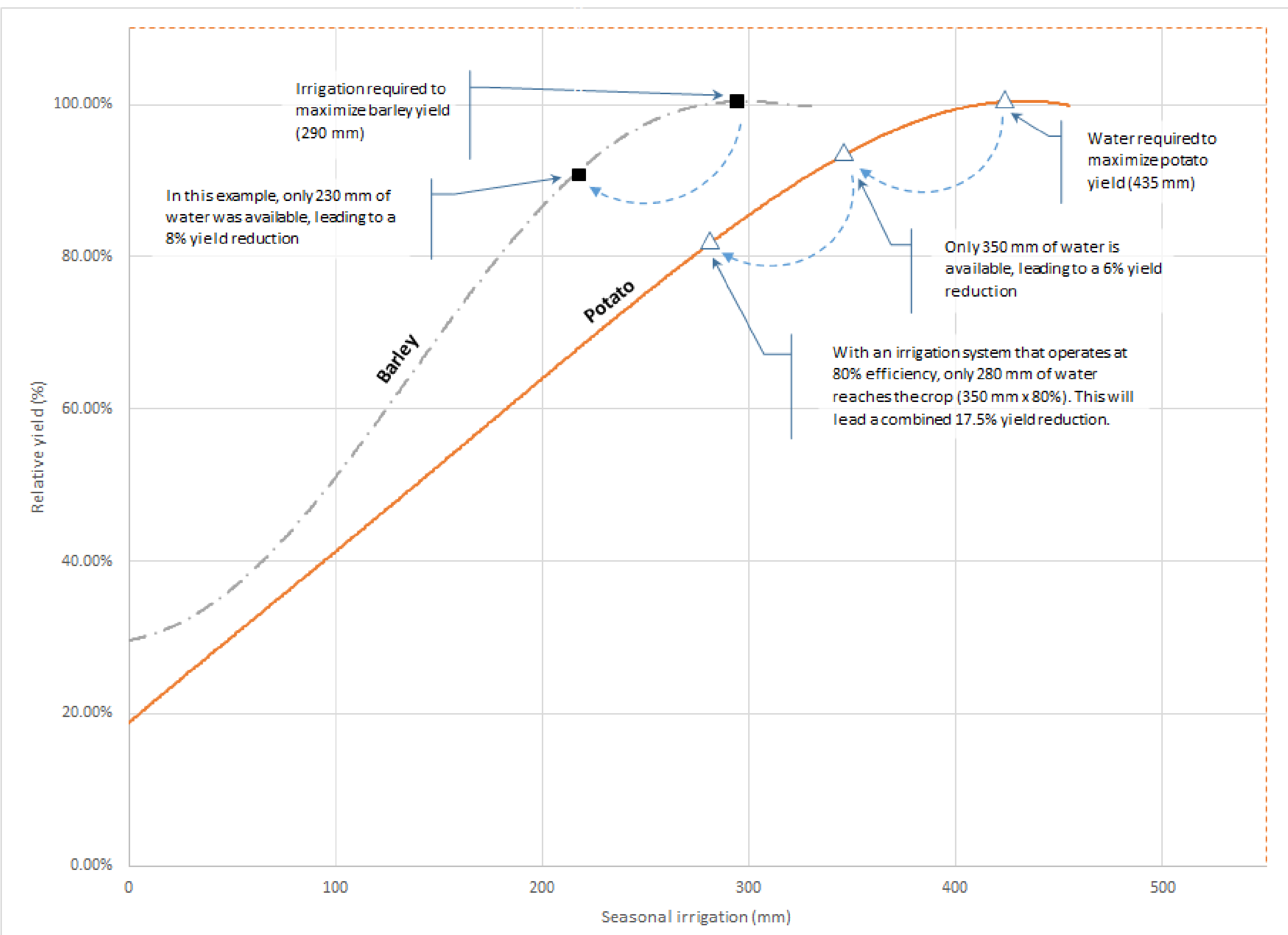


Figure 3. Estimating yield reduction due to water shortage and irrigation system inefficiencies: Modelled Water-Yield curves for irrigated barley and potato (Model output based on 2018 weather data from Outlook, Saskatchewan. Analysis completed using FAO AquaCrop 6.1).

THE RELATIONSHIPS AMONG SOIL, CROP AND WATER

Complicating the water x yield relationship is the fact that crops grow in soil. Soil is complex, made up of organic matter, inorganic material and pore space (spaces between particles) as well as a living component (bacteria, fungi, insects, other animals). Soil particles are variously sized ranging from very fine clay particles to coarse sand.

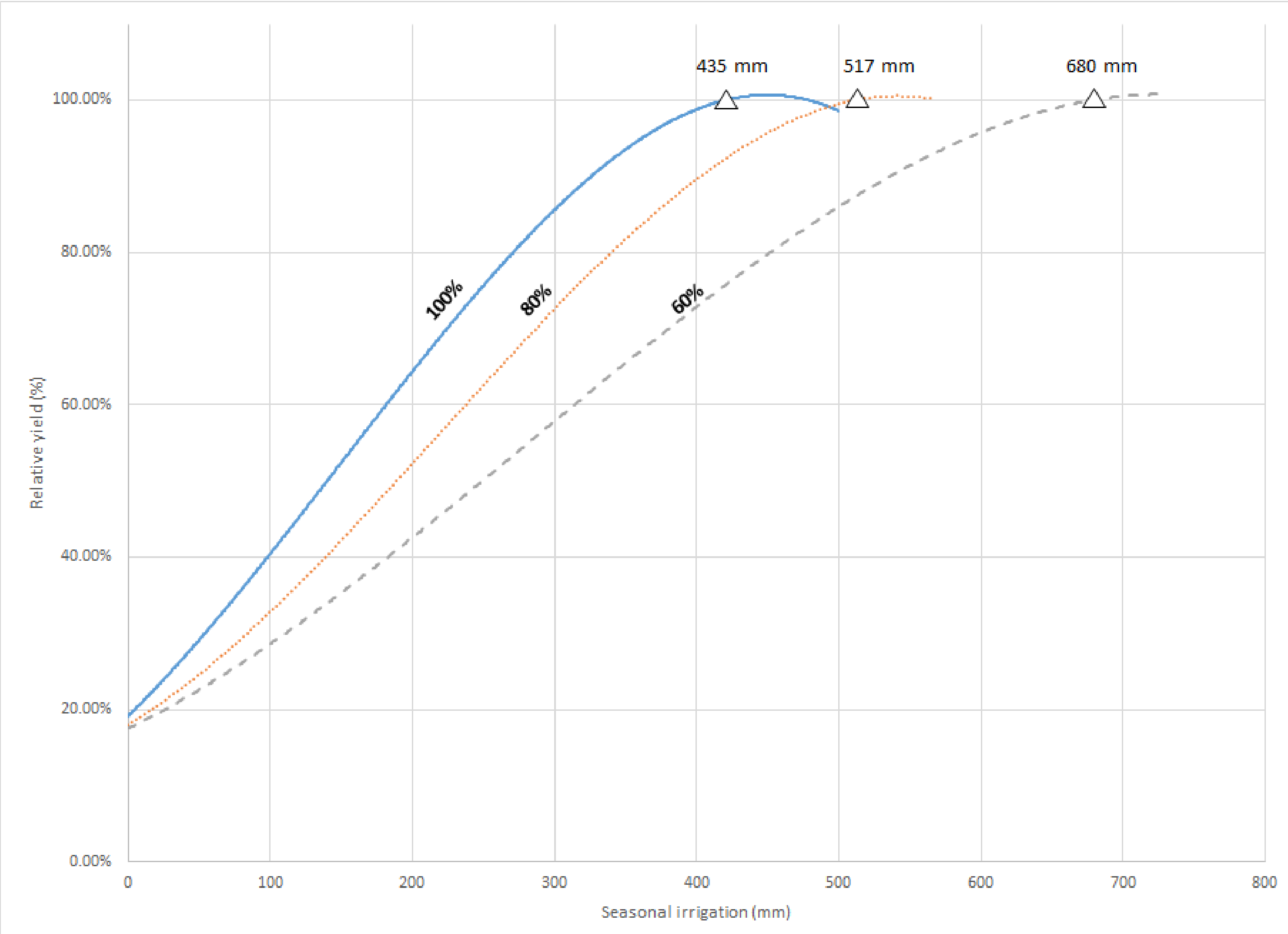


Figure 4: To maximize crop yield, you need to add additional water to compensate for an inefficient irrigation system: Modelled Water-Yield curves for irrigated potato under different system efficiencies (Model output based on 2018 weather data from Outlook, Saskatchewan. Analysis completed using FAO AquaCrop 6.1).

The amount of available water for crop growth in soils is found in the pore-space and depends on the soil texture (e.g. sand vs. clay), compaction and organic matter levels. Soil texture is characterized by the percent of sand, silt and clay (Figure 5). In addition, soil characteristics can vary significantly across a field, further complicating matters.

TAKE HOME MESSAGE:

Soil texture is a key factor in irrigation scheduling as soil texture affects the available water holding capacity which in turn affects the water available for crop growth.

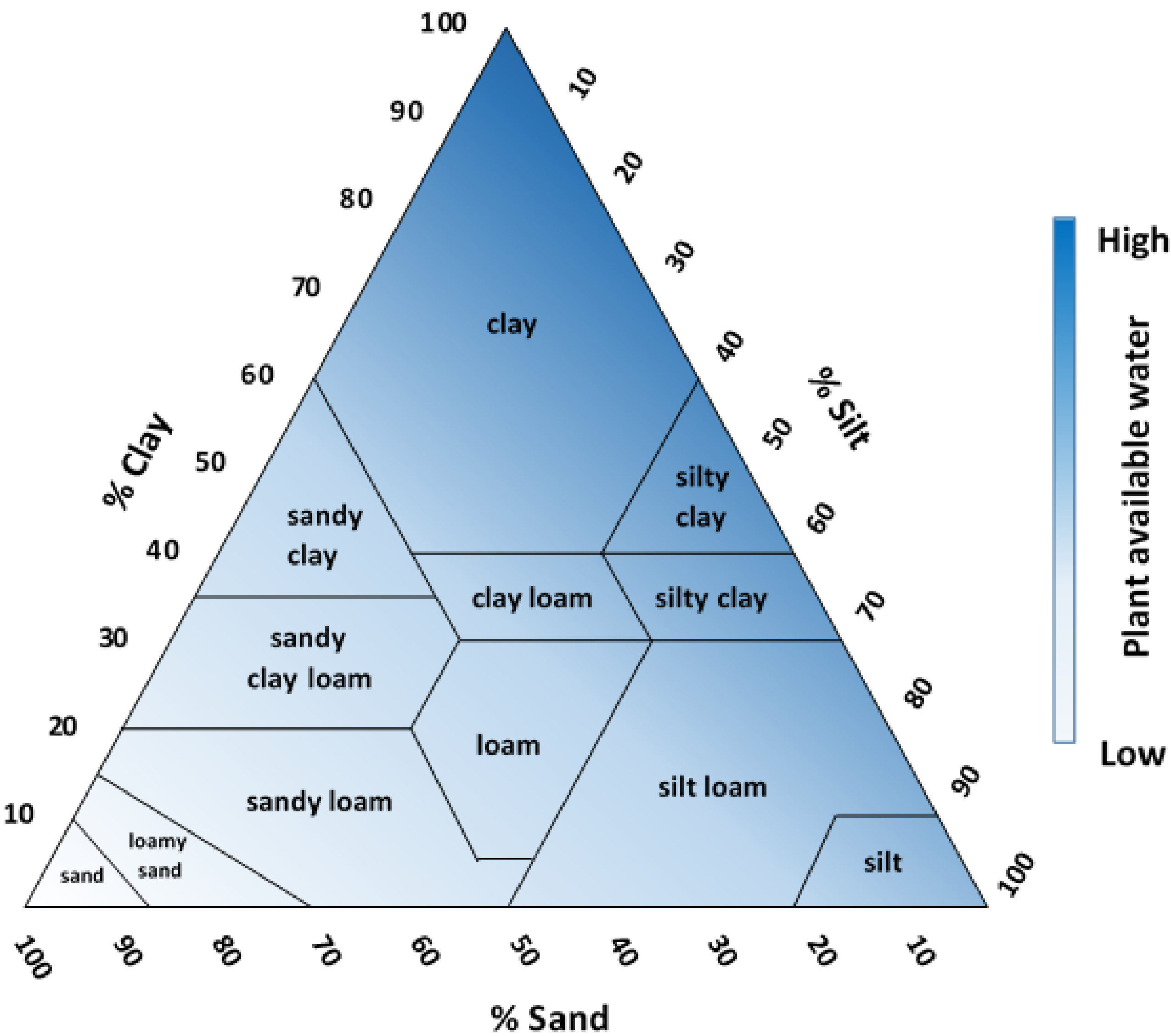


Figure 5: Soil textural triangle (based on USGS soil texture calculator, https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/research/guide/?cid=NRCS142P2_054167).

MAPPING OUT YOUR SOILS

Irrigation certification or historical soil survey maps can be used as a first step to map out soil texture (Canadian Soil Information Service, http://sis.agr.gc.ca/cansis/; Saskatchewan Soil Information System, https://SKSIS.usask.ca). Soil types are identified by a unique name which has specific characteristics associated with it (e.g. Bradwell [abbreviated BR] is a very fine sandy loam in the dark brown soil zone). However, these maps have low resolution (based on a limited number of samples) and they were not designed to be used at a field scale. In other words, the boundary between soil classes is not as sharp as may be assumed from viewing a soils map (Figure 6).

To increase the resolution, collect additional soil samples throughout the field. The number of sample locations will depend on field variability, the required level of detail and your budget. As field variability increases so does the number of soil samples required, which in turn increases the time and cost.

Soil samples can be collected using a number of commercially available tools. Common tools include a Backsaver soil core sampler (Figure 7) and a Dutch auger. Other tools can range from a simple spade to a truck-mounted hydraulic soil punch (Figure 8).

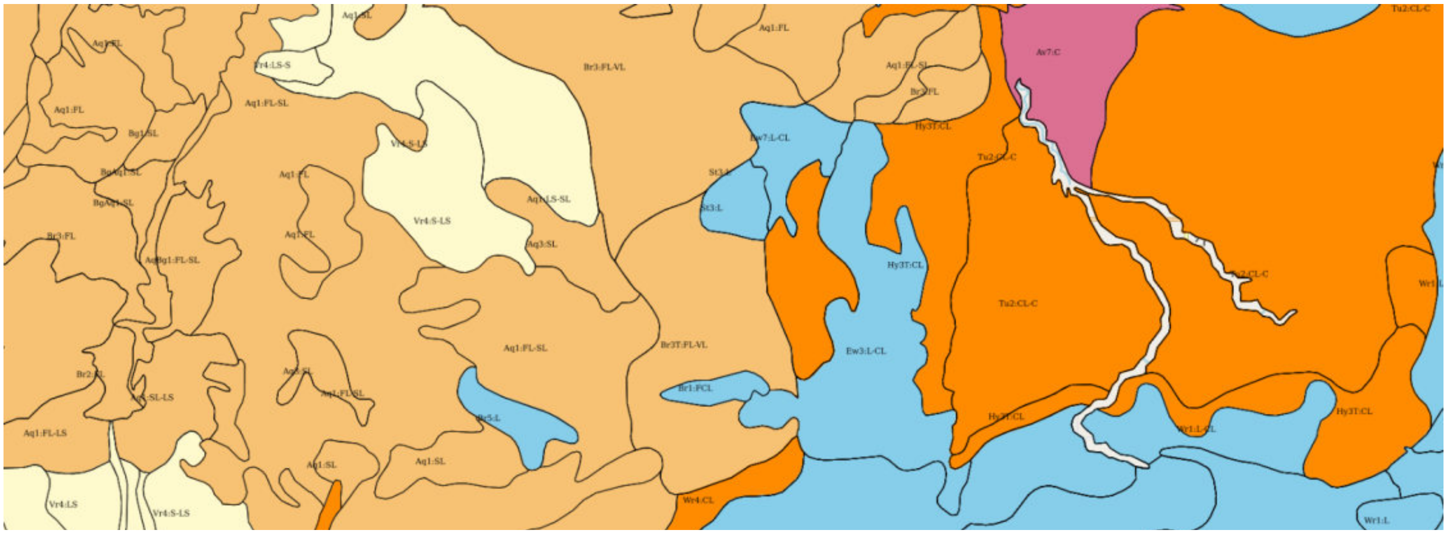


Figure 6. Soil survey map (1:100,000) near Outlook, Saskatchewan) [SKSIS Working Group. 2018. Saskatchewan Soil Information System – SKSIS. A. Bedard-Haughn, M. Bentham, P. Krug, K. Walters, U. Jamsrandorj, and J. Kiss, eds. [Online] Available: https://sksis.usask.ca [June 2, 2020].

Figure 7: Soil sample collection using a JMC Backsaver soil core sampler.

Figure 8. Hydraulic soil sampler/coring machine mounted to tractor.

When sampling soils for textural analysis, it is important to:

i) Take a sample to a depth that covers the bulk of the crop rooting zone (0.5–1.0 metre / 1.5–3.0 feet).
ii) Sample throughout the field (gridded or targeted) based on field variability.
iii) Divide samples into layers (e.g. 0–15 centimetres, 15–30 centimetres, 30–60 centimetres / 0–6 inches, 6–12 inches, 12–24 inches) for testing and reference.
iv) Take a large enough sample, as required by a testing lab or to analyse using the hand feel method (Appendix A: Figure A1, page 46).

You can determine the soil texture yourself using the hand-feel method (Appendix A: Figure A1, page 46) or contract an agrologist to complete the analysis for you (Figure 9). In addition, soils information is included in the Agri-Environment Report as part of the irrigation development process. Contact the Ministry of Agriculture to inquire about existing reports (see Irrigation Scheduling Assistance, page 43).

TAKE HOME MESSAGE:

Soil sampling is the only dependable method to determine the soil texture of your field and is the first step in developing a successful irrigation scheduling management plan.

SOIL TEST CHARACTERISTICS

Depth (inches)	Texture	pH 1S:2W	E.C. 1S:2W (mS/cm)	E.C. Calc. Sat. Extr. (mS/cm)	Salinity Rating	Organic Matter %	NH_4N (lb/ac)	Calculcated CEC meq/100g	Ca	Mg	K	Na	Base Saturation Ca	Mg	K	Na
									---------------- ppm ---------------				----------- % of CEC ---------			
0-6	Clay Loam	8.3	0.2	0.4	Non Saline											
6-12	Clay Loam	8.5	0.3	0.7	Non Saline											
12-24	Clay Loam	8.8	0.3	0.7	Non Saline											

SOIL TEST NUTRIENT LEVELS

Depth (inches)	NO_3-N	P	K	SO_4-S	Cu	Mn	Zn	B	Fe	Cl
	---------------------------- lb/ac ----------------------------									
0-6	4	31	256	32						
6-12	10			>43						
12-24	19			>86						

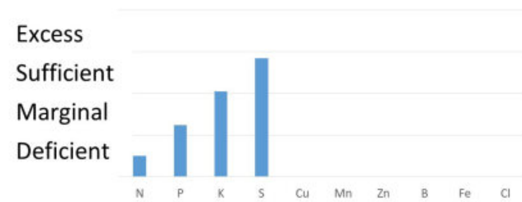


Figure 9. Sample soil report showing soil profile characteristics (texture) and nutrient levels.

SOIL-WATER CHARACTERISTICS

Understanding the following soil-water characteristics is key to developing and implementing an irrigation schedule:

- **Field capacity**: The maximum amount of water a soil can hold against gravity. Also known as water holding capacity.
- **Maximum allowed depletion**: Soil moisture level that triggers irrigation, a level set above the permanent wilting point.
- **Permanent wilting point**: The amount of water in soil below which will lead to permanent plant damage.
- **Plant available water**: The amount of water between field capacity and permanent wilting point (= Field capacity – Permanent wilting point)
- **Saturation**: The maximum amount of water a soil can hold when all the pore spaces are filled.
- **Water holding capacity:** See Field Capacity.

(See Soil-crop-water terms defined, page 11).

In general, the larger the soil particle (e.g. sand), the less plant available water there is at field capacity. Conversely, fine textured soils have more plant available water at field capacity (Appendix A: Figure A2, page 47). However, fine textured soils are also prone to waterlogging (due to poor drainage) and compaction, whereas coarse textured soils tend to be free from these issues.

Irrigation schedules are designed to maintain soil moisture levels in the 'safe zone.' Irrigation is typically triggered at a soil moisture level defined as the **maximum allowed depletion** within the crop's root zone. The maximum allowed depletion is usually set at 50% of plant available water (i.e. well above the permanent wilting point) to reduce the incidence of plant stress due to low moisture availability (Figure 10; Appendix D: Example 3, page 62).

TAKE HOME MESSAGE:

Once you have set the maximum allowed depletion and know how the crop's rooting depth changes throughout the growing season, you can calculate the amount of water that needs to be maintained in the soil. This information is the basis for developing an irrigation schedule.

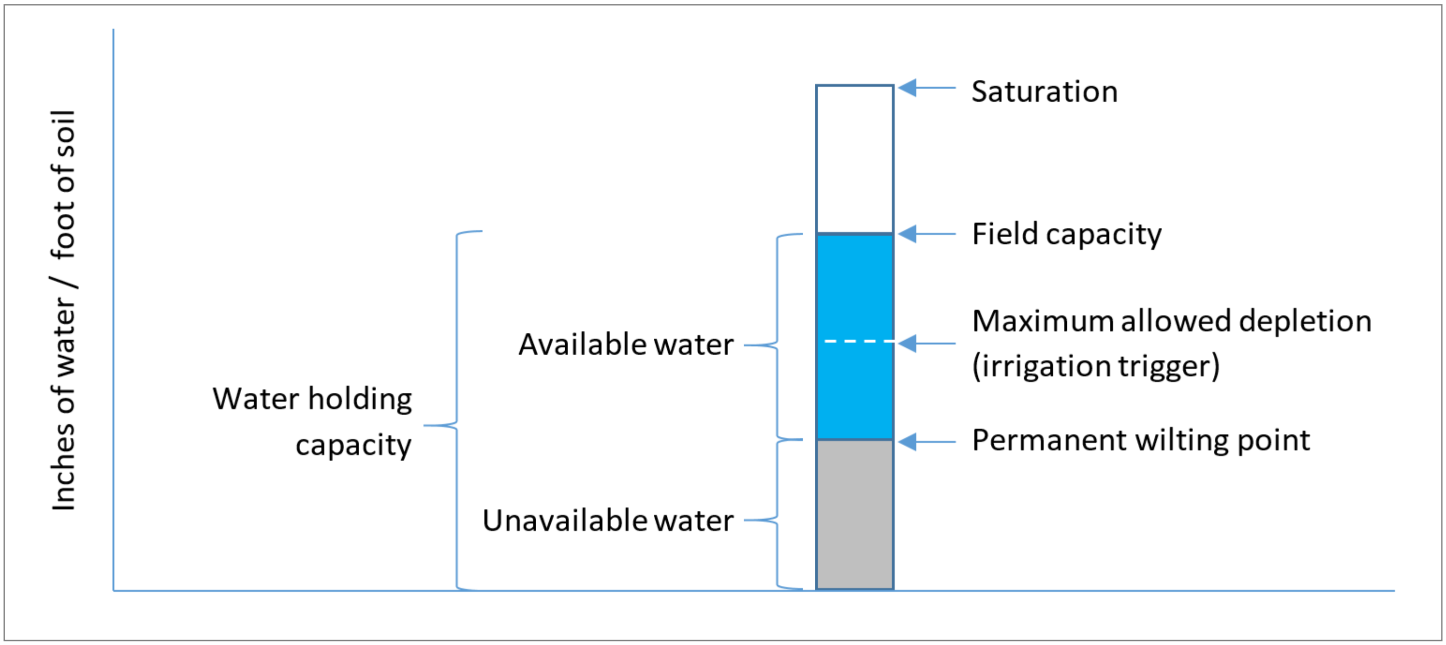


Figure 10. Illustration of water relations for a general soil in terms of plant available and unavailable water.
* see Figure A2, page 47, for soil-texture specific water depth values (e.g for clay, loam, sand)

Soil-crop-water terms defined

Capillary water: see Plant available water.

