2026 Lake Champlain Research Conference

Soil health diagnosis of Quebec portion of the Missisquoi Bay Basin following a remote sensing approach (ReSSoD Project-Remote Sensing Soil Diagnosis)

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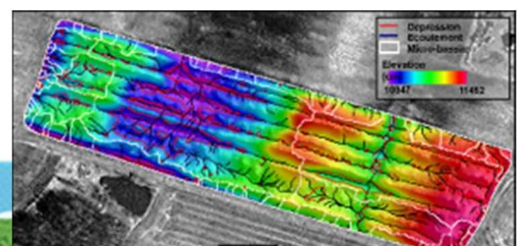
January 27th, 2026
Burlington, Vermont

Illustration: Stéphane Lemardelé



OBV BAIE MISSISQUOI
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Lake Champlain Basin Program
NEIWPCC

Intro

Soil health: An emerging issue with deep roots…

Source: Anne Weill, CRAAQ, 2009.

Intro

Wetness and heavy machinery: Determinant factors of soil physical condition

Intro

Water logged zones are main sources of field erosion and non-point surface water contamination

ReSSoD project objective

Objective:

Develop a user-friendly geographic information system:

- **For agricultural extension staff and farm managers of Missisquoi Bay watershed in Québec**
- **Dedicated to the diagnosis of:**
  - **soil physical condition,**
  - **related crop productivity**
  - **critical zones of surface runoff, sediment, and phosphorus loadings emissions.**


Tasks: A shared agenda

Remote sensing development (RS)

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Task #	Task title
QAPP	Develop QAPP
RS-1	Terrain analysis and generation of topographic indices
RS-2	Generation of soil indices
RS-3	Generation of crop development indices
RS-4	Generation of yearly agri-climatic indices
RS-5	Development of soil health indices Part I
RS-6	Development of soil health indices Part II

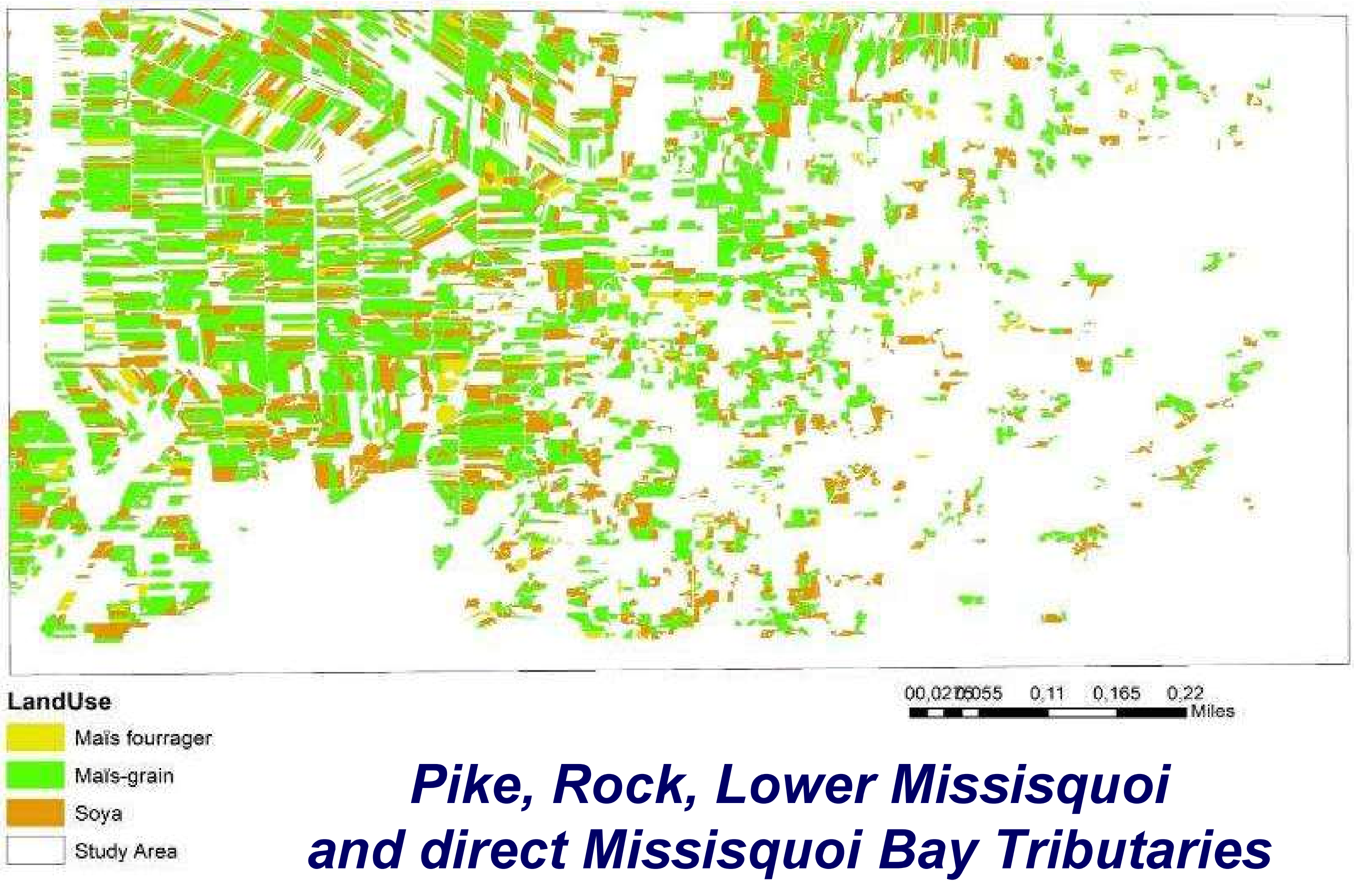
Farm network animation (FN)

OBV BAIE MISSISQUOI

Task #	Task title
FN-1	Farm network recruitment
FN-2	On farm data collection
FN-3	On farm data treatment and extension
FN-4	Summer on-farm workshop
FN-5	Winter workshop
FD	Final deliverables edition and outreach

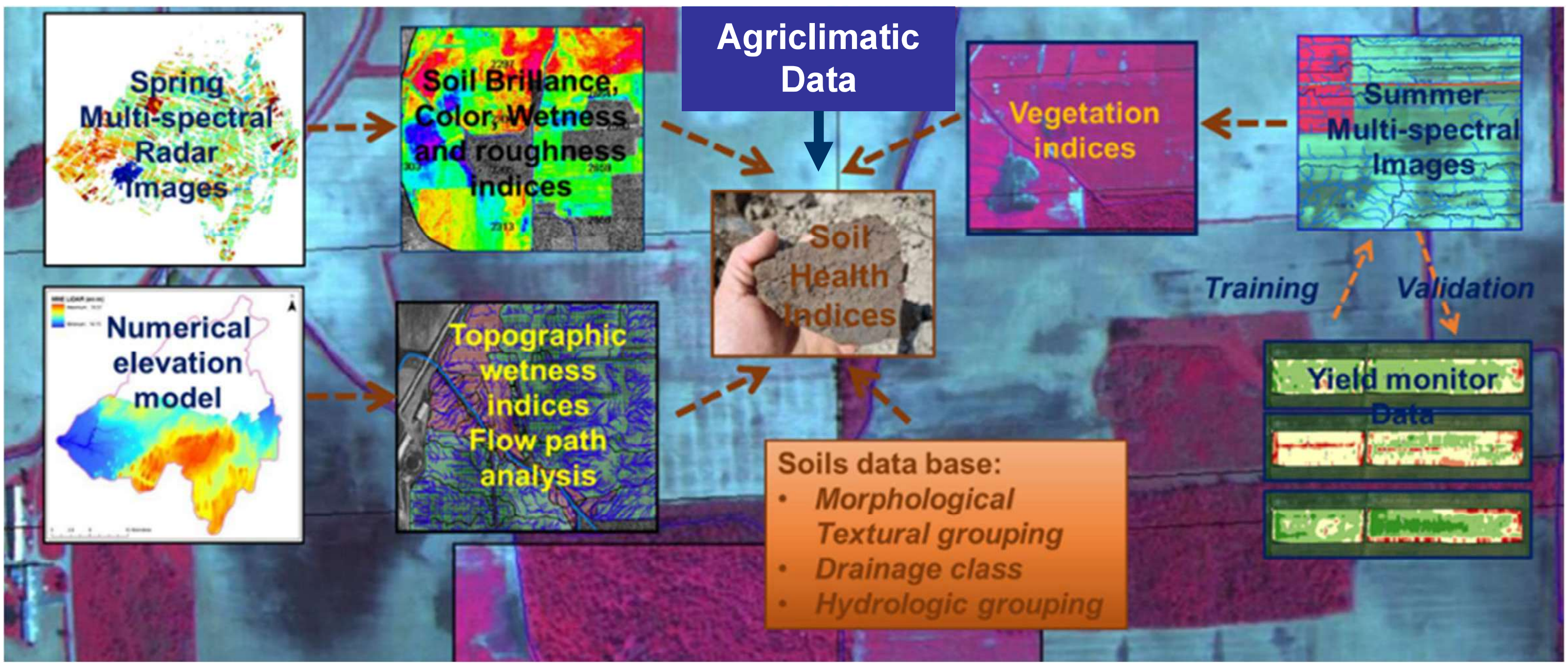
Final Study area:
All Corn and/or Soybean within 2017-2023 period

Final area covered by the soil health indices: 49,871 ha,



Pike, Rock, Lower Missisquoi
and direct Missisquoi Bay Tributaries

Remote Sensing Tasks description: Diagram of spatial data treatment



Remote Sensing Tasks description:

Locational data analysis Rationale (2017 to 2023):

- **Crop Development indices:** **Localize areas of persistent poor corn or soybean crop development using summer multispectral imagery of critical crop stage (early July).**

- **Soil indices:** **Localize areas of persistent wetness in early spring period using multispectral and radar imagery;**

- **Topographic indices:** **Localize areas of deficient surface drainage using LiDAR data.**

- **Agriclimatic indices: Classify precipitation data prior to early spring images selection (Period P1), and precipitation and heat prior to summer images (Period P2);**

- **Soil Health Indices:**
  - **Intersect locational Crop, Soil and Topographic indices**
  - **Identify their relationships through Machine Learning**
  - **Map Locational Soil Health Indices through an Oriented Object method**

- **Yield monitor data :**
  - **Validate the crop development indices**

RS-1: Terrain analysis and generation of topographic indices

METHODOLOGY

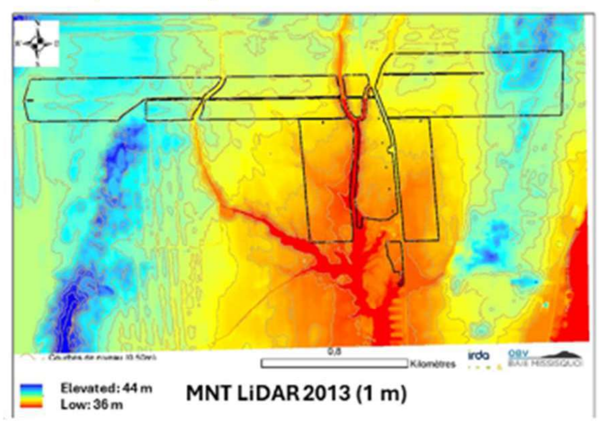
- **Generation of a numerical elevation model (NEM) from high resolution (1,0 m) LiDAR survey (Géomont, 2013);**

- **Generation of a 2,0 m wide buffer at field boundaries, to eliminate ditches and field edges artifacts, and also provide adequate locational data overlays;**

- **Generation of field scale topographic indices, as indicator of the surface drainage;**

- **Analysis and selection of "best" surface drainage indicator:**
  Best explanatory power for soil moisture patterns (NDWI) :

  - **The Topographic Position Index (TPI)**
  - **The Topographic Wetness Index (TWI)**



High resolution (1,0 m) LiDAR survey (Géomont, 2013)

RS-2: Generation of soil indices

METHODOLOGY

- **<u>Acquisition</u> of Multi-spectral (Sentinel 2) and Radar (Sentinel 1) data from Sentinel missions of the European Space Agency's (ESA) to project soil moisture patterns in early spring;**
- **Data acquisition from 2017 to 2023, based on analysis of cloud cover, for mid-April to mid-May period;**
- **Radiometric and geometrical <u>corrections</u> from The Google Earth Engine (GEE) tool kit;**
- **<u>Indices standardized</u> for the entire study region to allow:**
  - **Inter-annual comparisons (common distributions);**
  - **Generation of multi-year soil moisture index (median of annual standardized indices).**
- **<u>Selection of multi-spectral indices</u> for best explanatory power of the corn and soybean canopies (NDVI indices), following a random forest regression approach.**

Sentinel 2 Images (Multi-spectral reflectances)

May 8th 2018 180% of normal precipitation

April 20th 2020 10% of normal precipitation

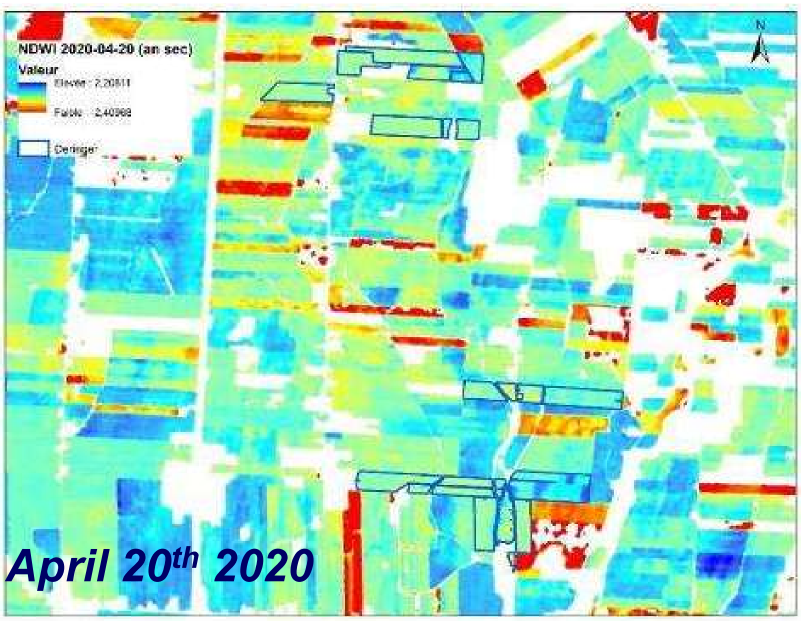
RS-2: Generation of soil indices (Ct'd)

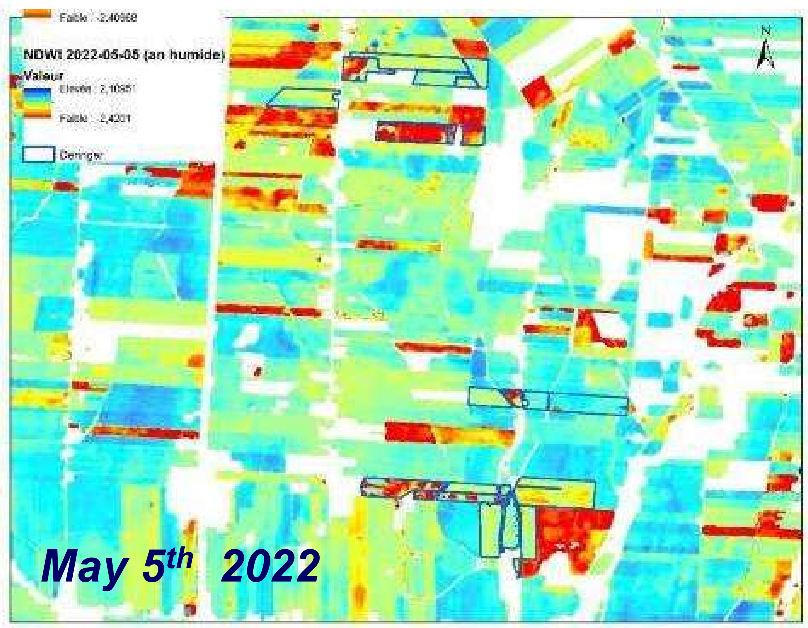
METHODOLOGY – NDWI Multi-spectral Index

- **The NDWI index derived from the multi-spectral images (SENTINEL-2) depict the soil moisture through the reflectance of the green and infrared spectral bands.**

$$NDWI = \frac{\text{V(B3)} - \text{PIR(B8)}}{\text{V(B3)} + \text{PIR(B8)}}$$

Annual standardized NDWI Indices (2020 and 2022)

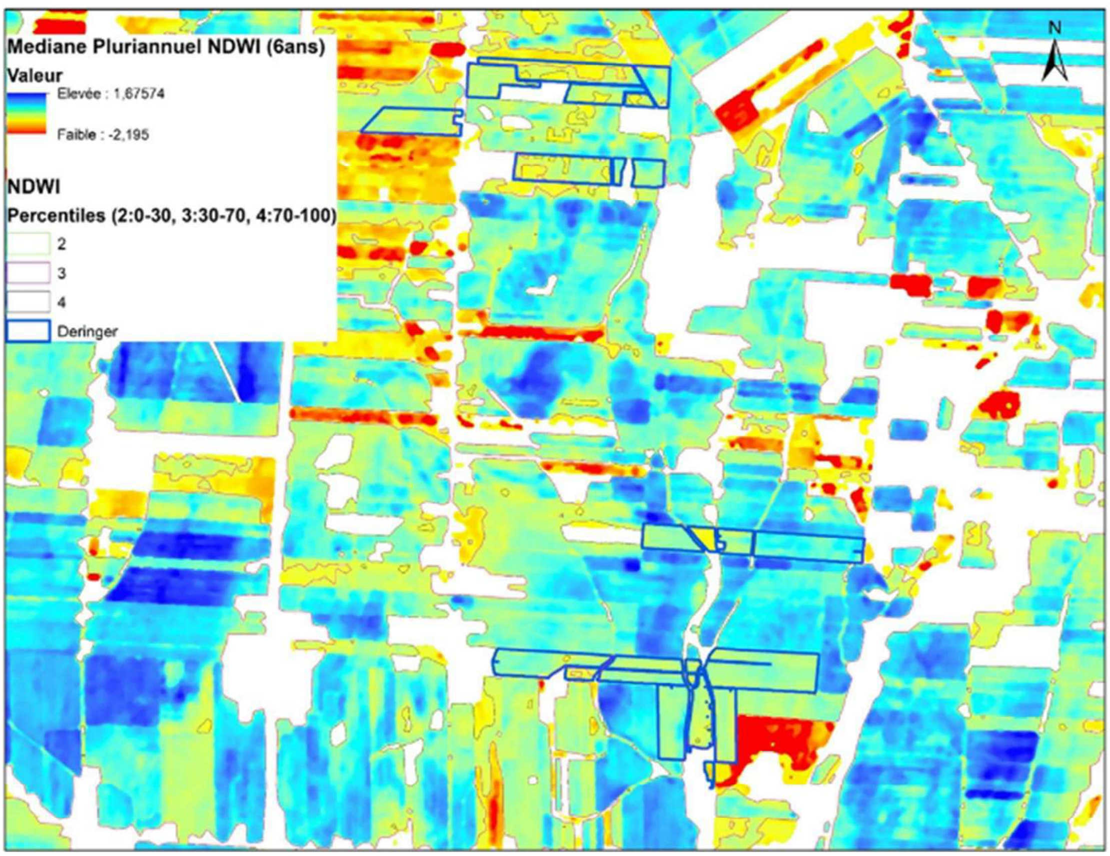




RS-2: Generation of soil indices (Ct'd)

METHODOLOGY – NDWI Multi-spectral Index

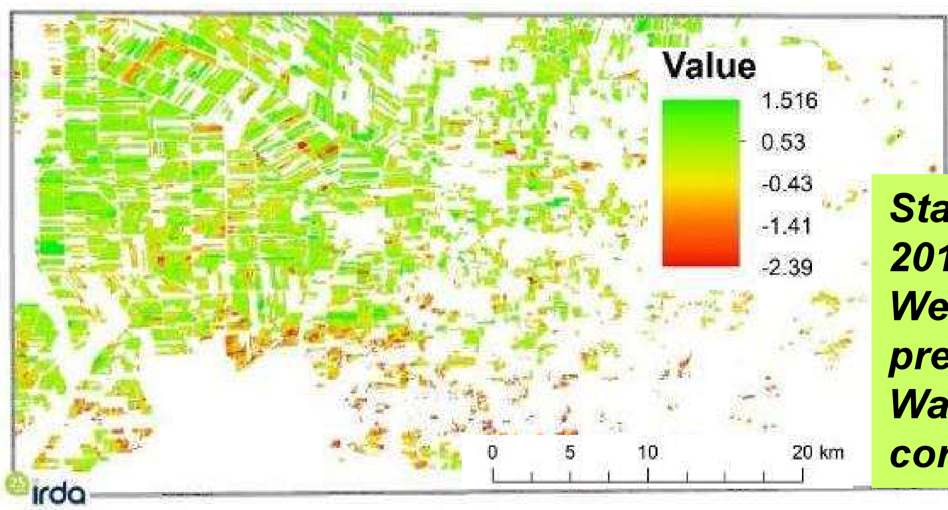
Multi-annual (6 years) median of standardized NDWI Indices
And corresponding Percentile Classes (0-30%, 30-70%, and 70-100%)



RS-3: Generation of Crop Development Indices

METHODOLOGY

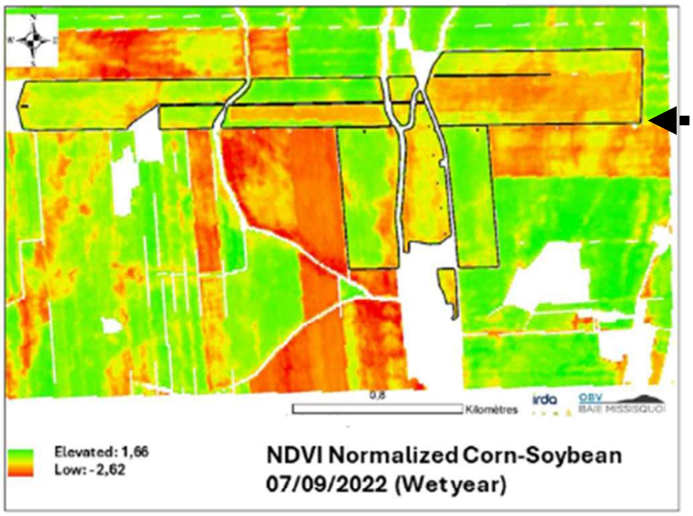
- ***Acquisition and selection*** ***of Multispectral images, 2017 to 2023***
- ***Generation of NDVI*** ***indices: Bands (Green-Red/(Red+ Infra-red)***
- ***Standardization*** ***of yearly NDVI for individual corn and soybean acreages;***
- ***Generation of a single Multi-year/Multi-crop index (merging of corn and soybean cropland) and estimation of its percentile distribution***



Standardized NDVI for July 22nd, 2017
Wet year: 132% or normal precipitation
Warm year: 113% of normal corn heat units

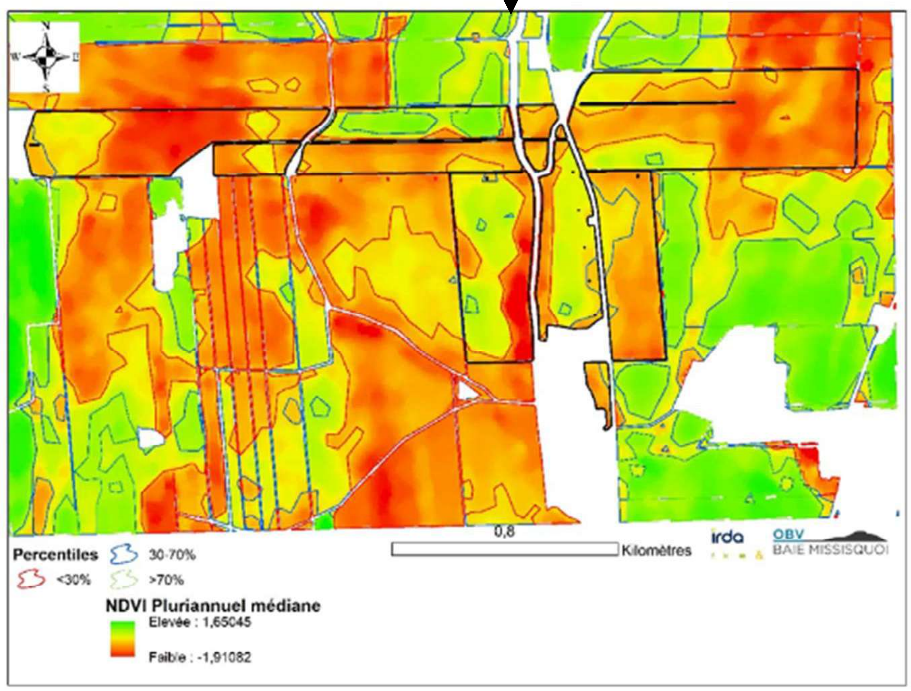
RS-3: Generation of Crop Development Indices

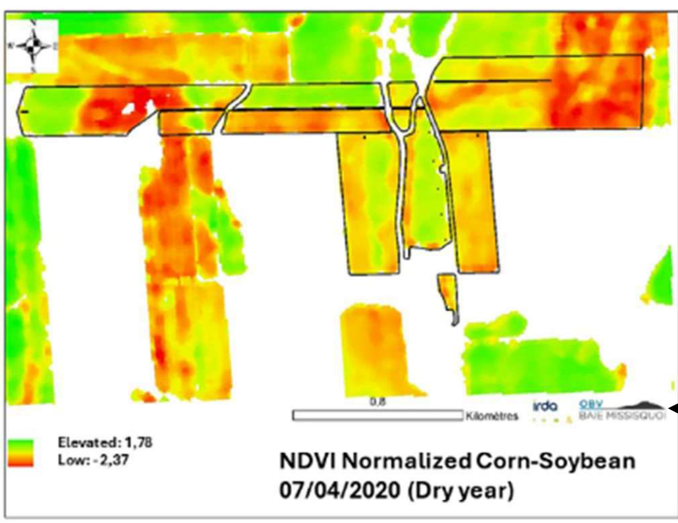
METHODOLOGY (Ct'd)



Standardized NDVI,
July 4th 2020 (Dry year)

Multi-annual
Standardized NDVI,
2017-2023



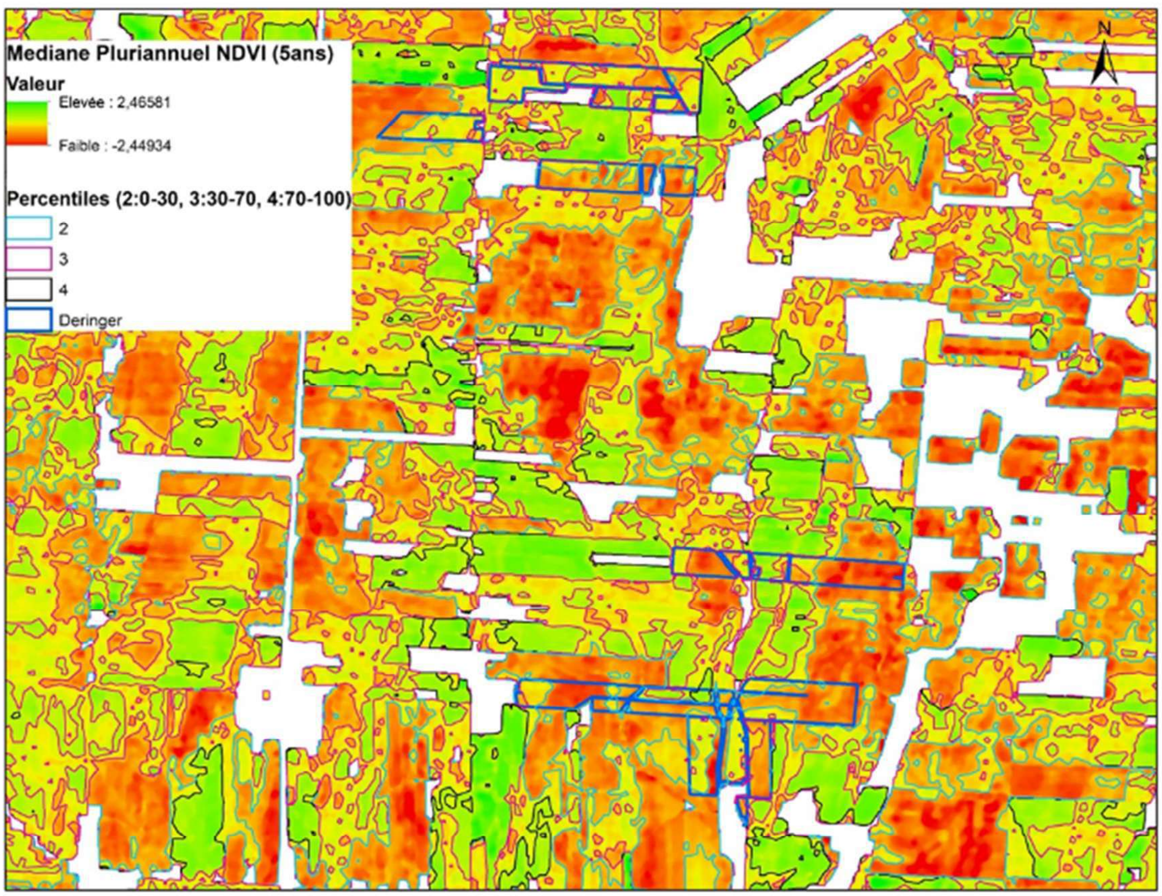


Standardized NDVI,
July 9th 2022 (Wet year)

RS-3: Generation of Crop Development Indices

METHODOLOGY (Ct'd)

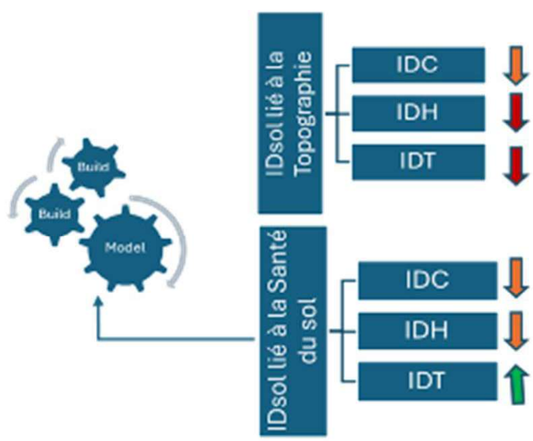
Multi-annual (5 years) median of normalized NDVI Indices
And corresponding Percentile Classes (0-30%, 30-70%, and 70-100%)



RS-5/6: Generation of Soil health indices

METHODOLOGY

- ***<u>The approach:</u> Explain explaining crop development indices with soil moisture and topographic indices.***
- ***<u>General assumption:</u> On deficient soil health zones, persistent soil wetness over the years correlates with persistent weak crop development;***
- ***<u>Variables selection</u> using a data-driven machine learning approach (The Random Forest Recursive Feature Elimination, Hijmans, 2019);***
- ***<u>Final classification</u> using an Object-Based Image Analysis (OBIA) applied to percentile classes of NDVI, NDWI and TPI using the multi-resolution segmentation algorithm (MRS) method (Baatz and Schäpe; 2000).***

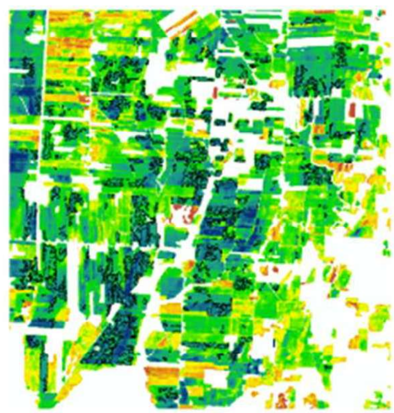


RS-5/6: Generation of Soil health indices

METHODOLOGY (Ct'd)

Filtring and final classification NDVI X NDWI X TPI

TPI median



NDWI median

NDVI median

- **Soil healh indices: Locational objects from the intersection of soil wetness, surface drainage and crop development gradients;**

- **A total of 27 percentiles classes: NDVI (3) X NDWI (3) X TPI (3);**

- **Final agregation in seven classes.**

RS-5/6: Generation of Soil health indices

METHODOLOGY (Ct'd)

Classification of soil health indices according to the superposition of crop development, soil moisture and topographical position indices.

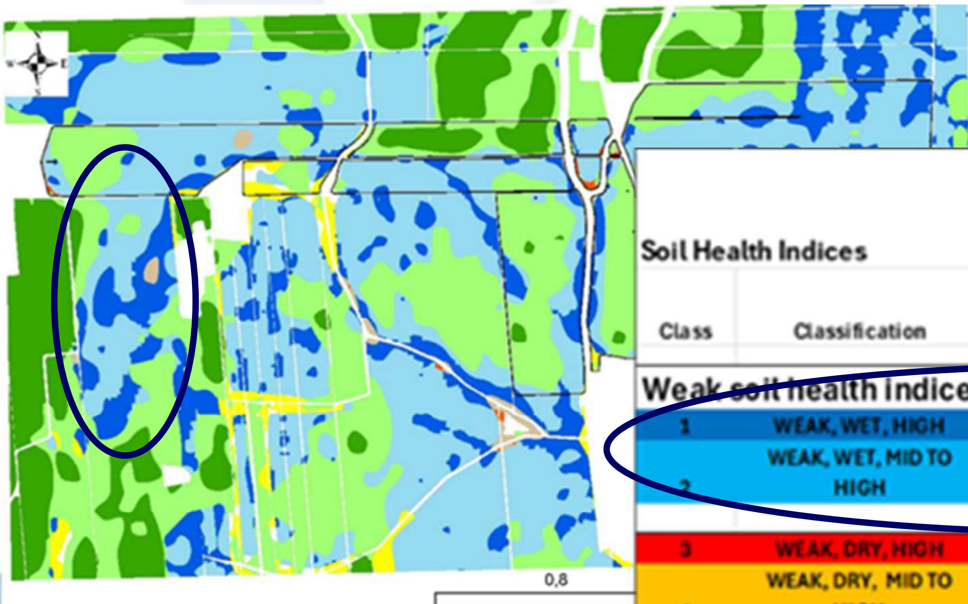
Soil Health Indices		Crop Development Indices [1]	Soil wetness Indices [1]	Topographic Indices [1] Position	Surface area	Distribution [2]
Class	Classification	(Weak, Mid, Best)	(Wet, Mid, Dry)	(Low, Mid, High)	(ha)	(%)
Weak soil health indices						
1	WEAK, WET, HIGH	NDVI - 2 (Weak)	NDWI - 4 (Wet)	TPI-2 (Low)	2820	5,65%
2	WEAK, WET, MID TO HIGH	NDVI - 2 (WEAK)	NDWI - 4 (Wet)	TPI 3-4 (Mid, High)	8646	17,34%
3	WEAK, DRY, HIGH	NDVI - 2 (Weak)	NDWI - 2 (Dry)	TPI-4 (High)	68	0,14%
4	WEAK, DRY, MID TO HIGH	NDVI - 2 (Weak)	NDWI - 2 (Dry)	TPI-2-3 (Low, Mid)	180	0,36%
5	WEAK, MID WETNESS	NDVI - 2 (Weak)	NDWI - 3 (Mid)	All TPI	2415	4,84%
Average soil health indices						
6	MID	NDVI-3 (Mid)	All NDWI	All TPI	19810	39,72%
High soil health indices						
7	BEST	NDVI - 4 (Best)	All NDWI	All TPI	15933	31,95%

[1] The classes are defined according to the percentile intervals below or equal to 30%, from 30 to 70% and above 70%.

[2] The percentage is expressed in relation to the total area analyzed 48,871 ha), including corn or soybean crops during the years 2017 to 2023 inclusively.

RS-5/6: Generation of Soil health indices

Projection of soil health indices according to the superposition of crop development, soil wetness and topographical position indices.



Soil Health Indices		Crop Development Indices	Soil wetness Indices	Topographic Indices Position
Class	Classification	(Weak, Mid, Best)	(Wet, Mid, Dry)	(Low, Mid, High)
Weak soil health indices				
1	WEAK, WET, HIGH	NDVI - 2 (Weak)	NDWI - 4 (Wet)	TPI-2 (Low)
2	WEAK, WET, MID TO HIGH	NDVI - 2 (WEAK)	NDWI - 4 (Wet)	TPI 3-4 (Mid, High)
3	WEAK, DRY, HIGH	NDVI - 2 (Weak)	NDWI - 2 (Dry)	TPI-4 (High)
4	WEAK, DRY, MID TO HIGH	NDVI - 2 (Weak)	NDWI - 2 (Dry)	TPI-2-3 (Low, Mid)
5	WEAK, MID WETNESS	NDVI - 2 (Weak)	NDWI - 3 (Mid)	All TPI
Average soil health indices				
6	MID	NDVI-3 (Mid)	All NDWI	All TPI
High soil health indices				
7	BEST	NDVI - 4 (Best)	All NDWI	All TPI

RS-7: Yield monitor data analysis

METHODOLOGY (Ct'd)

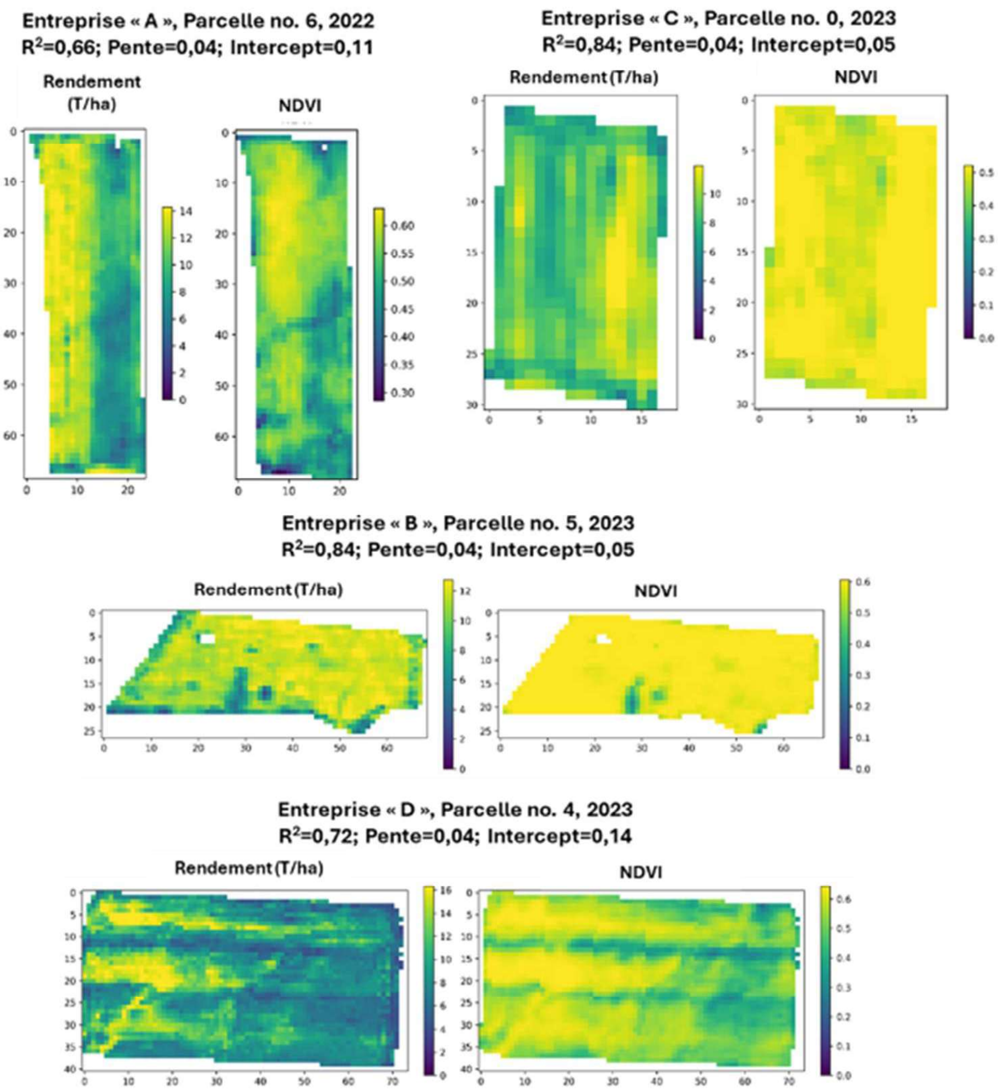
- **<u>The hypothesis to be tested:</u> "The NDVI index, reflecting the abundance and vigor of the corn canopy in early summer (around the 4-leaf stage), is a good indicator of end of season crop yield";**

- **<u>Data:</u> 49 cultivated fields from four farms in 2022 or 2023, generating a database of 1,015 ha.**

- **The capacity of the NDVI index to explain end-of-season grain corn yields was evaluated using a simple linear regression method.**

RS-7: Yield monitor data analysis

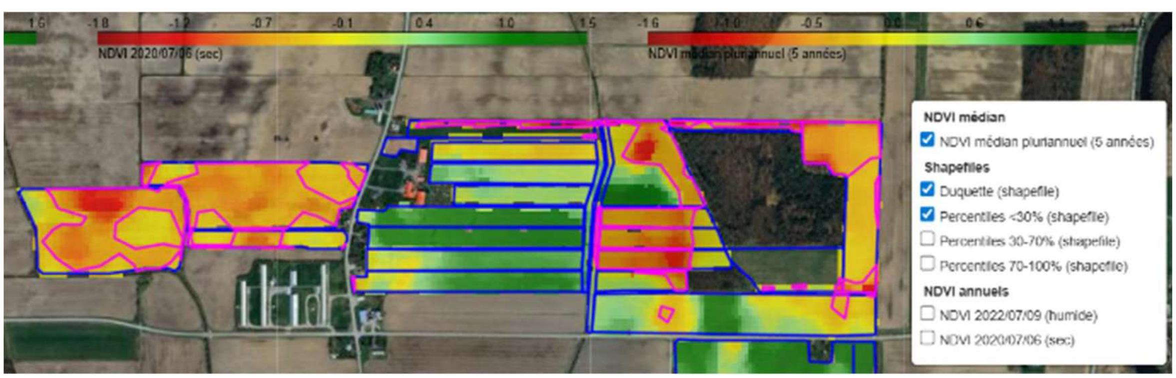
RESULTS



Overall, the model's adjustment (R^2) indicators for individual fields are satisfactory, with an average of 0.74 (N=49).

RS-8: Develop spatial tool kit

- **<u>Open source QGIS format</u> and user guide dedicated to local extension staff (confidential data status);**
- **Individual <u>Farm-scale GIS in HTML format</u> dedicated to agricultural producers.**
- **Developer information available for download on a <u>GitHub website.</u>**



Tasks: Farm network animation (FN)

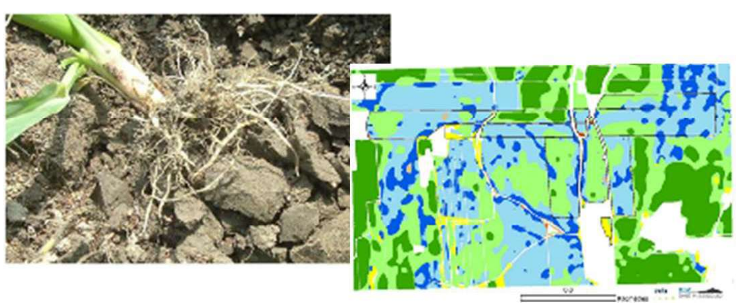
Scouting soil structures on Missisquoi bay watershed farmland during July 12-13th summer workshop

Tasks: Farm network animation (FN)

- **An interactive network:**
  - **14 local farm managers recruited;**
  - **Extension staff from a local extension club (DuraClub);**
  - **OBVBM, and IRDA's scientific staff.**

- **Objectives:**
  - **Validate the results obtained by remote sensing;**
  - **Identify land and crop management that present the best potential for mitigation.**

"Soil compaction, degraded soil structure, inefficient subsurface drainage and surface drainage issues were identified as the main causes of suboptimal crop development projected by ODiT-SSOL tool kit."

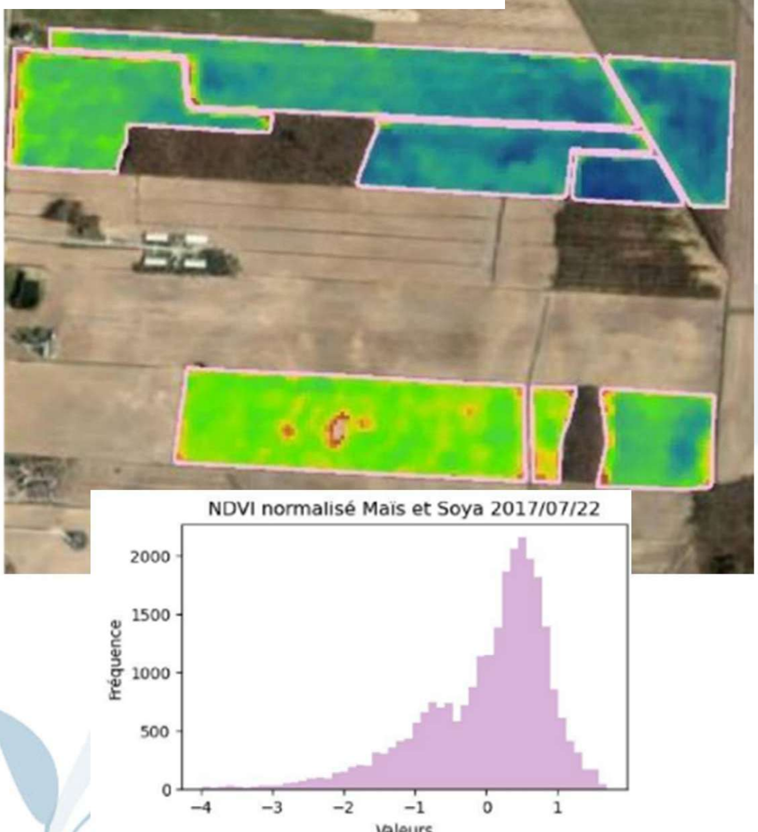


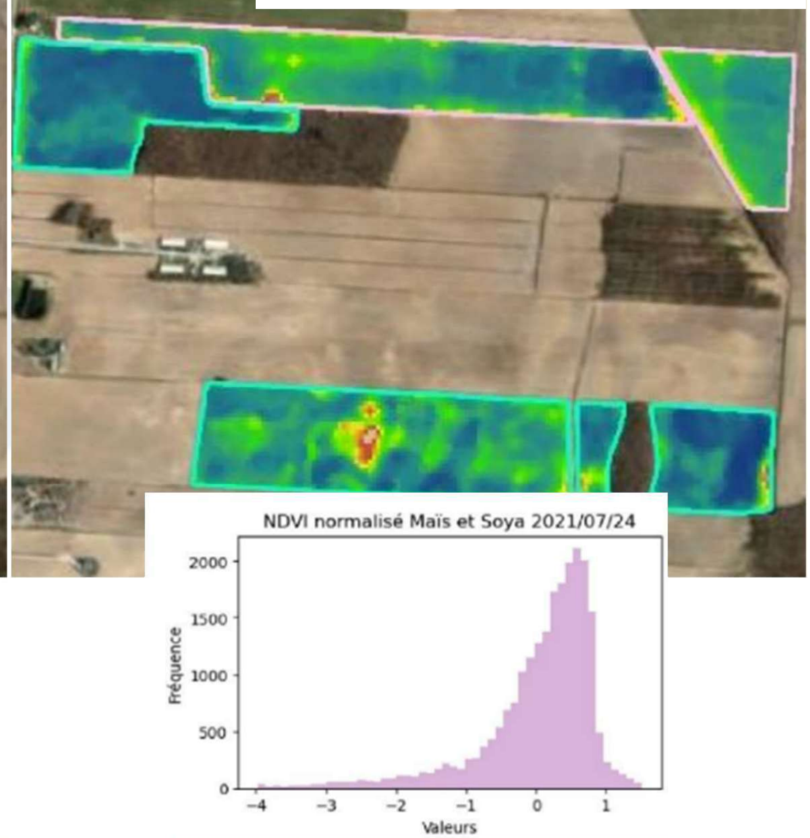
EXTRA's

RS-3: Generation of Crop Development Indices

METHODOLOGY (Ct'd)

Standardized annual NDVI





Date: July 22th 2017

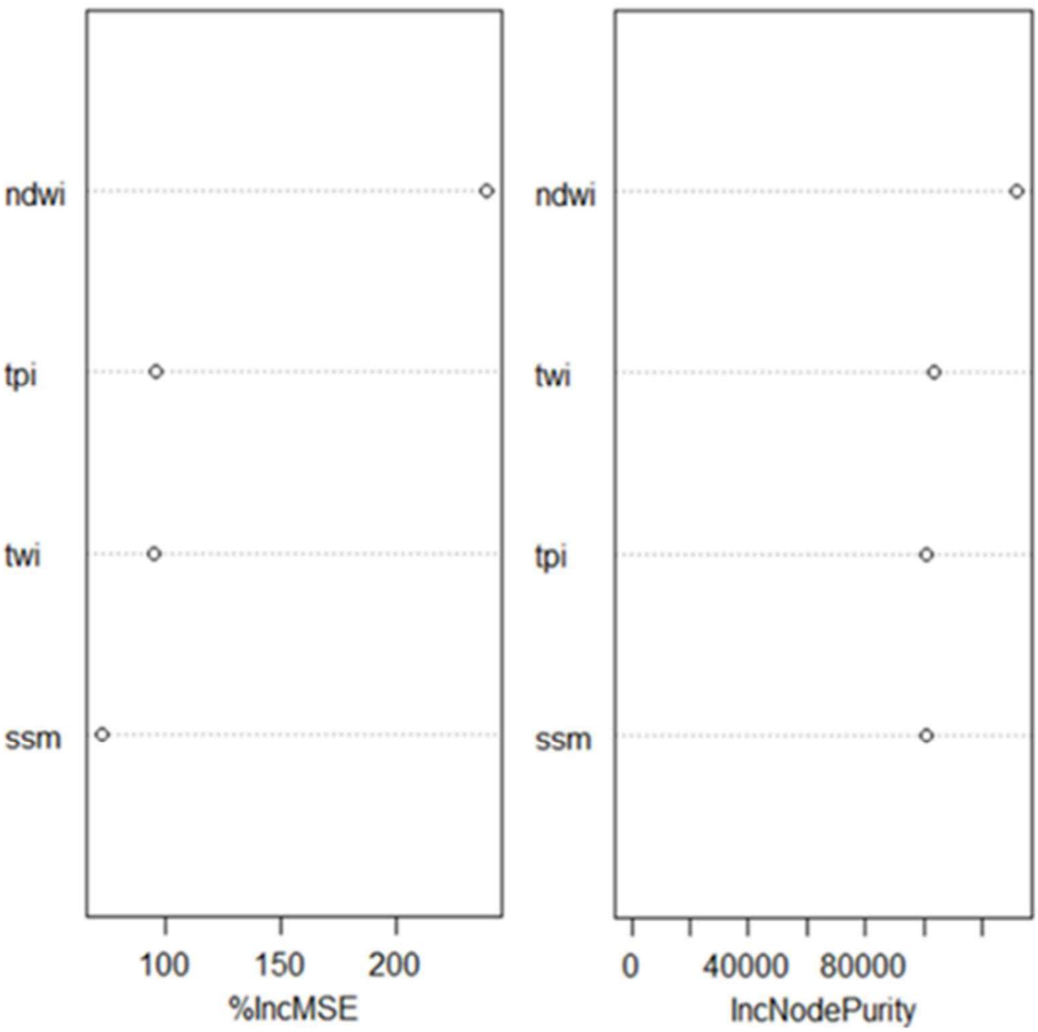
- ***Humid and warm conditions***
- ***132% normal precipitation***
- ***113% normal degree-days***

Date: July 24th 2021

- ***Dry and cold conditions***
- ***72% normal precipitation***
- ***91% normal degree-days***

RS-5/6: Generation of Soil health indices

METHODOLOGY (Ct'd)



Performance indicators of NDWI, SSM, TPI and TWI covariates from the random forest multiple regression analysis (RFRFE) using NDVI indices as dependent variables.