Evaluating Agricultural Sustainability Outcomes with APEX

Stone Webinar, 2026 Series

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Stone Environmental, Inc.

Our Challenge

10B

people to feed by 2050

4.3 Ac

of US farmland lost per minute per day over last 22 years

1/3

of carbon-rich topsoil lost to erosion in US Corn Belt

Source: https://agriculture.vermont.gov/sites/agriculture/files/documents/land_use/OnsiteMitigationReport_Final_Compressed.pdf

Sustainable Agriculture

Water Quality

Flooding of the Otter Creek as it enters Lake Champlain following Tropical Storm Irene in 2011. State of Vermont photo.

Soil Health

Source:https://www.vtfarmtoplate.com/sites/default/files/2024-01/Farm-to-Plate-Annual-Report-2023-Final.pdf

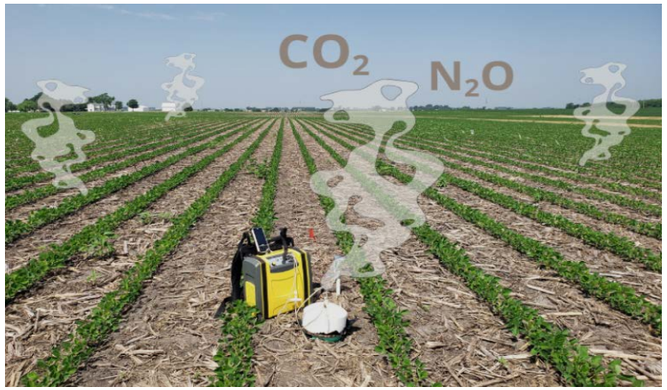
Complex, multi-faceted

Exist at multiple scales

Location-specific

Requires balance

GHGs and Carbon



Source: https://aces.illinois.edu/news/illinois-leads-most-rigorous-agricultural-greenhouse-gas-emissions-study-date

Agronomy

Source: https://agriculture.vermont.gov/agency-agriculture-food-markets-news/vermont-online-farm-feed-finder-marketplace-now-online

What is Stone doing to support sustainable outcomes in agriculture?

Farm Phosphorus Reduction Planner (Farm-PREP)

A web-based tool developed by Stone Environmental to incentivize management that improves adoption of conservation practices in Vermont, recently enhanced with additional sustainability-focused metrics.

Farm-PREP runs APEX model simulations designed to assess the impacts of long-term agronomic management at field and farm scales.

FARMPREP

Agricultural Policy/Environmental eXtender Model (APEX)

A USDA supported field to small watershed scale model that simulates water, sediment, nutrient, and pesticide transport from fields, as well as crop growth, biomass, yields, carbon/nutrient cycling.

Primary drivers are weather, physical characteristics of fields, and agronomic management.

APEX
Agricultural Policy Environmental eXtender model

Presentation Outline

1 **Background**
Tool background, programmatic implementation

2 **Tool Development**
Customization for Vermont Agency of Agriculture, Food, and Markets, public access, data entry, assessment framework

3 **Model Development**
Multi-objective calibration, evaluation of management scenarios

4 **Case Study**
Field and farm scale results, scenario comparison in the tool

5 **Take Aways**
Implementation of this work, potential avenues for future development

Background: Farm-PREP

In Vermont, agriculture contributes significant amounts of phosphorus (P) to our surface water bodies and is the primary contaminant of concern in the Lake Champlain Basin (LCB). Farm-PREP was originally developed to help LCB reach TMDL goals for phosphorus.

Collaborators and Funders:

- Vermont Agency of Agriculture, Food, and Markets (VAAFM)
- National Resource Conservation Service
- Lake Champlain Basin Program / New England Interstate Water Pollution Control Commission
- University of Vermont Extension
- University of Vermont Researchers
- Newtrient

