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Soil organic carbon: Nature, importance, management impacts and monitoring

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Summit on Canadian Soil Health: Healthy Soil – Healthy Planet

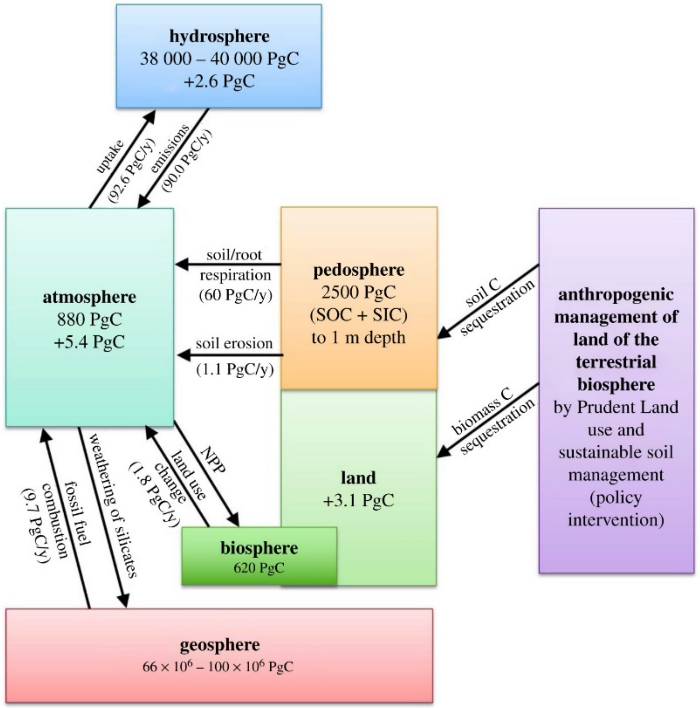
Soil Conservation Council of Canada

November 18, 2021

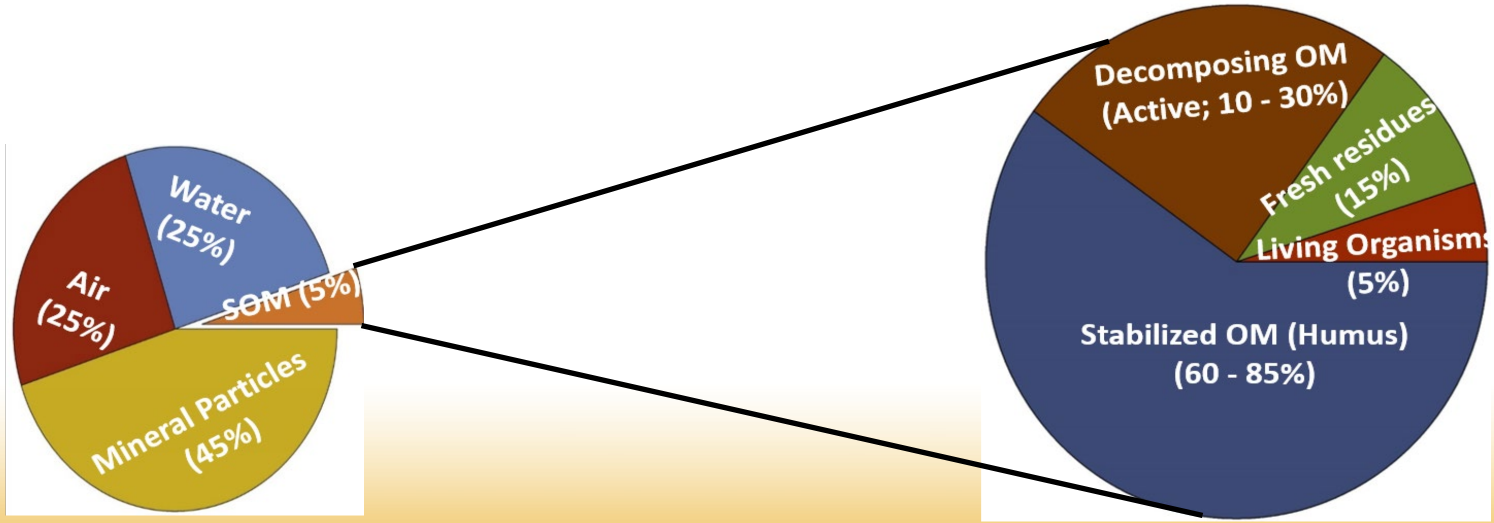
Canada

What is Soil Organic Carbon (SOC)?

- **SOC is carbon (C) derived from organic origins and is the major component of soil organic matter (SOM).**
- SOC heterogeneous in nature but importantly, **it is measurable**.
- Soils contain the 2nd largest C pool after oceans; SOC is the largest C stock in land-based ecosystems.
- SOM accounts for ≈5% of soil mass, but plays a critical role in influencing soil physical, chemical and biological functions.



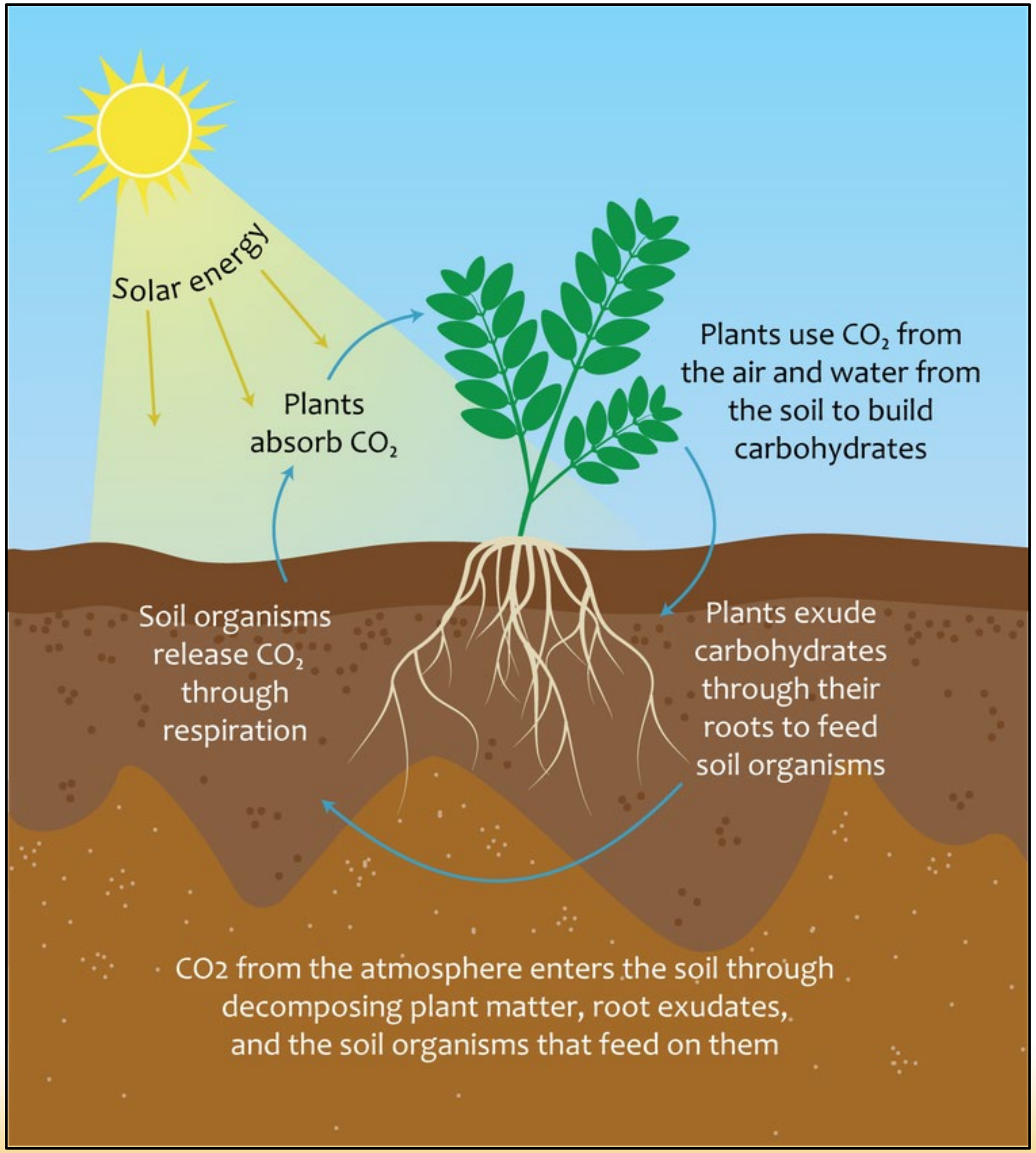
Lal et al. 2021



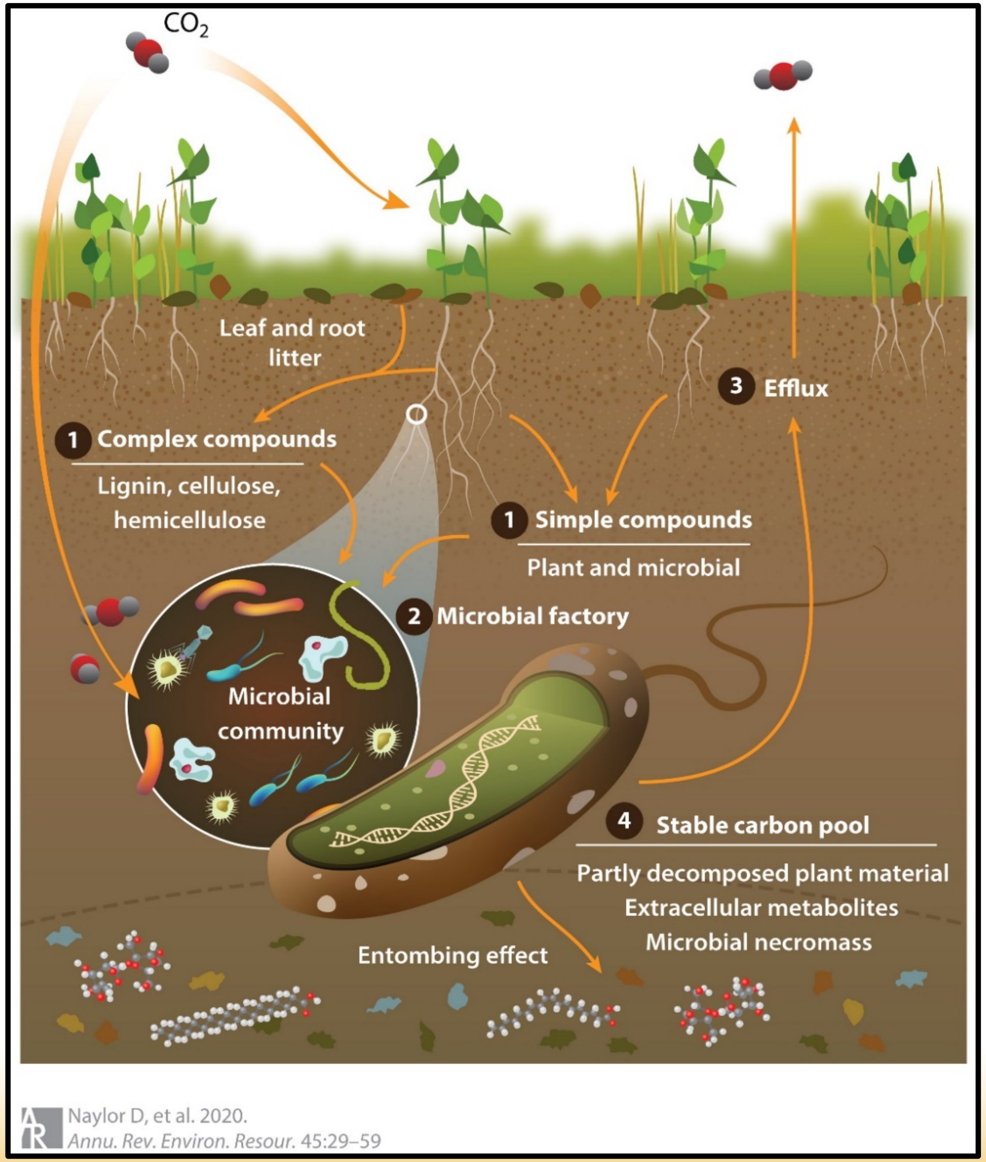
Stockmann et al. 2013

Formation of Soil Organic Carbon (SOC)

The amount of SOC is determined by the balance between C inputs (plants, manure, etc.) and outputs (losses through decomposition [C emissions] and harvested biomass.



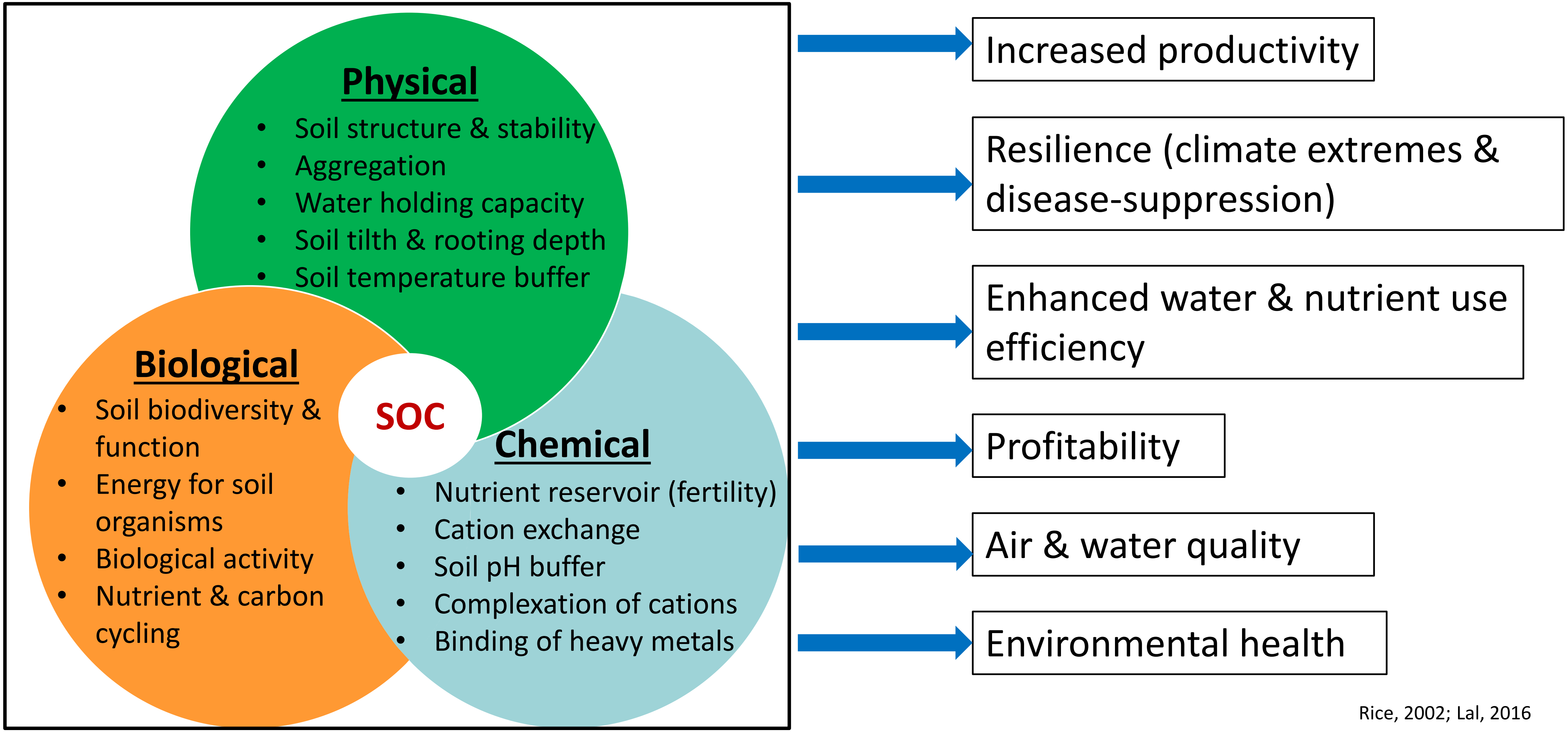
Source: Jocelyn Lavallee, CC BY-ND



Source: Naylor et al. 2020

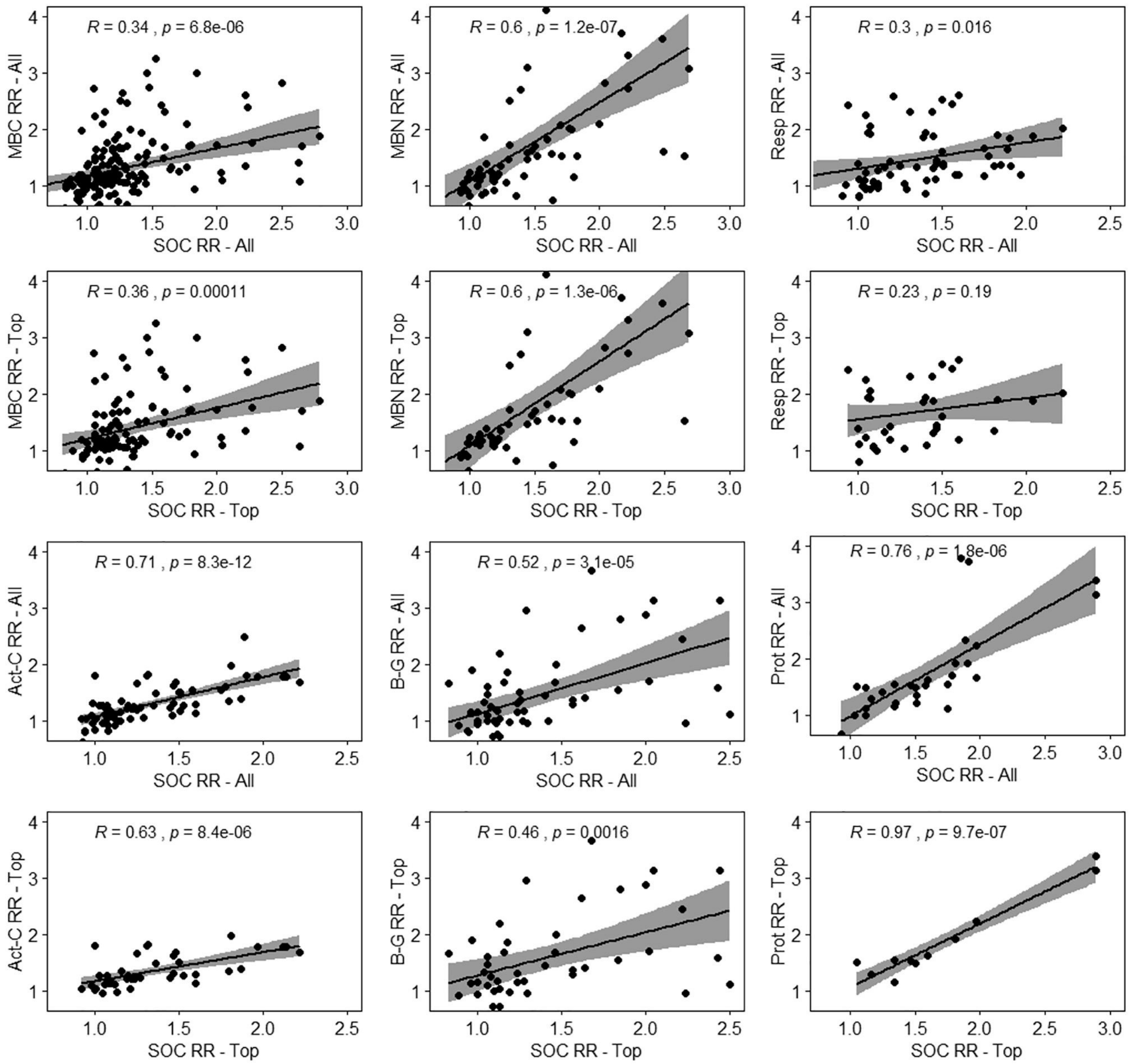
Soil Organic Carbon and Soil Health

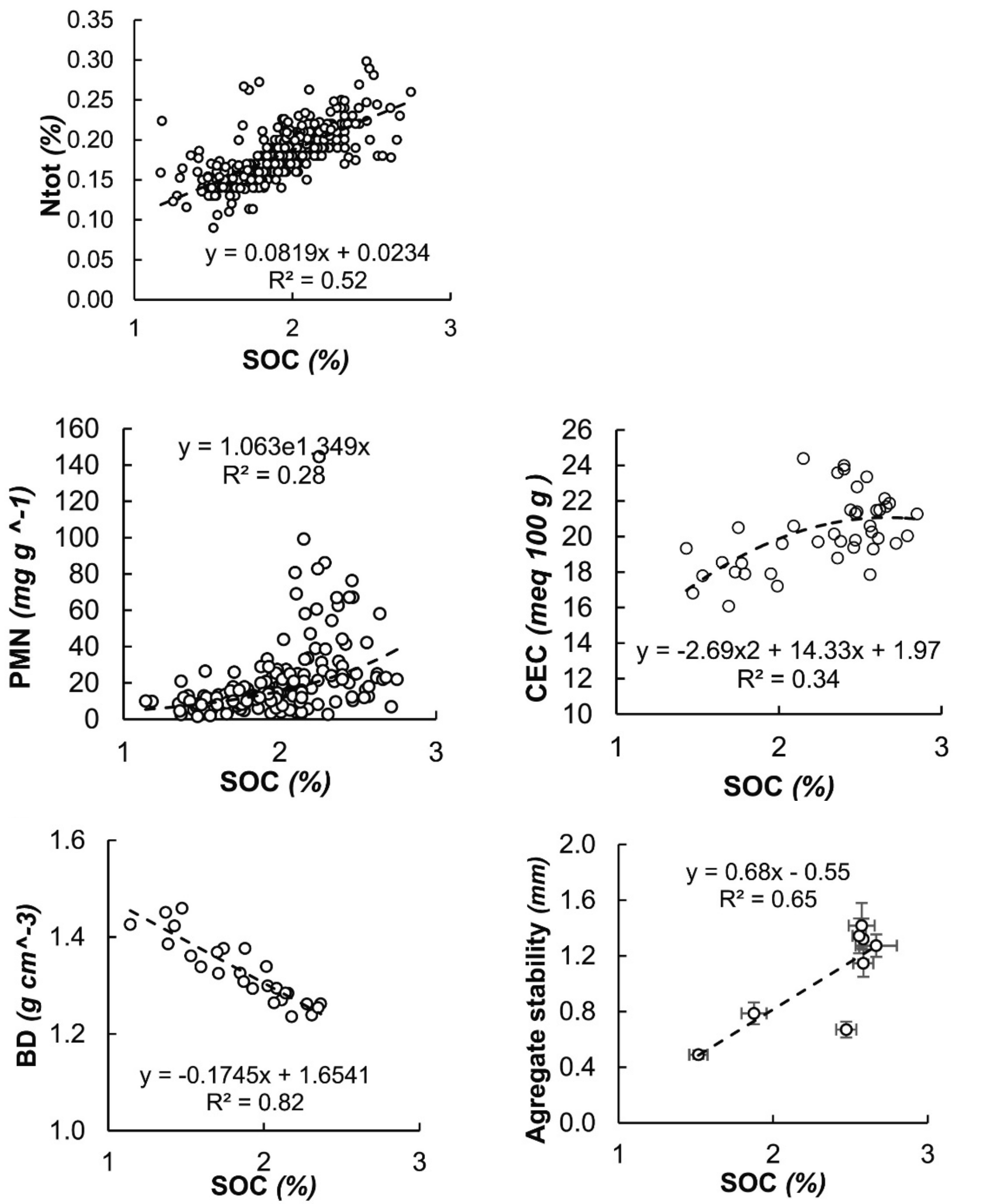
SOC affects soil physical, chemical and biological properties, and is therefore fundamental to soil health.



Rice, 2002; Lal, 2016

Soil Organic Carbon and Soil Health

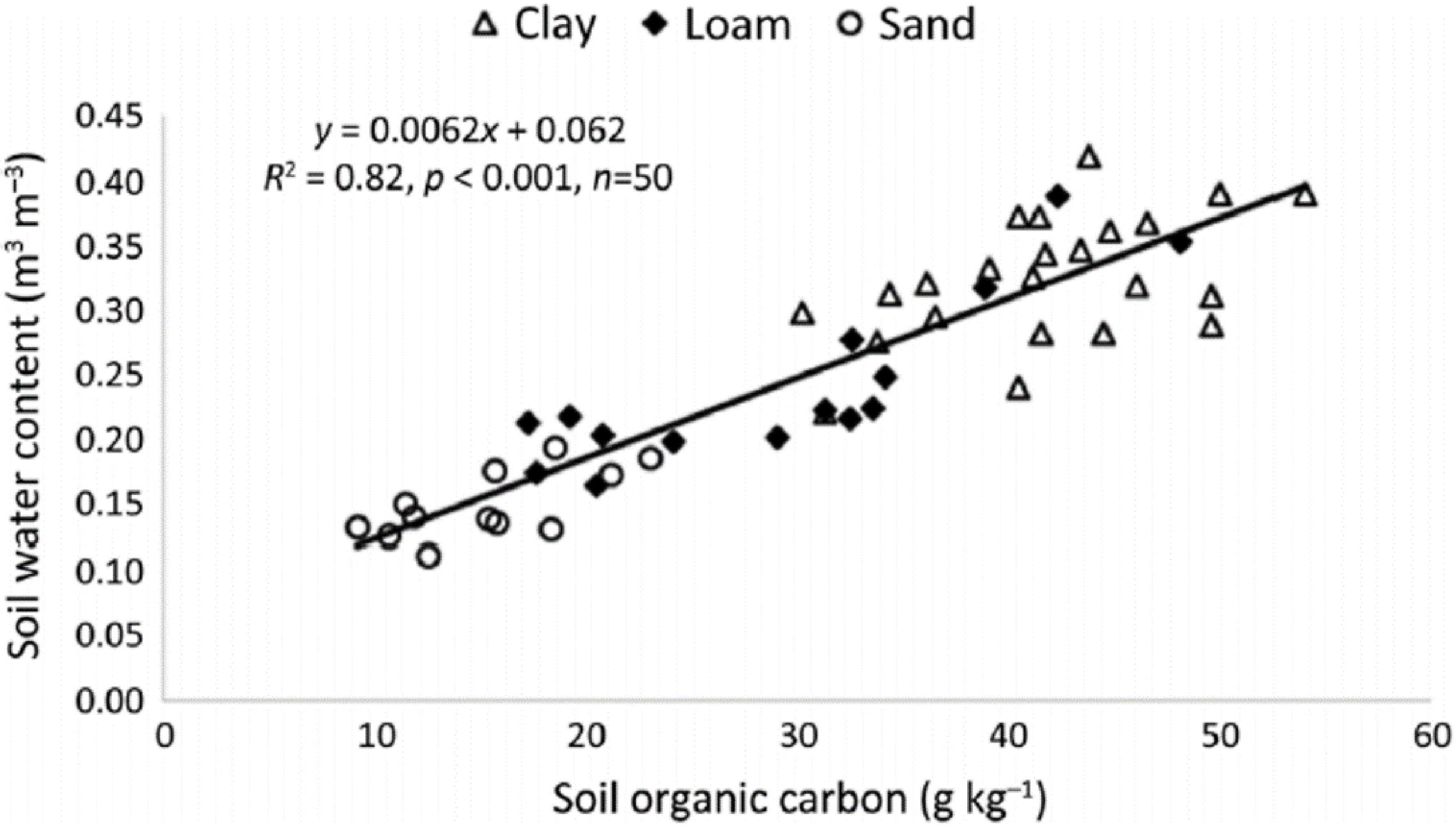




Source: Nunes et al. 2020

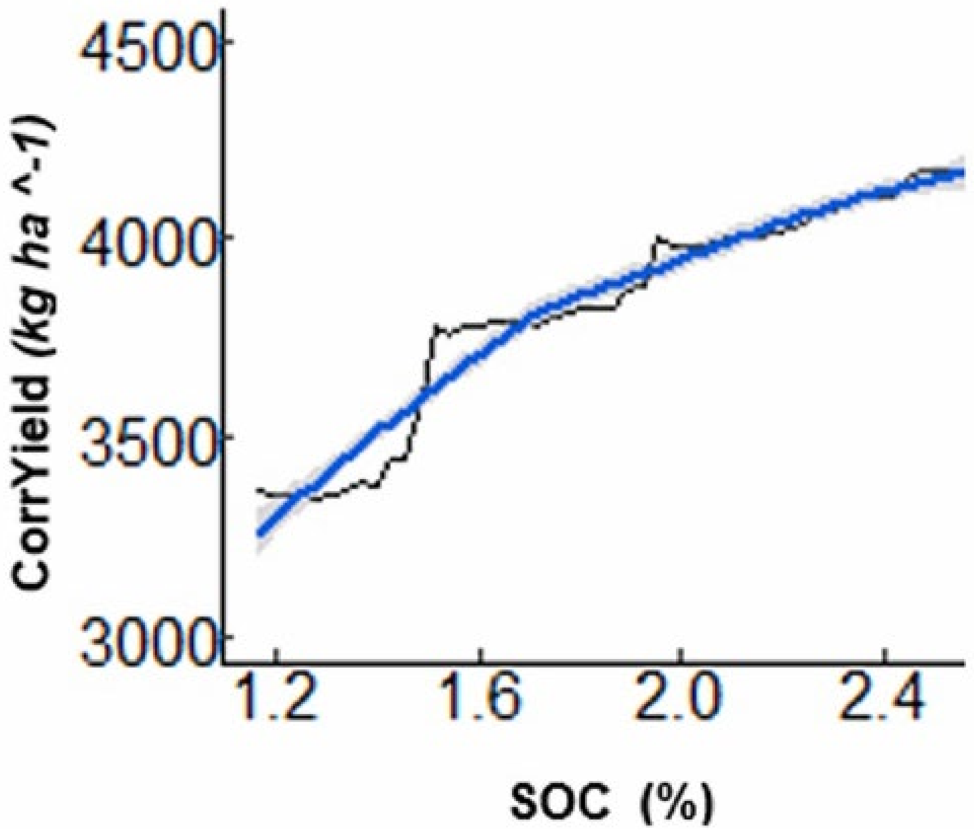
Source: Rubio et al. 2021

Soil Organic Carbon and Soil Water Content

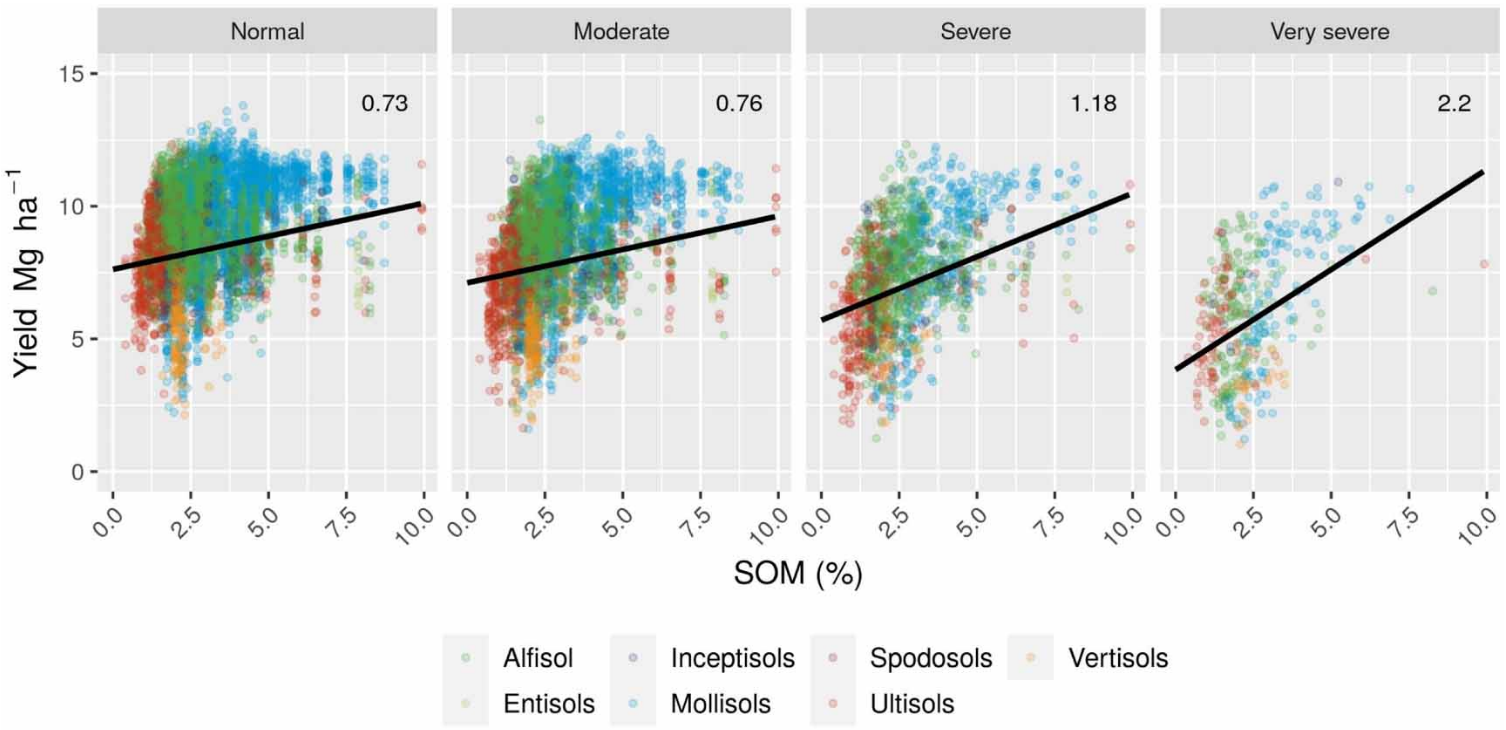


Source: Mann et al. 2016

Soil Organic Carbon and Crop Yield



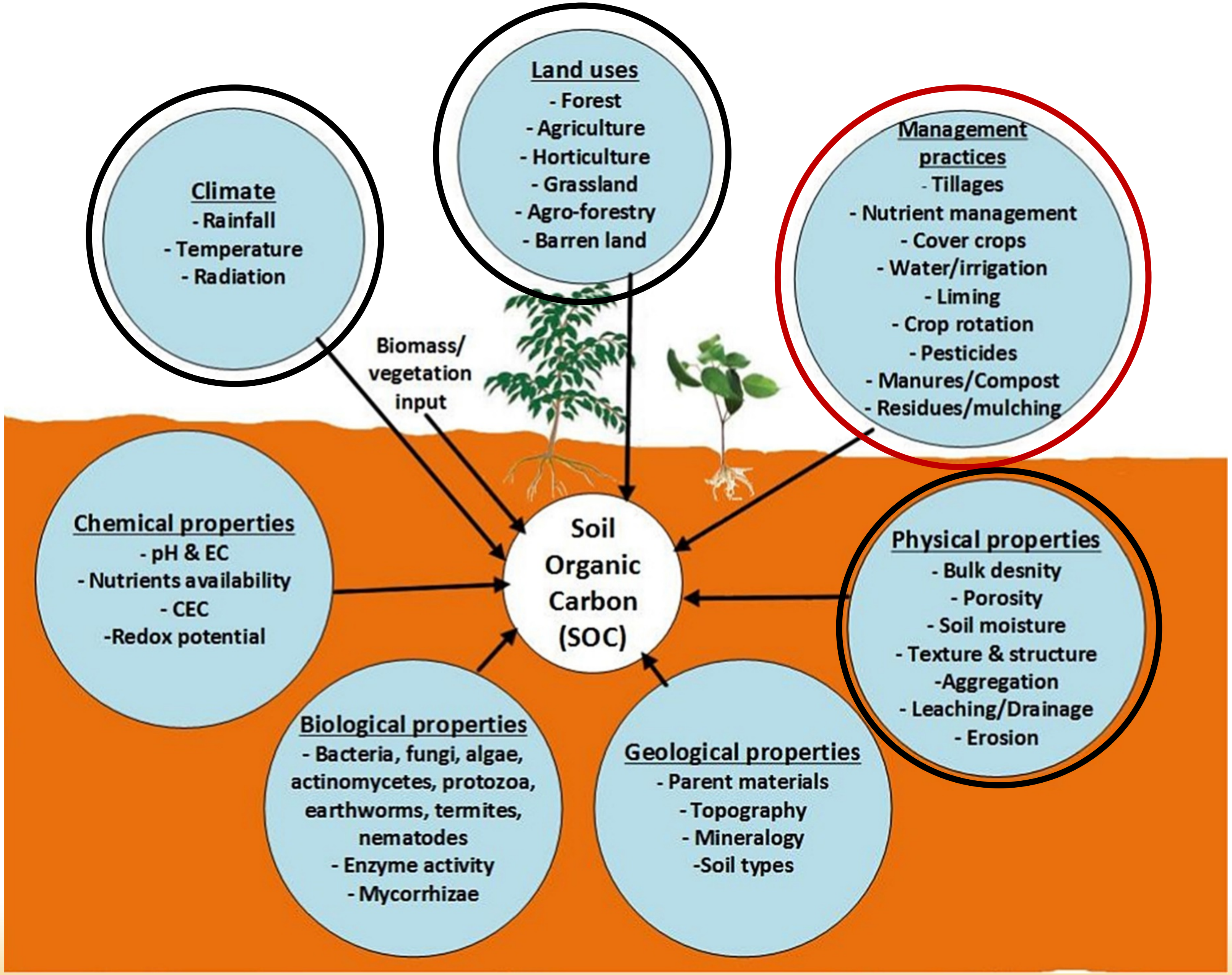
Source: Rubio et al. 2020



Source: Kane et al. 2021

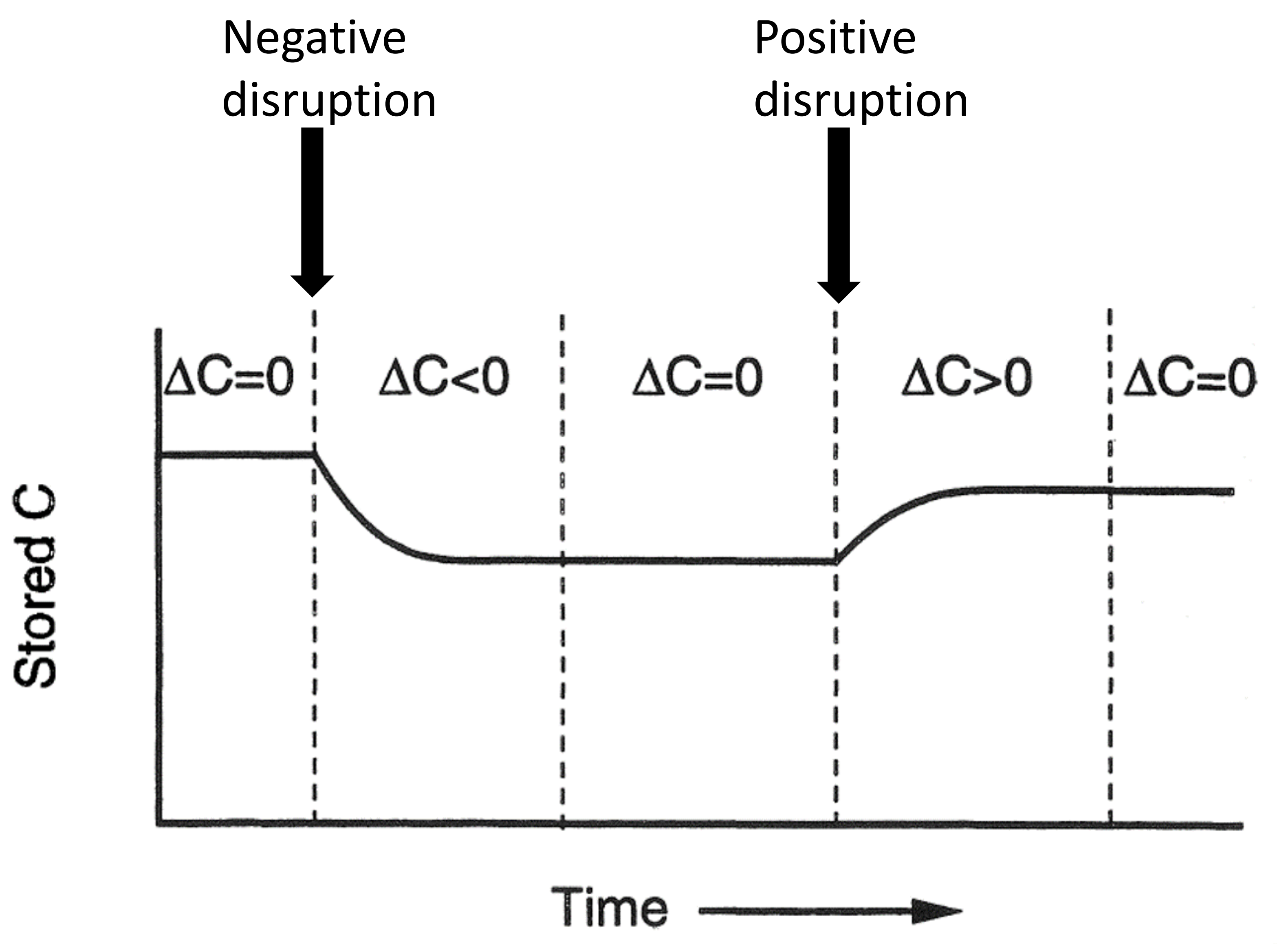
✓ Effect of SOC is more pronounced with increasing drought severity!

Factors that Influence the Formation of SOC



Source: Ramesh et al. 2019

How Does Management Affect SOC Change?



Examples of negative disruptions

- Tillage
- Summer-fallow
- Crop residue removal

Examples of positive disruptions

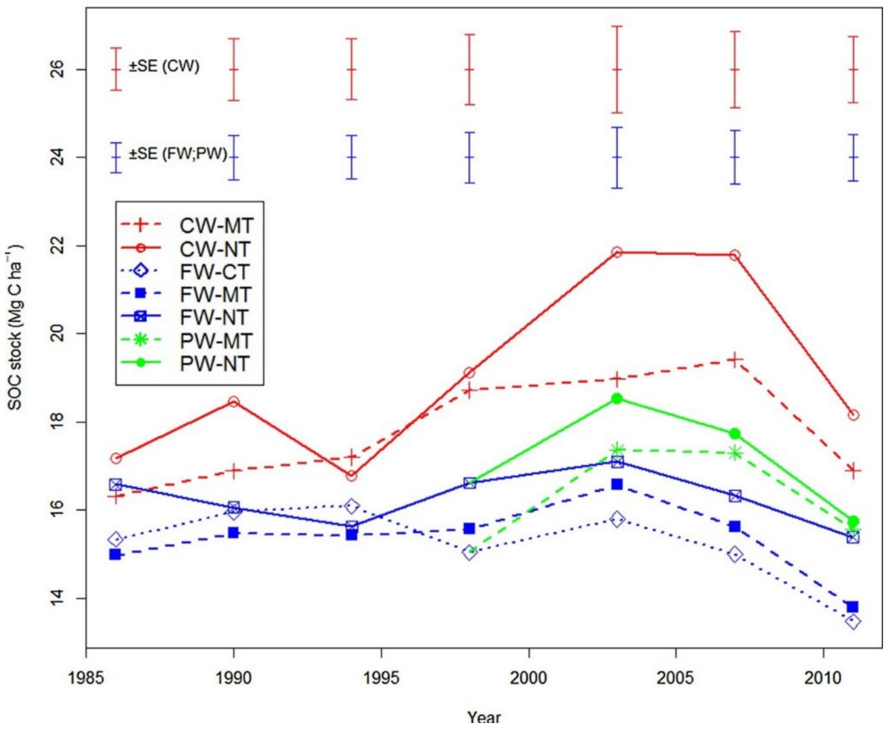
- Crop residue retention
- No-till & minimum tillage
- Continuous cropping
- Diverse rotations including pulses
- Adequate fertility
- Cover cropping
- Perennials/grasslands
- Deep-rooted crops
- Manure/compost additions

Modified from Janzen et al. 2018

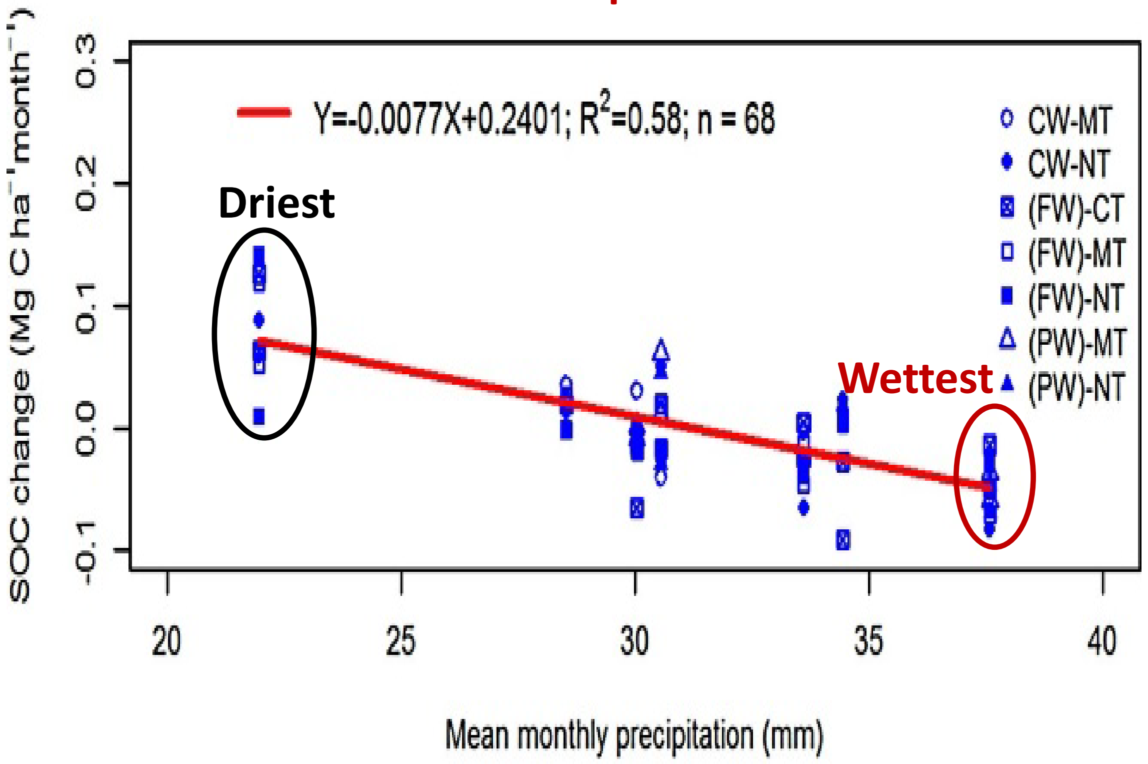
Tillage & Crop Rotation

Long-Term Experiment at AAFC-Swift Current under Semi-Arid Conditions

0-7.5 cm



Effect of Precipitation

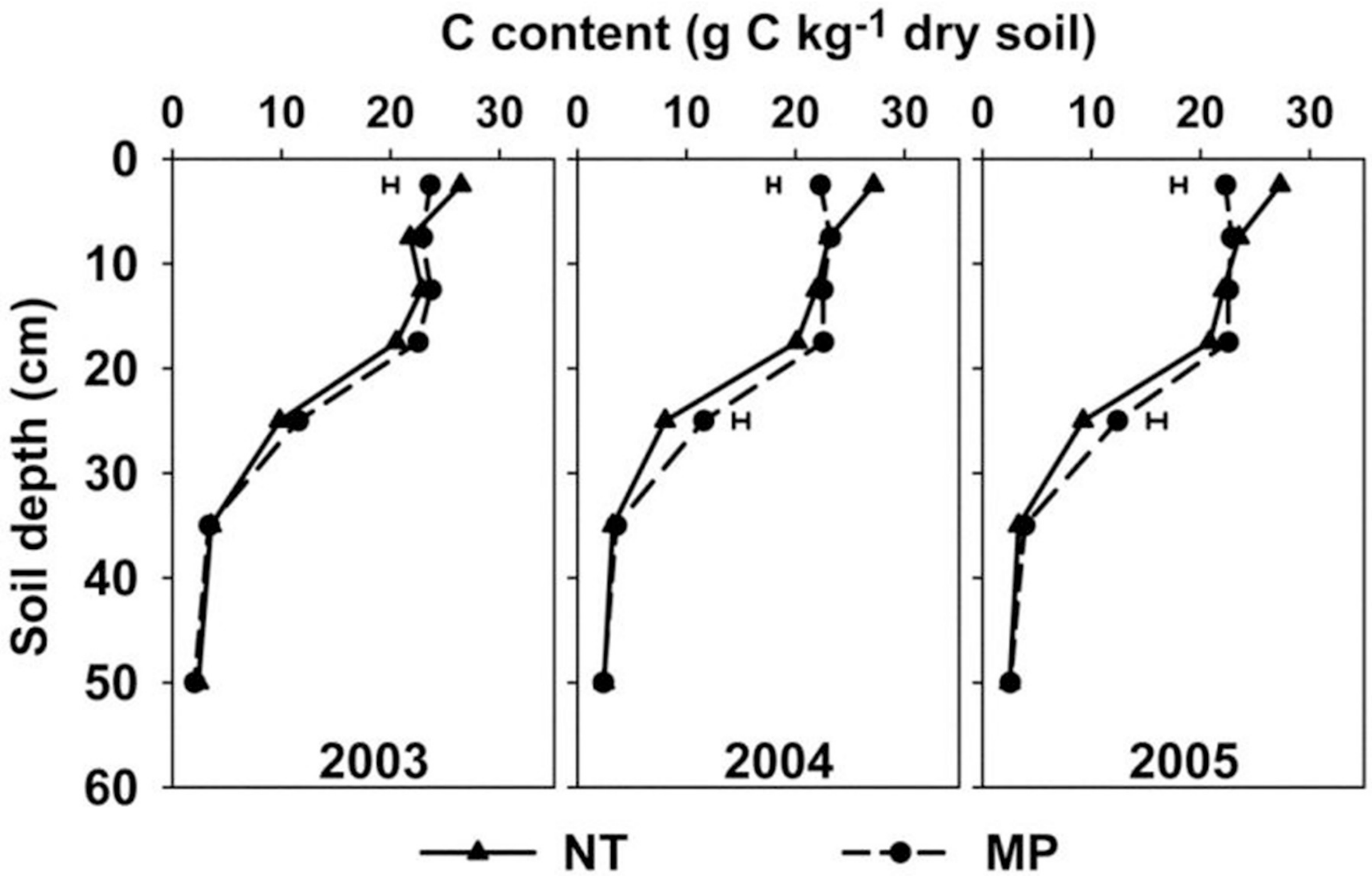


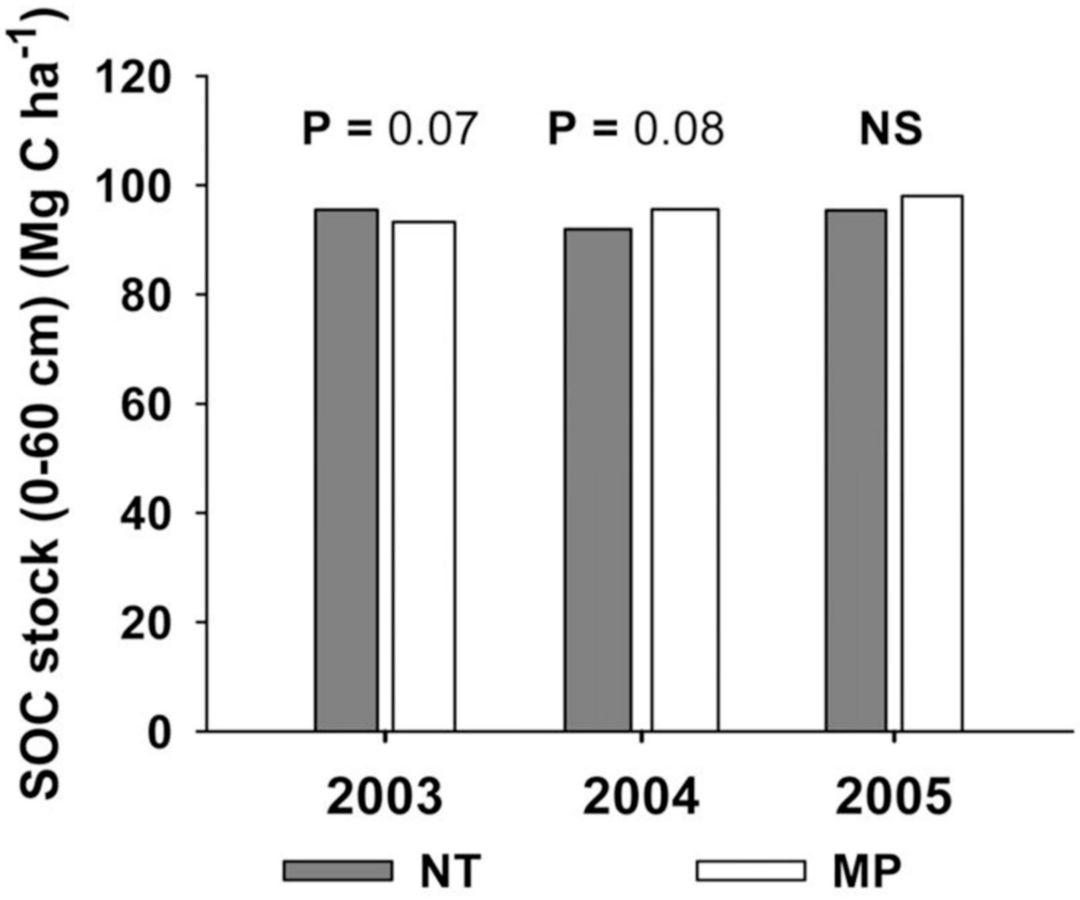
- ✓ Cropping frequency rather than tillage system predominantly influenced SOC stocks.
- ✓ Higher stocks under no-tillage than tilled systems, particularly with continuous wheat.
- ✓ Higher stocks with continuous cropping than summer-fallow; pulse-wheat, particularly with no-tillage, was beneficial over fallow-wheat.
- ✓ SOC dynamics is highly influenced by precipitation.

Maillard et al. 2018

Tillage: Moldboard Plow vs. No-Till

Long-Term Experiment at AAFC-Quebec City under Humid Conditions



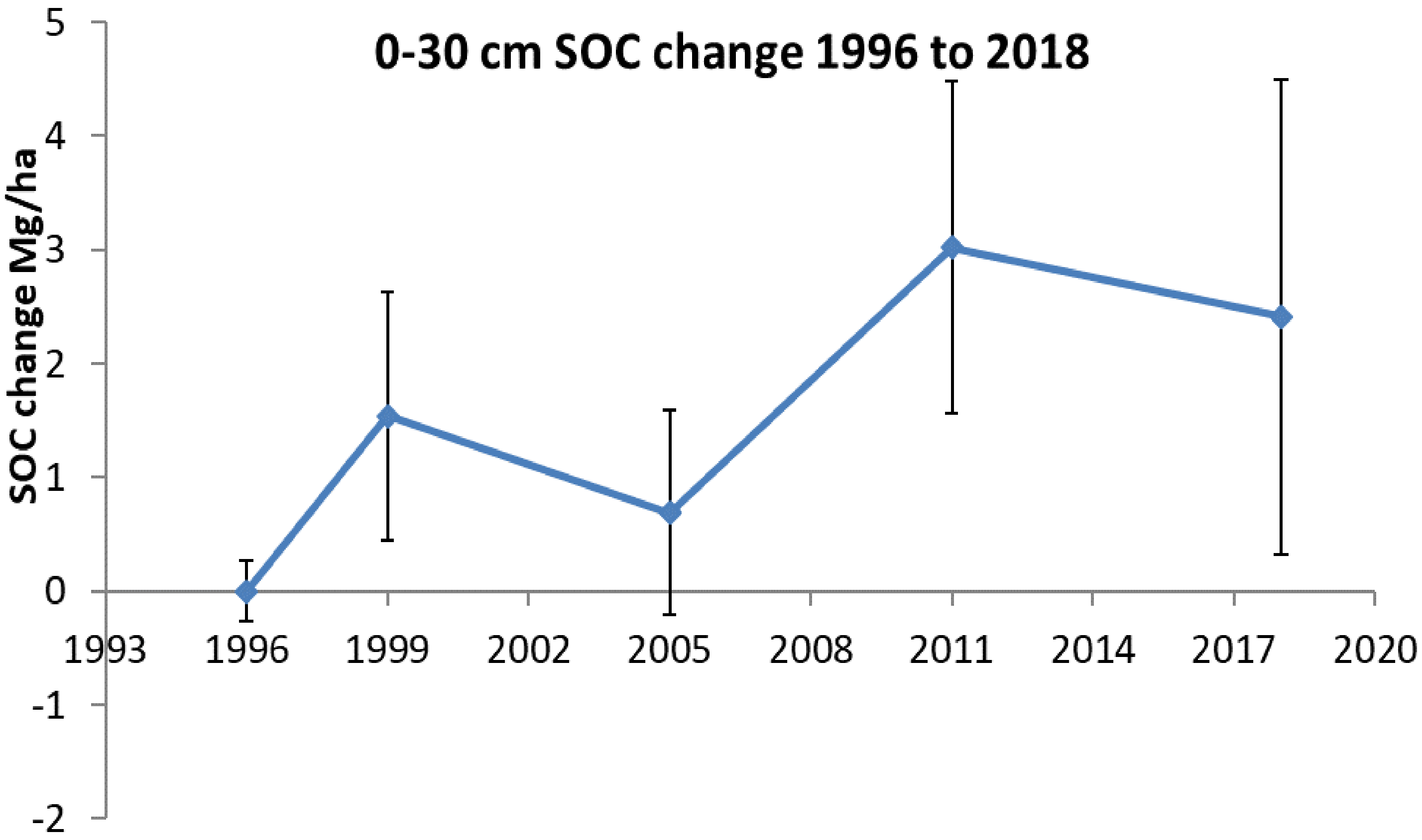


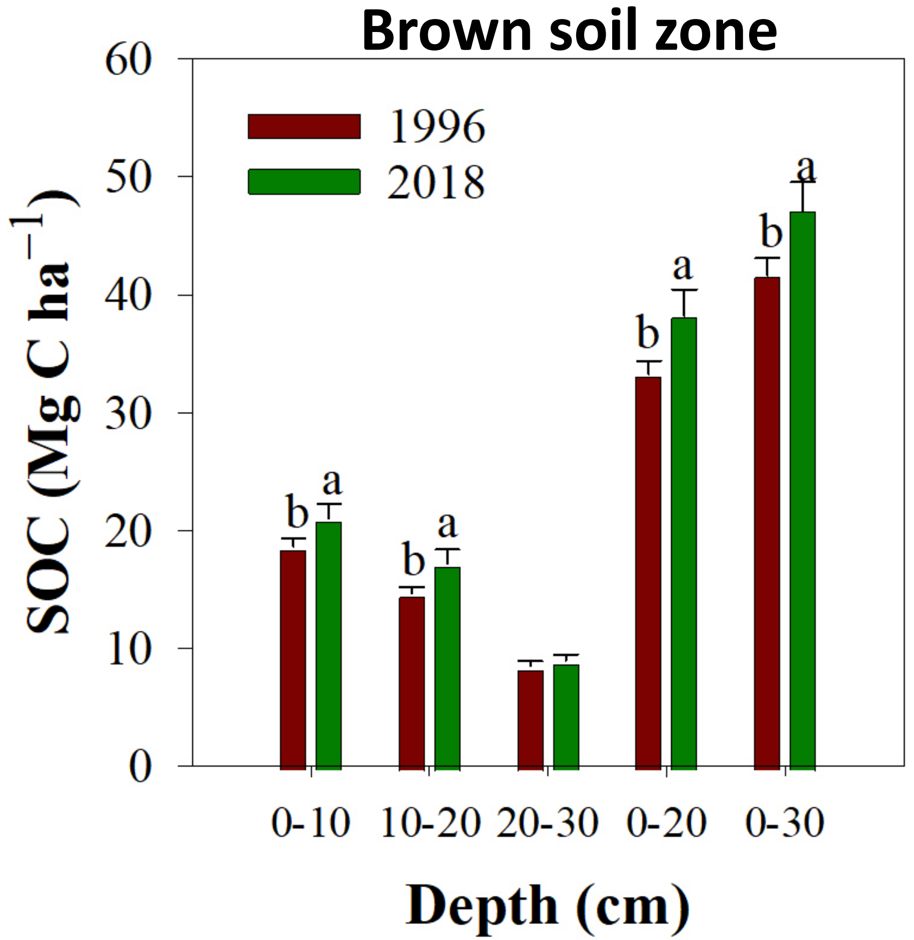
- ✓ Higher SOC near the soil surface under NT than MP.
- ✓ Higher SOC at 20-30 cm depth interval under MP than NT.
- ✓ Equivalent SOC stocks for both tillage systems for the whole soil profile (0-60 cm).

Poirier et al. 2009

Conservation Management

Prairie Soil Carbon Balance Project (Conversion to No-Till in 1997 in Saskatchewan)





- ✓ SOC change can be dynamic over spatial and temporal scales (changes are usually undetected in the short-term).
- ✓ Increase in SOC on direct-seeded commercial fields (conservation management).
- ✓ About 4% increase in SOC stocks from 1996 to 2018.
- ✓ Important gains in SOC at depth.

McConkey et al. 2020 (report)

Measuring and Monitoring SOC - Direct

Measuring SOC directly at the field scale. This is straightforward and universally accepted.

Soil sample collection

Analysis (e.g., dry combustion)

Advantages

- ✓ Outcome based.
- ✓ Most acceptable by stakeholders.
- ✓ Sampling and analysis protocol accepted by market.
- ✓ Farmers are most comfortable with direct measurements!

Disadvantages

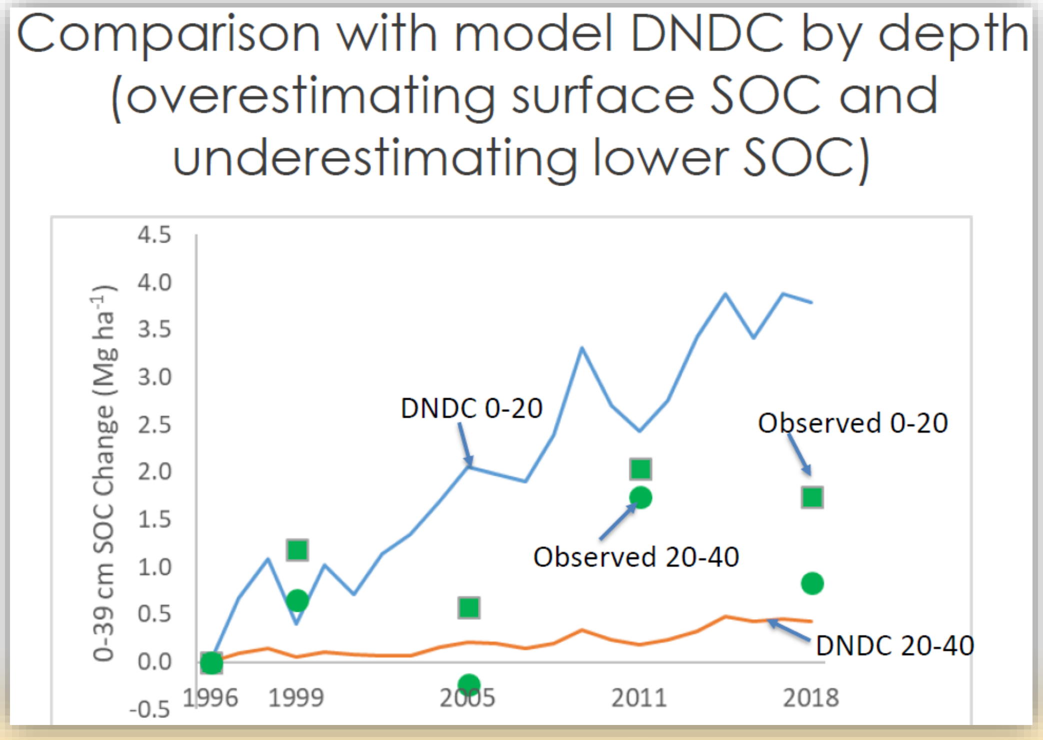
- ✓ Very costly!
- ✓ Time-consuming (depending on number of samples).
- ✓ Inflexible as initial sampling design constrains possible future modifications (location, analytical method, etc.).
- ✓ Integrity of the quantification is critical since deliberate biasing possible and results inherently not reproducible.

McConkey 2019

Measuring and Monitoring SOC – Process-based

One of the most practical strategies for SOC estimation over large areas while including the effects of farm-specific situations.

- Predictions of SOC as affected by management and weather.
- Important for decision making for managers and policy makers.
- Examples: DAYCENT, DNDC, CENTURY and DSSAT models



Source: McConkey et al. 2020

He et al. 2021

Measuring and Monitoring SOC – Process-based

One of the most practical strategies for SOC estimation over large area while including the effects of farm-specific situations.

Advantages

- ✓ Site-specific (accounts for site-specific input data).
- ✓ Able to estimate future behaviour.
- ✓ Able to model both with and without intervention conditions.
- ✓ Potential to be standardized globally, therefore attractive to multinationals.
- ✓ Highly flexible, multiple models can be used including new and better models as they become available.
- ✓ Estimates are reproducible given the same inputs and parameters.

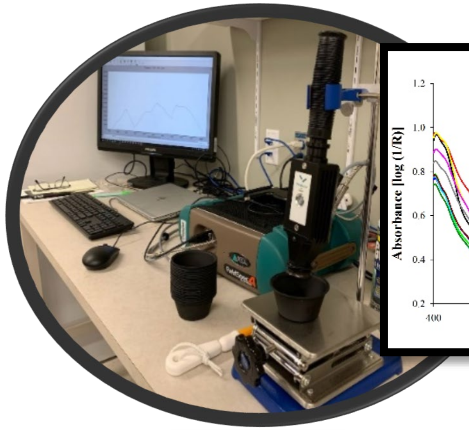
Disadvantages

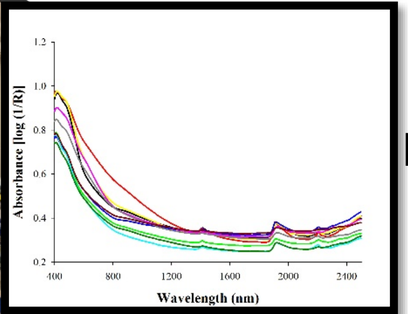
- ✓ May seem to be a black box (but model parameters can be verified for open source software)
- ✓ Trust issues as some do not trust the model estimates (requires proper validation against real observations for the situation for which it will be applied).
- ✓ Models have generally not been shown to accurately estimate SOC below 20-30 cm (deeper soil depths need more work).
- ✓ Modelling perennials more difficult than annuals due to uncertainties in C inputs from roots, especially in poorly studies multi-species plant mixtures.

Measuring and Monitoring SOC - Indirect

Soil Spectroscopy

Spectroradiometer (Vis-NIR)





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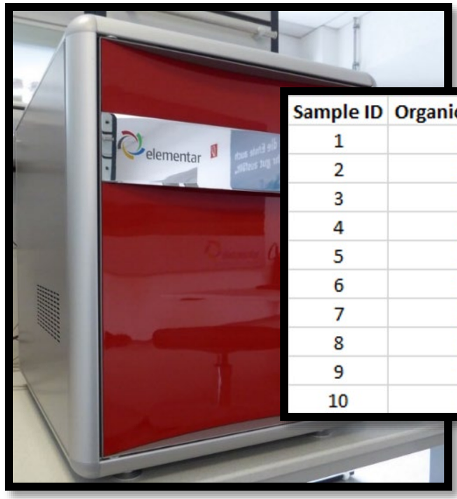
Analysis (e.g., dry combustion)



Sample ID	Organic Carbon (%)
1	1.38
2	1.64
3	2.42
4	0.41
5	1.25
6	1.06
7	0.78
8	0.41
9	1.34
10	1.47

+

Modelling

Machine Learning; Chemometrics

=

Prediction

Sample ID	Organic Carbon (%)
1	1.21
2	1.79
3	2.5
4	0.45
5	1.2
6	1.1
7	0.9
8	0.48
9	1.4
10	1.39

Advantages

- ✓ Cost-efficient!
- ✓ Highly repeatable.
- ✓ Non-destructive and no chemical reagents.
- ✓ Multiple soil parameters at once.
- ✓ Accurate for SOC; others with proper calibration and validation.
- ✓ Site-specific models are more accurate!
- ✓ Portable & handheld devices available (accuracy?)

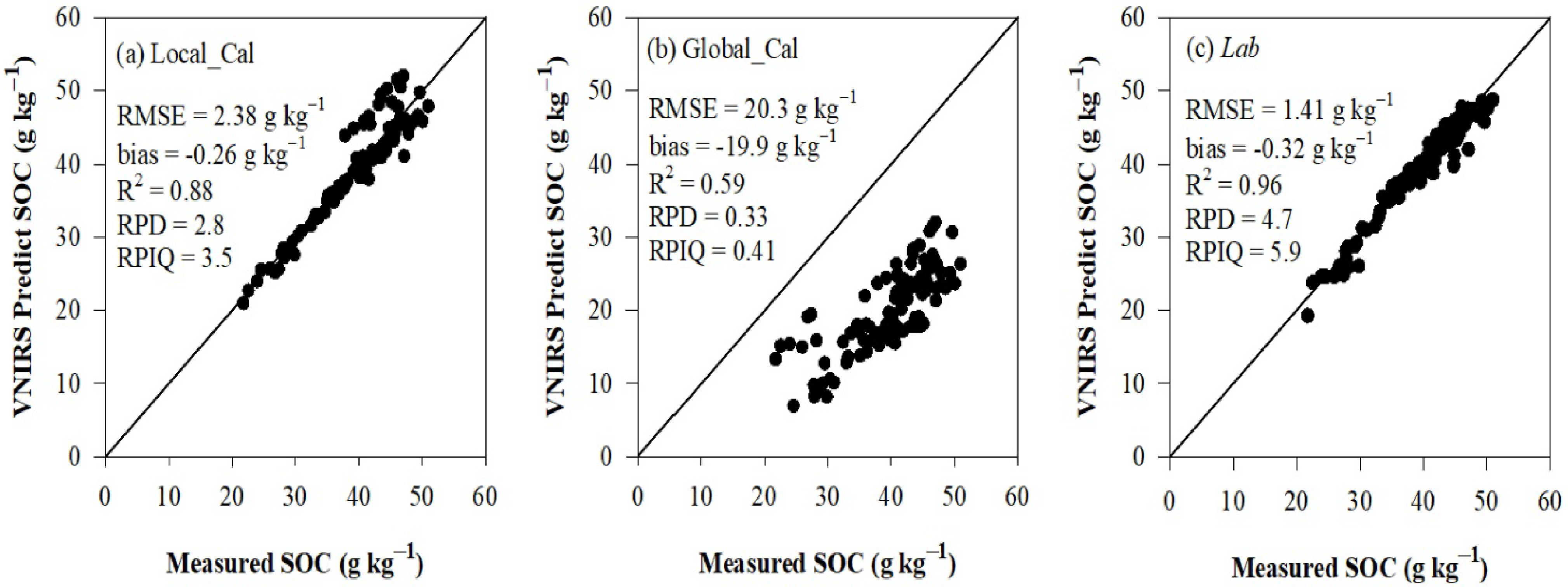
Disadvantages

- ✓ High initial equipment cost and set up!
- ✓ Requires reference soil laboratory data.
- ✓ Unable to predict future SOC changes.
- ✓ Requires spatial and temporal data, and validation against real observations for the target area.
- ✓ Requires specialized knowledge and experience in machine learning and other models (chemometrics).

Stenberg et al. 2010; St. Luce et al. 2014; Nocita et al. 2015, Viscarra Rossel et al. 2016.

Measuring and Monitoring SOC - Indirect

Soil Spectroscopy



- ✓ Site-specific models are more accurate than global models.
- ✓ Selecting samples that closely resemble the new samples can improve predictions.

St. Luce et al. 2021 (in preparation)

Summary

- SOC is a major component of SOM and is integral for soil health and productivity.
- SOC is the balance between input and output of C in the soil-plant system.
- Management practices have major impacts on SOC. Practices with positive impacts are encouraged (e.g., crop residue retention, no-till/minimum tillage, continuous cropping, summer fallow reduction, diversified crop rotations, optimum fertility).
- Measurement and monitoring of SOC is critical for improving and managing soil health.
- Well-known and accepted sampling and analytical methods can be expensive, time-consuming and risky.
- SOC estimating with various models (process-based and spectroscopy) are the future!

Acknowledgements

- Dr. Brian McConkey (Chief Scientist, Viresco Solutions Inc.).
- Technical staff from AAFC-Swift Current.
- Dr. Jeff Schoenau, Dr. Ryan Hangs and their team at the Department of Soil Science, University of Saskatchewan.

Funding and Partners

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

Saskatchewan Agricultural Development Fund

SaskCanola

SSCA Saskatchewan Soil Conservation Association

Saskatchewan Pulse Growers

Agriculture and Agri-Food Canada
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Thank you!

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