Field capacity: soil moisture content when excess moisture has been drained from soil profile due to gravity, typically measured two days after irrigation. Also known as Water holding capacity.

Maximum allowed depletion: in irrigation scheduling, soil moisture should be managed/maintained at a level above permanent wilting point. Plants begin to experience stress as the water level approaches permanent wilting point. In practice, maximum allowed depletion is generally set at 50% of plant available water for most crops (NRCS 2005).

Permanent wilting point: plants remove water from the soil via suction (a negative pressure). When the water level falls below a plant's ability to extract it via suction, it becomes stressed and, if not corrected immediately, permanent damage (permanent wilting, eventually death) occurs.

Plant available water: volume of water between field capacity and permanent wilting point (also known as Capillary water).

Pore space: soil volume that is not taken up by solid material. The pore space is filled by a combination of air and water. The average pore size is related to the physical soil characteristics such as particle size (large particles = large pore spaces), organic matter composition and compaction [for the purpose of irrigation scheduling, assume no compaction].

Saturation: soil moisture content where all pore space is filled with water. No air is present in the soil and if water is not drained, crop damage will occur.

Unavailable water: volume of water that is tightly bound to soil particles (hygroscopic water) which requires more suction to remove than a plant is capable of producing.

Water holding capacity: see Field capacity.

CROP WATER REQUIREMENTS

A crop's daily and total seasonal irrigation requirement depends on crop type, selected variety, development stage, crop condition, nutrient management and weather.

On a daily basis, water-use increases as the crop grows and matures. For annual crops, the daily crop water-use rate peaks during the critical periods of flowering and seed set (Figure 11). For perennial crops, the rate peaks after cutting/grazing. Seasonal crop water-use (also known as seasonal evapotranspiration) is the sum of daily crop water-use over the growing season that is consumed by the crop for growth and cooling.

Daily crop water-use charts are produced regionally for major crops, calculated using local climatic conditions (assumes soil moisture is non-limiting). The water-use is shown as a curve as daily water-use changes over the growing season as the crop progresses through its development stages. Daily water-use is also heavily influenced by the weather (e.g. temperature, wind speed, humidity, cloud cover, light intensity) and can range widely over the short term (i.e. over days). The range is shown on crop water-use charts as high, average and low water-use curves (Figure 11).

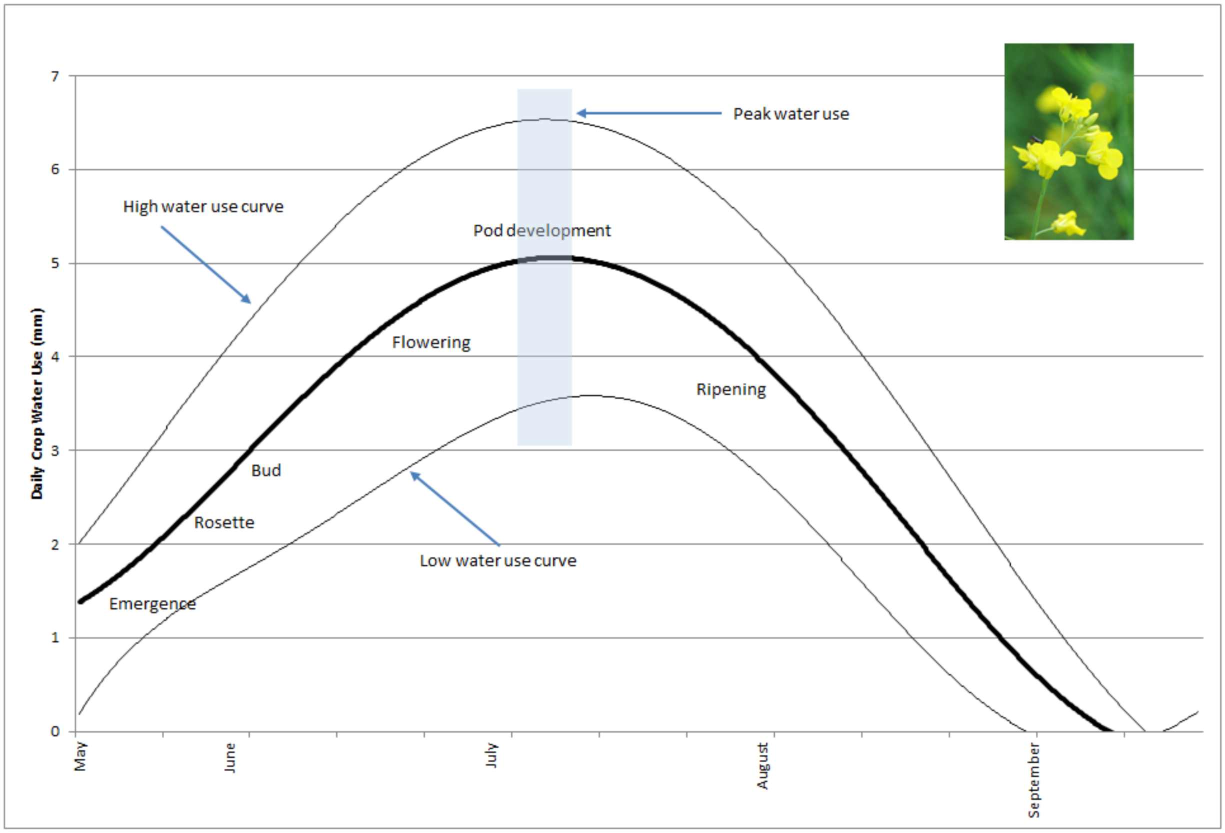


Figure 11. Daily water-use for canola, based on climatic data in Outlook, SK (calculated using 2004-2015 regional climate data). Additional crop-specific water-use curves available in Appendix B, pages 51-56.

In addition to understanding how water-use changes with crop stage, rooting depth is another important factor in determining how much water to apply. As the crop develops throughout the growing season, the active root depth increases (Figure 12; Appendix A: Table A1, page 47). This means that as the root zone increases, the plant has access to a greater volume of soil and potentially greater water resources. At the same time, it means that you need to increase the soil depth you are managing to ensure you are providing enough water to wet the entire root zone. Note that crops draw approximately 70% of their water from the top 50% of the active root zone. Therefore, do not allow this portion to dry out, even if there is adequate water deeper down (Figure 12).

A well-designed irrigation system should be able to keep up with the crop's water demand, with a safety margin to account for some irrigation system downtime, capacity and efficiency. In addition, the time required to apply irrigation is often significant enough that it should be taken into account when irrigating (irrigation applications should be scheduled in advance at a sufficient rate to account for this time). The amount of water that can be applied during a single event is limited by the system design.

Application rate charts are available from the manufacturer and should be considered when determining the irrigation depth to apply as the crop will continue to use water during the time it takes for the pivot makes its revolution. This factor is often missed in irrigation scheduling. Appendix A: Table A3 (page 48) is an example of the irrigation depth applied by a low-pressure centre irrigation pivot for various flow rates and circle times (Appendix D: Example 4, page 63).

In addition, system efficiency varies depending on the irrigation method. For example a high pressure centre pivot may only be 80% efficient whereas a low pressure centre pivot may be 90% efficient or higher. Converting to a higher efficient irrigation system means more water is applied to the soil over the same amount of time (Appendix D: Example 5, page 63).

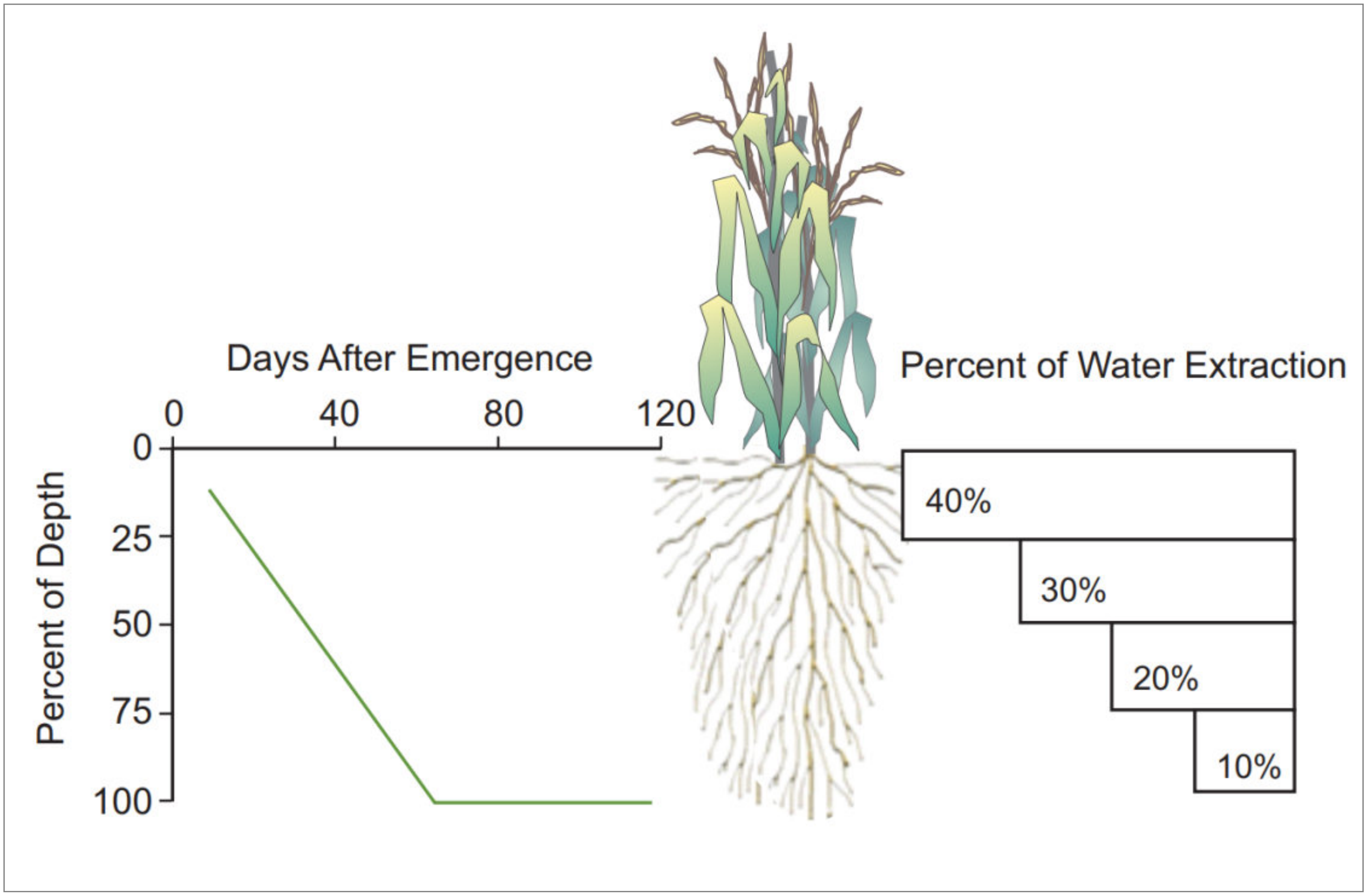


Figure 12. Effective root zone soil water extraction and plant root development (used with permission, University of Nebraska-Lincoln).

TAKE HOME MESSAGES:

1. Apply only what your crop needs

Irrigation depth is determined by either measuring soil moisture content or by estimating the crop water-use since the last irrigation. An irrigation application should bring the soil moisture content up to field capacity.

2. Know how deep to go

The depth of soil that you want to manage (irrigate) changes throughout the season as the crop develops and rooting depth increases. For example, early in the growing season the rooting depth of a crop may be 7.5–15 centimetres (3–6 inches), compared to the end of the growing season where the same crop may have a rooting depth of 90 centimetres (3 feet).

3. Design for your thirstiest crop

A multi-year crop rotation plan is the norm for Prairie crop production. Your irrigation system needs to be able to satisfy the thirstiest crop in your rotation at its peak water-use. The amount that the system needs to deliver over a 24-hour period during this time will be equal to how much it uses. During this critical peak water-use period, the irrigation equipment may be required to run continuously to keep up with crop water demand (Figure 11).

4. It takes time to irrigate

Take into account how long it takes for the irrigation system to deliver the required amount of water.

5. System efficiencies impacts how much water reaches the soil

USING SENSORS TO MEASURE/ESTIMATE CROP WATER NEEDS IN IRRIGATION SCHEDULING

[Note: This section provides a general overview of sensor types. See *Putting it Together: Irrigation Schedules*, page 17 for specific sensor types, application and interpretation]

In order to schedule irrigation to meet crop water needs, you need take into account actual soil moisture status or estimate the crop water use since the previous irrigation event. This requires time-consuming site visits and data collection. Technological advances in computing and communication has increased the practicality and applicability of using sensors to aid in irrigation scheduling. Sensors can monitor, record and in some cases transmit soil moisture levels automatically. Sensor placement depends on the technology used to measure soil moisture.

Sensor types

In-place and hand-held

The widest range of sensor types is in-place and hand-held types. However, while cost-effective, the user must take multiple readings and/or install several sensors throughout the field to get a good estimate of water requirements at the field level.

Site selection: Choose an average or representative location(s) in terms of soil texture, topography and productivity. If you select typically wet locations (low spot/fine texture), readings will tend to underestimate irrigation requirements elsewhere in the field. Conversely, if you select typically dry locations (knoll/coarse texture), readings will tend to overestimate irrigation requirements. If possible, select a site easily accessible (access-road or pivot track) to limit crop damage. Be sure to mark/flag or record the GPS coordinates of the sensor location(s).

Soil moisture sensors should be placed at 25% of the maximum root zone depth (e.g. if the maximum water extraction depth for canola is 100 centimetres / 39 inches, place the sensor at 25 cm / 10 inches from the soil surface. This is where 70–80% of the crop's water consumption occurs. However, at the beginning of the season, when the root system is much less developed and shallower, soil moisture should be monitored nearer to the soil surface (e.g. 15 centimetres / 6 inches below the surface). If resources allow, this means using two sensors or a multi-depth sensor at each monitoring location.

Remote Sensors

Remote type sensors measure soil moisture (or indicator of soil moisture, e.g. plant productivity) from a distance. They are non-contact sensors, meaning they do not need to be installed in the soil.

Irrigation system-mounted: System-mounted sensors are attached to the irrigation structure and multiple measurements are taken as the irrigation system moves around the field.

Satellite: Remotely sensed satellite data is available for free through government operated satellite systems or can be purchased from privately operated satellite companies. Depending on the satellite, sensors measure different reflected wavelengths from the ground (microwaves, RGB images, thermal, etc.) with varying resolution (6 to 100–metre pixels). The disadvantage of satellite-based data is the time between visits. Depending on satellite, return time can range from daily up to weekly. In addition, cloud cover can significantly limit data quality and availability.

Unmanned aerial vehicle (drone)-mounted: Drones can give you excellent resolution (< 1-metre pixel) and on-demand data collection. However, with drone-mounted sensors, there are weight considerations due to the limited physical carrying capacity of a drone. These systems also require data processing software or a service provider that can translate the data into a useable form (e.g. soil moisture or irrigation demand maps). In addition, drone pilots are required to follow Transport Canada rules and regulations. This means drone pilots need to complete approved training, obtain a licence and carry adequate insurance.

PUTTING IT TOGETHER: IRRIGATION SCHEDULES

In general, irrigation scheduling manages both the TIMING and DEPTH of irrigation events throughout the growing season. To simplify management, schedules are generally based on fixing one of the two variables (TIMING or DEPTH) and measuring or calculating the other variable.

i) **TIMING**: With a fixed time between irrigation events, the amount of water applied will vary as a result of daily demand. Fixed time schedules are useful in canal-based systems where water is ordered in advanced.

ii) **DEPTH** (or depletion): When applying a fixed water depth with each irrigation event, the timing between events varies as a result of crop use or demand. Fixed depth schedules simplify system operation (i.e. fixed pivot settings = same amount of water is applied at each irrigation event).

Regardless of whether your irrigation scheduling system is based on a fixed time or fixed depth, irrigation water requirements need to be either monitored or estimated. In general, there are three approaches to determine irrigation water requirements.

i) **Soil-based**: soil moisture is measured.

ii) **Weather-based**: estimated crop water-use based on weather data (temperature, humidity, wind, solar radiation, etc.).

iii) **Plant-based**: uses plant response data and weather models to estimate crop water-use.

SOIL-BASED IRRIGATION SCHEDULING

Soil-based schedules can use direct or indirect approaches to measure or estimate soil moisture content. As with any measurement when dealing with large areas, collect data from multiple locations throughout a field to get a reasonable estimation of the whole field.

Gravimetric method to measure soil moisture

The gravimetric method is reliable as it is a direct measurement of the water within the soil. This process is intensive and requires soil samples to be oven-dried. It is therefore used primarily as a periodic check of other scheduling methods.

PROS – Inexpensive; accurate

CONS – Requires experience, site visits, time

Method: Gravimetric

1. **Identify a representative location(s) in your field.**
2. **Use a soil probe (Figure 7) to take soil cores at 15- to 30-centimetre (6- to 12-inch) increments throughout the entire root zone.**
3. **Store samples in separate labelled plastic airtight bags to minimize evaporation prior to weighing.**
4. **Weigh wet soil sample using scale and record value.**
5. **Dry soil sample in oven: 110°C (230°F) for 12-16 hours.**
6. **Allow sample to cool before reweighing.**
7. **Calculate gravimetric and volumetric conversion (Appendix D: Example 6A, 6B, pages 63-64).**
8. **Is percentage below maximum allowed depletion?**
   a. **IF Yes, go to Step 9.**
   b. **IF No, resample in a few days.**
9. **Determine irrigation depth (Appendix D: Example 6C, page 64).**
10. **Take into account system efficiency (Appendix D: Example 6D, page 65)**
11. **Irrigate as necessary.**

Hand feel method to measure soil moisture

The hand feel method is exactly what it sounds like: handle/manipulate soil sample by hand to determine approximate soil moisture content. This method requires experience to estimate soil moisture content. In addition, soil texture behaves differently under different soil moisture contents depending on texture of soil.

PROS – Inexpensive
CONS – Requires experience to be accurate; requires site visits

Table 1. Estimating plant available soil moisture of common soil textures based on hand feel.

% Plant Available Moisture*, **	Sandy Loam	Loam	Clay Loam	Decision
0–25	Dry, loose, flows through fingers	Powdery or easily broken down into powdery soil	Hard, cracked, difficult to break into powdery soil	Irrigate
25–50	Appears dry, will not form ball with pressure	Crumbly but will hold together from pressure	Somewhat pliable, will ball under pressure	Irrigate
50–75	Balls under pressure, seldom holds together when bounced in hand	Forms ball, somewhat plastic, smears slightly with pressure	Forms ball, will ribbon between thumb and forefinger, slick feeling	Soil moisture sufficient
75–100	Forms weak ball, breaks easily when bounced in hand	Forms ball, very pliable, smears readily	Easily ribbons, has a slick feeling	Soil moisture sufficient
Field Capacity	Upon squeezing: no free water, wet outline of ball remains in hand, soil will stick to thumb when rolled			Soil moisture sufficient

* This is a rough estimate of moisture based on soil texture: use the soil classification that is closest in texture to your sample.

** Judgement should be used to determine where the soil moisture is within each range.

From: *Estimating Soil Moisture by Feel and* Appearance, United States Department of Agriculture-Natural Resources Conservation Service, 1998.

Method: Hand feel

1. **Identify a representative location(s) in your field.**
2. **Use soil probe/shovel (Figure 7) to take soil cores at 15–30 centimetre (6–12 inch) increments throughout the entire rooting zone.**
3. **Work soil sample in hand to estimate soil moisture content (Table 1, Figure 13).**

4. **Is the soil moisture range below maximum allowed depletion?**
    a. **IF Yes, go to Step 5.**
    b. **IF No, resample in a few days.**
5. **Based on estimated soil moisture content, determine the irrigation depth (Appendix D: Example 7, page 65).**
6. **Irrigate.**

Figure 13. Available soil moisture ranges for various soil textures using hand feel method (adapted from US-DA-NRCS, 1998; https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/EstimatingSoilMoisture.pdf).

Tensiometer

A tensiometer measures soil suction/tension (soil water potential: the force required to extract water from soil, measured in bars of pressure; the drier the soil, the greater the force required to extract water) which is translated into equivalent soil moisture content based on soil texture. The tensiometer body is a solid tube, sealed at the top and with a ceramic tip at the base (Figure 14). After installing the tensiometer in the soil, the tube is filled with water, primed and resealed. The ceramic tip allows water to pass from the sealed tube into the soil, creating a partial vacuum. The vacuum gauge at the top of the tensiometer indicates the change in suction pressure. When soil is wetted through rainfall or irrigation, moisture is drawn back into the tensiometer reducing the suction pressure in the tube. Tensiometers rely on the principle of matric potential, or tension, that varies in the soil with changes in soil moisture content. At field capacity, a soil readily gives up water (to a plant root) with little effort (suction). As the moisture level goes down, the soil particles 'hold' on to the moisture with greater force. As a result, plants need to exert more force (suction) to remove the water from the soil. Tensiometers measure this suction and translate it into a equivalent soil moisture content. Tensiometers are limited in practicallity at certain water contents and soil textures. At high moisture content (Field Capacity) or in coarse soils (sand) there are large changes in water content over relatively small changes in measured tension (Figure 15). Therefore these instruments are not always practical under all circumstances.

PROS – Inexpensive; mimics stress exerted on plant roots
CONS – Unreliable over range of pressures; pressure needs to be converted to available water

Method: Tensiometer

1. **Soak tensiometer tip for 24 hours prior to installation.**
2. **Keep tip wet until installed in field; transport to field in water-filled bucket.**
3. **Identify a representative location(s) in your field.**
4. **Use a soil probe to create a small access hole, just wider than the tensiometer, to the desired depth.**
5. **Fill access hole with a soil-water slurry.**
6. **Place tensiometer into the slurry-filled hole – this ensures there will be good contact between ceramic tip and soil.**
7. **Replace soil around the tensiometer.**
8. **Fill tensiometer with water and use a vacuum pump to prime the gauge to 0.80–0.85 bars.**
9. **Check water level in the tensiometer periodically; refill when necessary and repeat Step 8.**
10. **Determine plant available water by converting soil water potential readings (Figure 15).**
11. **Is the soil moisture below maximum allowed depletion?**
    a. **IF Yes, go to Step 12.**
    b. **IF No, return in a few days to re-read gauge.**
12. **Based on tensiometer reading, calculate irrigation depth (Appendix D: Example 8, page 66).**
13. **Irrigate as necessary.**

Figure 14. Tensiometers measure soil tension which can be translated into soil moisture content.

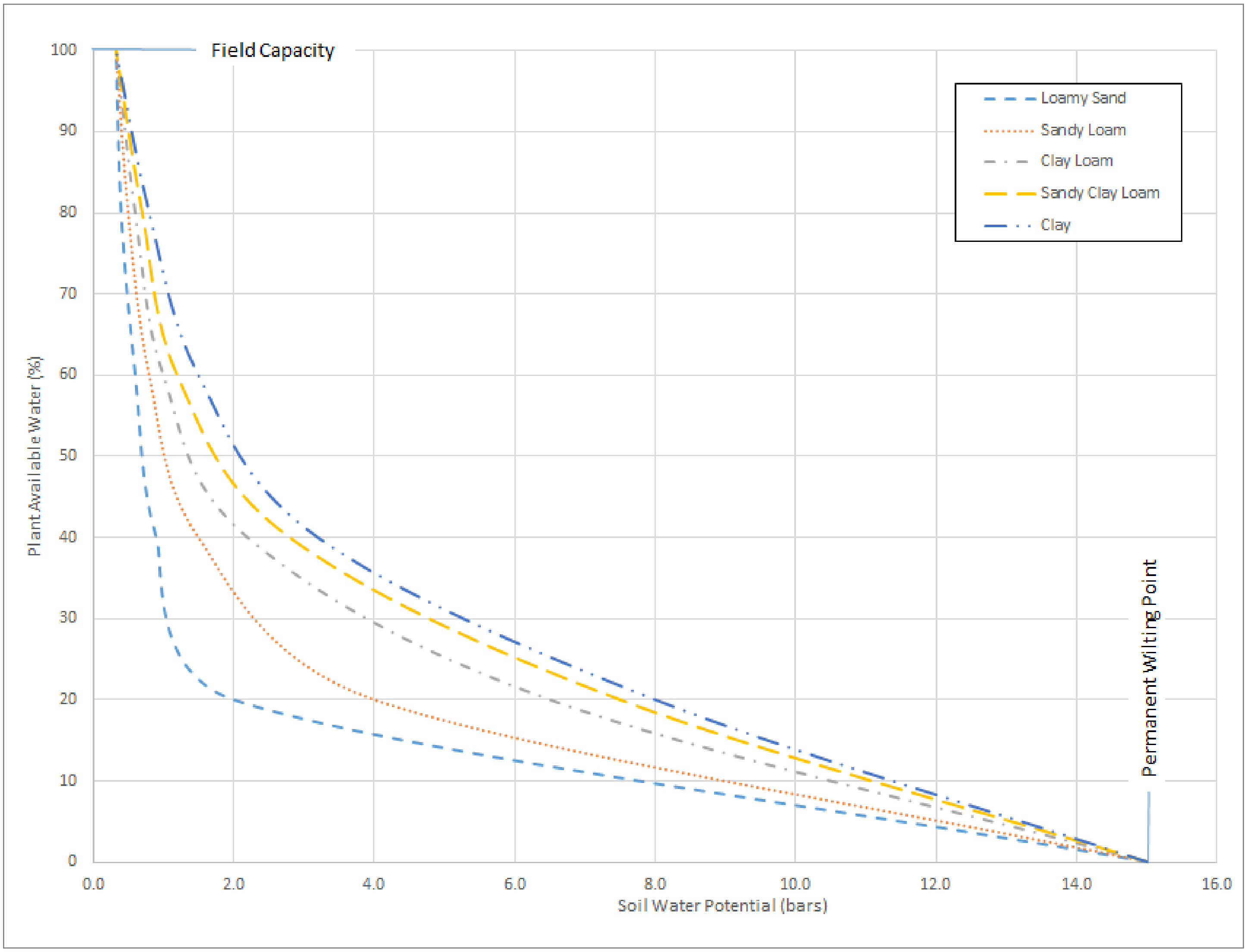


Figure 15. Plant available water (%) as it relates to the amount of suction (soil water potential, bars) required to access water for common soil textures.

Electrical resistance blocks: gypsum blocks and granular matrix blocks

Electrical resistance and granular matrix blocks consist of electrodes embedded within a porous block (e.g. gypsum or ceramic) or matrix (Figure 16). The block is soaked in water before inserting into the soil. After a short period, the amount of water in the block and the soil equalizes. An electric current can then be applied to the lead wires to measure resistance. The observed resistance is an estimate of soil moisture. In simple terms, as water content goes down resistance goes up (high resistance = dry soil) and as water content goes up resistance goes down (low resistance = wet soil). Sensor manufactures will offer readers that will display soil moisture tension or equivalent soil moisture content.

PROS – Inexpensive; mimics root environment; easy install
CONS – Requires conditioning before install; gypsum degrades in soil

Method: Electrical resistance block

1. Electrical resistance blocks require a preconditioning period prior to installation:
    a. Soak blocks in water for 30 minutes, then air dry for 24 hours.
    b. Repeat several times (minimum 3 cycles).
2. Saturate blocks immediately prior to installation: transport to field in a water-filled bucket.
3. Identify a representative location(s) in your field.
4. Use a soil probe/shovel to make create a small pit or access hole at the desired measurement depth(s) (15–30 centimetre / 6–12 inch increments).
5. Fill access hole with a soil-water slurry.
6. Place electrical resistance block into the slurry-filled hole — this ensures there will be good contact between the block and soil.
7. If installing blocks at multiple depths in one hole, replace soil in layers, compacting each layer to field conditions.
8. Connect wires to transmitter (automated readings). If using a portable meter instead (manual readings), protect wires.
9. Flag location for visibility and to prevent damage from equipment.
10. Determine plant available water by converting from soil water potential reading readings (Figure 15).
    a. NOTE: some readers will automatically convert reading into volumetric moisture content or available water.
11. Is the soil moisture below maximum allowed depletion?
    a. IF Yes, go to Step 12.
    b. IF No, resample in a few days.
12. Based on reading, calculate irrigation depth (Appendix D: Example 8, page 66).
13. Irrigate as necessary.

Figure 16. Example of a granular matrix block (left) attached to a PVC access tube (right).

Time domain reflectometry

Time domain reflectometry (TDR) probes are accurate and reliable, and can also be used to measure the electrical conductivity of the soil (useful in monitoring soil salinity levels).

TDR probes typically consist of two or three metal rods connected to a signal/power source (Figure 17). The time required for an electrical signal to travel to the end of the rods and return (reflect) is used to determine soil moisture content. TDR probes report soil moisture as percent volumetric water content. To interpret readings, irrigators must know the soil texture to determine field capacity and permanent wilting point. TDR probe are available in different lengths in order to measure soil moisture at various depths. In addition, some TDR probes have built-in wireless capability to transmit data to allow irrigators to view soil moisture data from their mobile or desktop devices 24/7 and observe trends over time.

PROS – Accurate; easily upgraded for remote monitoring
CONS – Installation results in soil disturbance which can affect accuracy; expensive

Method: Time Domain Reflectrometry

1. **Identify a representative location(s) in your field.**
2. **Dig a narrow pit (horizontal installation) or pilot hole (vertical installation) in the soil to a depth just below the desired deepest sensing depth.**
3. **Insert probes into profile at desired depths (use a rubber mallet if necessary); ensure tines are straight and parallel.**
4. **Replace soil in layers, compacting each layer to field conditions.**
5. **Flag location for visibility and to prevent damage from equipment.**
6. **Monitor readings to determine available water (Figure 18).**
7. **Is the soil moisture below maximum allowed depletion?**
    a. **IF Yes, go to Step 8.**
    b. **IF No, continue to monitor.**
8. **Based on reading, calculate irrigation depth (Appendix D: Example 9, page 66).**
9. **Irrigate as necessary.**


Figure 17. Example of TDR probes with built-in data transmission capacity (left) installed in irrigation field (right).

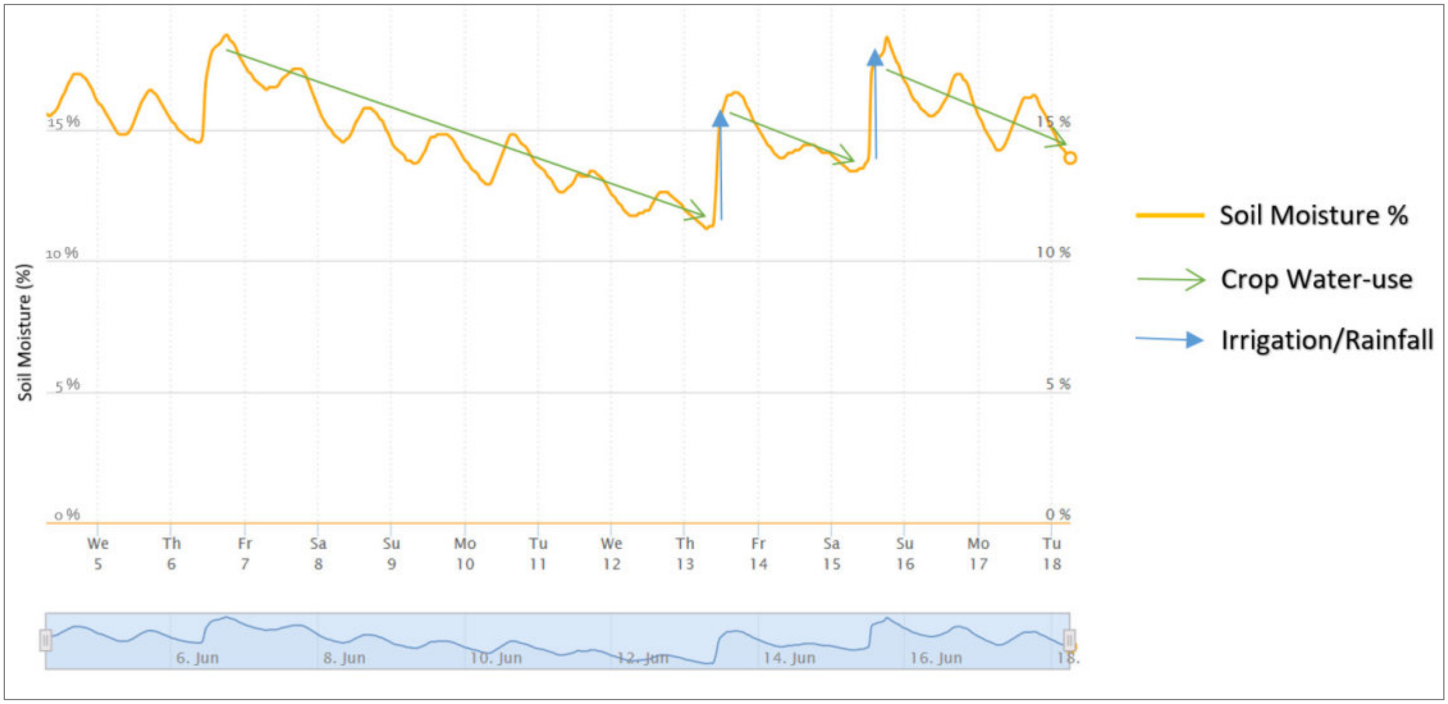


Figure 18. Typical soil moisture readings using TDR/Capacitance based irrigation sensor

Capacitance probe

Capacitance probes, also known as Frequency Domain Reflectometry (FDR) probes, generate an electric field with a power source and oscillator to measure changes in soil moisture (by sensing changes in soil dielectric properties) directly adjacent to the sensor. Capacitance based soil moisture sensors generally come in two styles: a wafer probe or tube style (Figure 19). The tube style probe can consist of multiple sensors spaced at pre-set distances (e.g. 15, 30, 45 centimetres / 6, 12, 18 inches) inside a plastic watertight housing to measure soil moisture at multiple depths with a single unit. Like TDR probes, soil moisture is reported as percent volumetric moisture.

Capacitance probes require good contact with the soil. Poor soil contact may introduce air gaps or allow water to flow alongside the probe (i.e. creates a water channel). Both situations reduce the probe's accuracy in measuring soil moisture.

PROS – Fully integrated (probe and communication); limited disturbance; multi-depth
CONS – Install requires good contact with soil; complex circuitry (prone to failure)

Method: Capacitance probe (tube style) (for wafer style, follow TDR method)

1. **Identify a representative location(s) in your field.**
2. **Dig a pilot hole using a soil probe or auger which is equal to or slightly smaller than the diameter of the probe.**
3. **Install the capacitance probe to the manufacturer's specified depth.**
4. **Fill gaps/space between around the probe at the soil surface, using hand to compress soil.**
5. **Activate the capacitance probe (if required) or connect probe to logging device.**
6. **Flag the location to prevent damage from equipment.**

7. **Monitor readings to determine available water (Figure 17).**
8. **Is the soil moisture below allowable depletion?**
    a. **IF Yes, go to Step 9.**
    b. **IF No, continue to monitor.**
9. **Based on reading, calculate irrigation depth (Appendix D: Example 9, page 66).**
10. **Irrigate.**

Figure 19. Example of a tube style capacitance probe (left) being installed in irrigation field (right).

Microwave radiometer

Microwave radiometers (Figure 20-left) measure natural microwave emissions from the soil profile at a specific frequency. Soil moisture can be estimated by combining microwave readings with additional information such as soil texture and crop stage.

The data processing involved is complex and sensors usually require a service subscription to process the data. The processed data is used to generate soil moisture maps (Figure 20-right). The detailed soil moisture maps can tell the irrigator specifically which parts of the field require water. Depending on the map units or sensor output, determining irrigation depth is similar to soil-based methods. Because these systems are model driven and use relatively new technology, a good practice is to install a soil moisture probe or take periodic soil samples to confirm microwave radiometer system results.

PROS – Spatial Information; non-contact; can measure at all crop stages
CONS – Complex calculations (requires service provider); new technology; results affected by hilled crops (e.g. potatoes)

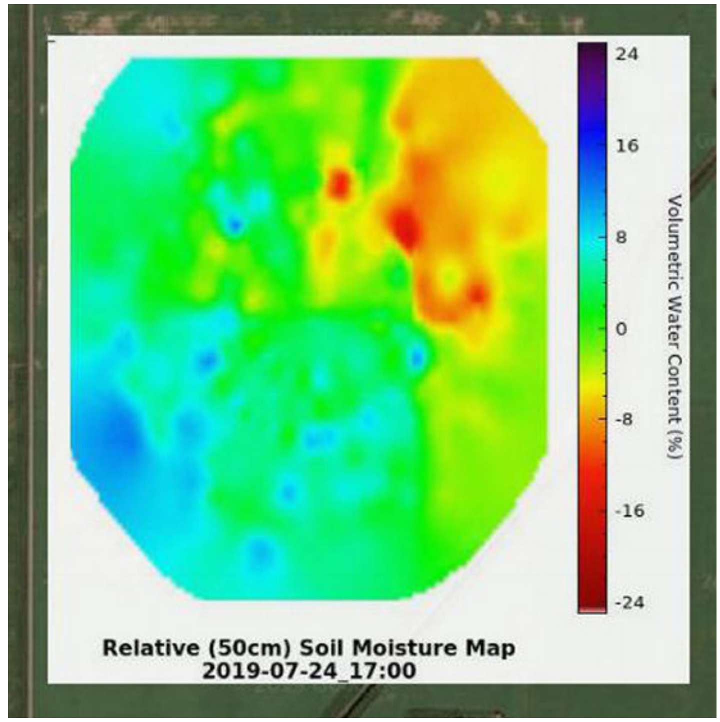


Figure 20. Pivot mounted microwave radiometer (left) and example soil moisture map (right).

WEATHER-BASED IRRIGATION SCHEDULING

Weather-based irrigation scheduling calculates changes to soil moisture by taking into account local weather data and estimated evapotranspiration. Runoff and drainage are additional factors, but in a well-managed system, these factors should be negligible and the calculation is simplified by assuming they contribute little to changes in soil moisture (Appendix C: Equation 1, page 58).

Cheque-book

The cheque-book method is an example of a water accounting method that relies on the principal of the water balance (water in and water out). Similar to using a cheque-book to keep track of home finances, this method tracks water deposits (irrigation and precipitation = credits) and withdrawal (evaporation and crop use = debits).

The cheque-book method is a simple system for estimating available soil moisture. The largest source of error is the evapotranspiration variable. Evapotranspiration estimates tend to be poor since they are based on crop stage and reported on a monthly basis (instead of taking into account day-to-day weather variability) (Appendix A: Table A4, page 48). A recommended best practice is to take periodic soil samples or use soil moisture sensors to correct for poor evapotranspiration estimates (Appendix D: Example 10, page 67).

Evapotranspiration

Evapotranspiration is dependent on the crop, variety, development stage, crop condition, management and weather conditions. The average daily evapotranspiration rate increases as the crop matures and reaches a maximum daily use during critical periods like flowering and initial fruit/pod/grain development (Appendix A: Table A4, page 48).

Evapotranspiration is difficult to measure directly. However, it can be accurately estimated using models such as the FAO Penman-Monteith equation (Appendix C: Equation 2, page 58). Evapotranspiration is initially calculated for a reference crop (e.g. grass/alfalfa) using local weather data (Figure 21). Since water-use varies between crops, the reference evapotranspiration rate is adjusted with a crop-specific coefficient (Appendix C: Equation 3, page 58). In addition, crop water-use is affected by crop stage (Figure 22). To account for these differences, the reference evapotranspiration is adjusted more finely with crop- and crop stage-specific coefficients (Appendix A: Table A5, page 49).

Figure 21. Weather station.

Calculating evapotranspiration rate is complex and requires access to detailed environmental data which may not be available for your area. To address these issues, some regional governments have developed irrigation scheduling software or online applications that can complete these calculations with minimum input from the irrigator. A commonly used irrigation scheduling calculator used in Saskatchewan is the Alberta Irrigation Management Model (AIMM) (Figure 23).

AIMM uses Environment and Climate Change Canada weather data from stations located throughout irrigation districts in Alberta as well as Outlook, Saskatchewan. Users can start by selecting the closest weather station to their operation. They then enter soil and cropping practice information to receive predicted soil moisture content and irrigation timing and rate recommendations. The free software, documentation and training material for AIMM are available online at https://agriculture.alberta.ca/acis/imcin/aimm.jsp. For additional information or support using AIMM, please contact your Provincial Irrigation Unit (see Irrigation Scheduling Assistance, page 43).

PROS – Inexpensive; visual; alerts available
CONS – Requires training; requires periodic corrections

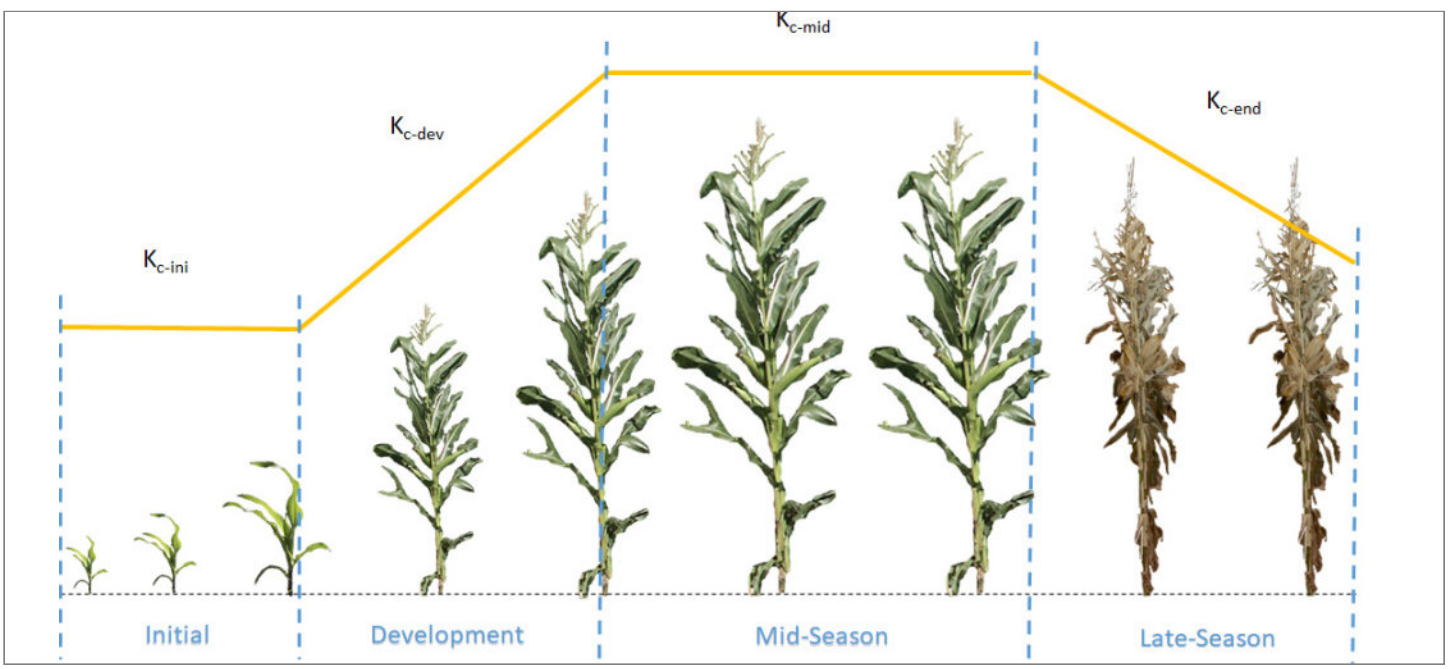


Figure 22. Crop water-use coefficient (Kc) representation for different growth stages.

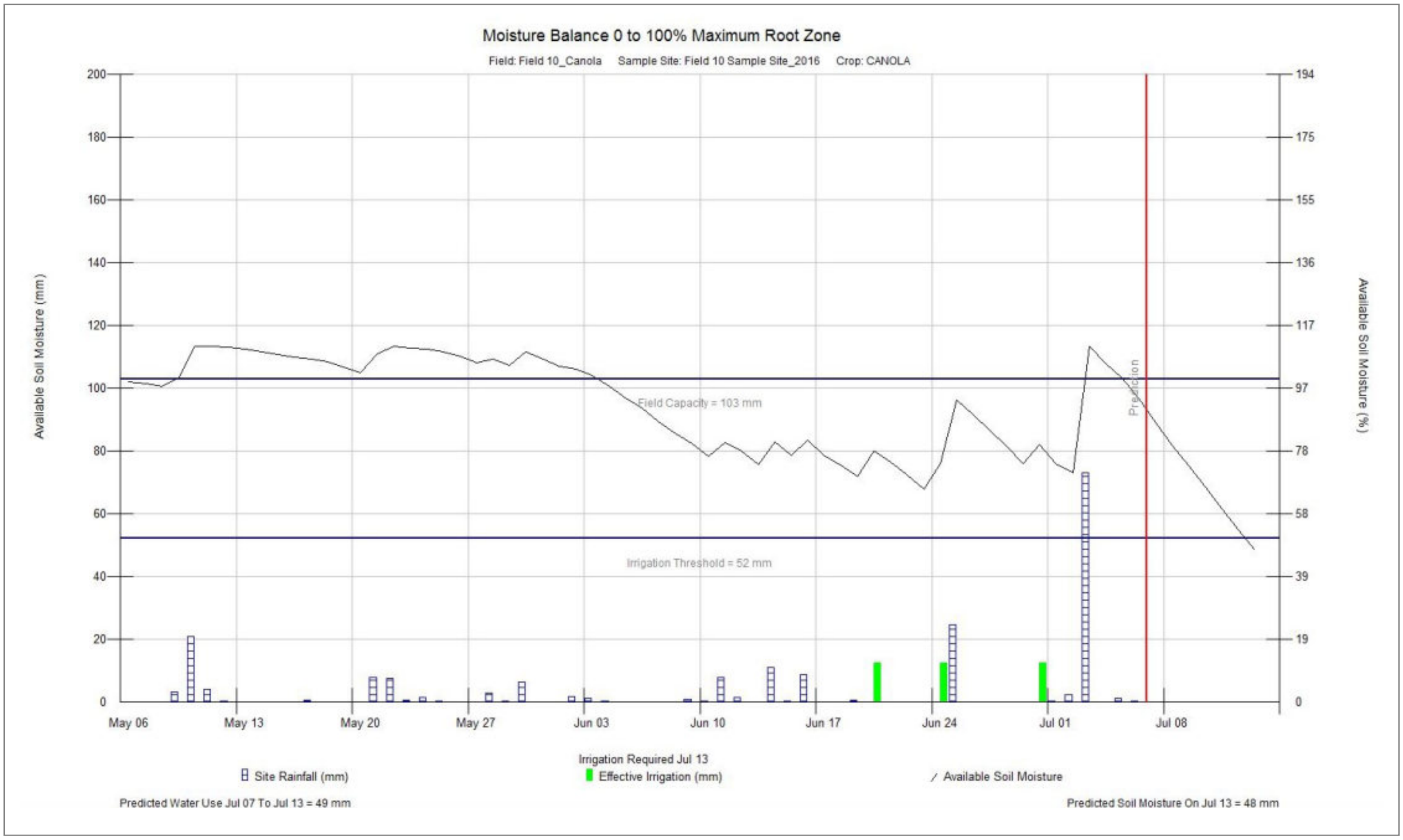


Figure 23. Alberta Irrigation Management Model (AIMM) sample graph output.

PLANT-BASED IRRIGATION SCHEDULING

Plant-based irrigation scheduling methods measure crop condition (e.g. plant stress) to determine when to trigger/schedule irrigation applications. However, without additional information, plant-based methods may only indicate when and where your crop needs water but not how much. One irrigation scheduling scheme is to simply apply a fixed amount (e.g. 0.5 inches) whenever the crop indicates it is under stress (fixed depth schedule). A more complex scheme combines plant stress measurements with weather models to estimate irrigation requirements.

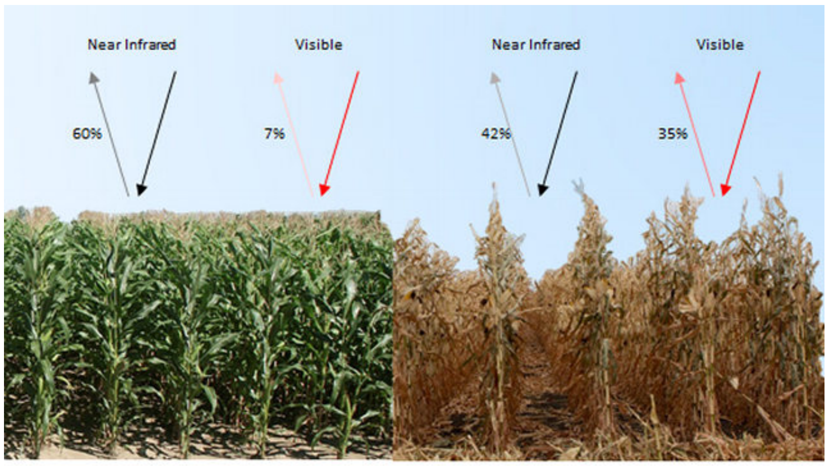
Two common plant indicators used in irrigation scheduling are the Normalized Difference Vegetation Index (NDVI) and crop canopy temperature.

Normalized Difference Vegetation Index (NDVI)

Sunlight is composed of several wavelengths. When sunlight hits a leaf, some of the visible light wavelengths is absorbed and used in photosynthesis (chiefly red, blue and, to a lesser extent, green), while other light wavelengths are reflected (e.g. non-visible near infrared). This means that the denser the canopy and the healthier the crop, the more visible light is absorbed and the more near infrared light is reflected (Figure 24). Satellites or unmanned aerial vehicles (drones) can be used to measure these light characteristics.

The remotely captured data is used to calculate the Normalized Difference Vegetation Index (NDVI) — a value that relates plant growth to the ratio of reflected (near infrared) vs. absorbed light (red) (Appendix C: Equation 4). The Index can range between −1 and 1, but in practice falls between 0 (bare soil) and 1 (healthy, dense canopy). From this simple relationship, irrigators can quickly get a sense of crop health and canopy density using remote imagery.

Irrigation scheduling based on NDVI is 'reactive' — irrigation demand is estimated from NDVI measurements. While matching irrigation to crop needs improves water-use efficiency, once water stress can be seen in NDVI imagery, yield may already be impacted and difficult to reverse (Bauer 2019). To counter this issue, producers can use historical NDVI images to identify areas susceptible to water stress to adjust irrigation schedules to potentially reduce/eliminate crop stress and improve yields. Other issues of relying on satellites to capture reflectance data are that they are not always overhead (return schedules range from daily to weekly depending on source) and cloud cover can significantly affect reading accuracy. Drones or other land-based technologies can be used to collect the light reflectance data to supplement or counter issues with satellite data.



$$NDVI = \frac{(0.60-0.07)}{(0.60+0.07)} = 0.79 \qquad NDVI = \frac{(0.42-0.35)}{(0.42+0.35)} = 0.09$$

Figure 24. Interaction between visible (red) and near infrared light with a crop canopy.

PROS – Spatial; minimal inputs; remote monitoring

CONS – Images affected by cloud cover; requires ground checks; requires training

Introducing IrriCAN: a new free online irrigation scheduling tool

An emerging option in irrigation scheduling is to combine remote imagery data with traditional weather-based models. This is the case with IrriCAN (www.irrican.com), a spatial irrigation scheduling tool developed for Canadian irrigators. It was adapted from a similar online tool developed in Australia, IrriSAT (https://irrisat-cloud.appspot.com/).

IrriCAN automatically imports data from Google Earth (satellite images, NDVI data, maps) and local weather feeds. The application takes into account the linear relationship between NDVI and crop water-use: a field with a dense, healthy crop (higher NDVI value) uses more water than a less dense, less healthy crop (lower NDVI value) (Appendix C: Equation 5, page 59). This relationship holds true regardless of the crop and is used to calculate evapotranspiration to estimate crop water use (Appendix C: Equation 3, page 58). Using NDVI combined with weather-based estimates of crop water use to schedule irrigation gives a good picture of the variable water requirements throughout the field (Figure 25). For assistance using IrriCAN, please contact your Provincial Irrigation Office (see Irrigation Scheduling Assistance, page 43).

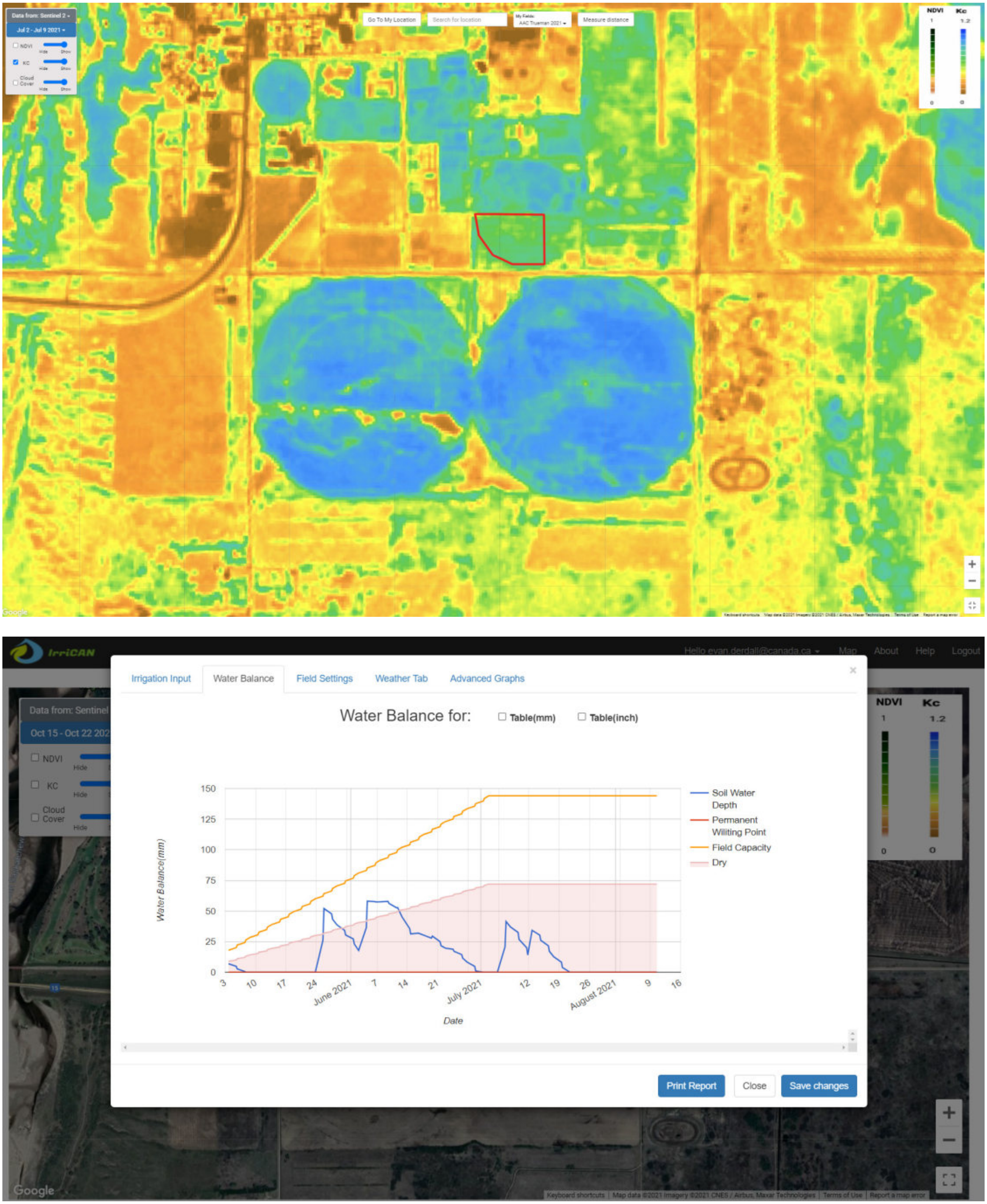


Figure 25. Top: IrriCAN map page showing weekly NDVI imagery. Bottom: Water balance generated for irrigated field.

Canopy temperature / crop water stress index (CWSI)

In daylight, the cooling effect of transpired water evaporating from a leaf's surface maintains internal leaf temperature near air temperature. When there is insufficient soil moisture (deficit), leaves reduce or shut down transpirational water loss by partially or fully closing their stomata to reduce drought stress effects. Unfortunately, this leads to a rapid temperature build up in the leaves, compounding drought stress with heat stress (soil moisture deficit ➥ drought response ➥ canopy warming). Crop canopy temperature can be measured with an infrared thermometer (Figure 26) to determine where and when canopy temperature is measurably higher than air temperature.

Note: the presence of insect pests and disease can also cause canopy temperature increases. If the pattern looks suspicious, especially if the temperature differences exist in low, normally wet area or remains high after an irrigation event, you should inspect your crop. These anomalies are true for all plant based scheduling methods and user judgement is required to determine cause of plant stress.

One way to describe the relationship between soil moisture stress and canopy temperature is to calculate the Crop Water Stress Index (Appendix C: Equation 6, page59): an index value of 0 means that the crop is under no moisture stress; the closer the index is to 1.0, the greater the moisture stress.

Using canopy temperature is a more 'responsive' approach to irrigation scheduling than using Normalized Difference Vegetation Index: water stress is detected earlier and triggers irrigation at the first signs of water stress, limiting potential yield reduction. However, similar to the Normalized Difference Vegetation Index irrigation scheduling method, the Crop Water Stress Index can only advise when and where to irrigate, not how much. Additional information (climate scheduling models, soil measurements, etc.) is still required to determine how much water to apply.

PROS – Good, early indication of plant stress; spatial applications
CONS – Does not indicate irrigation depth (additional measurements required); requires crop canopy temperature (additional tools/technology)

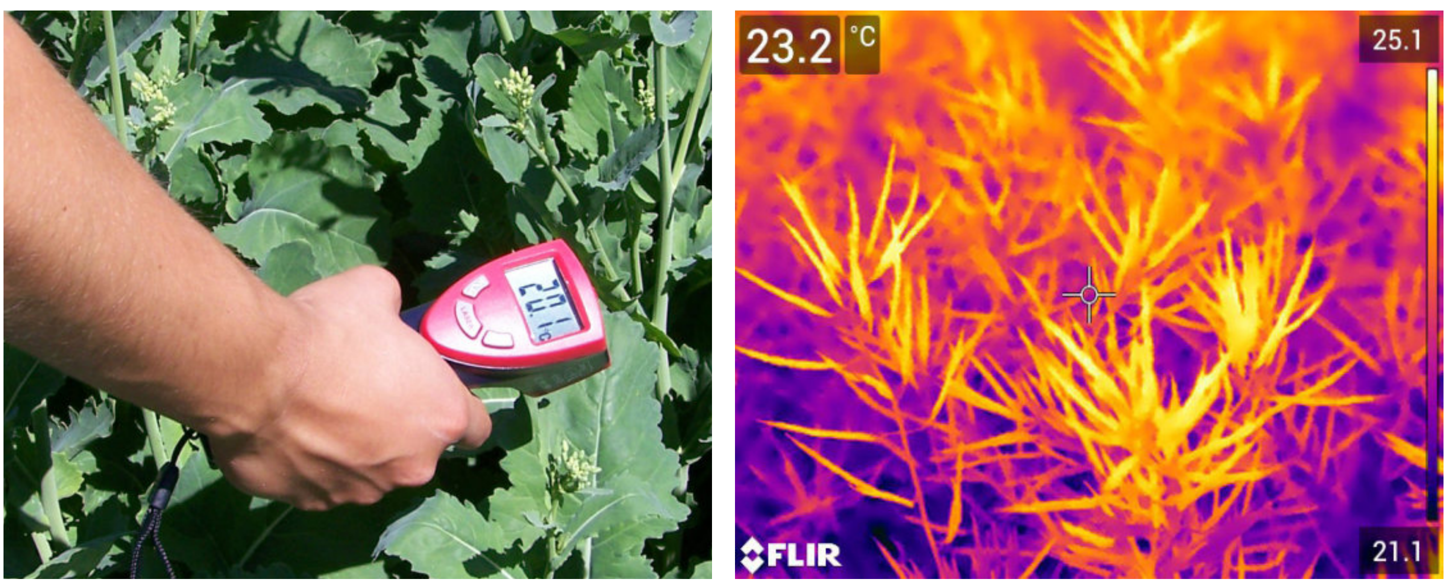


Figure 26. Handheld infrared thermometer (left) and thermal image of canola (right).

VARIABLE RATE IRRIGATION – PRECISION AGRICULTURE APPLIED TO IRRIGATION

Variable-Rate Irrigation (VRI) is a precision agriculture management practice applied to irrigation – only as much water as the crop needs (RIGHT AMOUNT) is applied where (RIGHT PLACE) and when (RIGHT TIME) the crop needs it.

Conventional irrigation systems are designed to apply water uniformly throughout the field with each application. However, fields are not uniform and can vary significantly in terms of elevation, soil texture, crop type and growth stage. This results in differences in crop water use/needs across a field. With irrigation technology advancements, irrigators can vary irrigation by small-area zones to better match the variability in crop requirements. Better control over in-field soil moisture reduces over- and under irrigation application and can significantly affect crop yield, quality and maturity synchronization (Figure 27).

Figure 27: Matching irrigation to soil and crop needs using variable rate irrigation can avoid instances of standing water (left) or water deficits which can lead to variable crop development (right).

VRI, as it relates to centre pivot irrigation, falls into two categories:

i) **Speed Control Variable Rate Irrigation (1-D control)**: The speed of the centre pivot is varied as it travels. Reduced speed results in increased irrigation depth, where increased speed results in decreased irrigation depth. This practice is limited to controlling the application depth in pie-shaped segments around the field (Figure 28a).

ii) **Site Specific Variable Rate Irrigation (2-D control)**: Both the speed of the pivot and sprinkler operation (on/off control valves) is varied. This allows irrigators to alter the application rate in small zones along the length of the irrigation system (Figure 28b).

VRI systems introduce a spatial component to traditional irrigation scheduling. Some irrigation scheduling methods are more easily adapted than others (e.g. remotely sensed vs. in-place monitoring), but all methods can be adapted.

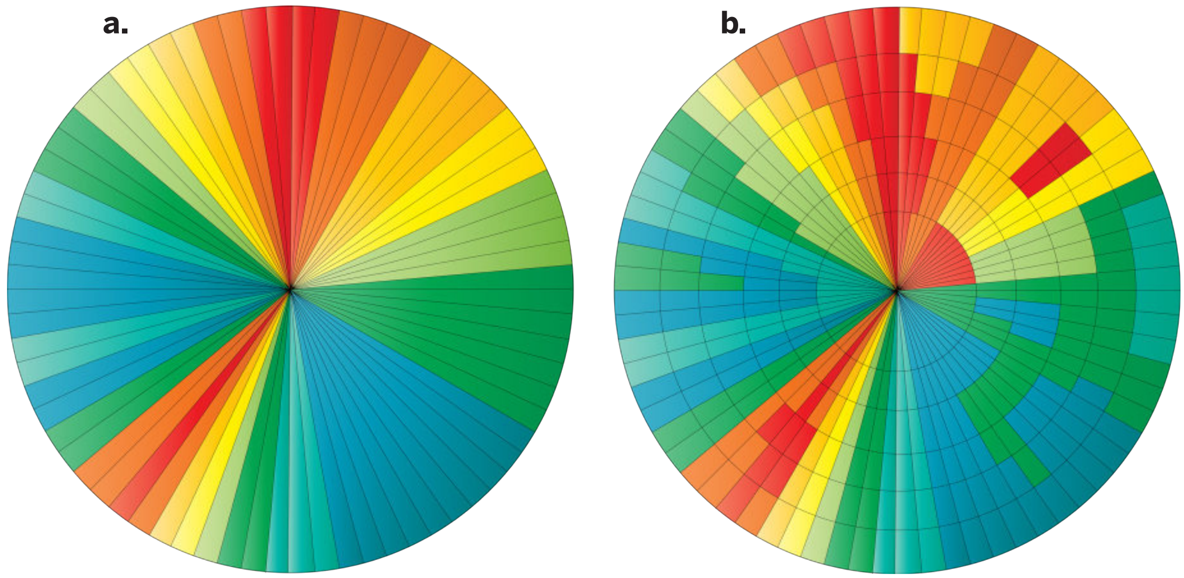


Figure 28. Schematic of a VRI plan: a) speed control and b) speed+sprinkler valve control.

To start, VRI requires a spatial irrigation application map referred to as a VRI-prescription. VRI-prescriptions have two components: zones (spatial) and rates (depths). Zones are areas of similar management with the number of zones and the irrigation rate that is applied to each zone depending on the variability of the field and capability of the irrigation system.

VRI zones are mapped out to follow one of two management methods (Figure 29):

- **Static**: Irrigation zones are created at the beginning of the growing season and remain constant (static) for the season. The application depth in each zone can change over the year but zone boundaries remain the same.
- **Dynamic**: Irrigation zones are created at the beginning of the growing season and their boundaries are continually updated throughout the growing season as spatial data becomes available.

Each method has benefits (simple vs. complex) and drawbacks (limited vs. adaptable). The management method will need to be adapted to suit the management system.

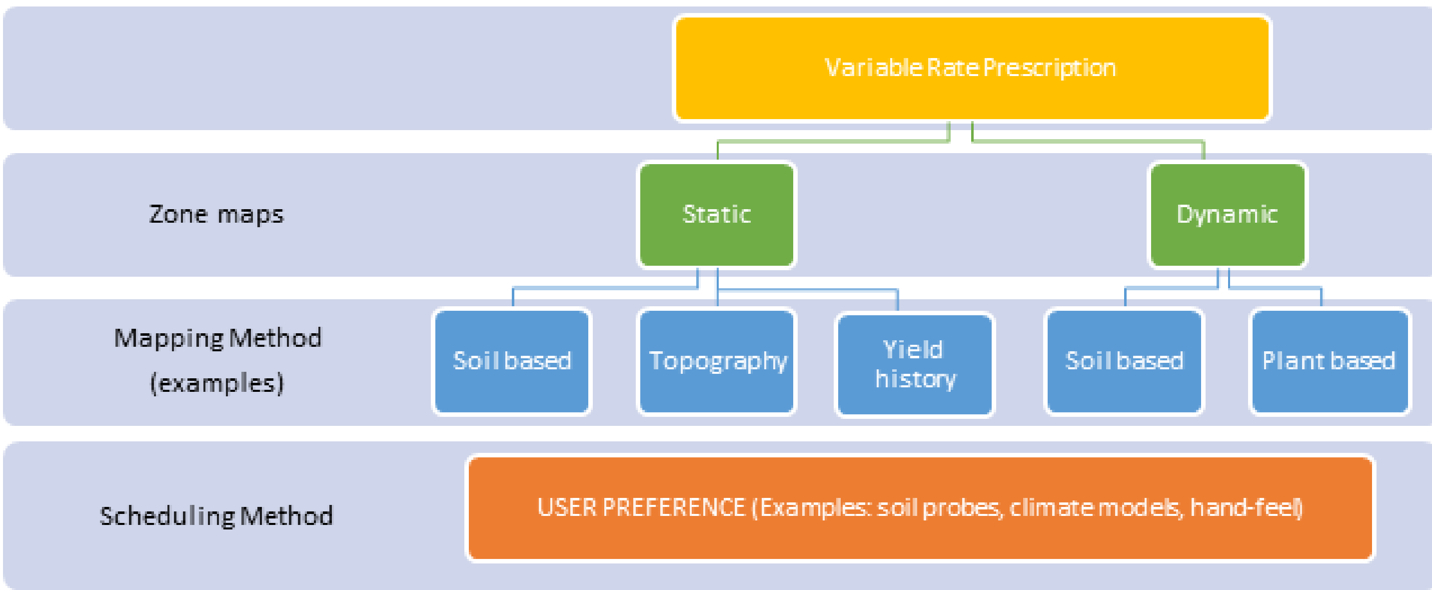


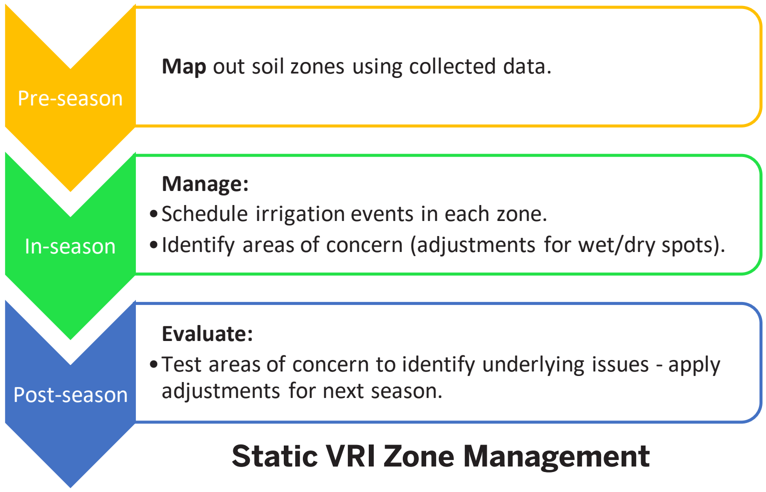
Figure 29. Variable Rate Irrigation prescription development method options.

STATIC VRI ZONES

Static zone management is broken down into three major components: zone mapping, manage and evaluate.

Mapping out the zones

Static management zones are based on field survey data collected outside the growing season and will not change during the growing season. Common survey types include soil texture, topography, fertility and yield.



Static VRI Zone Management

Soil Texture

Since soil texture strongly impacts water holding capacity which in turns affects water availability for crop growth, it is a key factor in irrigation scheduling. It is therefore a critical component in developing VRI zones. Historical soil survey maps can be a first step to mapping out soil texture (Figure 31a; Appendix D: Example 12, page 58). However, these maps are low resolution (typically 1:100,000 or lower) and should be supplemented with soil sampling (see: Mapping out your soils, pages 6-9).

Electromagnetic and Electrical conductance

Electromagnetic (EM) instruments (Figure 30) determine the electrical conductance (EC) of soil across a field (measured in milliSiemens/metre). Major factors influencing EC values are soil texture (particle size), moisture and salinity (and to a lesser extent, compaction and temperature). A high EC value could indicate high salinity, high clay content, high moisture (low area, seep) or some combination of these factors. A low EC value could be an eroded knoll, a relatively high area or sandy/gravelly soil or a combination of factors. To sort these issues out, sample soil from anomalous areas as well from a few average or representative sites. This data is then used to produce a spatial soil texture and salinity map by grouping areas of similar EC values adjusted with soil analysis and field history (e.g. poor crop, high kochia population).

Figure 30. Electromagnetic (EM) sensor on field sled for conducting EM and topographical surveys.

The number of irrigation management zones based on the EC-derived soil texture and salinity map should be selected to fit the irrigator's comfort level in managing zones (Figure 31b; Appendix D: Example 13, page 69).

Topography

Although not absolute, the relationship between soil moisture content to topography follows some well-established trends (Yari et al 2017):

- High areas (hills, knolls) tend to be more eroded, prone to evaporation and internal drainage to lower elevations.
- Lower areas tend to collect water.

Zones can be grouped by areas of high elevation, mid-slopes, low elevation, and local depressions. Topography by itself may not be enough to develop a good VRI map, but it can add value to existing soil texture maps for identifying features or responses that are not captured in a soil texture map (Figure 31c; Appendix D: Example 14, page 69).

Yield Maps

A yield map is a good indicator of productivity under normal management practices. Areas or zones of similar productivity are assumed to have similar water demand throughout the growing season. VRI-prescriptions would be developed similar to other static methods (EC, topography) by grouping areas of similar yield ranges (e.g. top third, mid third and lower third).

Putting it together

Static-based zone mapping methods are based on surveys or field data collected outside of the growing season. Each survey method results in a unique map but with many points of similarity (Figure 31). Using soil texture as a starting point, the other data can be used to adjust irrigation management zones.

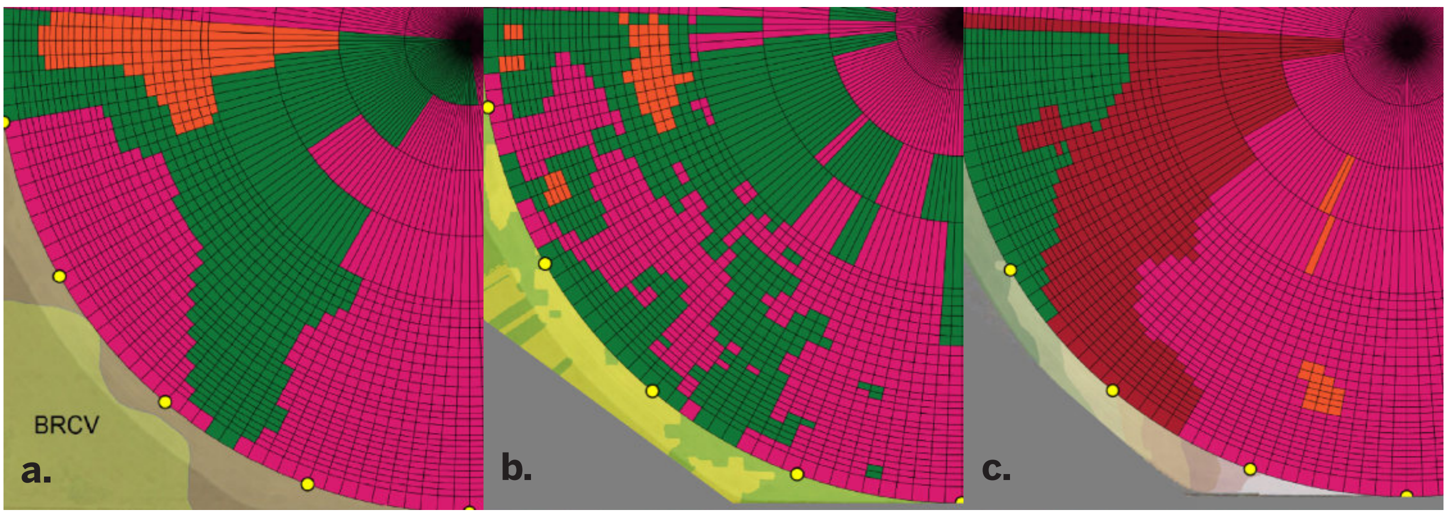


Figure 31. Example static zone maps based on (a) soil texture, (b) electrical conductivity, (c) topography for the same field.

Manage

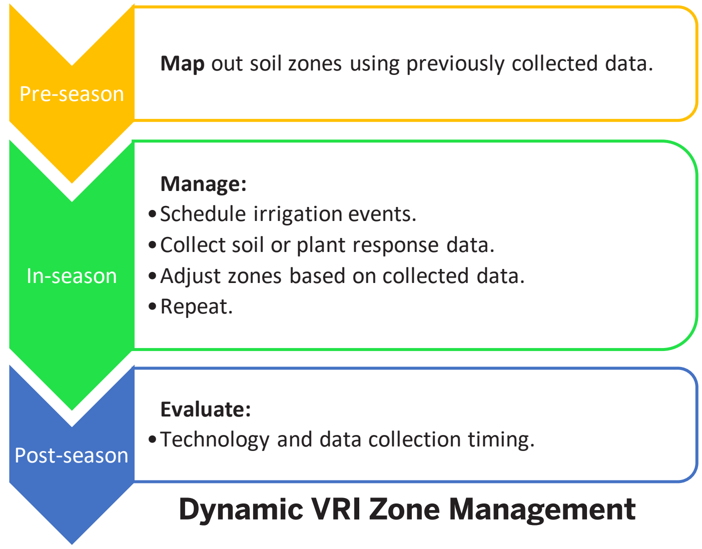
Once the management zones have been created, the irrigator should schedule irrigation within each zone using the preferred irrigation scheduling method. This can be soil-based (eg. tensiometers, hand feel), weather based (eg. cheque-book) or plant-based (eg. IrriCAN). It is important to map out the zones and apply the method that works best with your production system, taking into account cost, location, labour, etc.

Evaluate

Evaluate the performance of your zone maps at the end of the irrigation season to determine if your management method is producing the desired results. Evaluation can consist of simple observations throughout the growing season, noting areas of concern (wet/dry). More intensive analysis may include review of yield or NDVI maps to identify areas of concern or adjust zone boundaries. It is important to continue to evaluate the irrigation zones to ensure you are getting the desired results from the investment in a VRI system.

DYNAMIC VRI ZONES

Dynamic management zones are developed at the beginning of the growing season and the boundaries are adjusted throughout the growing season as data is collected, following a process of mapping, manage (including ongoing data collection and adjustment) and evaluate.



Dynamic VRI Zone Management

Mapping out the zones

The benefit of dynamic response maps is that irrigation decisions are based on monitoring soil moisture conditions and/or plant response to environmental conditions. This is a better representation of what the plant experiences throughout the growing season.

Creating VRI dynamic management zones is more complex than for static management zones, requiring additional data collection and ongoing adjustments to the VRI-prescription throughout the growing season. Data collection is limited to remote sensing, as continual in-field sampling would end up damaging the crop. Advancements in remote sensing options and automated computer mapping systems has reduced much of the labour and time requirements of intensive dynamic mapping.

Soil-based

There are limited technologies available for remote soil moisture monitoring. One emerging technology is using microwave radiometers to estimate soil moisture. A relatively new sensing technology in agriculture, microwave radiometry has been used by NASA to estimate large-scale soil moisture status. Microwave radiometers measure specific microwave wavelength emissions from the soil. Like TDR and capacitance sensors (pages 23-25), soil moisture affects microwave emissions. Depending on the microwave wavelength (i.e. frequency), the sensing depth ranges from 5–30 centimetres (2–12 inches).

The data processing is complex and available sensors are partnered with a service subscription to generate soil moisture maps (e.g. SMARTDROP, Figure 32). Because microwave radiometer maps report in volumetric water content, these maps can be used for both irrigation zone mapping AND irrigation scheduling.

Figure 32. SmartDROP microwave radiometer (left) and an example soil moisture map (right).

Figure 33 is an example of how radiometer imagery displays soil moisture status in a field and how it can change over as little as a week. In the August 8 image, some areas of the field have become wetter (area marked (1)) while others have become drier (area marked (2)). This difference could be due to irrigation on the left side only and/or due to topography with water draining from high (right) to low (left) elevation after a rainfall or irrigation event.

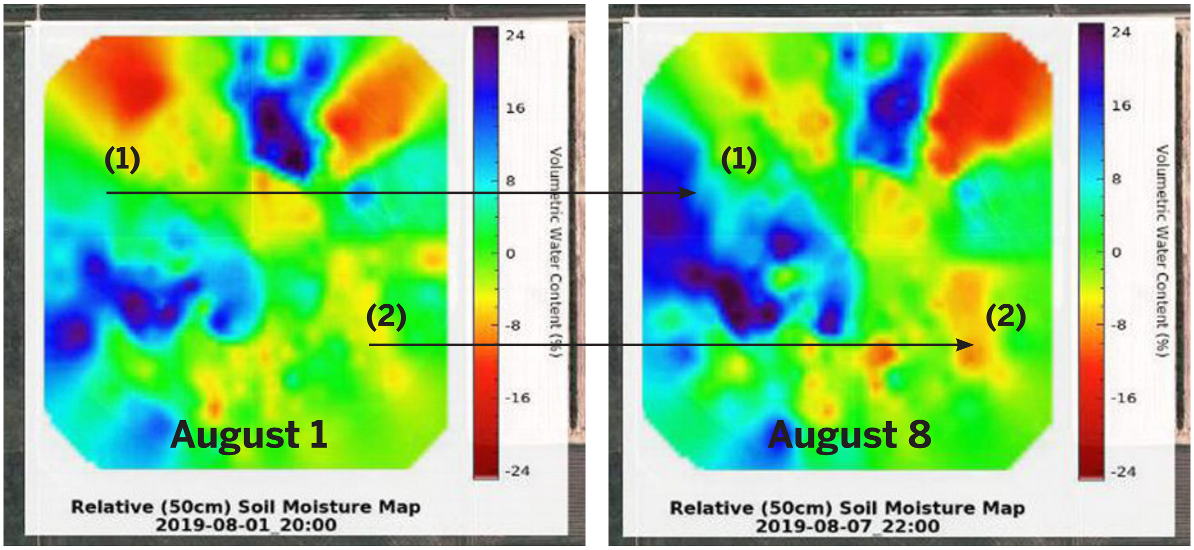


Figure 33. Microwave radiometer images for the same canola field taken one week apart. Values represent difference from average soil moisture content in percent volumetric water content for the day that the image was captured. Arrows highlight areas that have changed in their moisture status (i.e. become wetter (1) or drier (2)) relative to the average.

Plant-based

Plant-based zone mapping uses remotely sensed data on plant response to moisture stress (excess/deficit) to create zones. Options available for remotely sensing plant stress include i) Normalized Difference Vegetation Index (page 28) and ii) Crop canopy temperature or Crop Water Stress Index (page 31).

Normalized Difference Vegetation Index: Normalized difference vegetation index values can be broadly categorized into high, medium and low and fields can be mapped out along these categories. With each new image, the zones can be re-mapped according to the three categories (Appendix D: Example 15, page 70).

Historical images/data can be used to map out fields when current imagery is not available (e.g. due to cloud cover) or for those times in the season when remote imagery does not accurate accurately reflect estimates of soil moisture, crop productivity or plant stress (e.g. early season, before canopy closure). Historic photos can also help determine where and when crops are most likely to become stressed as well as to gain a better understanding how water is distributed in the field after irrigation/rainfall events (e.g. where does the water drain from and where does it drain to?) (Figure 34).

Crop Canopy Temperature/Crop Water Stress Index: Internal leaf temperature is maintained at or near air temperature through the cooling effect of the transpired water evaporating off the leaf's surface. Canopy temperature variability throughout the field can therefore be used to estimate soil water holding capacity. Areas with low soil water holding capacity will show increased canopy temperatures more quickly than soil with higher soil water holding capacity (Bauer 2019). Temperature differential (canopy vs. air) can be grouped into broad ranges to map out zone boundaries.

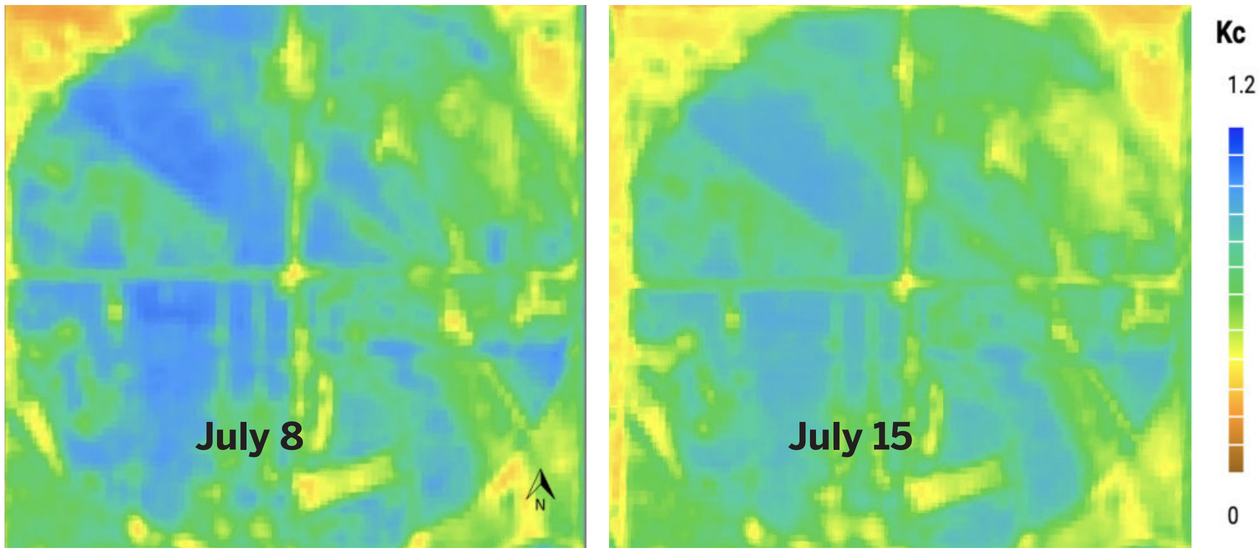


Figure 34. NDVI images from July 8th (left) and July 15th (right). In general, the overall crop health decreased over this period, indicating possibility of insufficient moisture to maintain crop health.

Manage

Soil-based

Remotely sensed soil moisture status can be used in conjunction with estimates of crop water demand (e.g. using crop- and growth stage-specific coefficients) to schedule irrigation for each identified zone. For example, the SmartDROP system (microwave radiometry) reports percent volumetric soil moisture content (Figures 31, 32). Soil texture can be used to determine plant available water in each zone (Appendix A: Figure A2, page 47). Using these two pieces of information, it is relatively straight-forward to determine how much water to apply at the next scheduled irrigation event to bring the soil up to field capacity in each zone. (More details on soil-based methods, pages 17-26.)

With further analysis of the soil moisture maps over time, water distribution patterns emerge (i.e. can see where water accumulates after irrigation/rainfall). This information can be used to fine-tune irrigation scheduling with the goal to even out soil moisture across the field. For example, areas with soil moisture near/just above maximum allowed depletion would be irrigated to meet crop water demand until the next scheduled irrigation event (MAINTAIN). Areas that are wet (e.g. near field capacity) would only need to be irrigated to keep soil moisture above maximum allowed depletion (no irrigation may be necessary, DRAW DOWN). The drier areas would need to be irrigated enough to bring the soil moisture level up to alleviate potential crop stress (e.g. up to maximum allowed depletion) **plus** enough to satisfy crop water demand (CATCH UP). Irrigation amounts would be recalculated for each scheduled irrigation event by evaluating how soil moisture status changed following the last irrigation event.

Plant-based

<u>Normalized difference vegetation index</u>: Normalized difference vegetation index values are closely correlated to crop water demand: high index values indicate a crop with a thick, lush canopy (high water demand); low index values indicate a weak, sparse canopy (lower water demand). This relationship can be used to convert index values into crop water-use coefficients and then plugged into crop water use equations/ models to estimate irrigation needs for each zone. One advantage is that this data is then crop- and growth stage-independent, reducing the need to rely on published crop water-use coefficients which (a) have been calculated on historical data (may no longer be accurate) and (b) may not be available for your area (Appendix D: Example 9, page 66).

Crop canopy temperature/Crop water stress index: Crop canopy temperature, as it relates to the surrounding air temperature, can indicate soil water availability. This method only shows the relative crop water stress (e.g. Crop water stress index) and does not indicate actual moisture status or irrigation requirements. Therefore, it should be used in conjunction with an existing irrigation scheduling method (Appendix D: Example 15, page 70). Alternative indices (e.g. Time-Temperature Threshold) are being evaluated that look at providing a better indication of when to irrigated based on canopy temperature. (More details on plant-based methods, pages 28-31.)

Evaluate

The core principle of dynamic zone irrigation scheduling is continual adjustment of the irrigation prescription throughout the irrigation season. Irrigation zones and irrigation depths are adjusted with each new data set/image. The in-season evaluation can be supplemented by checking field and crop conditions to ensure the irrigation scheduling system is working as expected.

At harvest, yield maps can add to the performance analysis. Question to ask include:

- Did average yield go up?
- Did yield variation across the field decrease?
- How did typically low-yielding areas respond?
- How did typically high-yielding areas respond?
- How well does the yield variation map correspond to the mapped out irrigation zones?

WHEN TO STOP IRRIGATING

The last irrigation should be scheduled to provide sufficient soil moisture to carry the crop to maturity. However, unnecessary late season irrigation, depending on the crop and crop stage, can have little to no effect on final yield and adds additional input costs (pumping, water) and unnecessary equipment wear and tear. In addition, wet soil due to unnecessary irrigation can delay harvest (can affect maturity/seed moisture content, field access) and lead to soil compaction from heavy harvest equipment. Avoiding late season irrigation has the added benefit of allowing the soil to dry down so that it can hold more snow melt and spring precipitation leading to less run-off (Appendix A: Table A6, page 49; Appendix D: Example 11, pages 67-68).

IRRIGATION SCHEDULING ASSISTANCE

One of the objectives of the Saskatchewan Ministry of Agriculture's irrigation strategy is to enhance returns from existing irrigation. One way of doing this is to make sure that irrigation water is being used efficiently. Applying the wrong amount of water (too much/too little) at the wrong time can result in crop stress or increase the risk of disease development. These issues can result in lower yields and increased costs.

Irrigation Agrologists with the Saskatchewan Ministry of Agriculture can provide technical assistance related to irrigation scheduling and can demonstrate on-farm practices to irrigators.

Provincial Irrigation Agrologists can work with new or existing irrigators throughout the growing season to help ensure they understand the fundamental principles of effective irrigation scheduling. They can also provide instructions on how to use the Alberta Irrigation Management Model (AIMM) which will give producers another tool to assist with irrigation scheduling. At the end of the growing season, the irrigator will have the technical knowledge and practical skills to continue scheduling in the future.

Contact the Irrigation Branch office in Outlook, Saskatchewan (306 867-5500) to work with an Irrigation Agrologist.

APPENDIX A: REFERENCE FIGURES AND TABLES

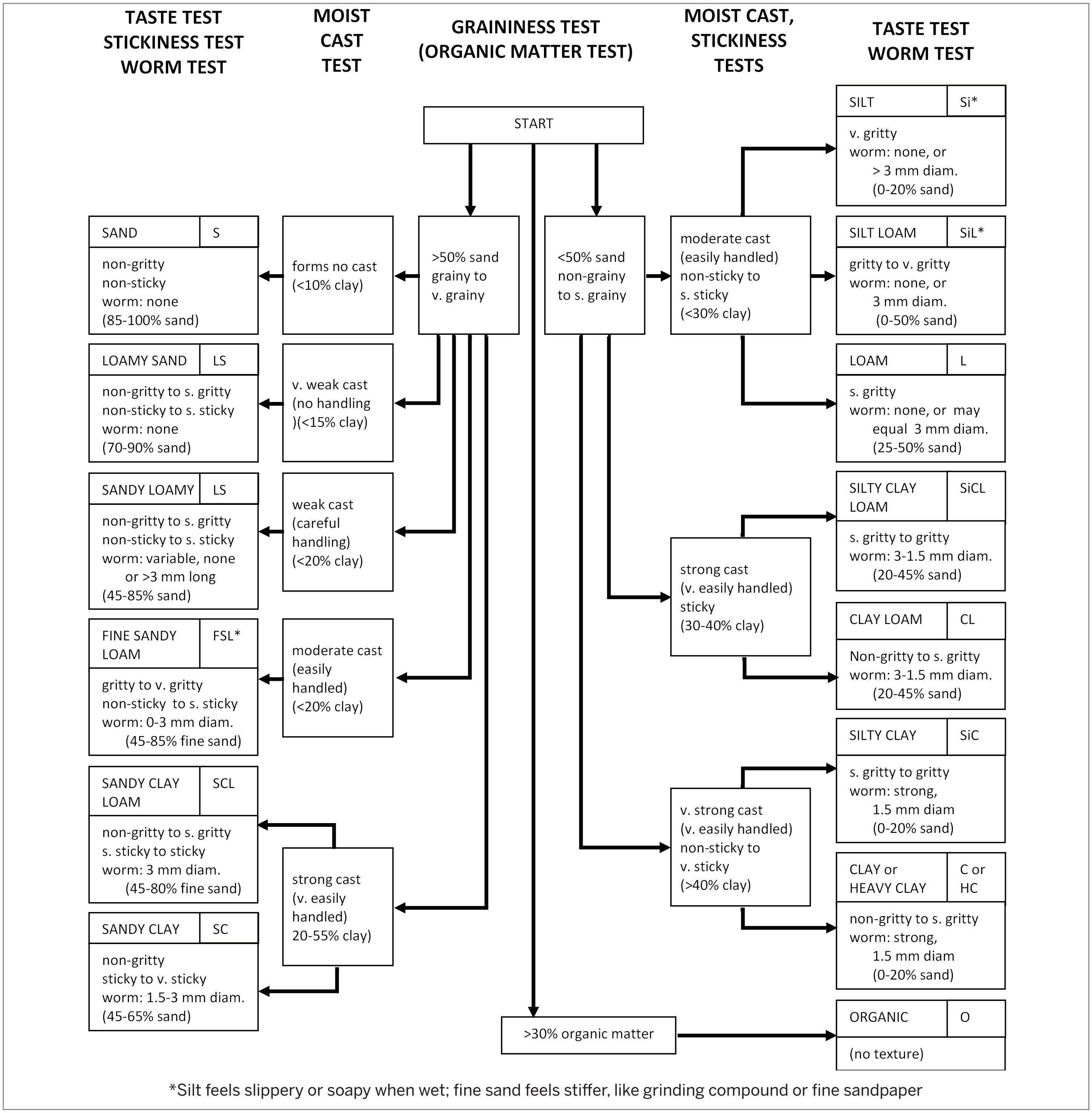


Figure A1. Estimating soil texture in the field. The field determination of soil texture is subjective and can only be done consistently with training and experience. The field tests, outlined below, are used in sequence with the accompanying flow chart to assist in the field determination of soil texture:1) **Graininess Test:** Rub the soil between your fingers. If sand is present, it will feel "grainy". Determine whether sand comprises more or less than 50% of the sample. 2) **Moist Cast Test:** Compress some moist soil by clenching it in your hand. If the soil holds together (i.e., forms a "cast"), then test the durability of the cast by tossing it from hand to hand. The more durable it is, the more clay is present. 3) **Stickiness Test:** Wet the soil thoroughly and compress between thumb and forefinger. Degree of stickiness is determined by noting how strongly the soil adheres to the thumb and forefinger upon the release of pressure, and how much it stretches. Stickiness increases with clay content. 4) **Worm Test:** Roll some moist soil between the palms of your hands to form the longest, thinnest worm possible. The more clay there is in the soil, the longer, thinner and more durable the worm will be. 5) **Taste Test:** Work a small amount of soil between your front teeth. Silt particles are distinguished as fine "grittiness", unlike sand which is distinguished as individual grains (i.e., graininess). Clay has no grittiness at all.
Abbreviations: s: slightly; v: very, diam: diameter.
Adapted from *British Columbia Forestry Service. Estimating Soil Texture in the Field. Publication FS238, 2 pages* (Used with permission).

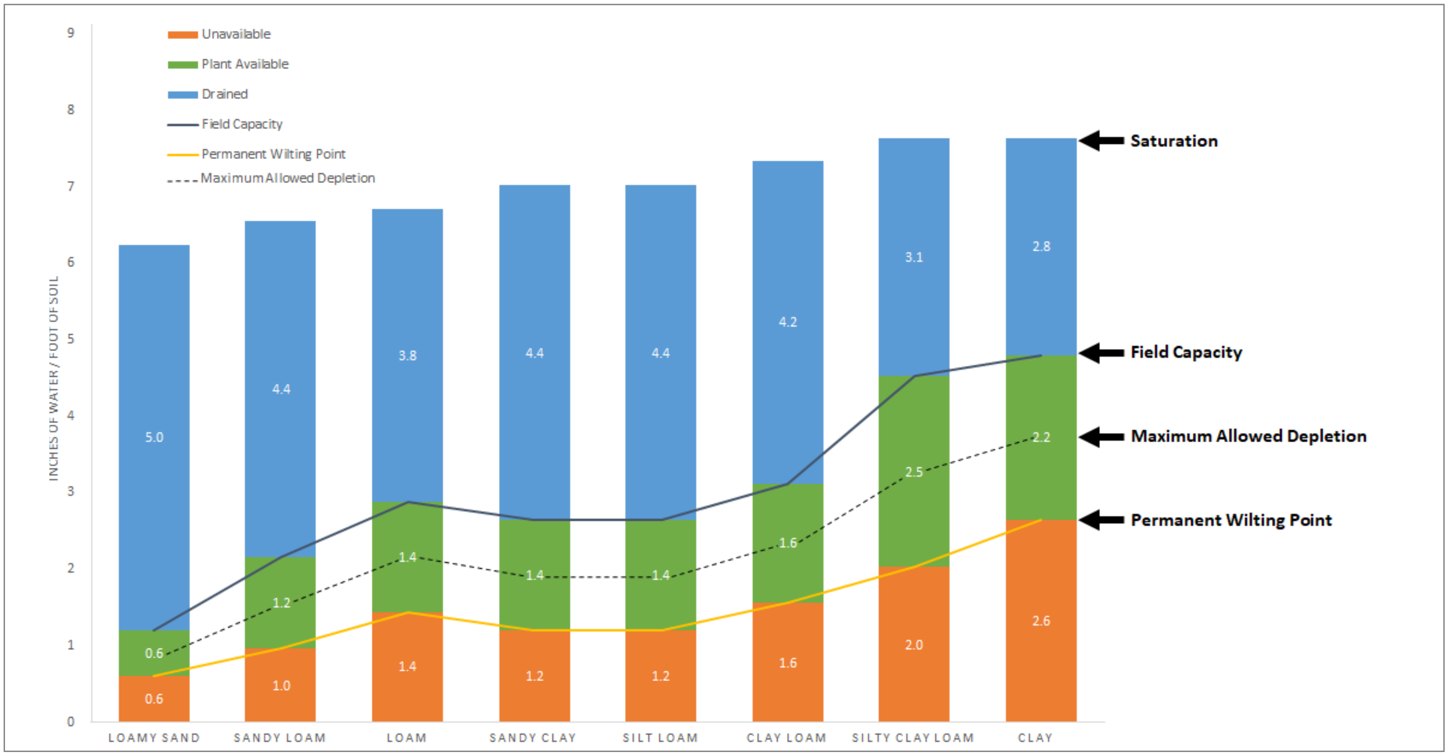


Figure A2. Relationship between saturation, field capacity and permanent wilting point for common soil textures.

Table A1. Maximum active root zone depth for various crops.

Crop	Active Root Zone centimetres (feet)	Crop	Active Root Zone centimetres (feet)
Alfalfa	120 (4.0)	Flax	100 (3.0)
Barley	100 (3.0)	Grass	80 (2.5)
Beans, dry	60 (2.0)	Lentil	60 (2.0)
Beans, faba	80 (2.5)	Pea	80 (2.5)
Canola	100 (3.0)	Potato	80 (2.5)
Corn, silage	100 (3.0)	Wheat	100 (3.0)

Saskatchewan Ministry of Agriculture and Food

Table A2. Approximate application efficiencies of irrigation equipment.

Irrigation Method	Irrigation Efficiency
Low Pressure Centre Pivot	90% +
Micro/Drip/Trickle	90% +
High Pressure Centre Pivot	80% +
Sprinkler Wheel Move	70% +
Volume Gun	60% +
Gravity	60% or less

Table A3. Centre pivot application depth based on a 54-ha (133-acre) pivot (assuming 100% efficiency).

Circle time Hours	System Flow Rate litres/sec (USA gal/min) 38 (600)	44 (700)	50 (800)	57 (900)	63 (1000)	69 (1100)	76 (1200)	82 (1300)
	Irrigation depth Millimetres (inches)							
24	6 (0.24)	7 (0.28)	8 (0.32)	9 (0.36)	10 (0.40)	11 (0.44)	12 (0.48)	13 (0.52)
48	12 (0.48)	14 (0.56)	16 (0.64)	18 (0.72)	20 (0.80)	22 (0.88)	24 (0.96)	26 (1.04)
72	18 (0.72)	21 (0.84)	24 (0.96)	27 (1.08)	30 (1.20)	34 (1.32)	37 (1.44)	40 (1.56)
96	24 (0.96)	28 (1.12)	33 (1.28)	37 (1.44)	40 (1.59)	44 (1.75)	49 (1.91)	53 (2.07)

Table A4. Average daily evapotranspiration and critical water-use periods

Crop	Irrigation depth millimetres (inches) May	June	July	August	September	Critical Period
Wheat	1 (0.04)	3 (0.10)	6 (0.22)	2 (0.08)	n/a	Tillering and flowering
Barley	1 (0.04)	3 (0.12)	6 (0.22)	1 (0.04)	n/a	Tillering and flowering
Canola	2 (0.06)	4 (0.16)	5 (0.20)	2 (0.08)	n/a	Flowering and pod development
Silage Corn	1 (0.02)	2 (0.06)	4 (0.14)	5 (0.18)	2 (0.06)	Tasseling and grain filling
Dry Bean	1 (0.02)	2 (0.08)	4 (0.16)	3 (0.12)	1 (0.02)	Late bud through pod formation
Potato	1 (0.02)	2 (0.06)	4 (0.14)	4 (0.16)	3 (0.10)	Tuber initiation and bulking
Faba Bean	1 (0.02)	2 (0.08)	6 (0.22)	4 (0.16)	1 (0.02)	Early flowering
Flax	1 (0.04)	3 (0.10)	6 (0.22)	3 (0.10)	n/a	Flowering
Field Pea	1 (0.04)	2 (0.08)	5 (0.20)	2 (0.08)	n/a	Early flowering

Values are an estimate based on daily water-use data from 2004–2015 in Outlook, Saskatchewan; actual values may vary by ± 20%.

Table A5. Crop water-use coefficient (K_c) for common irrigated crops (Source – FAO).

Crop	$K_{c\text{-}ini}$	$K_{c\text{-}mid}$	$K_{c\text{-}end}$	Maximum crop height metres (inches)
Canola	0.35	1.15	0.35	0.6 (24)
Cereals	0.3	1.15	0.4	1.0 (39)
Corn	0.3	1.2	0.6	2.0 (79)
Dry bean	0.4	1.15	0.35	0.4 (16)
Potato	0.5	1.15	0.75	0.6 (24)
Soybean	0.5	1.15	0.5	0.5–1.0 (20–39)

Table A6. Critical water requirements (growth, disease, termination) for crops grown in Saskatchewan.

Crop	**Critical water requirement period**	**Critical disease infection period**	**Irrigation termination period**
Alfalfa	All the time, especially after cutting	N/A	Prior to killing frost
Barley	Tillering through flowering	Flag leaf to early milk	Soft dough
Canola	Late vegetation/spiking through flowering and pod development	Flowering	Initial seed ripening
Corn Grain Grazing Silage	Tasseling and grain filling	N/A	Dent stage
Dry beans	Late bud through pod formation	Early flowering to pod filling	Mid-August
Faba beans	Beginning of flowering	Early flowering to pod filling	When half the pods are filled
Flax	Flowering	Flowering	Prior to seed ripening
Grass	All the time	N/A	Prior to killing frost
Peas	Beginning of flowering	Early flowering to pod filling	Pod filling
Potatoes	Tuber initiation and tuber bulking	N/A	Beginning of vine ripening
Wheat Hard spring Soft spring	Tillering and flowering	Flag leaf to early milk	Soft dough Late soft dough

APPENDIX B: DAILY CROP WATER-USE CURVES FOR OUTLOOK, SASKATCHEWAN

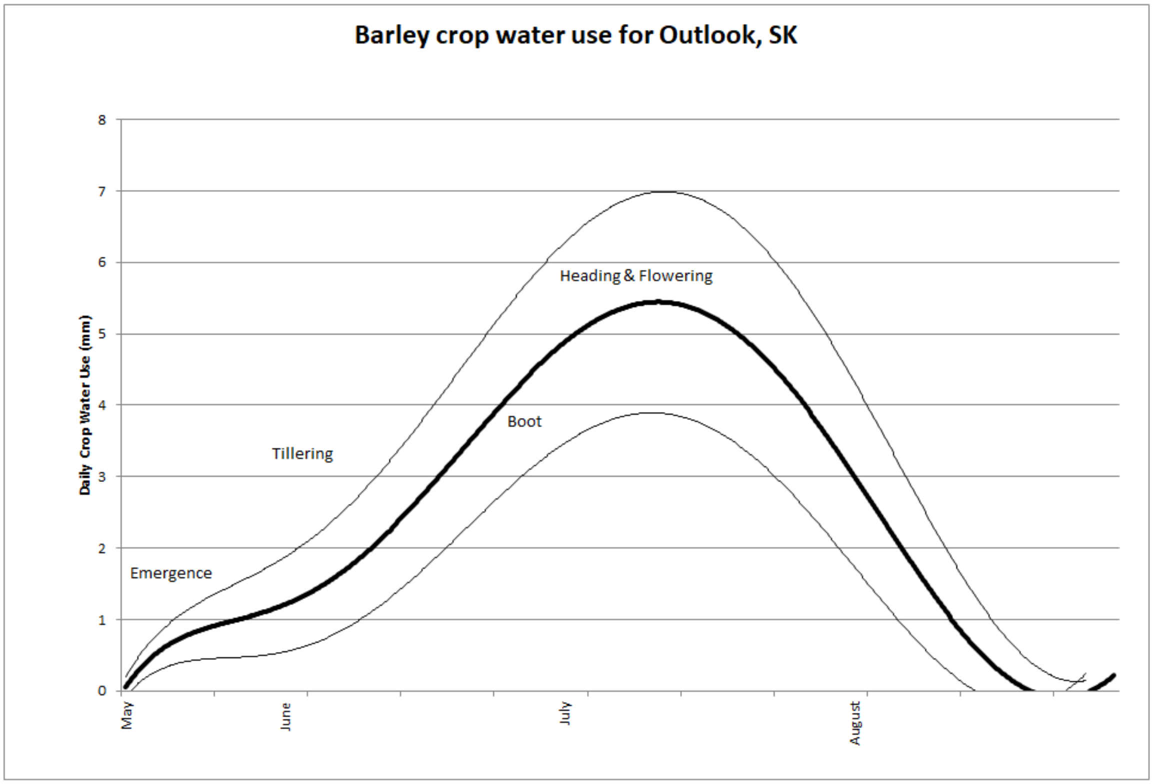


Figure B1. Daily water-use during the different growth stages of barley using a trend line based on average data from 2004–2015 in Outlook, SK.

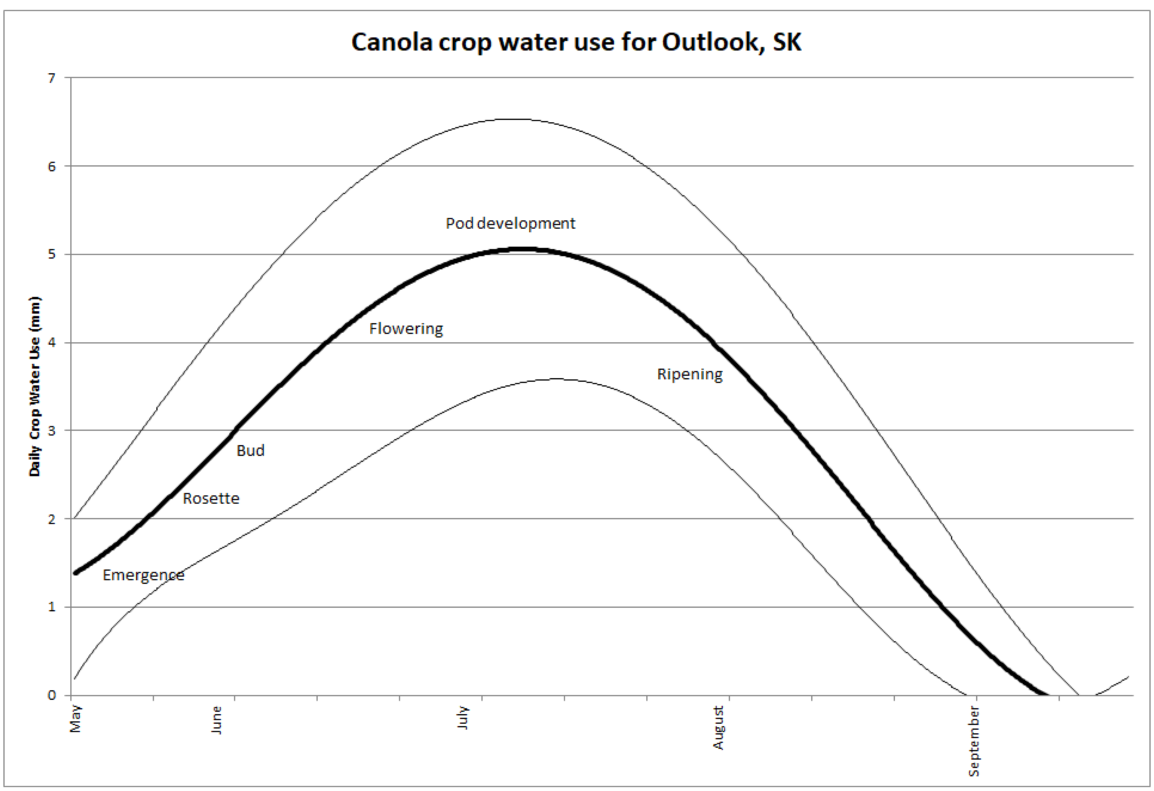


Figure B2. Daily water-use during the different growth stages of canola using a trend line based on average data from 2004–2015 in Outlook, SK.

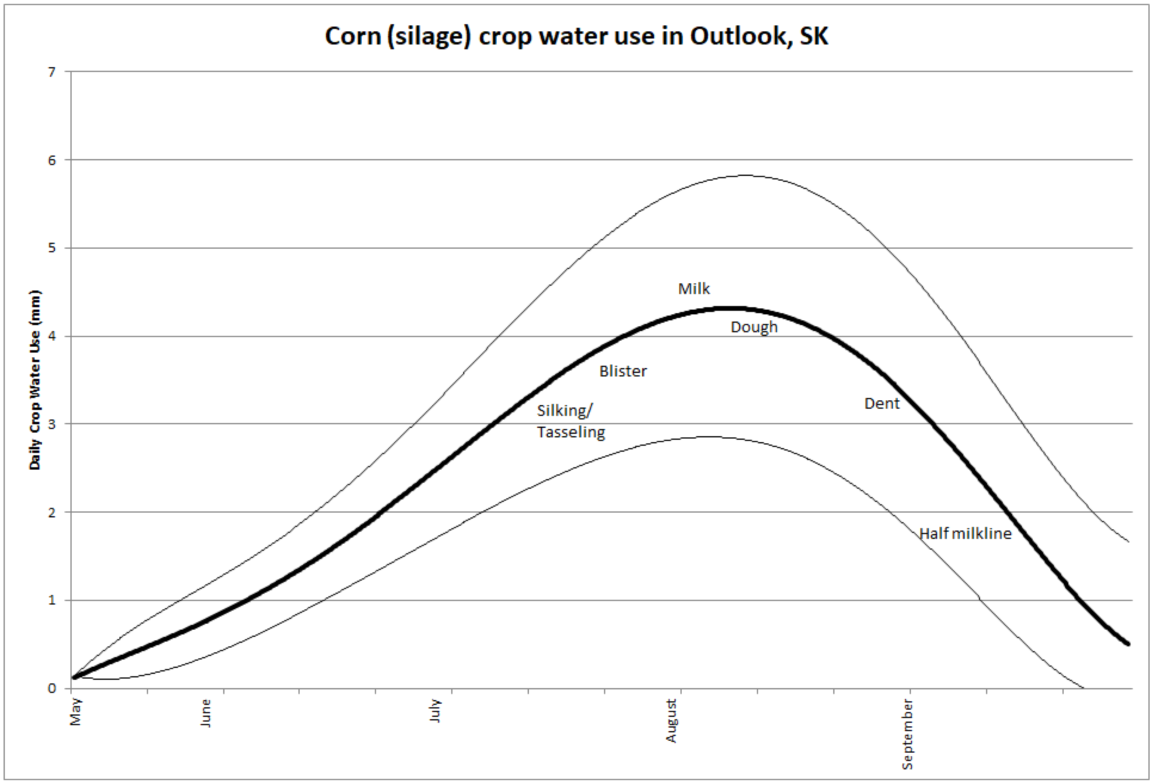


Figure B3. Daily water-use during the different growth stages of silage corn using a trend line based on average data from 2004–2015 in Outlook, SK.

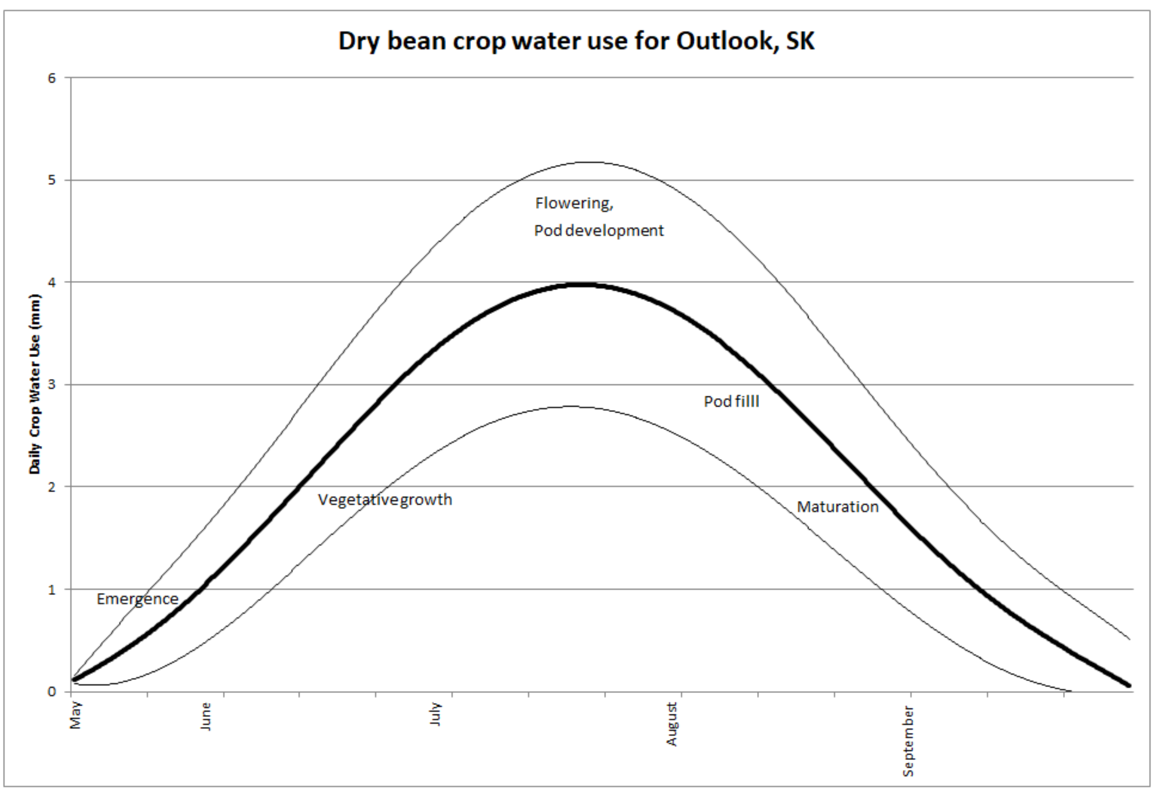


Figure B4. Daily water-use during the different growth stages of dry bean using a trend line based on average data from 2004–2015 in Outlook, SK.

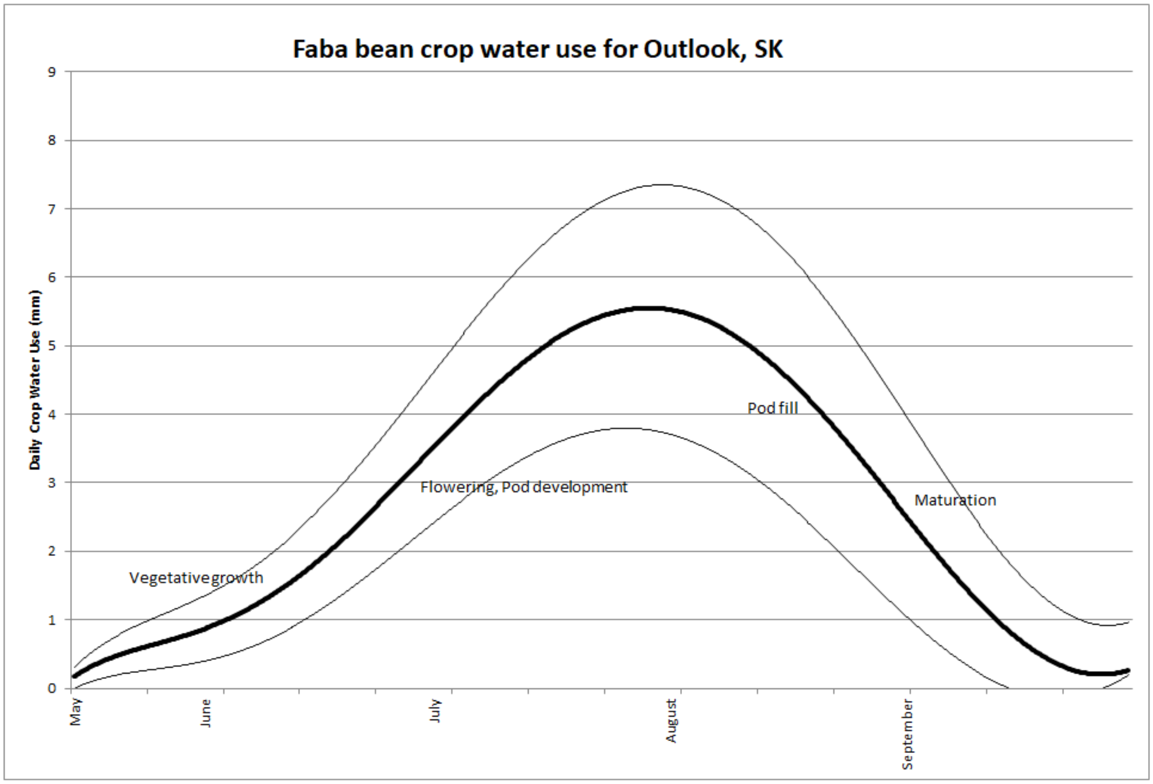


Figure B5. Daily water-use during the different growth stages of faba bean using a trend line based on average data from 2004–2015 in Outlook, SK.

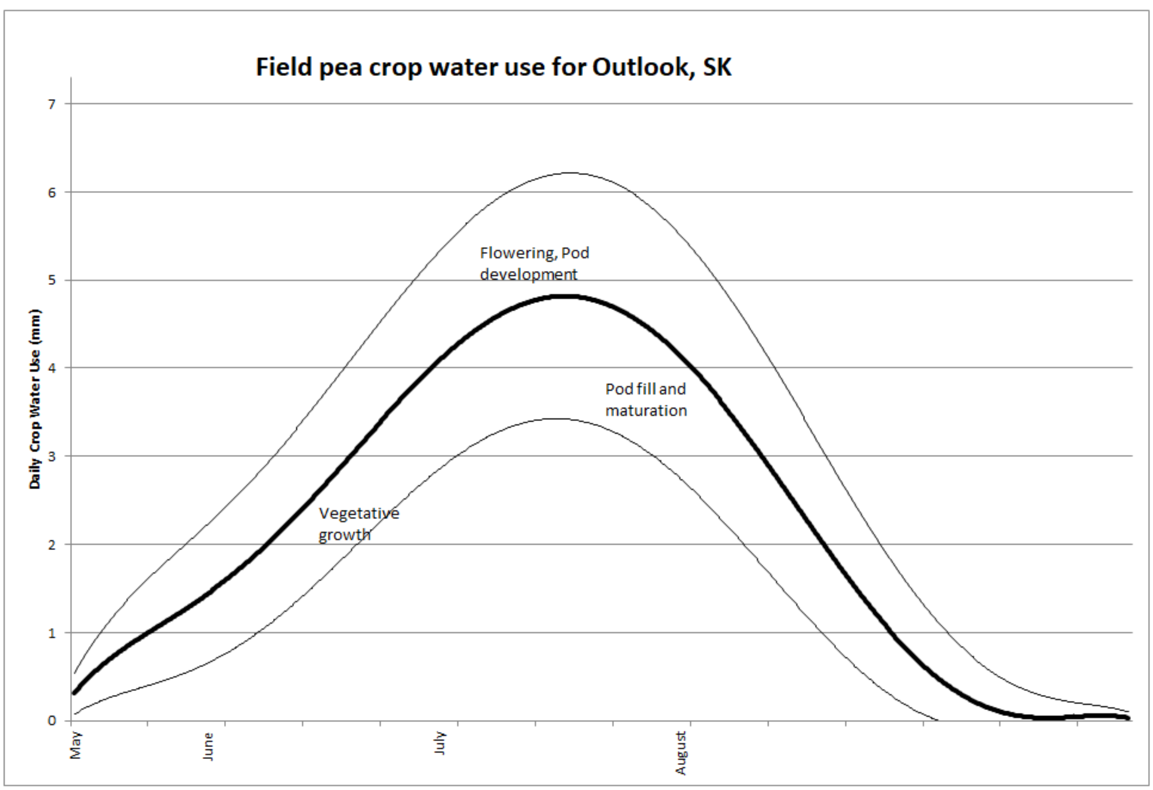


Figure B6. Daily water-use during the different growth stages of field pea using a trend line based on average data from 2004–2015 in Outlook, SK.

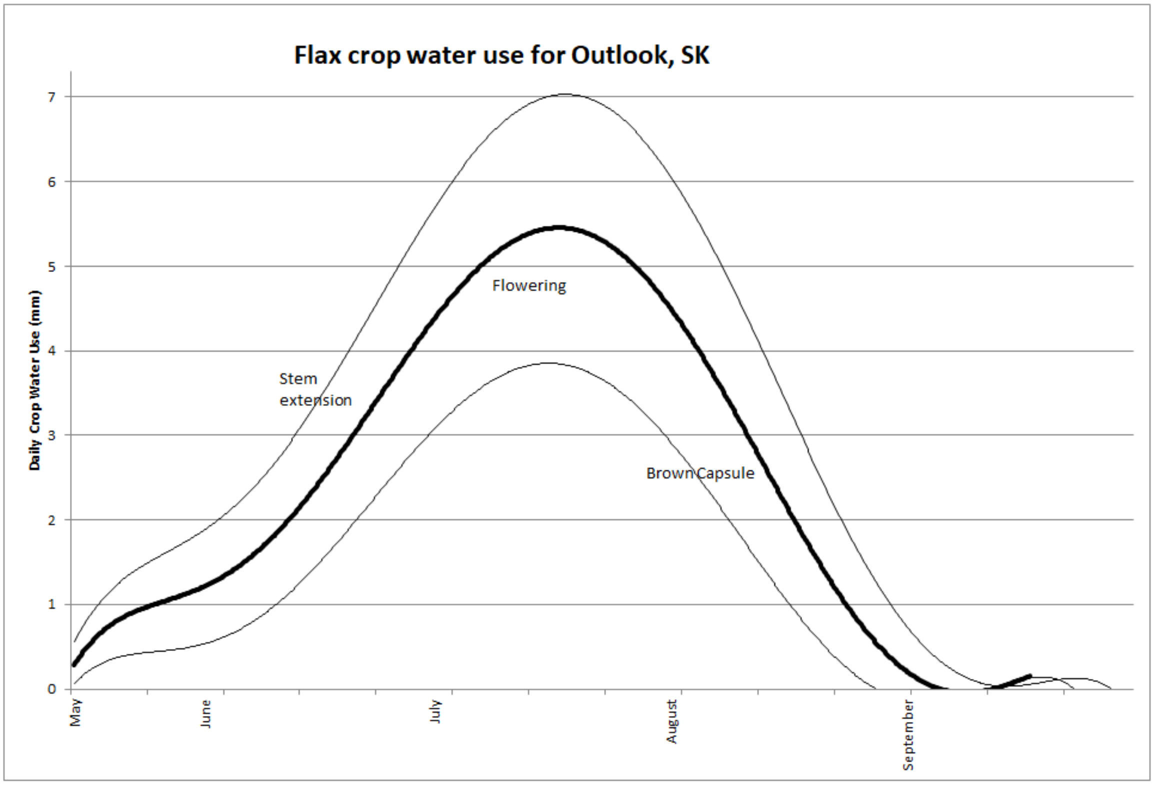


Figure B7. Daily water-use during the different growth stages of flax using a trend line based on average data from 2004–2015 in Outlook, SK.

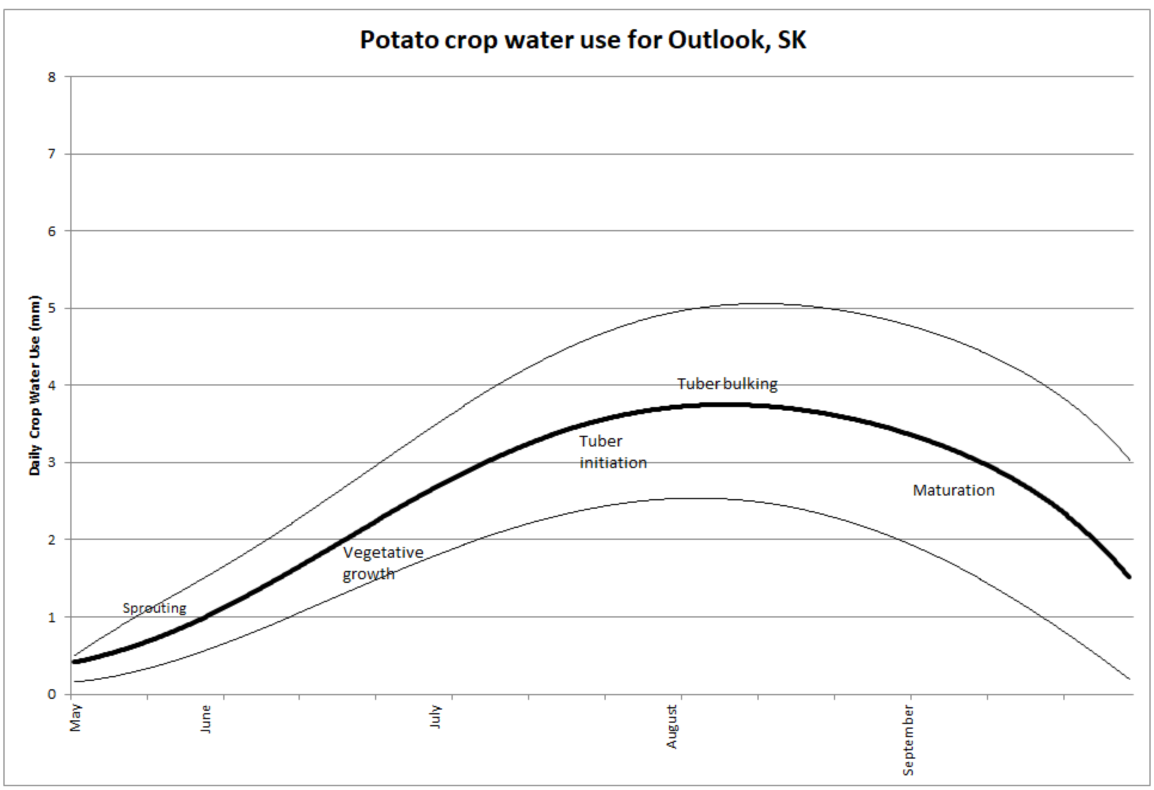


Figure B8. Daily water-use during the different growth stages of potato using a trend line based on average data from 2004–2015 in Outlook, SK.

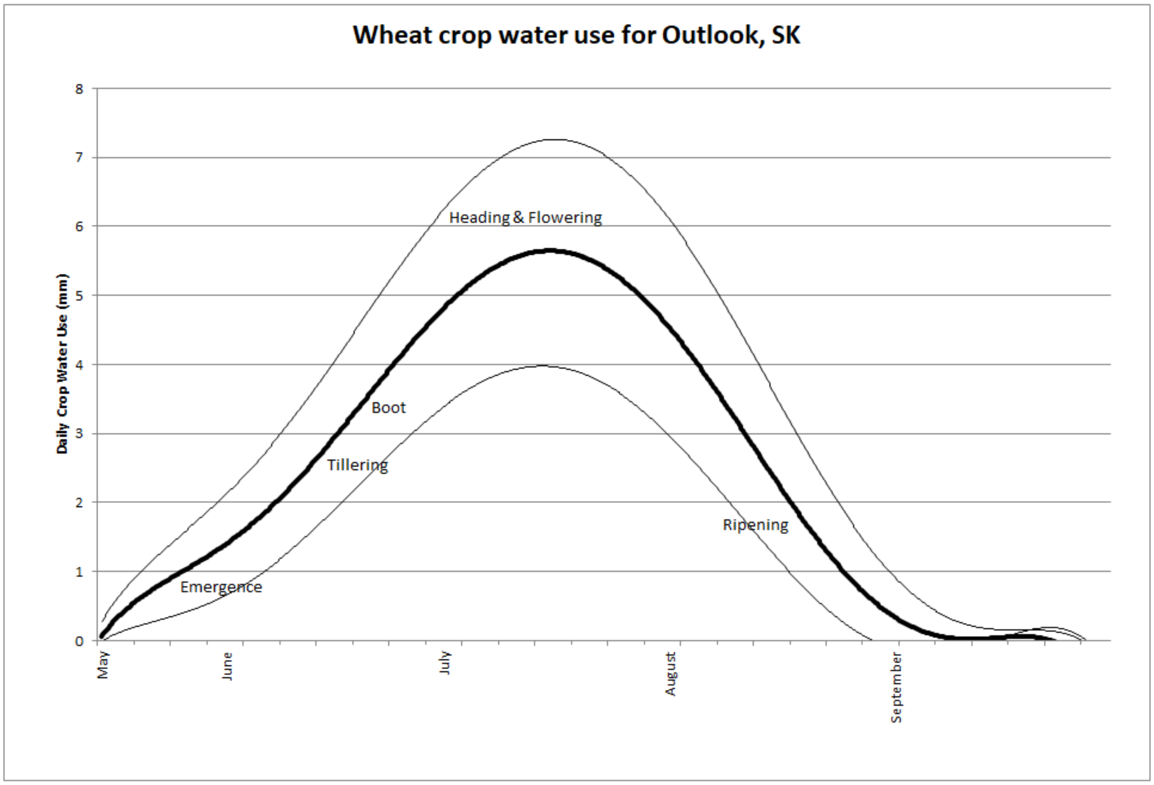


Figure B9. Daily water-use during the different growth stages of wheat using a trend line based on average data from 2004–2015 in Outlook, SK.

APPENDIX C: EQUATIONS

Equation 1: Calculating changes in soil moisture

Soil Moisture = Irrigation + Precipitation – Evapotranspiration

Where:

- Irrigation: amount applied by the irrigation system, accounting for irrigation system efficiency (Appendix A: Table A2, page 47).
- Precipitation: measured from regional weather station or local rain gauge.
- Evapotranspiration: water removed from the system through evaporation (soil surface) and transpired through the crop, estimated from crop water-use charts/tables or calculated from local weather data.

Equation 2: Calculating evaporation

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where:

ET_o – reference evapotranspiration (mm/day)
R_n – net radiation at the crop surface (MJ/m²/day)
G – soil heat flux density (MJ/m²/day[1])
T – mean daily air temperature at 2-metre height
(°C) u_2 – wind speed at 2-metre height (m/s[1])
e_s – saturation vapour pressure (kPa)
e_a – actual vapour pressure (kPa)
Δ - slope vapour pressure curve (kPa/°C[1])
γ – psychrometric constant (kPa/°C[1])

Equation 3: Adjusting reference evapotranspiration for specific crops

$$ET_c = ET_o * K_c$$

where:

ET_c – crop-specific evapotranspiration (mm/day)
ET_o – reference evapotranspiration (mm/day)
K_c – crop-specific water use coefficient

Equation 4: Calculating Normalized Difference Vegetation Index

$$NDVI = \frac{NIR - R}{NIR + R}$$

where:

$NDVI$ – Normalized Difference Vegetation Index

NIR – Near infrared reflectance value

R – Red (visible) reflectance value

Equation 5: Calculating crop water use from Normalized Difference Vegetation Index

$$K_c = (1.37 * NDVI) - 0.086$$

where:

K_c – Crop water use coefficient

$NDVI$ – Normalized Difference Vegetation Index

Equation 6: Crop Water Stress Index (CWSI)

$$CWSI = \frac{(T_c - T_a)_M - (T_c - T_a)_{LL}}{(T_c - T_a)_{UL} - (T_c - T_a)_{LL}}$$

Where:

T_c – Temperature of the crop canopy (°C)

T_a – Air temperature at the field location (°C)

$(T_c - T_a)_M$ – Temperature differential of the measured location (°C)

$(T_c - T_a)_{LL}$ – Temperature differential at lower limit (no stress) (°C); can substitute wet bulb temperature T_{wb}

$(T_c - T_a)_{UL}$ – Temperature differential at upper limit (full stress) (°C); can substitute maximum daily air temperature + 5°C (O'Shaugnessy et al. 2011)

APPENDIX D: EXAMPLE IRRIGATION SCHEDULING CALCULATIONS

EXAMPLE 1: YIELD LOSS WHEN IRRIGATION WATER IS INSUFFICIENT TO MEET PEAK YIELD

A 20% reduction in irrigation water required for peak barley yield could result in approximately an 8% potential yield loss (Figure 3, page 4).

EXAMPLE 2: YIELD LOSS, TAKING INTO ACCOUNT IRRIGATION DEFICIT AND IRRIGATION SYSTEM EFFICIENCY

To maximize potato yields, 435 mm (17.1 in.) of water is required. An irrigator was able to apply 350 mm (13.8 in.) to his potato crop in 2018, or 80% of optimal irrigation needs. In addition, his system and management practices were only 80% efficient, resulting in only 280 mm (11 in.) effectively reaching the crop representing 64% of crop needs to achieve maximum yield. If system was 100% efficient, yield would only have been reduced by 6% of optimum. However, the system inefficiencies cost more than an additional 10% of yield for a total reduced yield of 17.5% (Figure 3, page 4).

EXAMPLE 3: MAXIMUM ALLOWED DEPLETION (MAD)

A Silt Loam field seeded to potato with a rooting depth of 45 centimetres (1.5 feet).
Using Maximum Allowable Depletion (MAD) as an irrigation trigger, how much water should be applied to bring the root zone up to Field Capacity?

Root Zone depth: 45 centimetres (1.5 feet)

Plant Available Water = Field Capacity – Permanent Wilting Point (Appendix A: Figure A2, page 47)

= 2.6 inches water/foot – 1.2 inches/foot = 1.4 inches/foot
(= 217 mm/m – 100 mm/m = 117 mm/m)

Maximum allowed depletion ~ 50% of Plant Available Water

= 1.4 inches/foot x 50% = 0.7 inches/foot
(= 117 mm/m x 50% = 58 mm/m)

Maximum allowed depletion

= 0.7 inches/foot x 1.5-foot root zone = 1.1 inches of water
(= 58 mm/m x 0.46-m root zone = 27 mm of water)

1.1 inches (27 mm) of water needs to be applied to bring the root zone up to field capacity

EXAMPLE 4: NET WATER DEPTH FOR OF WATER APPLIED TO A FIELD OVER A 48-HOUR PERIOD

During mid-June, canola uses approximately 0.16 inches (4 mm) of water per day (Appendix A: Table A4). Using a 900 US gallon/minute high pressure irrigation pivot (Appendix A: Table A2), what is the net depth of water applied to the field over a 48 hour period (Appendix A: Table A3)?

Depth applied in 48 hours = 0.72 inches (18.3 mm)

Crop use during 24 hours = 0.16 inches (4 mm)

Crop use during 48 hours = 0.32 inches (8 mm)

Net water retained in field = 0.72 inches – 0.32 inches = 0.4 inches (10.1 mm)

EXAMPLE 5: WATER SAVING POTENTIAL WHEN CONVERTING TO A HIGHER EFFICIENT IRRIGATION SYSTEM

If a centre pivot irrigation system was converted from a high pressure pivot to a low pressure center pivot, how much water will be saved on a 48hr circle (Appendix A: Table A2) if the system flowrate is 900 usgpm?

Depth applied in 48hrs (Appendix A: Table A3) = 0.72 inches (18.2 mm) (100% efficiency)

Depth applied – high pressure centre pivot (Appendix A: Table A2) = 0.72 inches x 80%/100% = 0.58 inches (14.6 mm)

Depth applied – low pressure centre pivot (Appendix A: Table A3) = 0.72 x 90%/100% = 0.65 inches (16.4 mm)

Net water savings = 0.65 inches – 0.58 inches = 0.07 inches (1.8 mm)

EXAMPLE 6: IRRIGATION DEPTH REQUIRED TO BRING ROOT ZONE TO FIELD CAPACITY

Soil samples were taken from a field with Sandy Loam soil. Rooting depth was 15 cm. The irrigation system is a high pressure centre pivot.

A. Calculate gravimetric moisture content (% water by WEIGHT)

% water by weight = $\frac{wet\ sample\ weight - dry\ sample\ weight}{dry\ sample\ weight} x\ 100\%$

Container weight = 50 grams (account for container when weighing)

Wet soil sample weight = 153.4 grams – 50 grams = 113.4 grams

Dry soil sample weight = 151.1 grams – 50 grams = 101.1 grams

% water by weight = $\frac{113.4\ grams - 101.1\ grams}{101.1\ grams} x\ 100\% = \mathbf{12.2}\%$

B. Convert gravimetric to volumetric moisture content (% water by VOLUME)

% water by volume = $\% \, water \, by \, weight * \frac{bulk \, density \, of \, soil}{bulk \, density \, of \, water} * 100\%$

Bulk density of water = ~ 1.0 gram/centimetre^3

Bulk density of soil $= \frac{dry \, sample \, weight}{soil \, sample \, volume}$

Soil sample volume $= \pi \; * \; radius^2 \; * \; \text{length}$

Soil core radius = soil core diameter/2 = 2.54 centimetres/2 = 1.27 centimetres

Soil core length = 15 centimetres

Bulk density of soil = $\frac{101.1 \; grams}{\pi * (1.27 \text{ centimetre})^2 * 15 \text{ centimetres}} = 1.33 \; grams/centimetre^3$

(= silt loam)

% water by volume = $12.2 \; \% * \frac{1.33 \; grams/centimetre^3}{1.0 \text{ grams}/centimetre^3} * 100 \; \% \; = \mathbf{16.2} \; \%$

C. Calculate required irrigation depth to bring soil to Field Capacity

Irrigation depth = (Field capacity – Soil moisture content) x root depth

Field capacity of silt loam (Appendix A: Figure A2, page 47) = Available water + Unavailable water

= 1.2 + 1.4 inches water / foot soil depth = 2.6 inches water / foot soil depth
(= 100 + 117 mm water / m soil depth = 217 mm water / m soil depth)

Soil moisture content = 16.2 % x 12 inches water/foot soil depth = 1.9 inches of water/foot soil depth
≤ Maximum allowed depletion* → **irrigation required**

(Soil moisture content = 16.2 % x 1000 mm/m soil depth = 162 mm / m soil depth
≤ Maximum allowed depletion* → **irrigation required**)

*Maximum allowed depletion = Available water at Field capacity/2 + Permanent wilting point [Appendix A: Figure A2 (silt loam), page 47]

= (1.4/2 + 1.2) inches of water/foot soil depth = 1.9 inches water/foot soil depth
(= (117/2 + 100) mm of water / m soil depth = 159 mm water / m soil depth)

Irrigation depth = (2.6 – 1.9) inches water/foot soil depth * 1-foot root zone **= 0.7 inches water**
(Irrigation depth = (217 – 162) mm water/m soil depth * 0.3048 m root zone **= 16.8 mm water**)

D. Calculate required irrigation depth, taking into account system efficiency

The system efficiency of a high pressure centre pivot is 80% (Appendix A: Table A2)

Irrigation Depth = ((Field Capacity – Soil Moisture Content) x Root Depth) / Irrigation Efficiency

$$= \frac{(2.6-1.9) \text{ inches of water/foot of soil} * 1 \text{ foot root depth}}{80/_{100}} = 0.875 \text{ inches of water}$$

$$\left(= \frac{(217-162)\ mm\ of\ water/m\ of\ soil * 0.3048\ m\ root\ depth}{80/100} = 21\ mm\ of\ water\ \right)$$

An irrigation depth of 0.875 inches (21 mm) of water is needed to bring root zone to field capacity.

EXAMPLE 7: IRRIGATION DEPTH REQUIRED BASED ON HAND FEEL METHOD

Samples were taken from a field with Sandy Loam soil. Samples were taken to a depth of 2 feet. Samples were broken into two sub-samples: 0–1 foot and 1–2 feet. Based on the texture and referring to Appendix A: Figure A2, page 47, plant available moisture was estimated to be:

0–1 foot: 25–50% plant available moisture (estimate 40%) *(below maximum allowed depletion →* ***Irrigate****)*

1–2 feet: 50–75% plant available moisture (estimate 60%)

Sandy Loam Soil has 1.2 inches plant available water/foot of soil at field capacity (Appendix A: Figure A2, page 47). To bring the root zone back to field capacity we must irrigate:

0–1 foot: (100 – 40%)/100% * 1.2 inches water/foot of soil = 0.72 inches of water (0–0.3 m: (100 – 40%)/100% * 100 mm water/m of soil * 0.3m = 18 mm of water)

1–2 feet: (100 – 60%)/100% * 1.2 inches water/foot of soil = 0.48 inches of water
(0.3–0.6 m: (100 – 60%)/100% * 100 mm water/m of soil * 0.3 m = 12 mm of water)

Total irrigation water required to bring field up to field capacity = 0.72 + 0.48 inches of water
= 1.2 inches of water

(Total irrigation water required to bring field up to field capacity = 18 + 12 mm of water
= 30 mm of water)

EXAMPLE 8: IRRIGATION DEPTH REQUIRED BASED ON RESISTANCE BLOCK OR TENSIOMETER METHOD

Electrical resistance blocks, placed at two depths (6” and 12”) in a Sandy Loam soil, sense soil water potentials of 6 and 2 bars respectively. Based on Figure 15 (page 21), plant available water is

0–6 inch depth (0 – 15 cm): 6 bars = 15 % plant available water

6–12 inch depth (15 – 30 cm): 1 bar = 50 % plant available water

Sandy Loam soil has maximum plant available water level of 1.2 inches water / foot soil depth (100 mm water / m of soil depth) (Appendix A: Figure A2, page 47) at field capacity.
To bring the root zone back to field capacity we must irrigate:

0–0.5 feet: (100–15%)/100% * 1.2 inches water/foot of soil depth* 0.5 feet = 0.5 inches of water
(0–0.15 m (100-15%)/100% * 100 mm water/m of soil depth*0.15 m = 13 mm of water)

0.5–1.0 feet: (100–50%)/100% * 1.2 inches of water/foot of soil depth * 0.5 feet = 0.3 inches of water
(0.15–0.3 m (100-50%)/100% * 100 mm water/m of soil depth*0.15 m = 8 mm of water)

Total irrigation water required = 0.5 inches + 0.3 inches = **0.8 inches of water**
(Total irrigation water required = 13 mm + 8 mm = **21 mm of water)**

EXAMPLE 9: IRRIGATION DEPTH REQUIRED BASED ON TDR OR CAPACITANCE PROBE(S)

A capacitance probe is placed in a Sandy Loam soil with a single sensor at 15 centimetres (6 inches). At the current crop development, the root zone is approximately 20 centimetres (8 inches) deep. Sandy Loam soil has a field capacity of 18.3% (2.2 inches of water / 12 inches of soil depth) and a permanent wilting point of 8.3% (1.0 inches of water / 12 inches of soil depth) (Appendix A: Figure A2, page 47).

The current soil moisture is 12%. a) Should you irrigate? B) If yes, how much?

a) Irrigation trigger is at 50% of plant available water (i.e. maximum allowed depletion)

   = [(Field capacity – Permanent wilting point)/2 + permanent wilting point]

   = [(18.3% – 8.3%)/2 + 8.3%] = 13.3%

   Current soil moisture (12%) is less than 50% plant available water (13.3%)
   ➔ **Irrigate**

b) To bring the root zone back to field capacity
   Irrigation Depth = [(field capacity – current soil moisture)/100%] x root depth
   = (18.3% – 12%)/100% x 8 inches
   (= (18.3% – 12%)/100% x 203 mm)
   = 0.5 inches of water
   (= 13 mm of water)

EXAMPLE 10: CHEQUE-BOOK EXAMPLE OF IRRIGATION SCHEDULING FOR CANOLA GROWN ON LOAM SOIL

Field capacity = 2.4 inches of water/foot of soil depth (Appendix A: Figure A2, page 47)

Permanent wilting point = 1.0 inch of water/foot of soil depth

Maximum allowed depletion (50% available water = irrigation trigger)

= (2.4 − 1.0)/2 + 1.0 = 1.7 in. water/foot of soil depth

Date	Initial soil water content*	Crop water-use*,† (ET)	Irrigation/ precipitation*	Final soil water content*
July 28	2.0	0.2	0	1.8
July 29	1.8	0.2	0	1.6
July 30	1.6	0.2	0.5	1.9
July 31	1.9	0.2	0	1.7
August 1	1.7	0.1	1.0	2.6
August 2	2.4 ‡	0.1	0	2.3
August 3	2.3	0.1	0	2.2

*All values in inches

†Estimated daily crop water-use (Appendix A: Table A4, page 48)

‡Field capacity is 2.4 inches of water/foot of soil; the excess 0.2 inches applied the day before has drained away by gravity

EXAMPLE 11: SCHEDULING THE LAST IRRIGATION

What is the minimum required irrigation to take a wheat crop to full maturity?

Crop: Wheat

Crop stage: Late milk (Appendix A: Table A6, page 49)

Daily crop water use (Appendix A: Table A4, page 48 for August): 0.08 inches water/day

Root depth (Appendix A: Table A1, page 47): 3 feet

Maturity date (expected): in 12 days

Soil: sandy loam

Plant available water (sandy loam) at field capacity (Appendix A: Figure A2, page 47):

1.2 inches water/foot of soil depth

Current soil moisture status: 14% (volumetric)

Current soil water content: volumetric content x 12 inches water/foot soil depth

= 14% x 12 inches of water/foot soil depth = (0.14 x 12) inches water/foot soil depth

(= 14% x 1000 mm of water/m soil depth = (0.14 x 1000) mm water/m soil depth)

= 1.68 inches of water/foot soil depth

(= 140 mm of water/m soil depth)

Maximum allowed depletion (Appendix A: Figure A2, page 47): Total unavailable water + (total available water/2)

= (1.00 + 1.20/2) inches water/foot of soil depth = 1.60 inches water/foot of soil depth

(= (83 + 100/2) mm water/m of soil depth = 133 mm water/m of soil depth)

Available water above Maximum allowed depletion: Current soil water content - Maximum allowed depletion

= (1.68 – 1.60) inches water/foot of soil depth = 0.08 inches water/foot of soil depth

(= (140 – 133) mm water/m of soil depth = 7 mm water/m of soil depth)

Total available soil water (root depth) above Maximum allowed depletion: soil water content x root depth

= 0.08 inches of water/foot of soil depth x 3 feet = 0.24 inches of water

(= 7 mm water/m of soil depth x 0.9 m = 6 mm of water)

Crop water needs until maturity: Daily crop water use x days

0.08 inches water/day x 12 days = 0.96 inches of water

(2 mm water/day x 12 days = 24 mm of water)

Irrigation required: Crop needs until maturity – available soil water

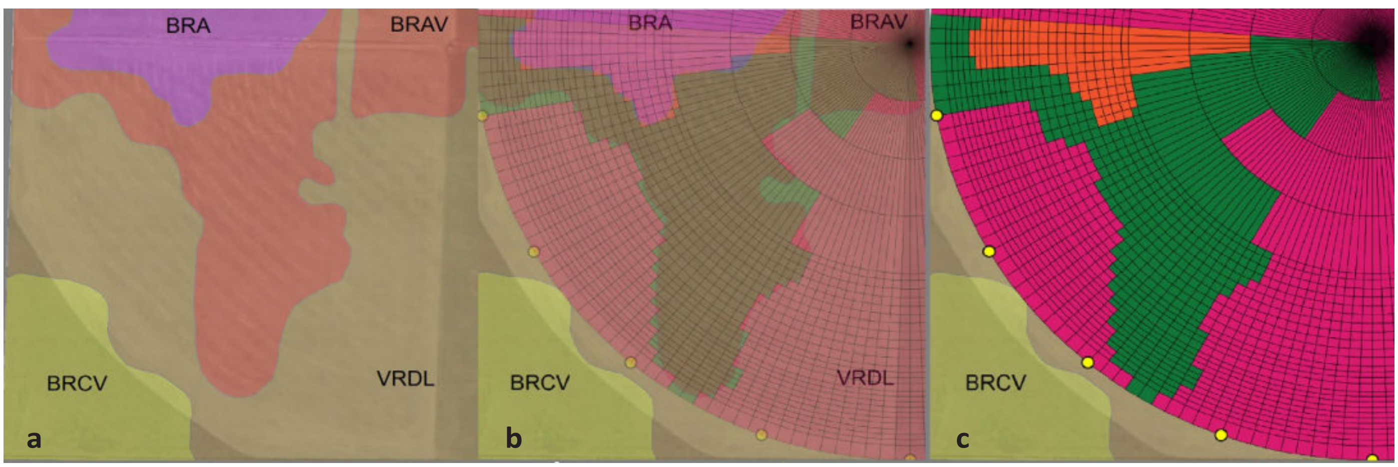
(0.96 – 0.24) inches of water = 0.72 inches of water ≈ 0.75 inches of water

[(24 – 6) mm of water = 18 mm of water]

→ **0.75 inches of water** is required to carry the crop to maturity

(→ **18 mm of water** is required to carry the crop to maturity)

EXAMPLE 12: VRI ZONE MAPPING USING HISTORICAL SOIL SURVEY MAP



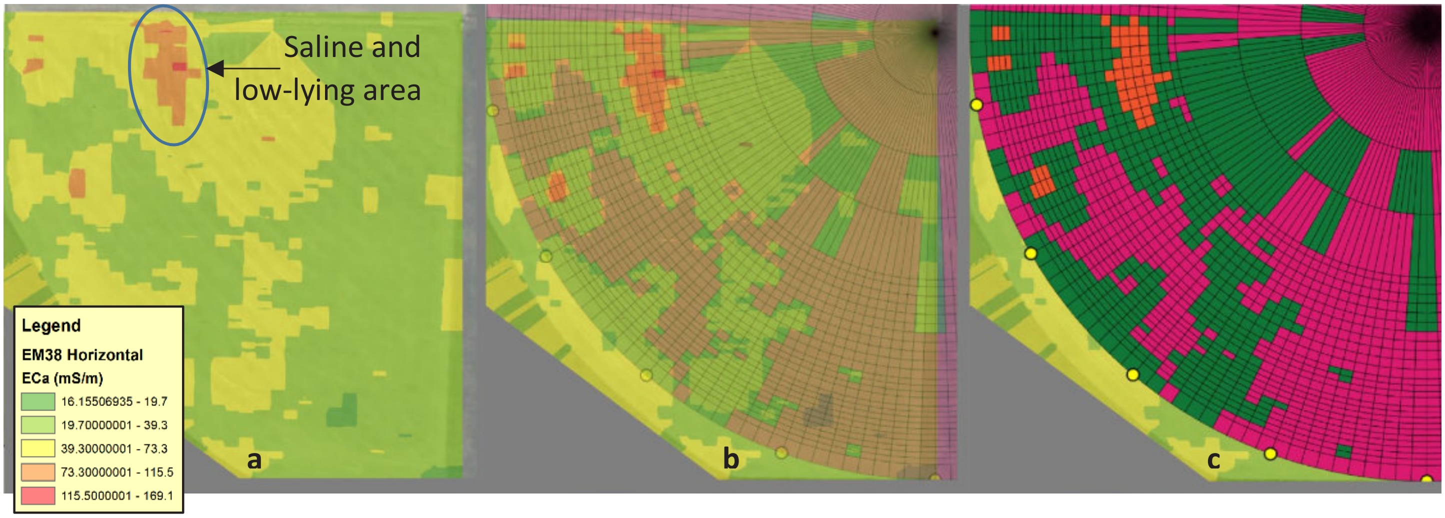
Historical soil survey maps (a) map out areas for each uniquely named soil association (usually abbreviated). Each soil association has unique soil characteristics including soil texture. A limited number of soils samples were taken to define a soil class and to identify its boundary. As a result, the resolution is coarse and not usually at a field scale.

In this example, the portion of the field investigated has three unique soil associations under the pivot (b):

- BRA (GREEN) – Bradwell Orthic Dark Brown – loam soil
- BRAV (ORANGE) – Bradwell/Vera – loam soil with sand, low dunes
- VRDL (PINK) – Vera Orthic Regosol – sand, low dunes, with till substrate

Based on this information, the field was initially mapped into 3 zones (c). The soil water holding capacity will increase from the sand (VRDL) to the loam soil (BRA). This will result in different schedules (timing and depth) for each zone.

EXAMPLE 13: VRI ZONE MAPPING USING APPARENT ELECTRO-CONDUCTIVITY MAP

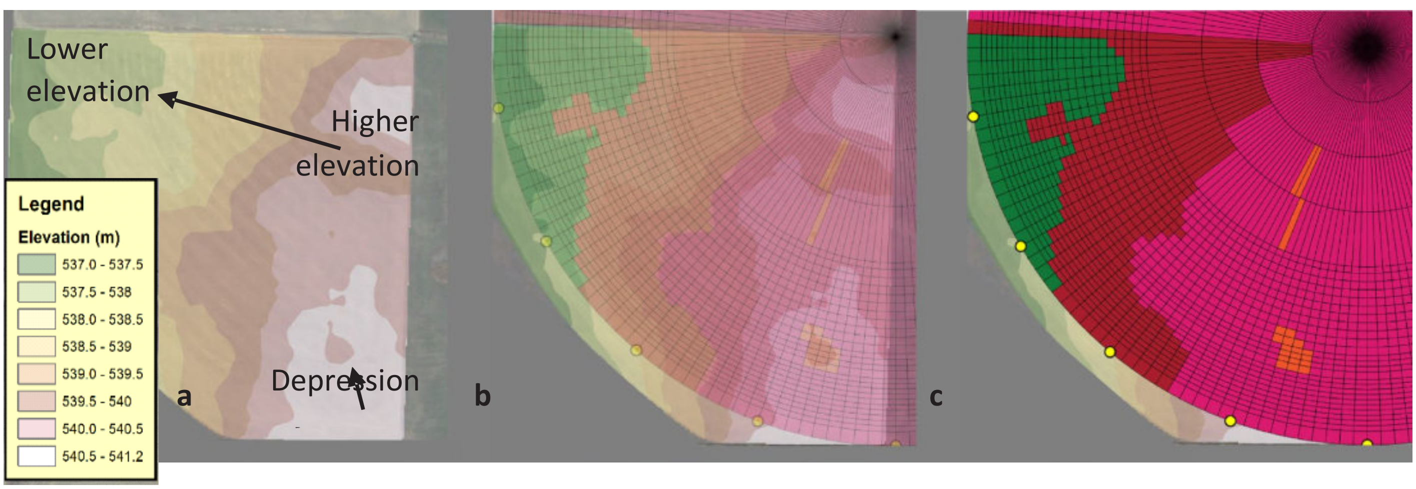


A field was surveyed with a Geonics EM38 (a, b). Electrical conductivity ranged between 16–170 milliSiemens/metre (mS/m). Based on the survey data, the field was divided into 3 zones (c):

Zone 1 (GREEN): 16–39 mS/m Zone 2 (PINK): 39–73 mS/m Zone 3 (ORANGE): 73+ mS/m

The land owner indicated that Zone 3 matched up to a saline area and a few low-lying areas that collect water. A combination of drainage and precision irrigation could bring this area into higher productivity (i.e. lower EC value).

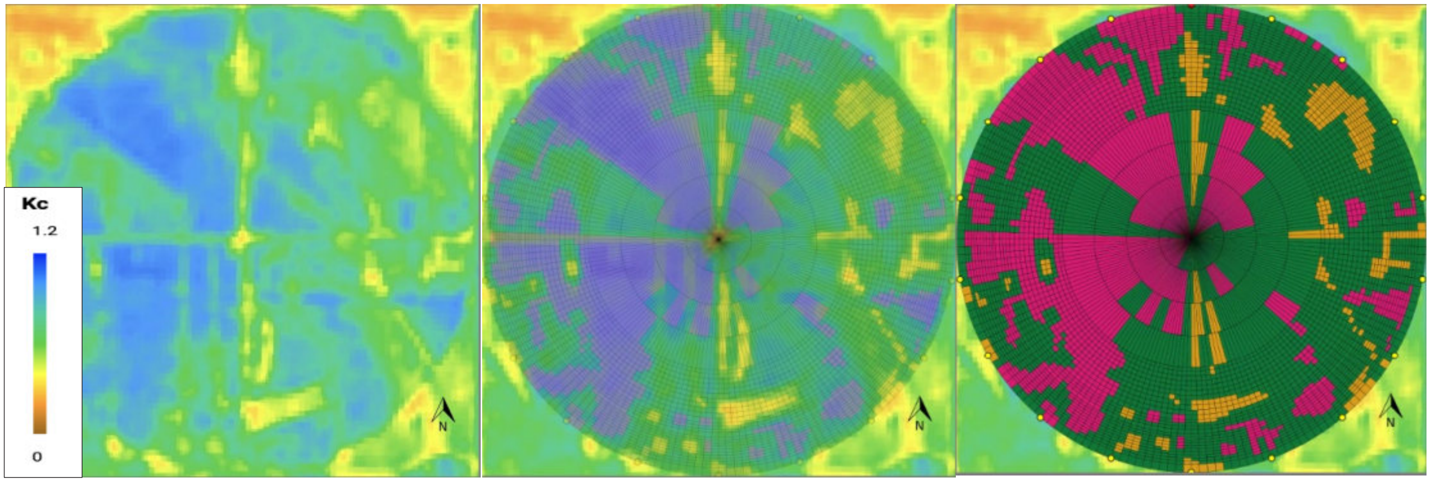
EXAMPLE 14: VRI ZONE MAPPING USING TOPOGRAPHIC MAP



A topographic survey showed an elevation range of 538–541m (a, b). Based on this, the field was mapped into 4 zones (c):

Zone 1: 537–538 metres (low elevation GREEN)
Zone 2: 538–539.5 metres (mid-slope RED)
Zone 3: 539.5–541 metres (high elevation PINK)
Zone 4: depressions (potholes ORANGE) – limit irrigation in these areas

EXAMPLE 15: VRI ZONE MAPPING AND SCHEDULING USING NORMALIZED DIFFERENCE VEGETATION INDEX IMAGERY



Using normalized difference vegetation index imagery, develop a dynamic irrigation prescription to schedule the next irrigation event.

Step 1: Convert normalized difference vegetation index values to crop water-use coefficients (K_c)
[automatic in some systems, e.g. Irrican] – Appendix C: Equation 5, page 59

Step 2: Map field into distinct zones based on crop water-use ranges
Zone 1: high water use (blue), $K_c>1$ (average = 1.1)
Zone 2: moderate water use (green), $1 > K_c > 0.5$ (average = 0.75)
Zone 3: low water use (yellow), $K_c<0.5$ (average = 0.4)

Step 3: Calculate required irrigation amount to satisfy crop demand
Estimated evapotranspiration (ET_o) since the last irrigation/rainfall event for the area for reference crop (grass/alfalfa) = 0.75 inches of water (e.g. published by Saskatchewan Ministry of Agriculture, AIMM)
Use Equation 3 ($ET_o \times K_c$ = water use) to calculate crop water demand for each zone
Zone 1: 0.75 inches of water x 1.1 = 0.825” → **0.8 inches of water**
(**Zone 1:** 19 mm of water x 1.1 = 20.9 mm → **21 mm of water)**
Zone 2: 0.75 inches of water x 0.75 = 0.56" → **0.6 inches of water**
(Zone 2: 19 mm of water x 0.75 = 14.25 mm → **14 mm of water)**
Zone 3: 0.75 inches of water x 0.4 = 0.3” → **0.3 inches of water**
(Zone 3: 19 mm of water x 0.4 = 7.6 mm → **8 mm of water)**

IRRIGATION SCHEDULING MANUAL FOR SASKATCHEWAN