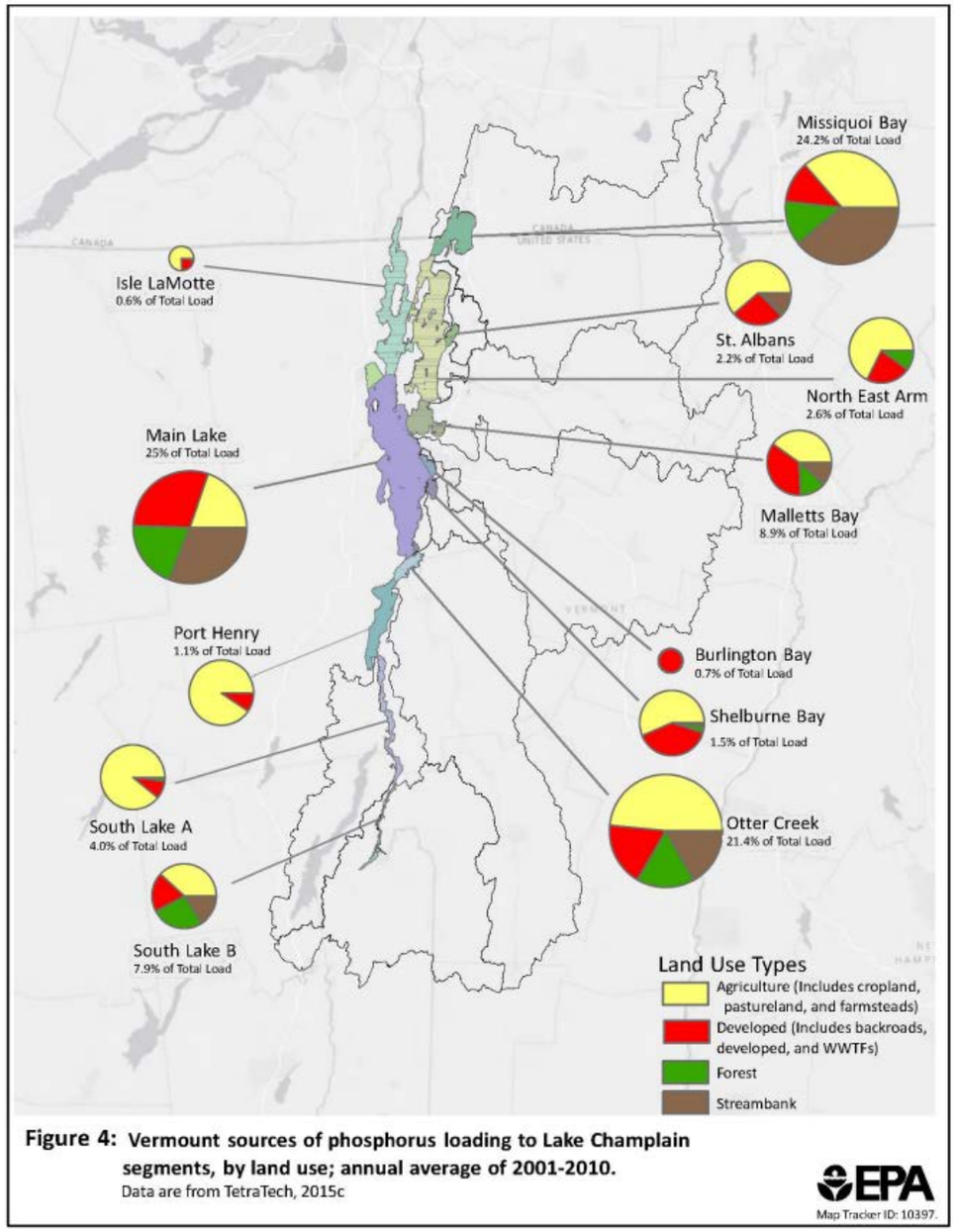


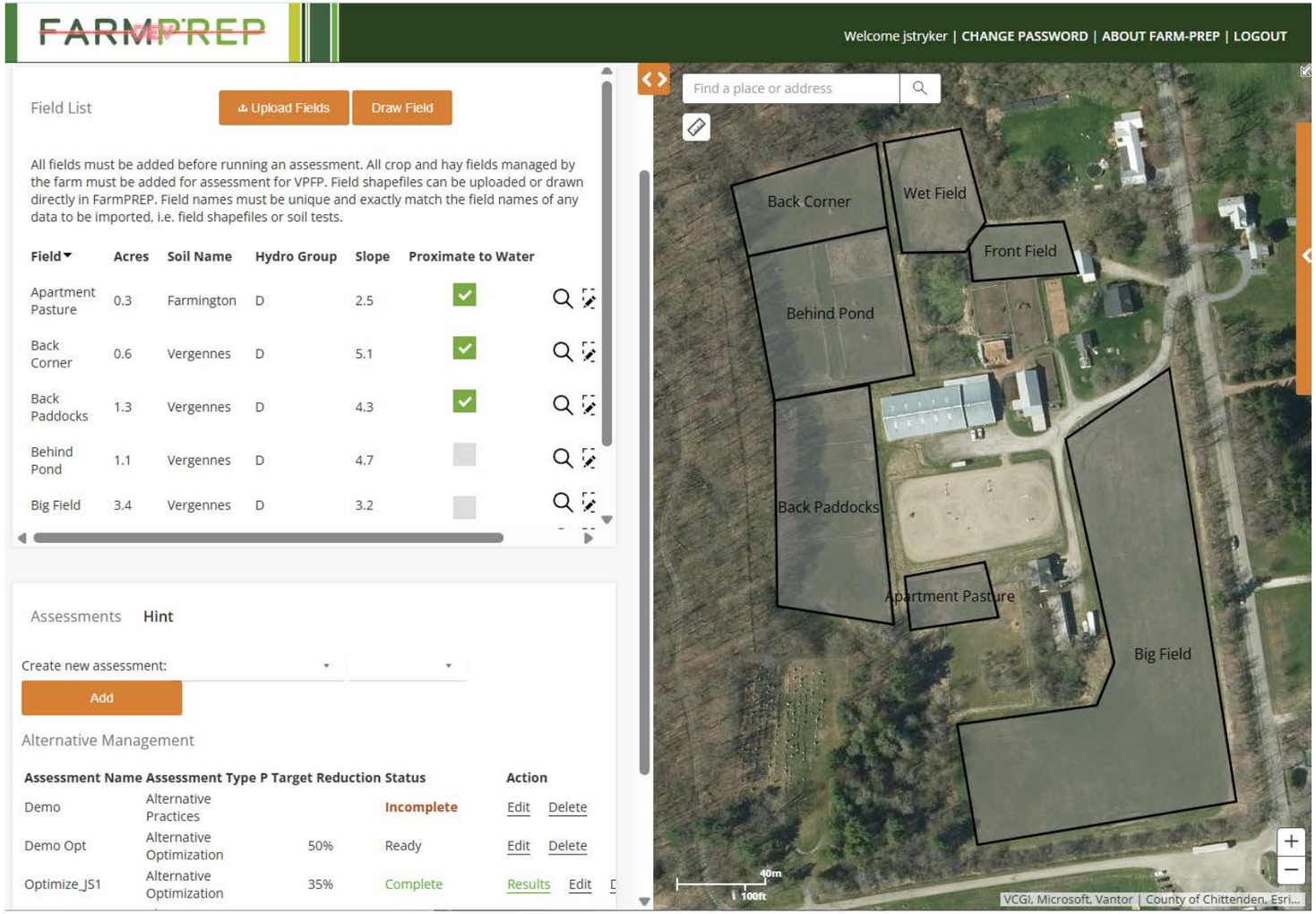
Figure 4: **Vermount sources of phosphorus loading to Lake Champlain segments, by land use; annual average of 2001-2010.**
Data are from TetraTech, 2015c

EPA
Map Tracker ID: 10397.

Background: Farm-PREP (2)

Key components of the tool framework include:

- Customized web-based user interface
  - Streamlined data entry
  - User specific
  - User role-based functionality
- Secure backend database including thousands of options for agronomic management representative of common practices in Vermont
- Dynamic, on-the-fly APEX simulations
- Multiple types of assessments (comprised of many APEX simulations)
- Field and farm-level model analysis and reporting



Background: Vermont Pay for Performance

For the last 5 years, Farm-PREP has been used in support of the Vermont Pay for Performance program, goals of which were:

- Reduce **phosphorus** loss from agricultural fields to meet phosphorus TMDLs and state water quality goals
- Increase farmer buy-in by allowing farmers to decide what practices to implement on their fields
- Produce verifiable, measurable, location-specific outcomes
- Incentivize stewardship
- Provide sufficient and equitable payments to farms

VAAFM uses Farm-PREP to execute field-specific APEX modeling of current and baseline management for cropland and pasture fields.

- Predicts relative changes in runoff, erosion, and phosphorus loss
- Calculates payments (performance and stewardship) based on APEX predictions
- Customized reporting to show what fields contribute to payments or lack of payments

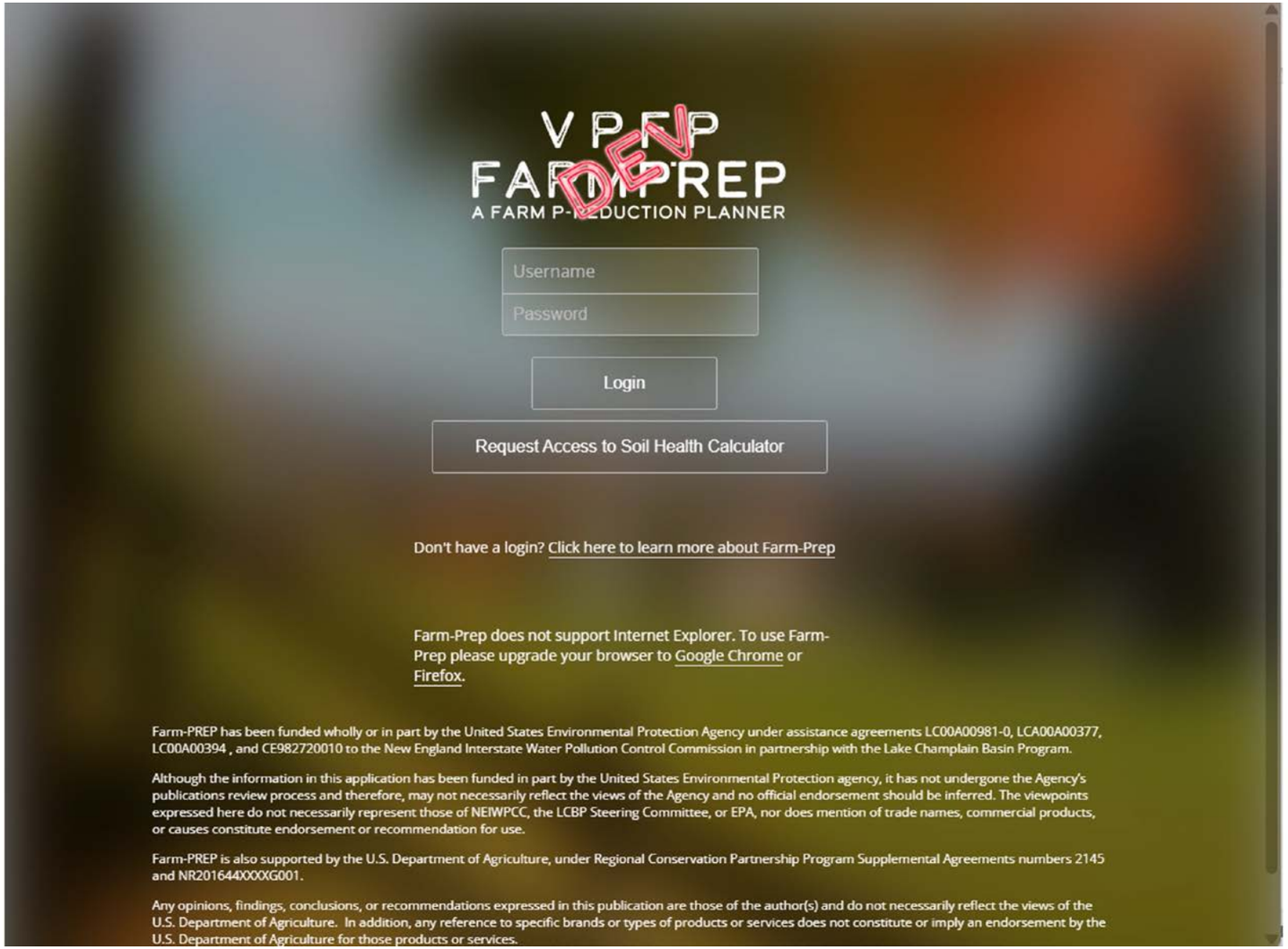
VPFP FARM PREP
A FARM P-REDUCTION PLANNER

Figure 1: Percentage of field acreage, percentage of phosphorus loss, and percentage of payment by current phosphorus loss levels (lb/ac). Fields with lower phosphorus loss levels represent a lower percentage of total phosphorus loss (lb) and a higher percentage of payment.

Tool Development: Farm-PREP Functionality

Data entry:

- Pulls soil and weather data for fields.
- Creates APEX management inputs from dynamic drop-down options.
- Conservation practice implementation options.
- Customized data entry workflows
  - Streamlined for public users
  - Additional requirements for programmatic use
  - Verification/review
  - Coordination with other tools in Vermont (goCrop, Nutrient Management Plans, etc.)
  - Uploads for farms with large numbers of fields



Tool Development: Farm-PREP Assessments

Planned/Actual Assessments

- Assess user specified (current) management against a spatially explicit baseline management
- Baseline representative of TMDL modeling
- Used to calculate performance-based and stewardship payments
- Pay for Performance users

Practice Assessments

- Tool creates alternative practice-based management for all included fields
- Baseline is current management
- Shows users predicted impact of practices on all included fields (where applicable)
- All users

Optimization Assessments

- Tool creates and tests various configurations of practices on included fields to meet user specified farm-scale reduction of phosphorus
- Baseline is no practice scenario
- Shows users first 10 management configurations that achieve desired reduction (within 5% threshold)
- User can prioritize or exclude practices
- All users

Model Development: How do we ‘calibrate’ the tool?

APEX, as with many process-based models, has many inputs and requires calibration/validation.

Two categories of inputs into APEX when we run from Farm-PREP:

- Site-specific
  - in Farm-PREP these are acquired from publicly available datasets (e.g., SSURGO, NOAA land station weather time series) and user inputs
  - these contribute to expected variability across fields
- ‘Global’ parameters
  - these apply to all fields simulated in the tool
  - dictate which algorithms are used to estimate certain processes and coefficients/parameter values for certain equations.

Source: Stone Environmental, Inc.

Global parameter set requires calibration/validation to observed data.

Model Development: Multi-Objective Calibration, Observed Data

Data Type	Number of data points (mostly reflects data-years)	Number of sites
Runoff	34	9
Erosion	32	8
Soluble Phosphorus Loss	30	7
Sediment Phosphorus Loss	25	6
Total Phosphorus Loss	29	8
Soluble Nitrogen Loss	22	5
Sediment Nitrogen Loss	22	5
Total Nitrogen Loss	25	6
Tile Drain Flow	24	8
Tile Drain Phosphorus	14	7
Tile Drain Nitrogen	14	7
Crop Yield	51	7
Net Ecosystem Production	4	4
Carbon Dioxide	18	8
Nitrous Oxide	22	12
Carbon Stocks	6	6
Soil Nitrogen	6	6
Soil Respiration	52	8
Soil Organic Carbon	52	8
Total	**482**	**32**

Data used for model evaluation:

- Site specific comparisons (outputs in table, management known, location or physical characteristics known)

Model Development: Multi-Objective Calibration, Observed Data (2)

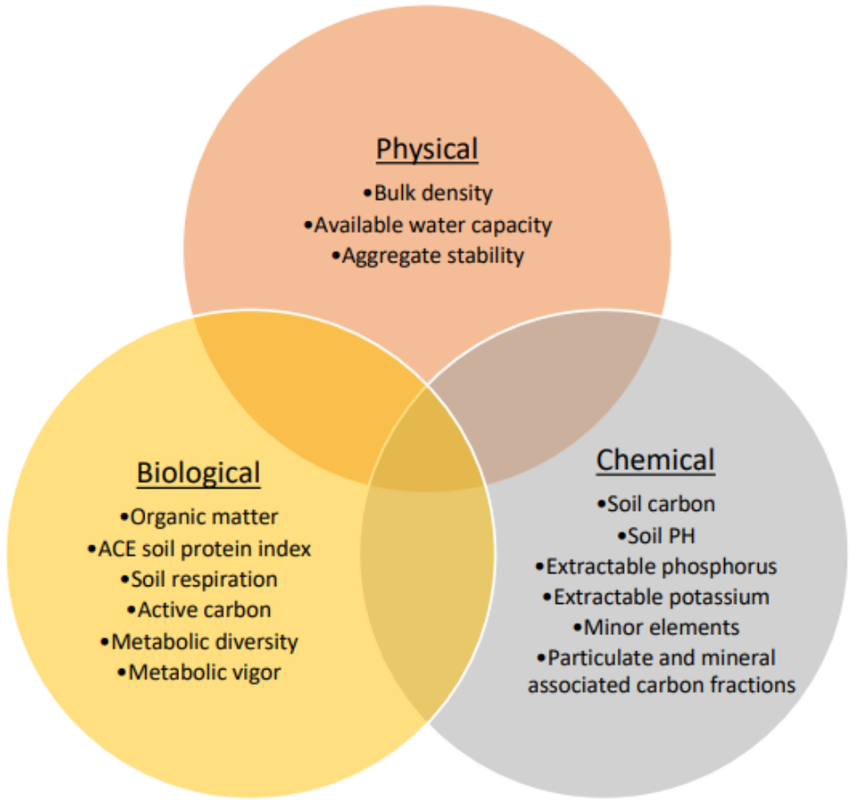
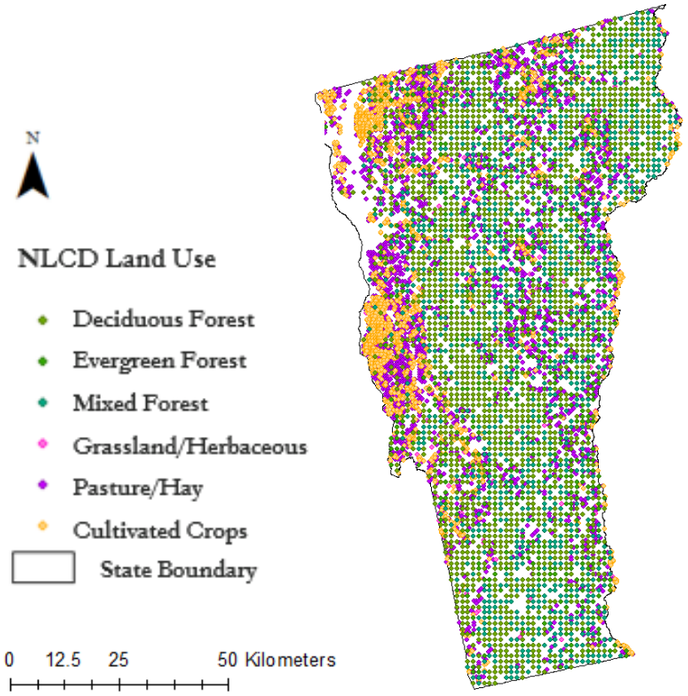


Figure 2. Physical, Chemical and Biological indicators of soil health measured by the 2021 State of Soil Health initiative.

Source: The State of Soil Health in Vermont: Summary statistics from Vermont Agriculture in 2021 (White et al., 2022).

Data used for model evaluation:

- Site specific comparisons (outputs in table, management known, location or physical characteristics known)
- Larger standardized datasets to compare to lots of hypothetical model runs



Model Development: Multi-Objective Calibration, Observed Data (2)

COMET Farm

USDA Natural Resources Conservation Service U.S. DEPARTMENT OF AGRICULTURE

COLORADO STATE UNIVERSITY

Data used for model evaluation:

- Site specific comparisons (outputs in table, management known, location or physical characteristics known)
- Larger standardized datasets to compare to lots of hypothetical model runs
- Comparison to other models

Model Development: Multi-Objective Calibration, Observed Data (2)

Adoption of agricultural conservation practices in the United States: Evidence from 35 years of quantitative literature

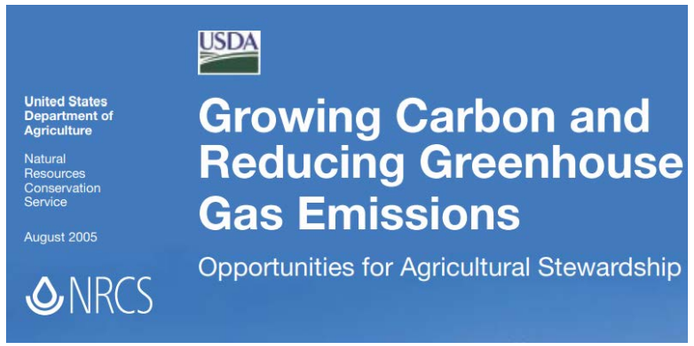
L.S. Prokopy, K. Floress, J.G. Arbuckle, S.P. Church, F.R. Eanes, Y. Gao, B.M. Gramig, P. Ranjan & A.S. Singh

Impact of Agricultural Practices on Soil Health

Chapter | First Online: 27 May 2020

Conservation Agriculture as a Sustainable System for Soil Health: A Review

Belén Cárceles Rodríguez[1], Víctor Hugo Durán-Zuazo[1,*], Miguel Soriano Rodríguez[2], Iván F. García-Tejero[3], Baltasar Gálvez Ruiz[1] and Simón Cuadros Tavira[4]



Data used for model evaluation:

- Site specific comparisons (outputs in table, management known, location or physical characteristics known)
- Larger standardized datasets to compare to lots of hypothetical model runs
- Comparison to other models
- Evaluation of known/established trends from literature

Conservation Agriculture for Sustainable Soil Health Management: A Review of Impacts, Benefits and Future Directions

Fatihu Kabir Sadiq[1,2,*], Ojone Anyebe[2], Fatima Tanko[3], Aisha Abdulkadir[2], Bonface O. Manono[4,*], Tiroyaone Albertinah Matsika[5], Fahad Abubakar[6] and Suleiman Kehinde Bello[2]

Greenhouse gas emissions under conservation agriculture: a synthesis of field observations on integrating conservation tillage and cover crops

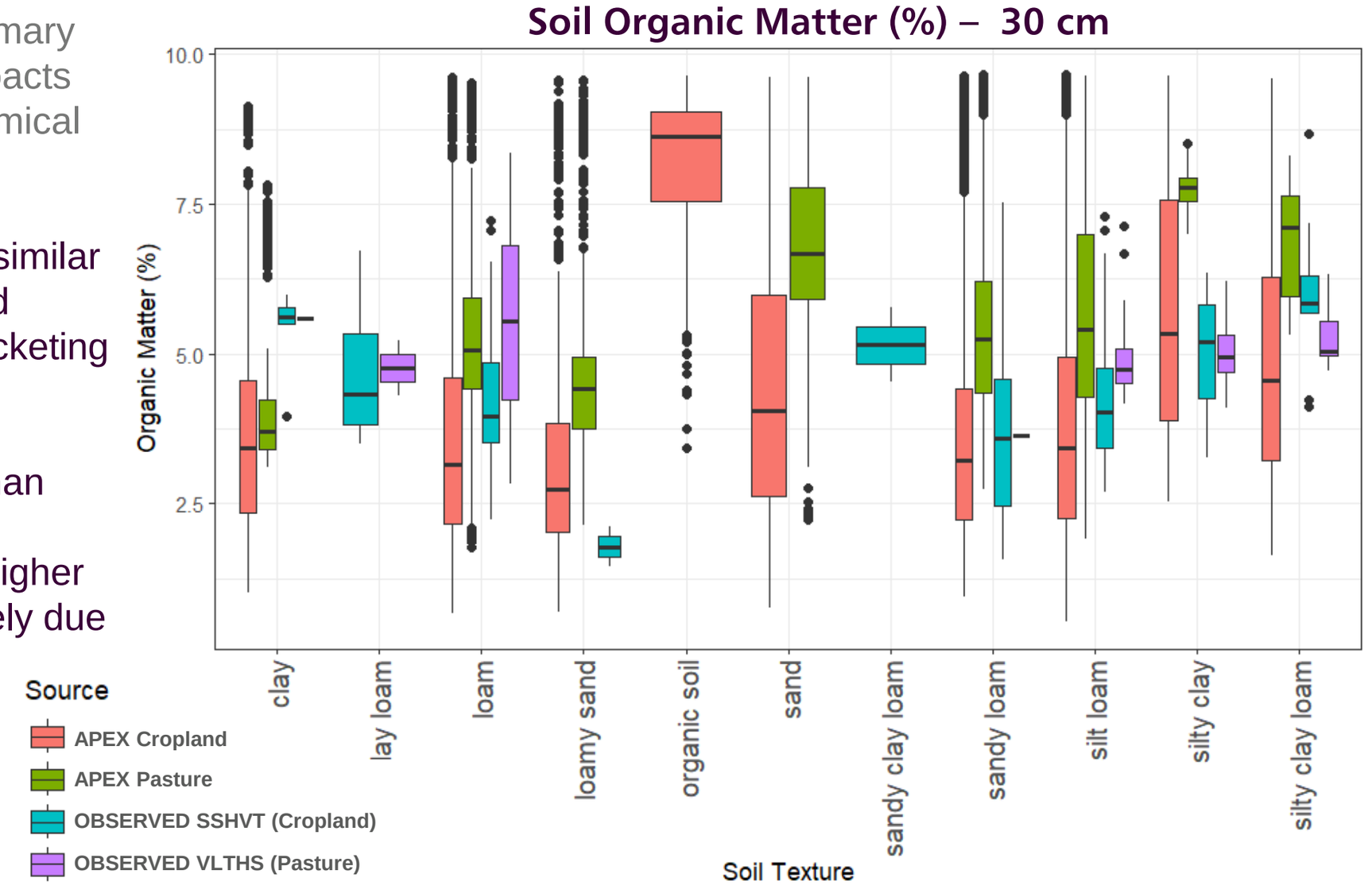
Sandhya Karki, Rattan Lal & Klaus Lorenz

Model Development: Batch Simulations, Comparison to Observed Results

Soil organic matter (SOM): Primary driver of carbon storage and impacts the physical, biological, and chemical properties of soil.

The range of values for SOM is similar between modeled and measured datasets, with model results bracketing the observed.

APEX predicted SOM is lower than SSHVT measured SOM while predicted OM is generally a bit higher that VLTHS measured OM, largely due to simulated management.

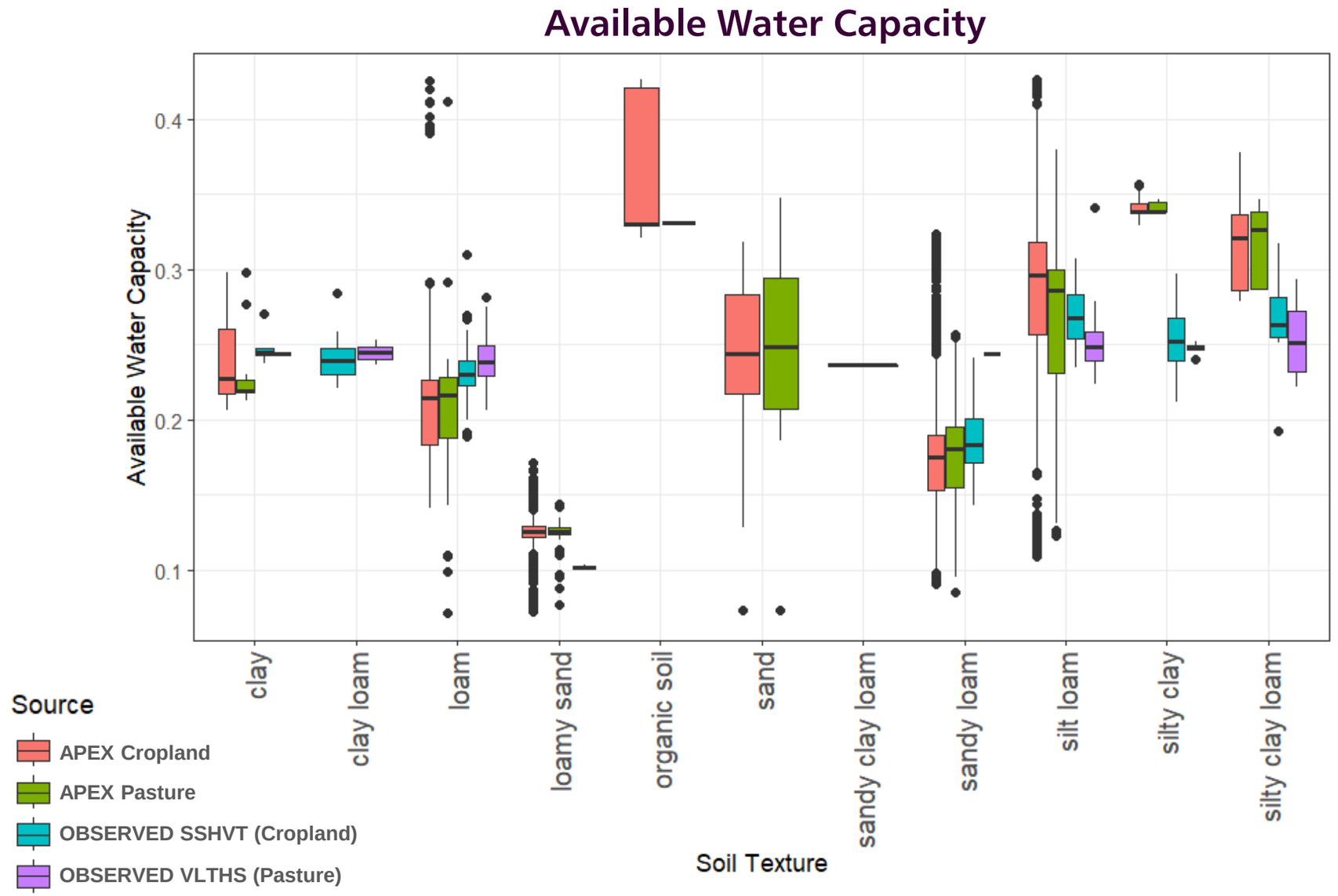


Model Development: Batch Simulations, Comparison to Observed Results (2)

Available water capacity (AWC): related to porosity and represents the amount of water stored in the soil that is available for plant uptake.

Calculated with APEX as the difference between field capacity and wilting point (dynamic).

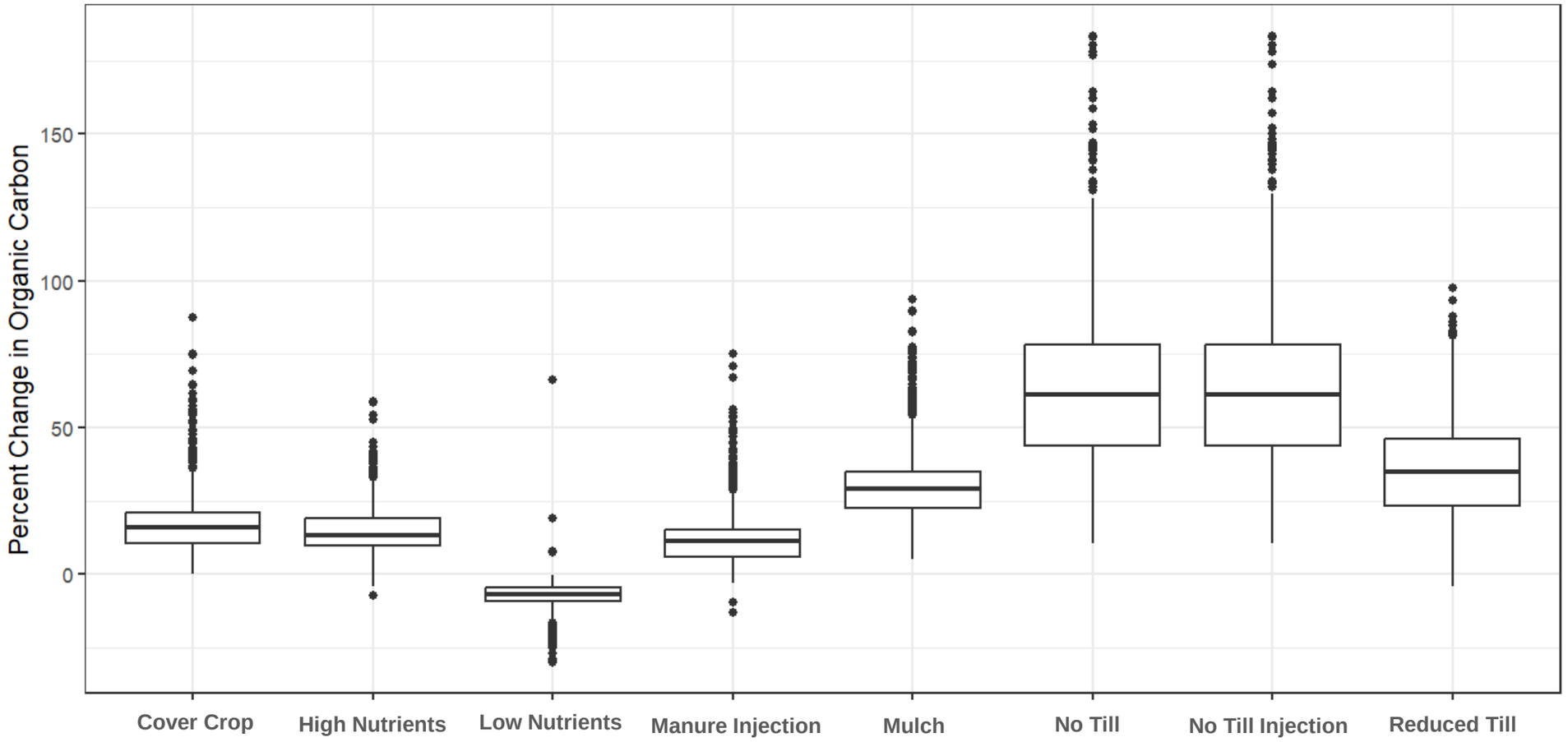
There is strong agreement between modeled and measured AWC in both cropland and pasture soil.



Model Development: Batch Simulations, Management Trends

Soil Organic Carbon/Matter – 15 cm

All practice scenarios except low nutrients result in higher modeled annual average percent soil organic carbon. This is consistent with research that has demonstrated that cover crops increase SOC and that long-term no till systems increase SOM.

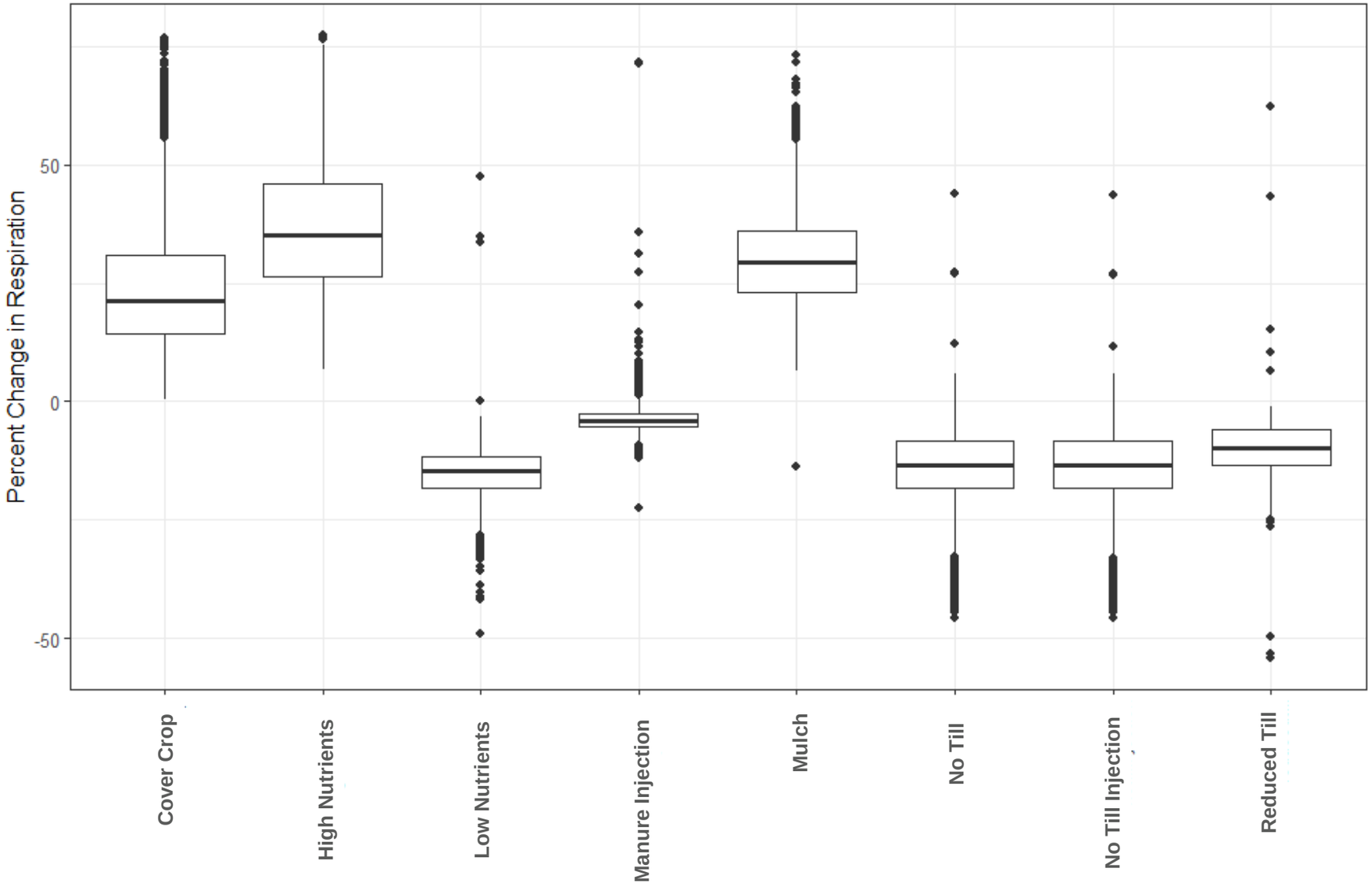


Model Development: Batch Simulations, Management Trends (2)

Respiration

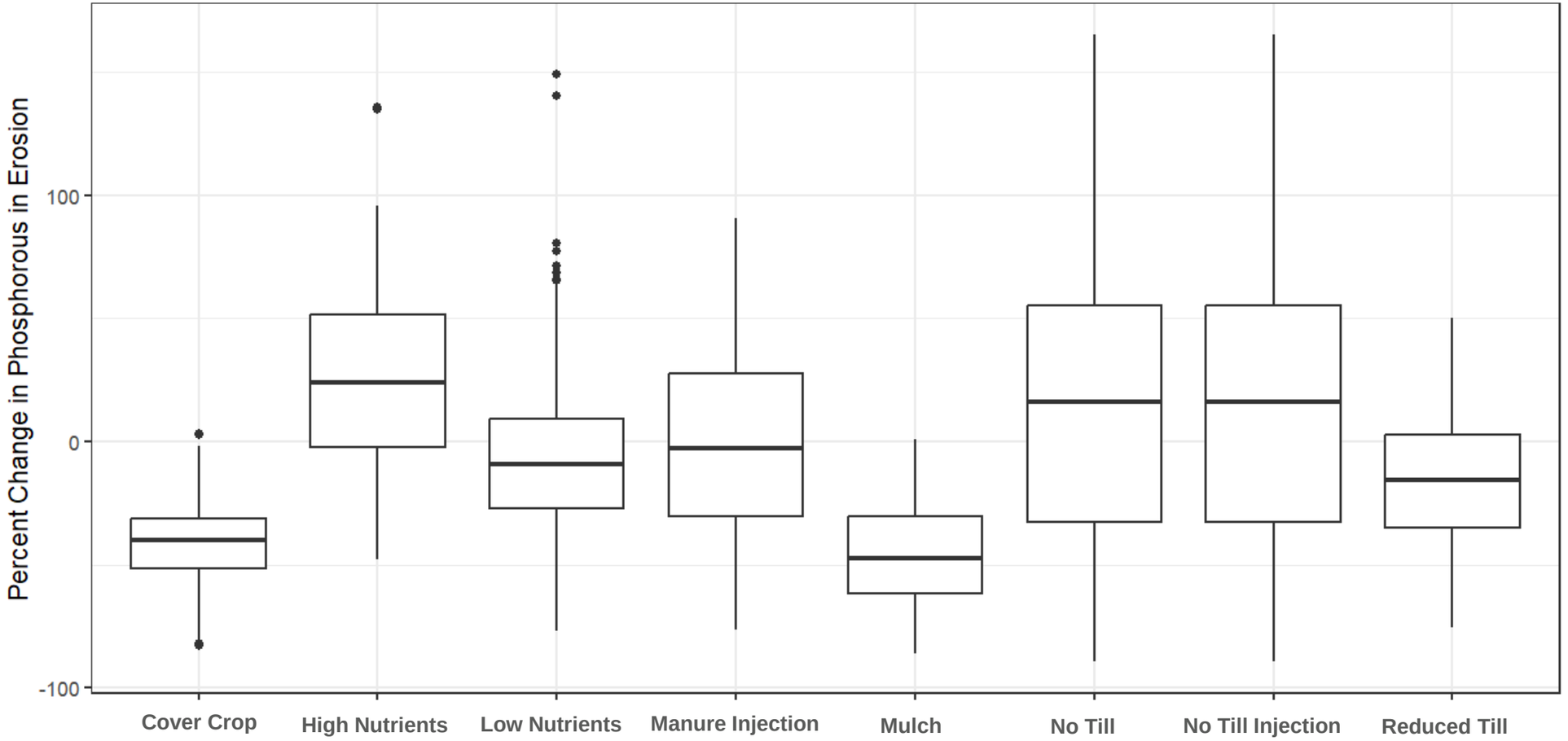
No-till and reduced tillage systems generally increase soil moisture and surface residue, both of which lower soil temperatures. These factors reduce aeration, slow microbial decomposition, and therefore soil respiration.

Other practices that increase available nutrients like mulching and high nutrient inputs also represent additional carbon inputs, favoring plant root growth by providing additional C and N, and increasing respiration.

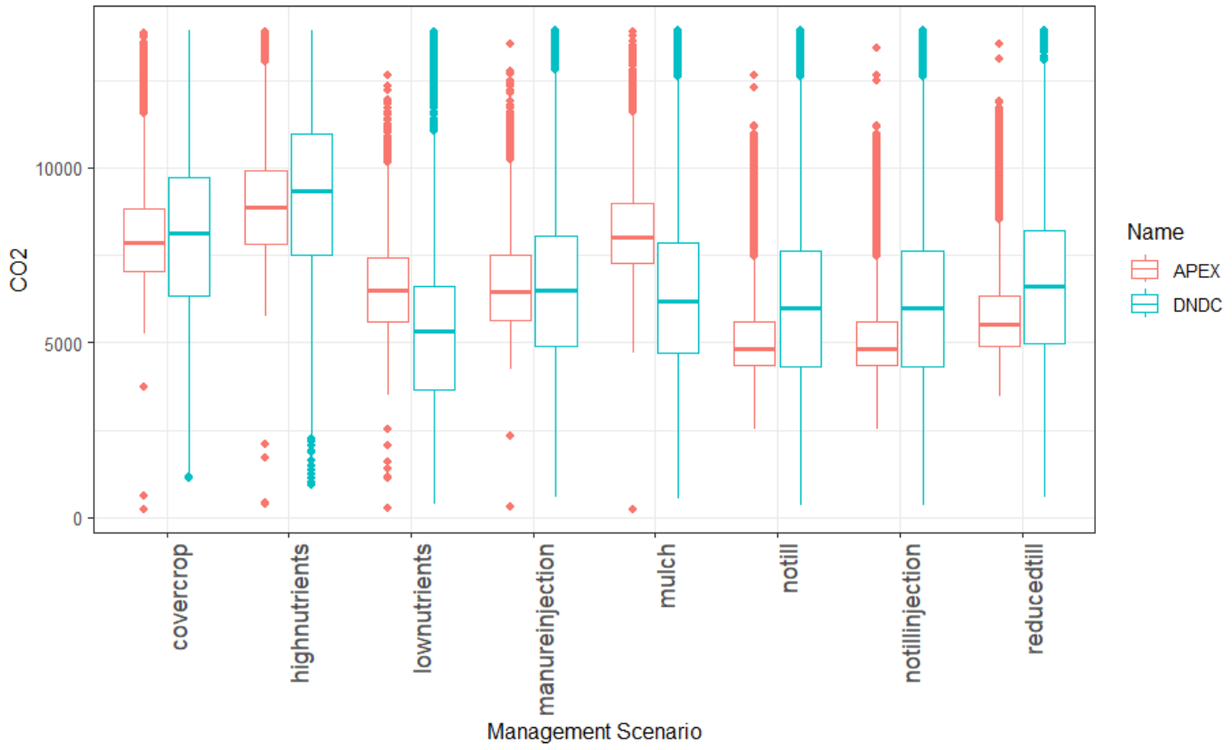


Model Development: Batch Simulations, Management Trends (3)

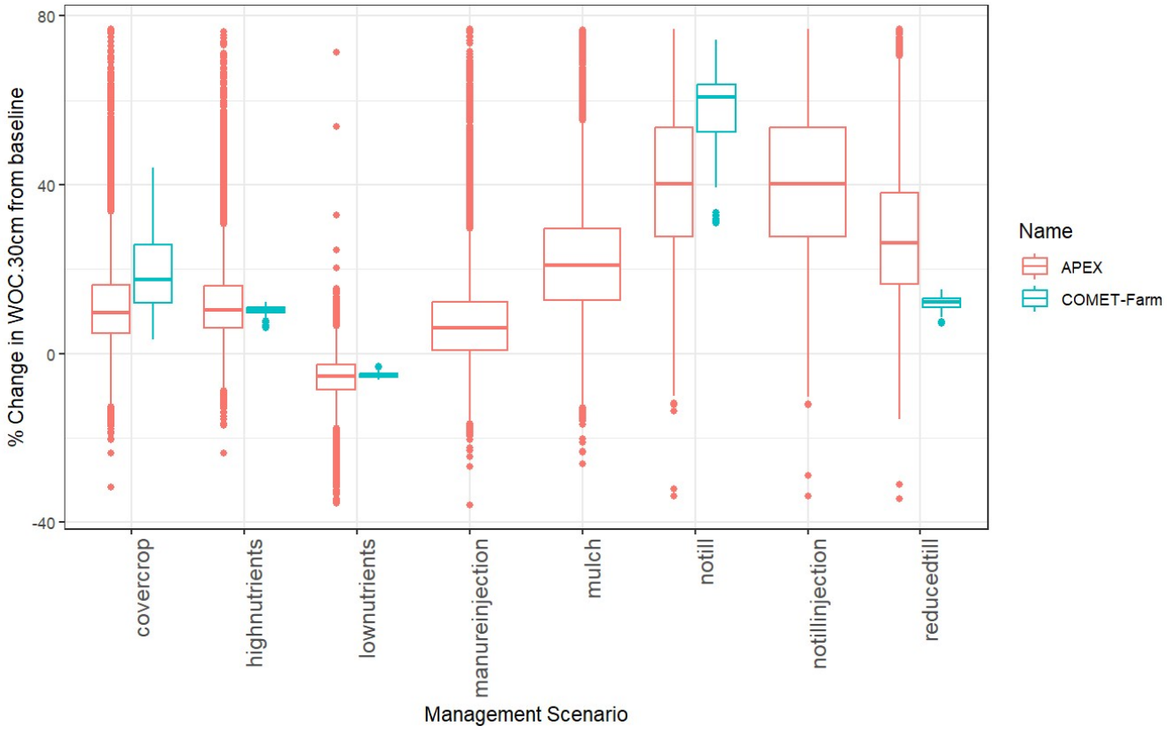
Sediment-driven phosphorous loss declines with cover cropping, lower nutrient inputs, mulching, and reduced tillage due to reduced erosion and lower near surface soil phosphorus concentrations.



Model Development: Greenhouse Gas Comparison, Preliminary



Comparing COMET-Farm and DNDC to APEX results for outputs and scenarios we can harmonize, predictions generally show decent agreement.



Are predicted values from different models similar?

Do different models respond similarly to simulated management?

Modeling Results: Sustainability Metrics

Soil Health

- Bulk density
- Soil organic matter
- Respiration
- Active carbon
- Peak soluble P in soil
- Plant available water capacity

Crop Metrics

- Crop nitrogen stress
- Crop phosphorus stress
- Yields
- Total nitrogen applied
- Total phosphorus applied

Greenhouse Gases

- CO_2 Flux
- N_2O Flux
- Gross GHG Emissions
- Carbon Sequestered in Soil
- Soil Carbon Stocks

Surface Losses

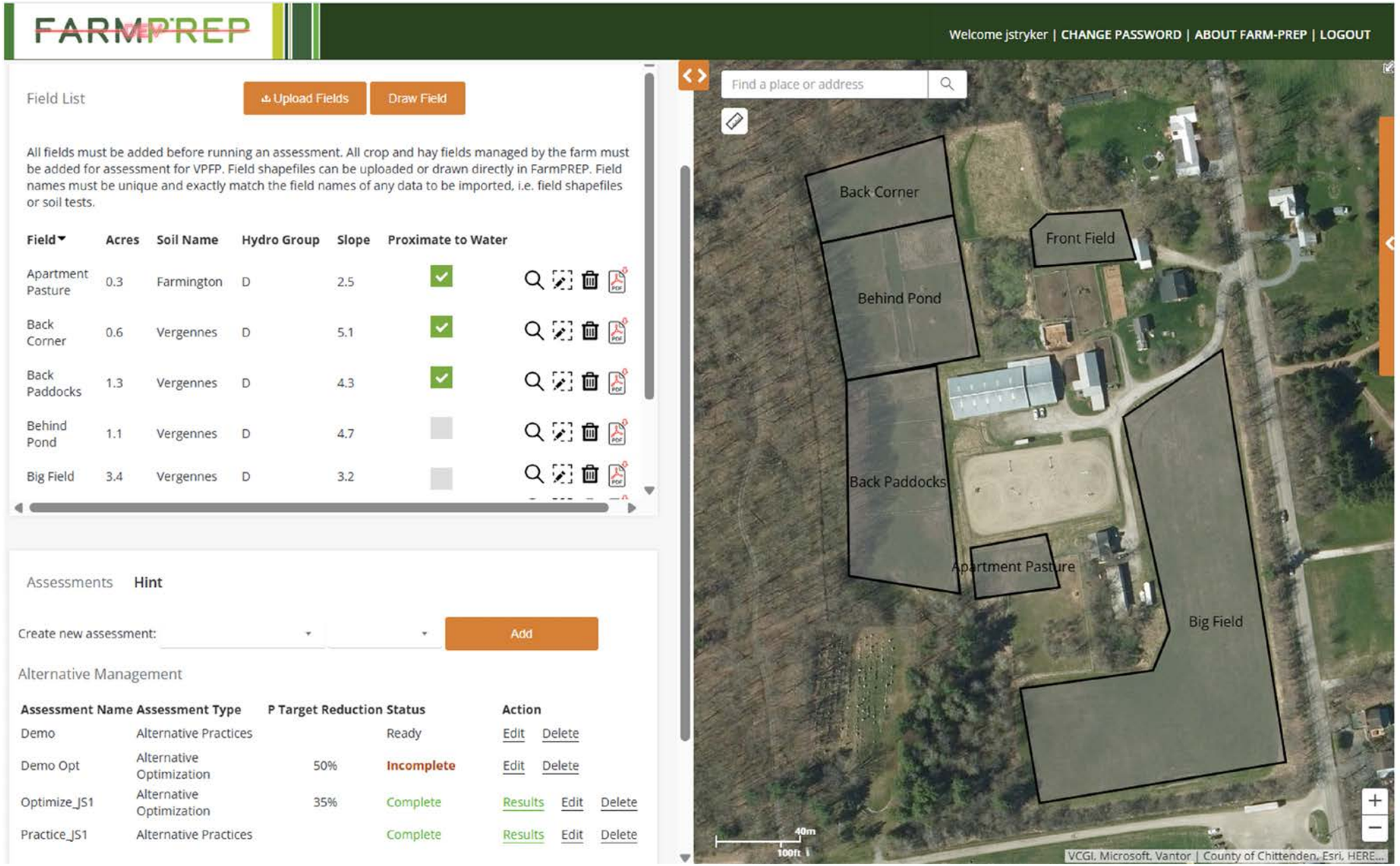
- Precipitation
- Runoff
- Erosion
- