The implications of changing stubble and crop residue management practices from a water perspective

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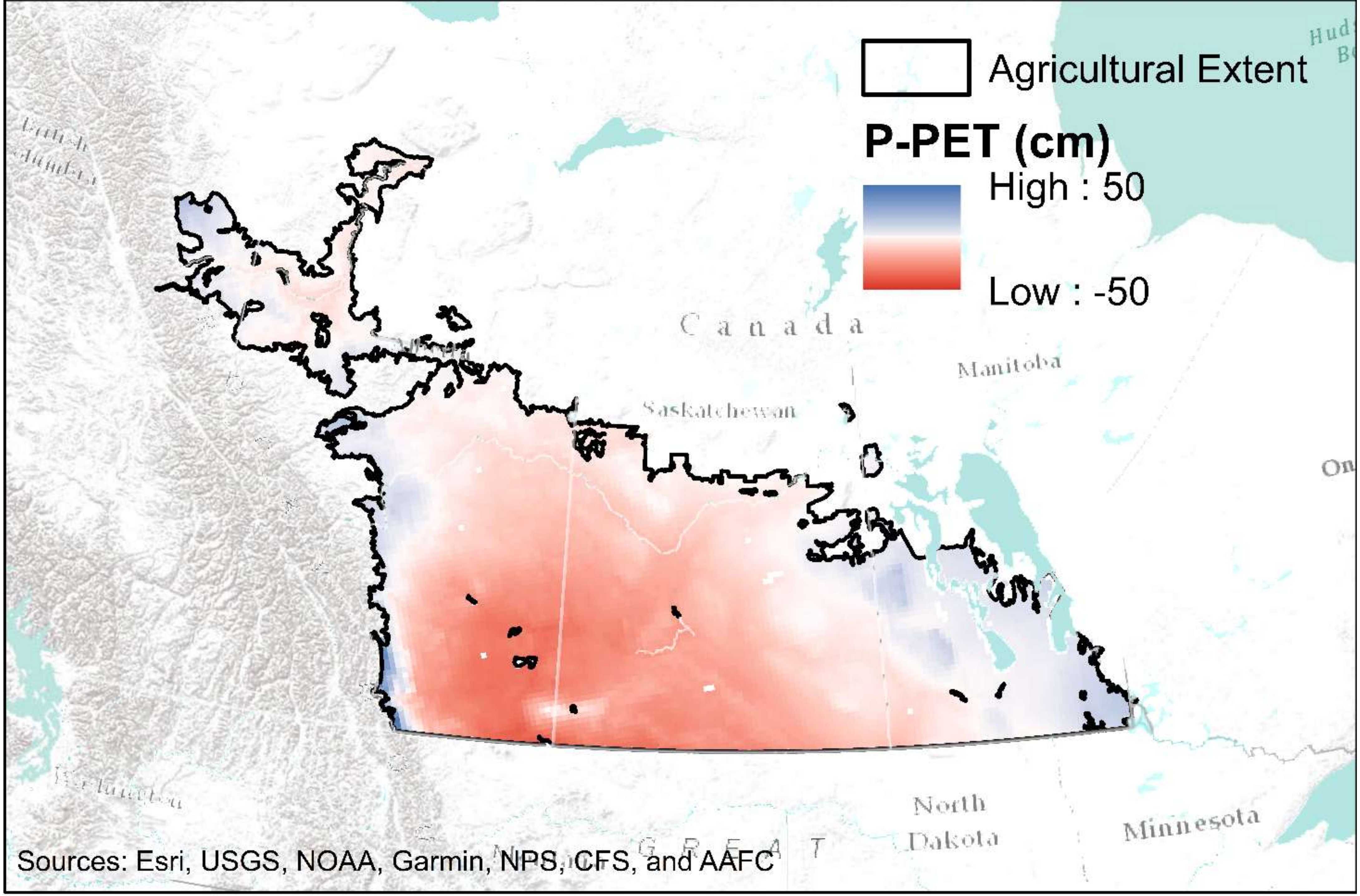
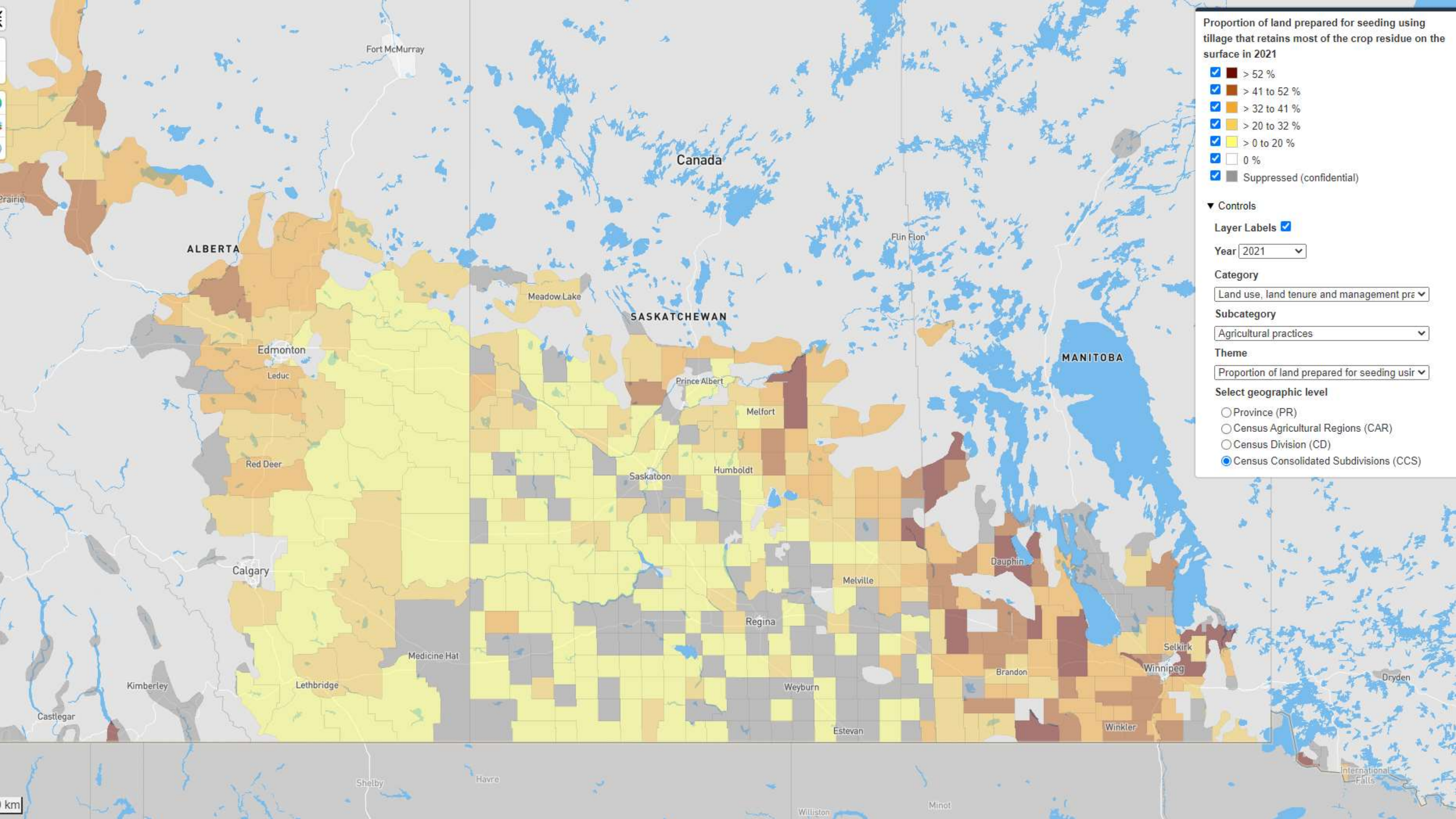
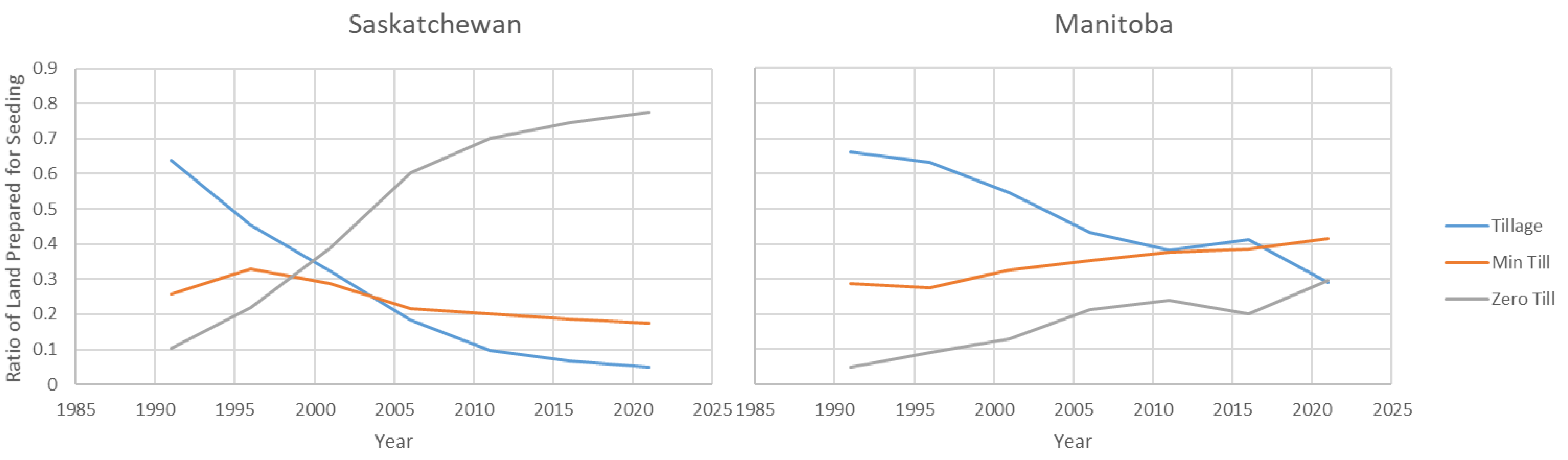
GWF


Agricultural Extent
P-PET (cm)
High : 50
Low : -50
Canada
Manitoba
Saskatchewan
North Dakota
Minnesota
Sources: Esri, USGS, NOAA, Garmin, NPS, CFS, and AAFC


Proportion of land prepared for seeding using tillage that retains most of the crop residue on the surface in 2021
> 52 %
> 41 to 52 %
> 32 to 41 %
> 20 to 32 %
> 0 to 20 %
0 %
Suppressed (confidential)
Controls
Layer Labels
Year 2021
Category
Land use, land tenure and management pra
Subcategory
Agricultural practices
Theme
Proportion of land prepared for seeding usir
Select geographic level
Province (PR)
Census Agricultural Regions (CAR)
Census Division (CD)
Census Consolidated Subdivisions (CCS)
Canada
ALBERTA
SASKATCHEWAN
MANITOBA
Fort McMurray
Flin Flon
Meadow Lake
Edmonton
Leduc
Prince Albert
Melfort
Red Deer
Humboldt
Saskatoon
Calgary
Dauphin
Melville
Regina
Selkirk
Medicine Hat
Winnipeg
Brandon
Dryden
Kimberley
Lethbridge
Weyburn
Winkler
Castlegar
Estevan
Shelby
Havre
International Falls
Minot
Williston
km

Tillage practises over time



1. How much water do crops use and where does it come from?
2. How does stubble and residue management influence crop available water?
3. How much can we manipulate crop available soil water with stubble and residue management?

Relating Crop Growth and Hydrology

- Summer Water balance

$$P + \Delta S = E + T + R$$

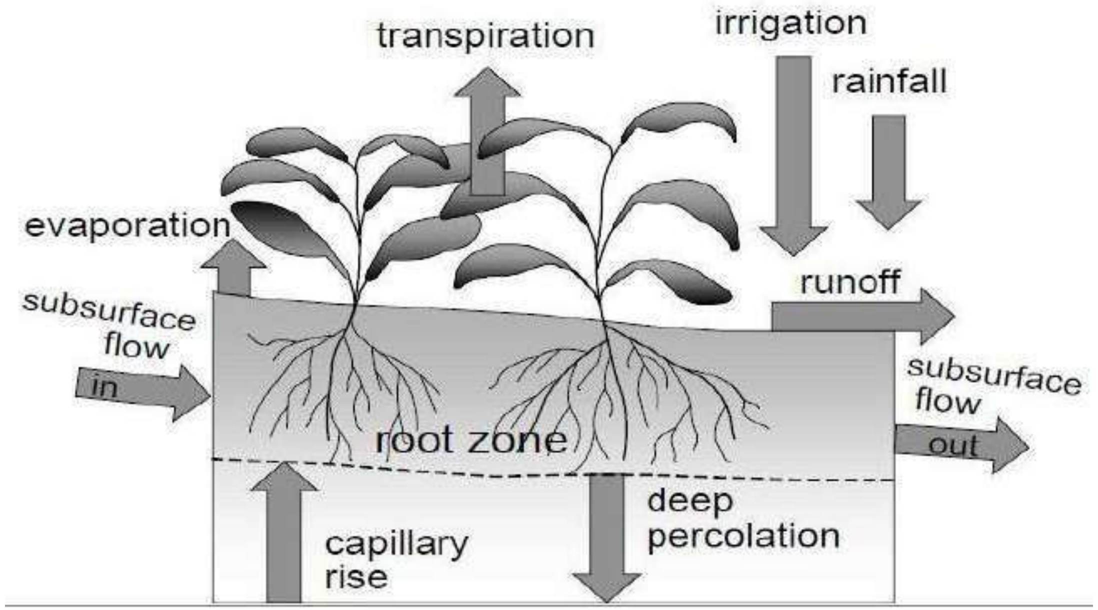
ΔS= Change in soil moisture

P=Precipitation

E=Evaporation

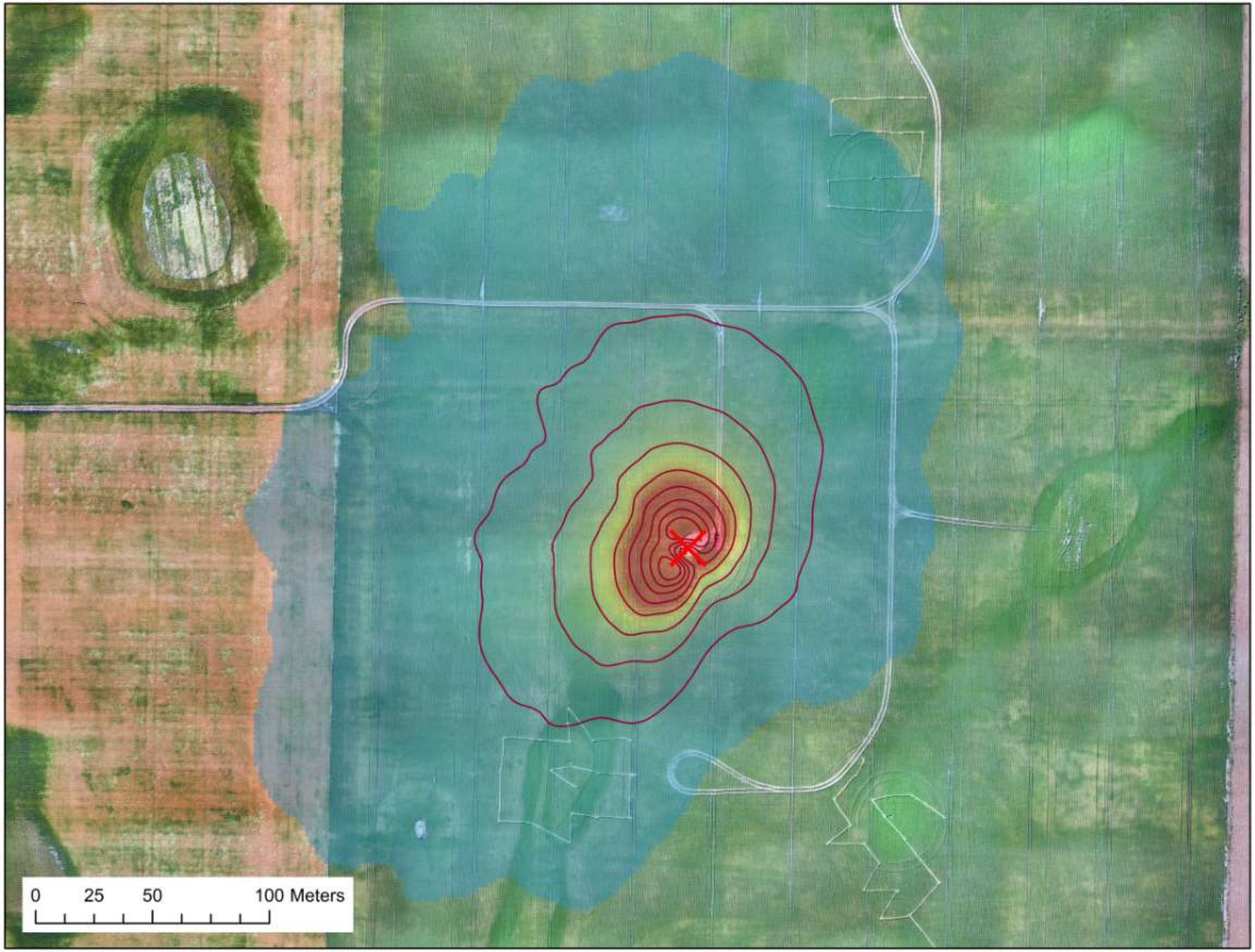
T=Transpiration

R=Runoff



Alqaisi and Shammari (2018)

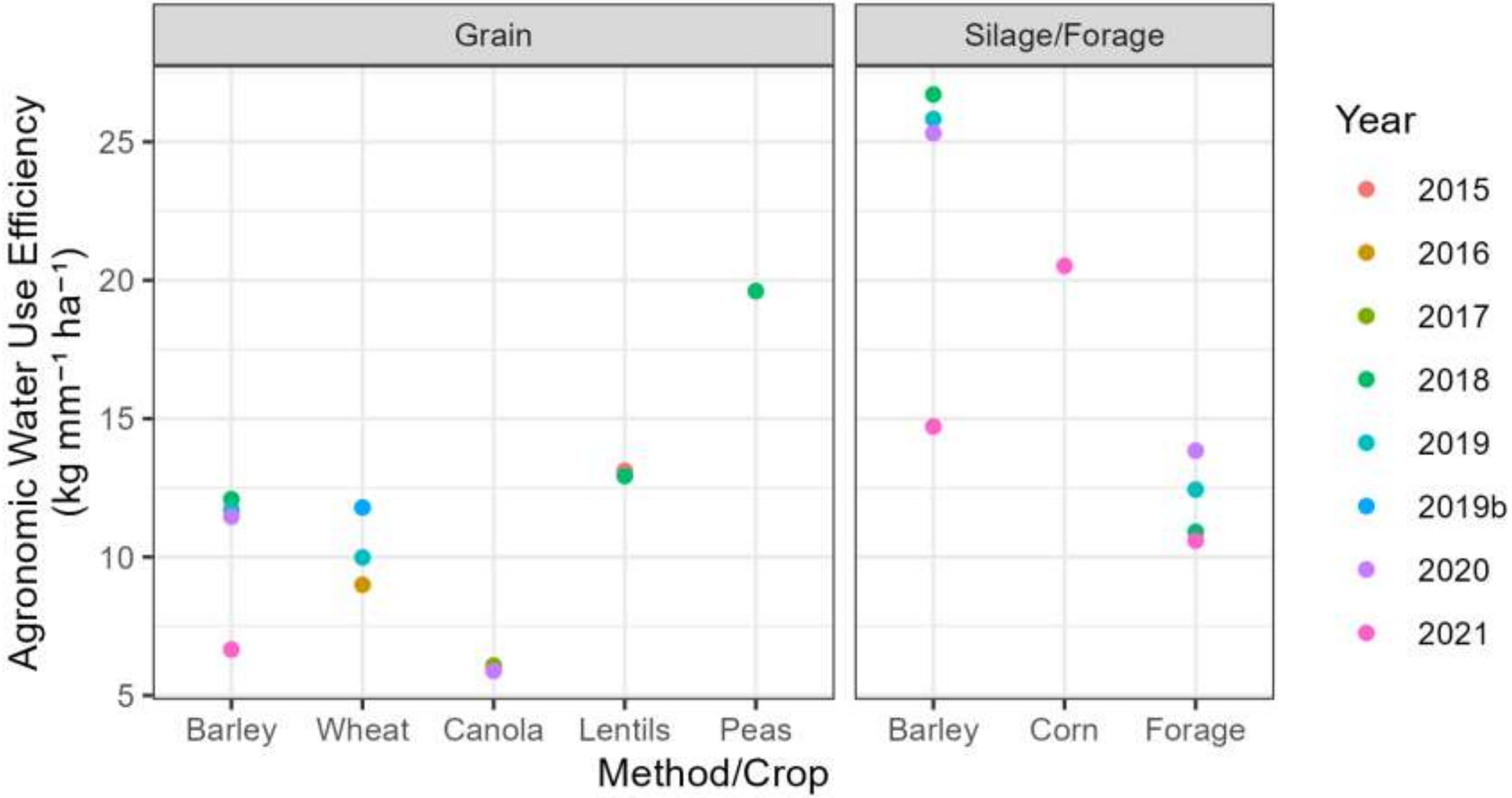
Direct Measurement


0
25
50
100 Meters

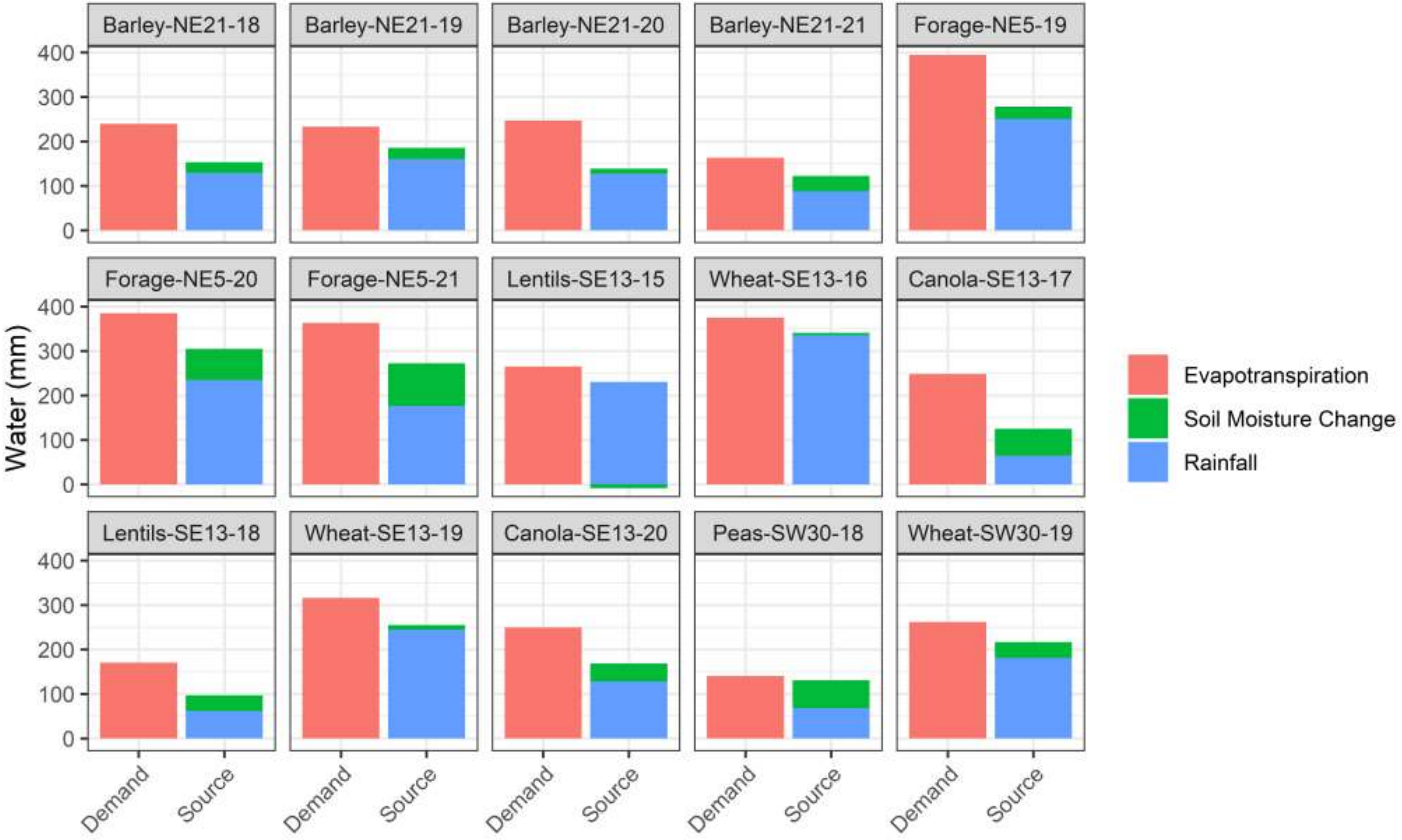
Crop Water Use Efficiency

$$WUE = \frac{Crop\ Yield(kg\ ha^{-1})}{Water\ Use\ (mm)}$$

- WUE is dynamic:
  - Increases with water demand/stress
  - Until heat stress damage and then WUE plummets



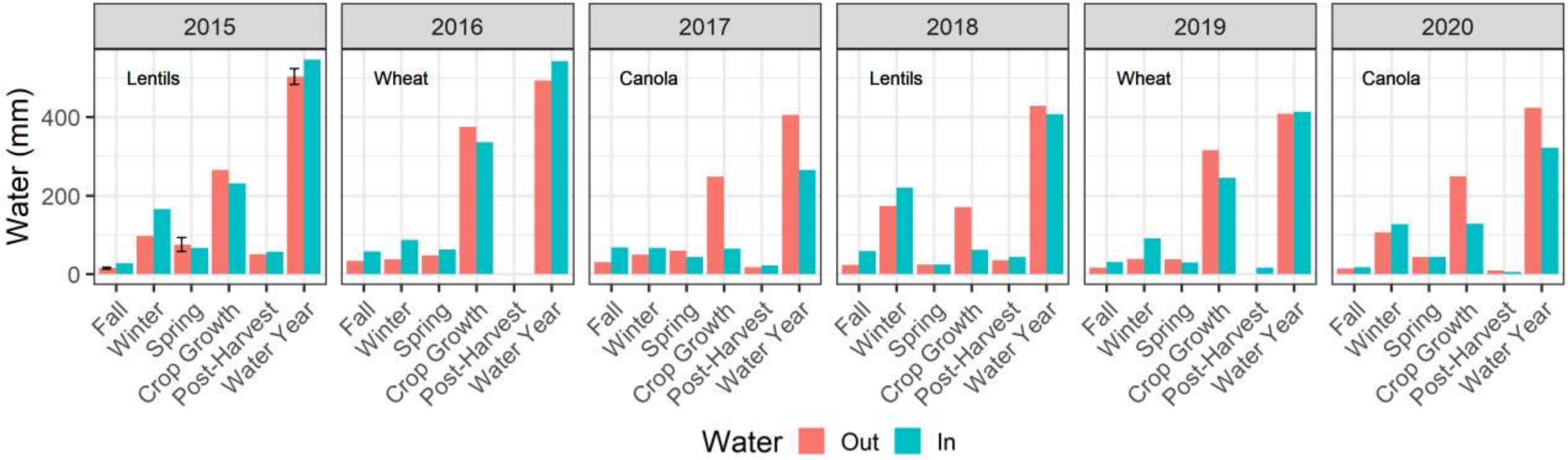
Growing Season Water Balance



Water Balance Averages:

- 60% from rainfall
- 13% from soil moisture*
- 27% unaccounted*

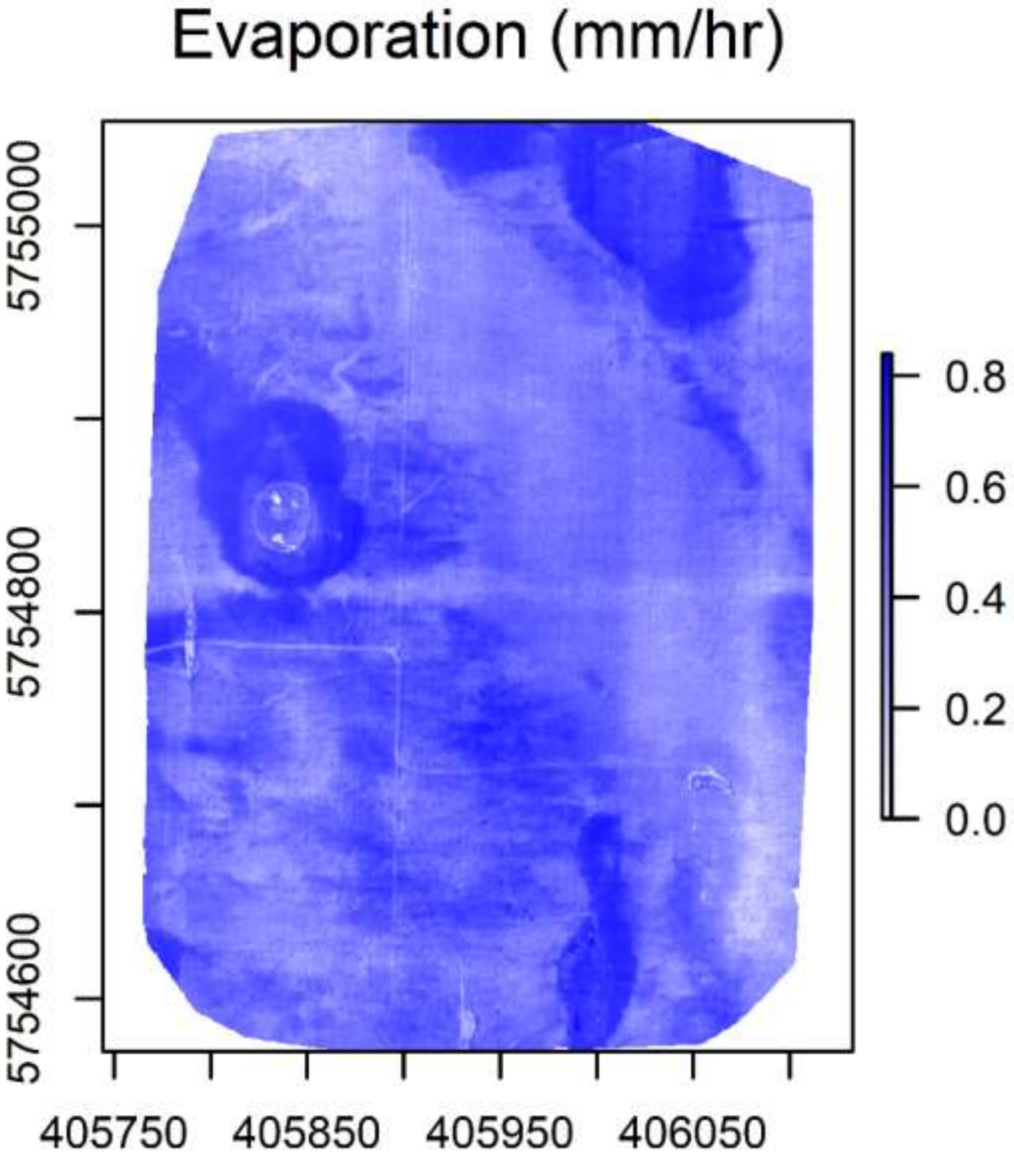
Seasonal Water Balance



- Observations near Kenaston, SK
- Multi-year soil moisture legacies are important
- Summer precipitation deficit on average 104mm
- Winter processes most consistent water input (50mm average)

Spatial Variability

- Depression focused hydrology drives spatial variability
- Variability in crop water use increases in drier conditions

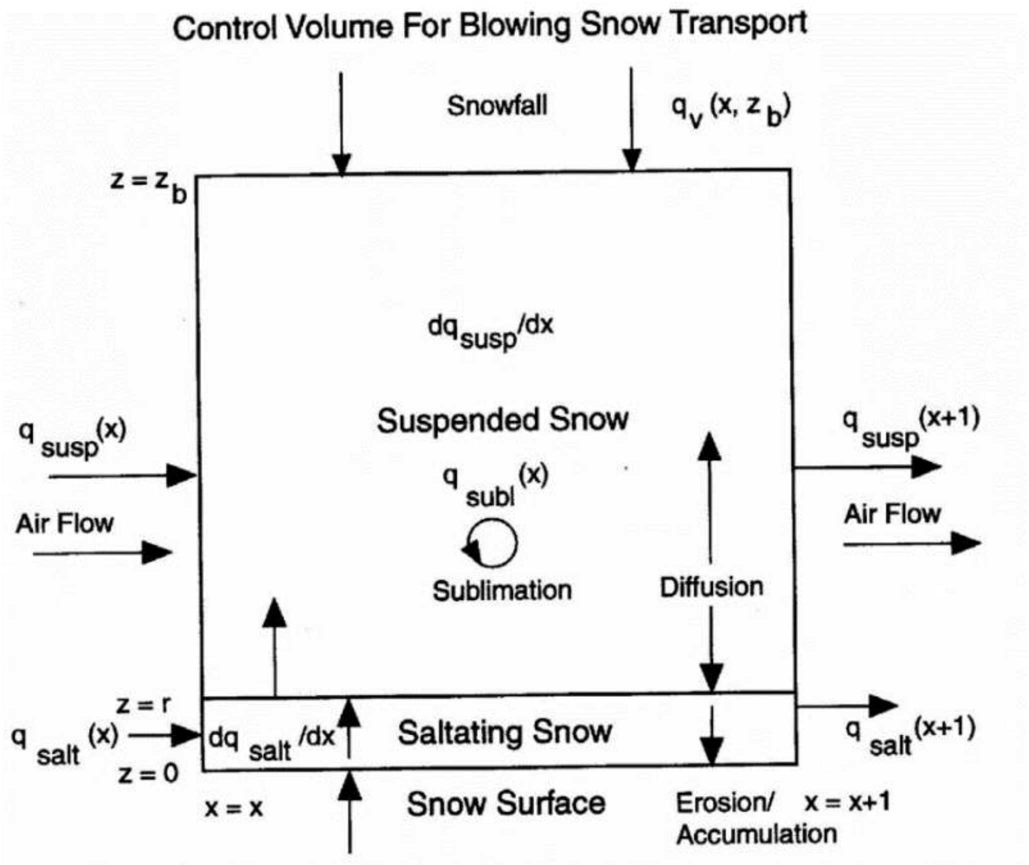


How does stubble and residue management influence crop available water?

Stubble-Snow Interactions

Blowing Snow Processes

- Creep: movement of snow particles by rolling on the snow surface
- Saltation: the bouncing of snow particles along the snow surface
- Suspension: snow particles entrained in the airflow above the surface
- Sublimation: suspended snow particles sublimate in the turbulent unsaturated airflow



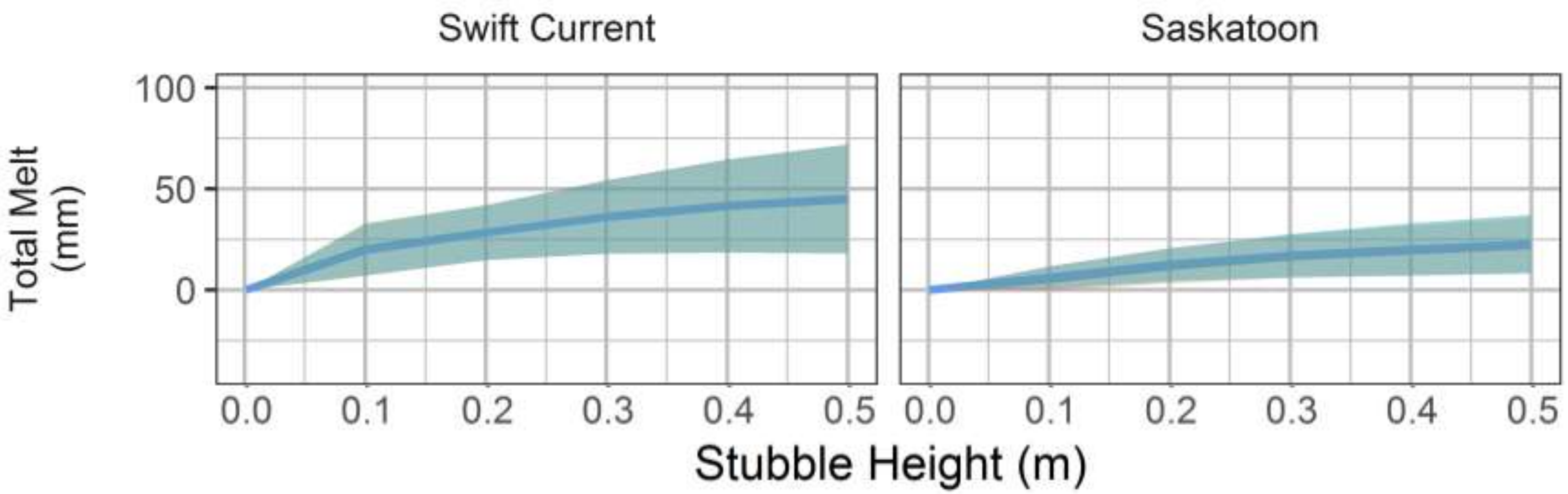
45 cm Wheat Stubble

15 cm Wheat Stubble

Blowing Snow

Snow Management with Stubble

- Increasing surface roughness suppresses blowing snow



- Influence varies with local climate

Site (Winter Temperature and Wind Speed)	Land Cover	Snowfall (mm)	Transport (%)	Sublimation (%)	Accumulation (%)
Prince Albert (−11.6 °C, 4.5 m/s)	Fallow	103	13	27	60
	Stubble	103	9	23	68
Yorkton (−10.6 °C, 4.7 m/s)	Fallow	125	13	23	64
	Stubble	125	8	15	77
Regina (−8.9 °C, 6.0 m/s)	Fallow	113	36	41	23
	Stubble	113	19	34	48
Swift Current (−6.7 °C, 6.6 m/s)	Fallow	132	29	29	42
	Stubble	132	11	22	67

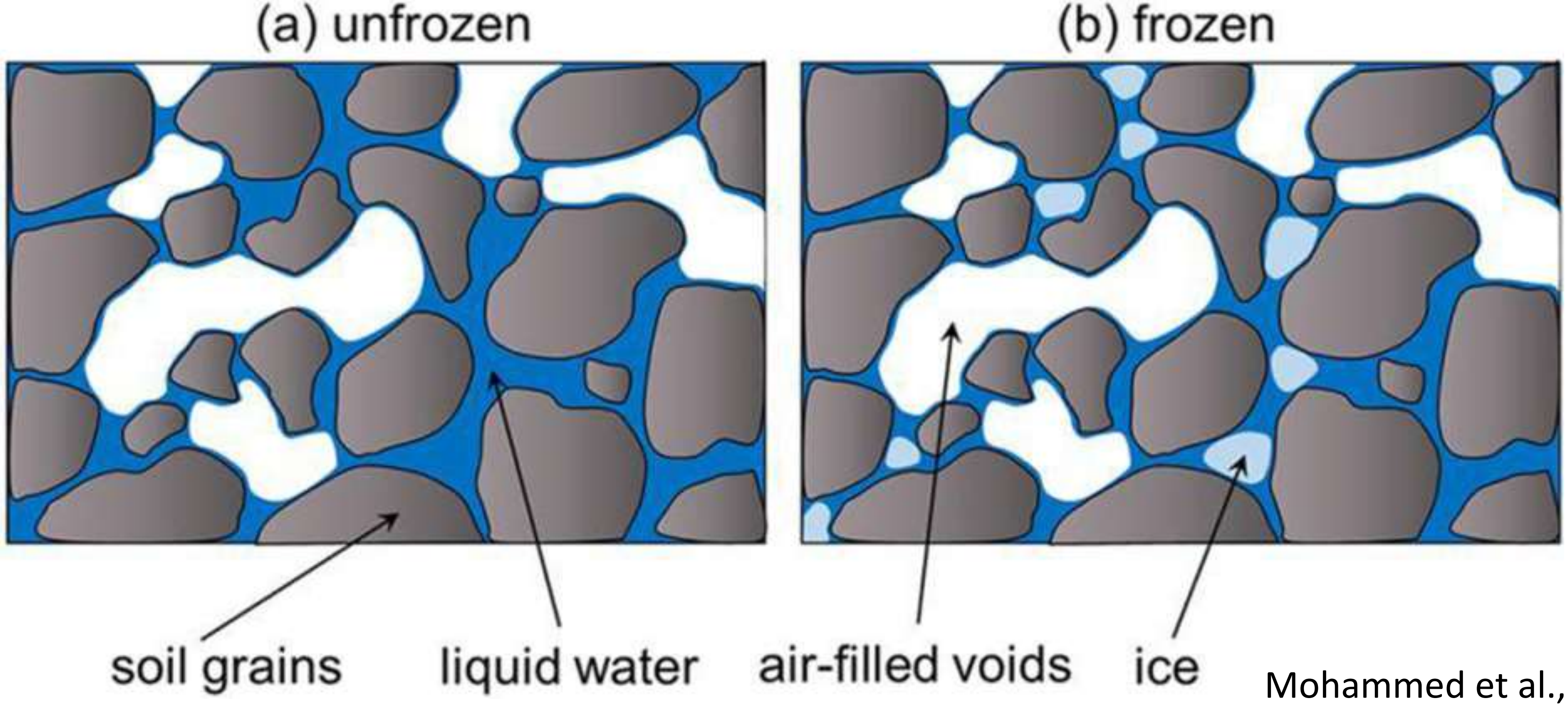
Pomeroy and Gray, 1993

Measuring Snow

- Snow surveying most reliable/simplest way to quantify water equivalent
- Best Practices:
  - >100m transect
  - Regular depth observations every 3 paces (at least 50)
  - Density sample every 5-10 depths
- Snow Survey Spreadsheet

Frozen Soil Infiltration

- Ice crystals complicate water movement through soils
- Average storage potential is 60% of air-filled pore space at start of infiltration



Mohammed et al., 2018

Frozen Soil conditions

1. Unlimited (predominately gravity flow): soils are capable of infiltrating most or all available meltwater.
   - Dry, cracked, coarse, or permeable soils
2. Restricted
   - soils whose infiltrability is restricted by an impervious surface such as a basal ice lens or saturated soil ("concrete frost")
3. Limited (predominately capillary flow):
   - soil infiltrability is governed primarily by the **soil moisture content** and **soil temperature** at the start of snow ablation and the **infiltration opportunity time**.

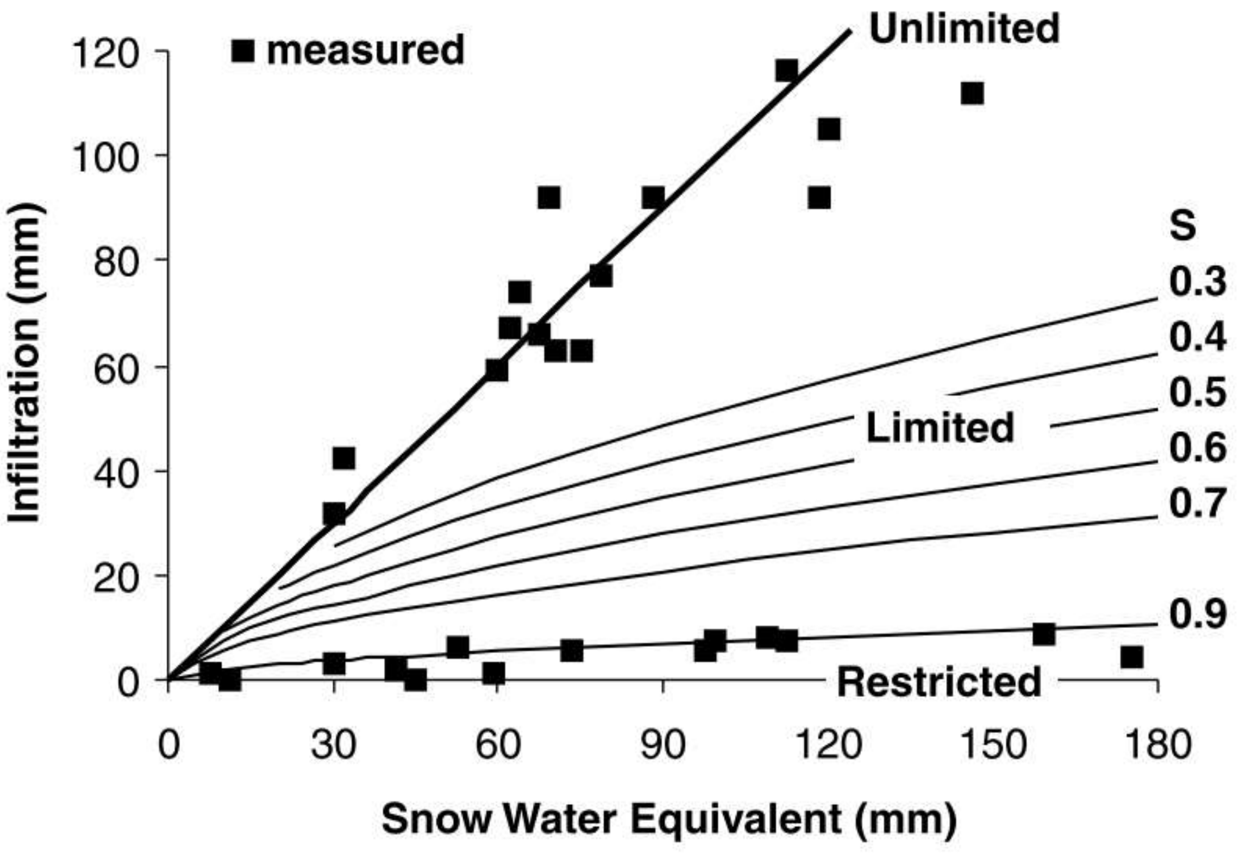


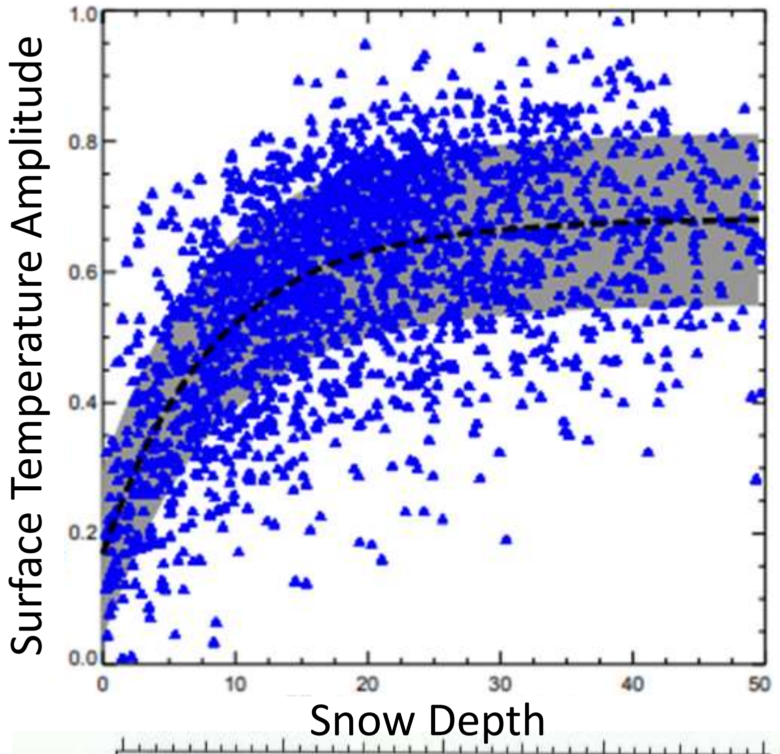
Figure 1. Infiltration versus snow water equivalent for *Unlimited*, *Limited* and *Restricted* frozen soils

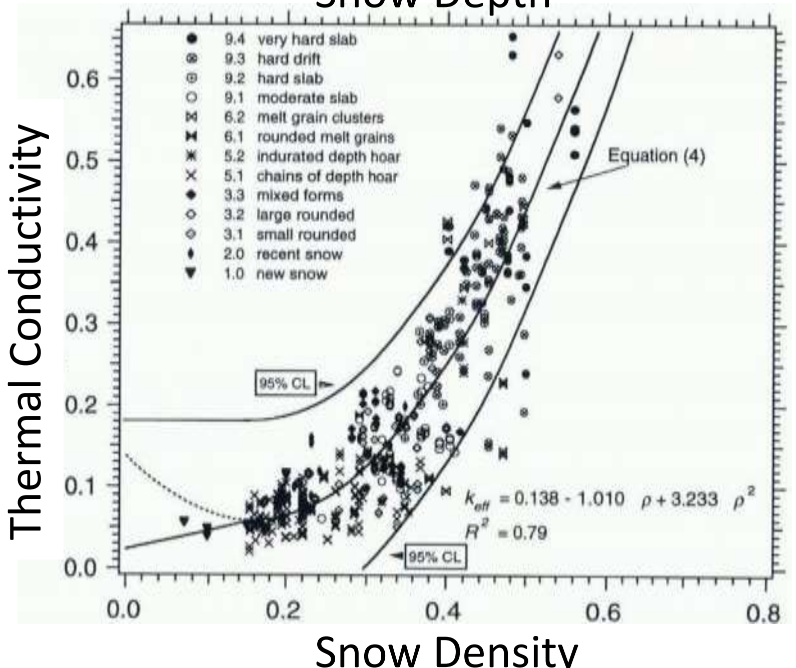
Gray et al., 2001

Snow-Stubble-Residue…

Snow-Stubble-Residue-Thermal Interactions

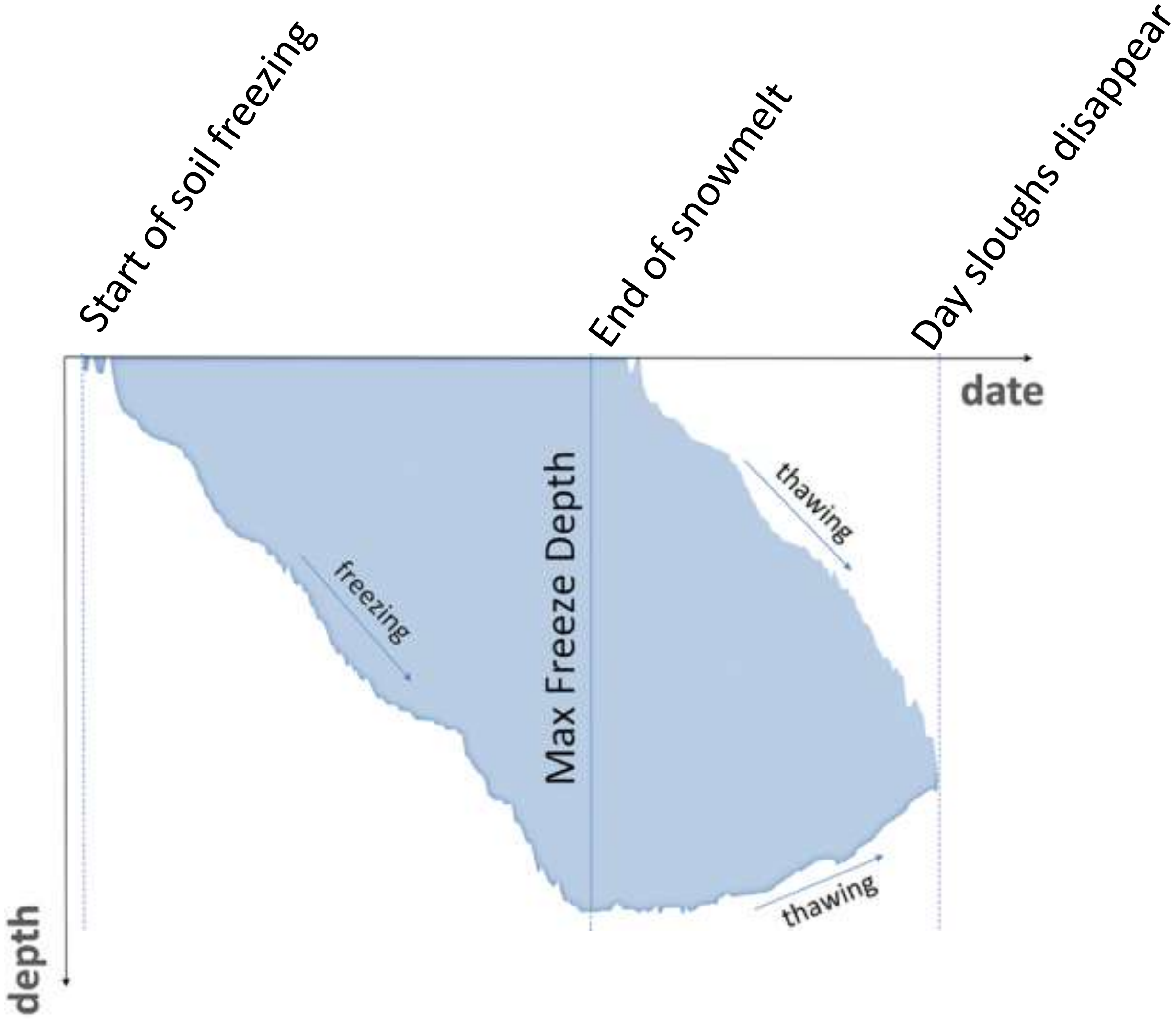
- Snow is a highly effective insulator
- Deeper snow = greater insulation
- Denser snow = higher thermal conductivity
- Crop residues have low thermal conductivity
    - Disrupt temperature gradient





Soil Frost Dynamics

- Soil frost dynamics sensitive to surface and subsurface energy exchange
  - ↑stubble height =↑snow depth and ↓ snow density = ↓soil freezing
  - ↑crop residues ↓ energy exchange = ↓soil freezing
- Shallower the freezing the earlier the thaw



Chen et al (2022)

Snow-Stubble-Thermal-Infiltration Net Feedbacks

- SHAW modelling:
  - Minneapolis, 30 year average
  - No difference in snow
- Feedbacks can be contradictory
- Bare soil is slowest to warm
  - Deepest freezing
- Stubble/residues reduce soil evaporation by 20%

Surface	Stubble Height (cm)	Residue Depth (cm)	Frost Depth (cm)	Day of year with 5cm soil >5 °C	Annual Evaporation (mm)
Bare Soil	0	0	86	April 20	518
Standing Wheat	23	0.3	79	April 13	393
Flat Wheat Residue	0	2.5	80	April 19	333

Flerchinger et al., 2003

Tillage and infiltration

- In general tillage ↑runoff and ↓ infiltration rates
  - can ↑ infiltration in short term and for small inputs
- Reduces available water when water limited
- Increases runoff when water excess

- Tillage Feedbacks:
  - Limits water holding capacity of surface
  - Formation of surface crust
  - Disrupts hydraulic connectivity
  - Development of hydrophobicity in extreme dry/hot conditions

Table 1. Textural groupings and associated physical characteristics

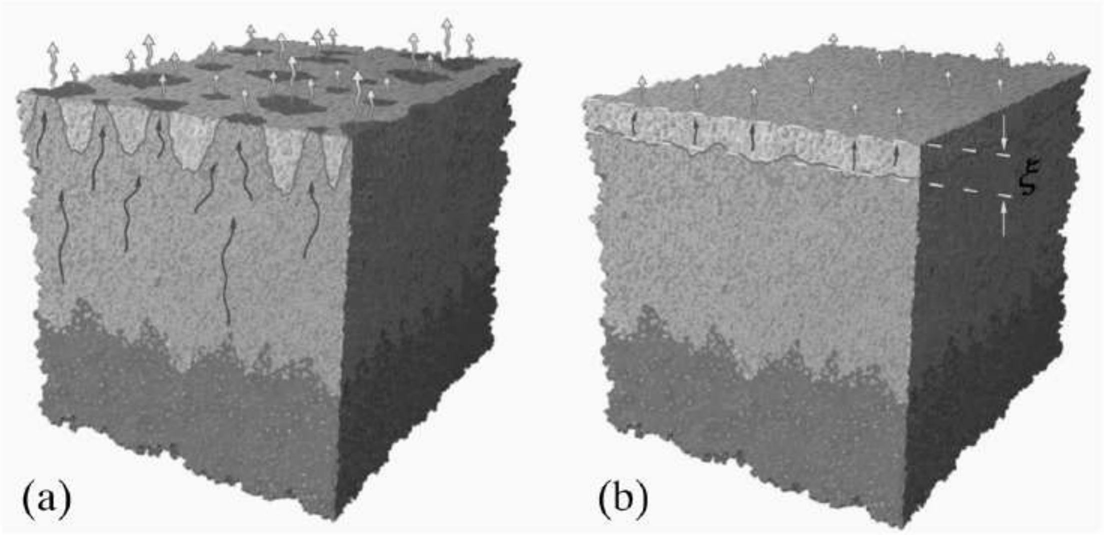
Texture Grouping	Texture classes	Hydraulic conductivity (cm h^{-1})[z]	Infiltration rate (cm h^{-1})[y] by ground cover class: Bare Soil	Row Crop	Poor Pasture	Small Grain	Good Pasture	Forest
Coarse	Sand, loamy sand	5 to 20	0.8	1.3	1.5	1.8	2.5	7.6
Moderately coarse	Sandy loam, fine sandy loam	2 to 5	0.5	0.9	1.1	1.4	1.9	4.0
Medium	Very fine sandy loam, loam, silt loam	0.5 to 1.5	0.3	0.5	0.8	1.0	1.3	1.5
Moderately fine	Sandy clay loam, clay loam,silty clay loam	0.15 to 0.5	0.2	0.3	0.5	0.7	0.9	1.0
Fine	Sandy clay,clay, silty clay, heavy clay	0.01 to 0.15	0.1	0.2	0.3	0.4	0.5	0.6

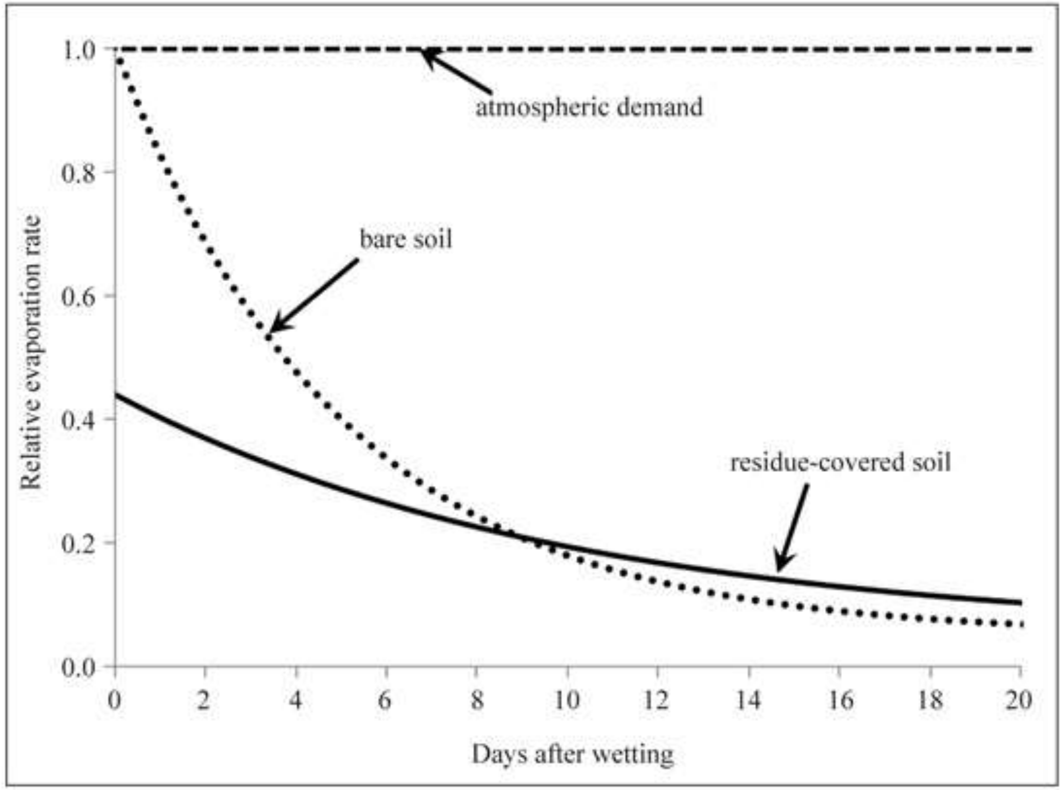
[z]Compiled from: Ahuja et al. (1999), Bennett et al. (1983), and Radcliffe and Rasmussen (2000).
[y]Infiltration rate for unfrozen soil after upper soil has reached saturation [adapted from Gray et al. (1970)].

Bedard-Haughn 2009

Crop residues and soil evaporation

- Residues reduce soil evaporation between 10-65%
  - 5% ↓in E for every 10% ↑cover
  - reduce energy at soil surface
  - disrupt the water vapor gradient between soil and atmosphere
- Tillage increases soil evaporation by mechanically moving moisture to surface
  - Dependent on soil moisture
  - US studies report 8-15mm/pass
  - Can reduce subsequent infiltration/redistribution as dry soils have low conductivity



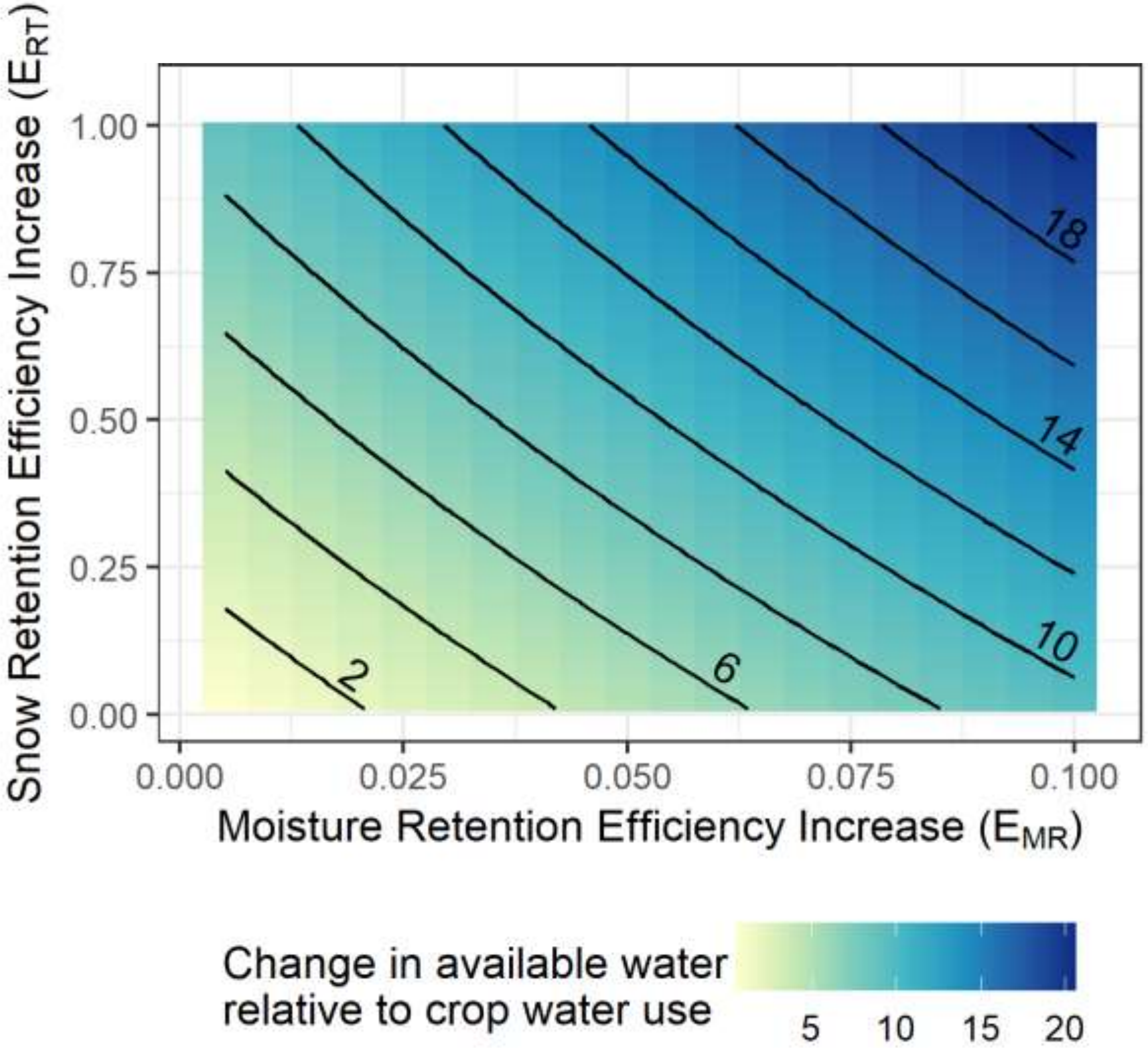


How much can we manipulate crop available soil water with stubble and residue management?

For 15 years of water balance observations

- Increase snow retention efficiency from observed 60% to 100%
- Increase soil moisture retention by 10%

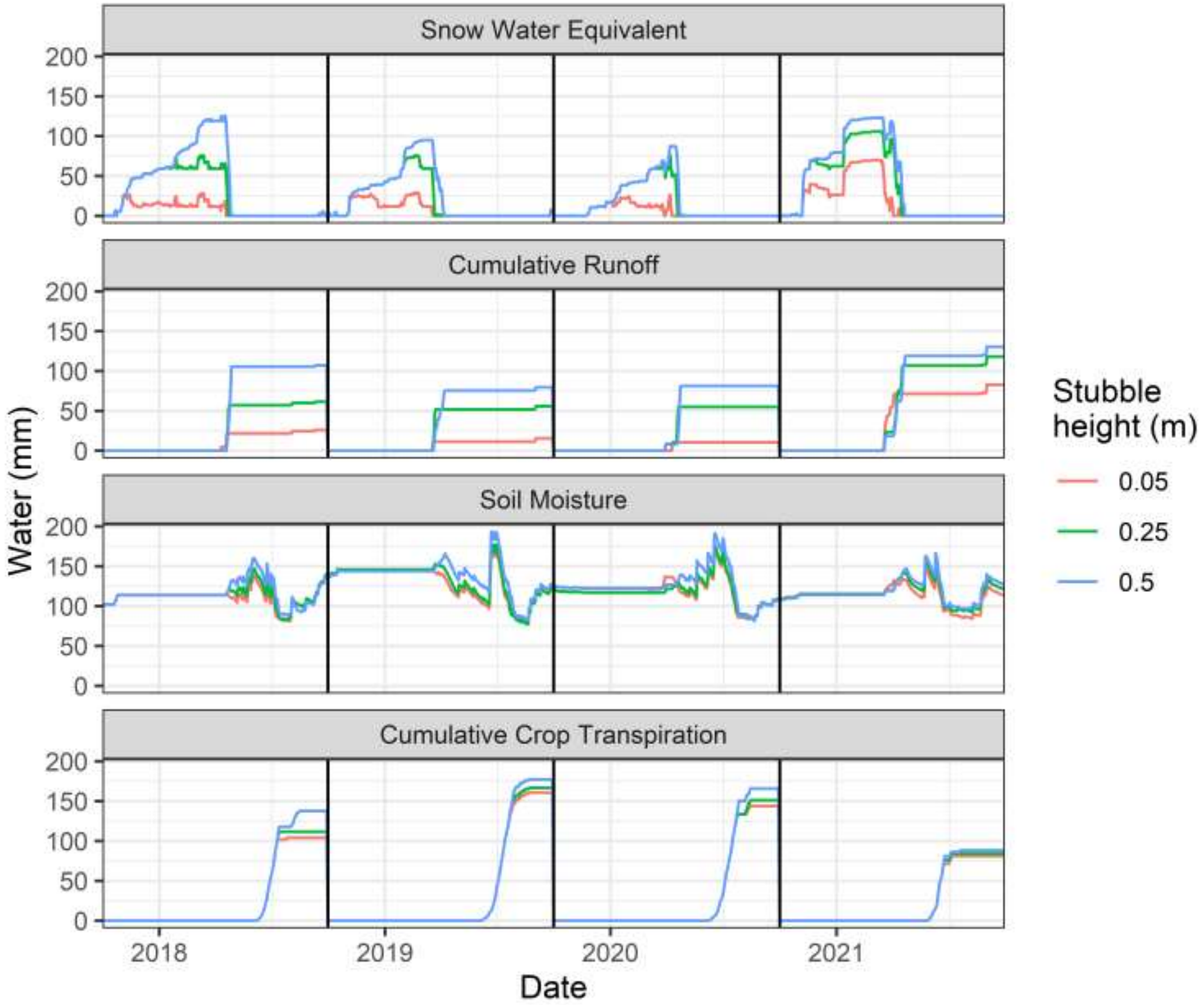
Up to 20% increase in growing season water availability



Implications: Modelling stubble height-crop growth interaction

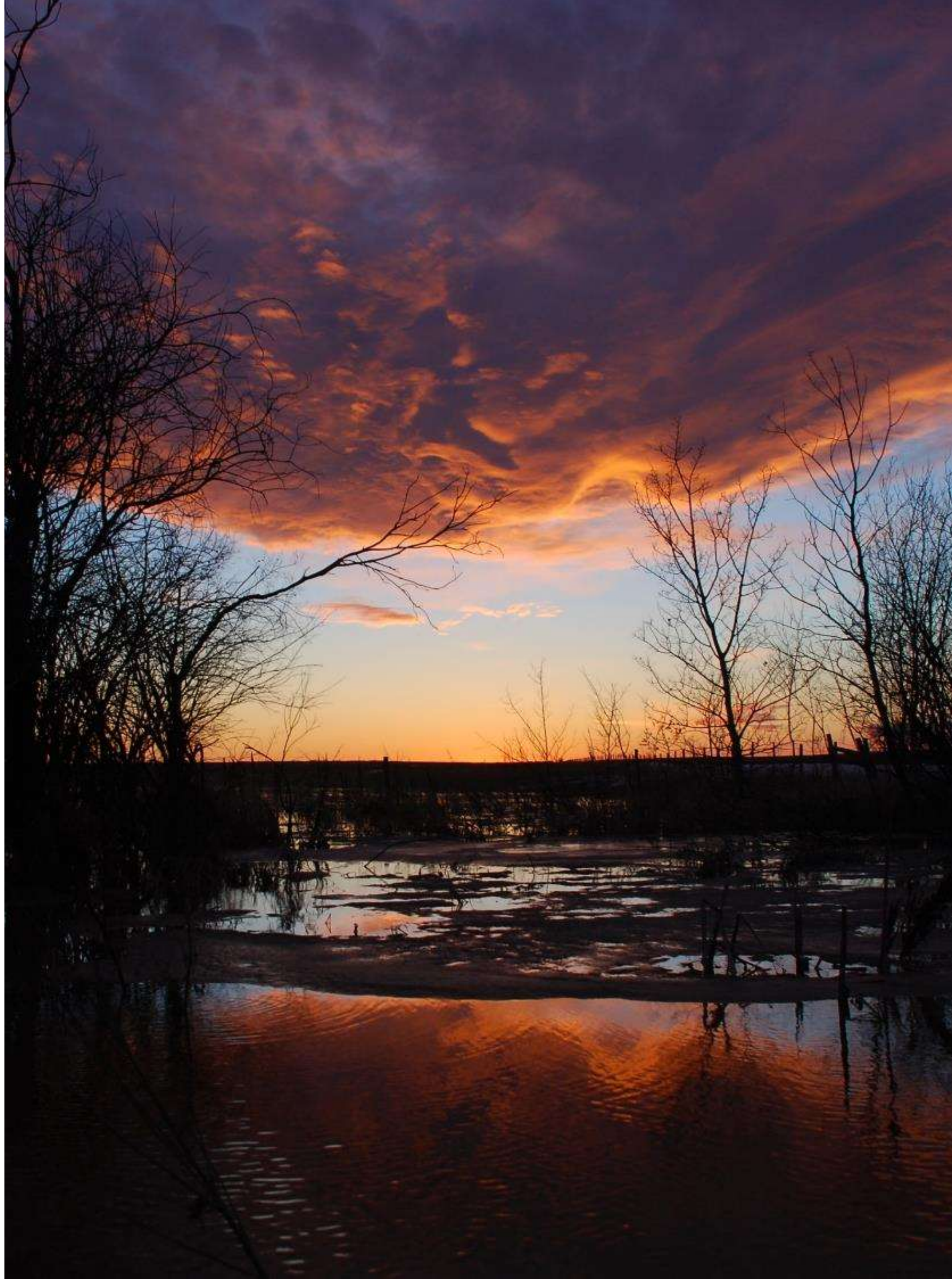
- Barley
- 5, 25 and 50 cm stubble height

- Yield increase:
    - 3-6% for 5->25cm
    - 10-32% for 5->50cm



Summary

- Crop water use in Canadian Prairie dryland ag depends on year round hydrology
- Typically water limited so water conservation needs to be an ongoing objective
- Complex snow-soil-energy-water interactions are needed to describe the impact of changing stubble and residue management
- Net impacts can be counter intuitive.
  - Bare soils can thaw slower
- ↑stubble height ↑ water input
- ↑residue cover ↑ water infiltration and retention
- Net impact is variable
  - 10-30% increase in crop water availability possible



Questions?

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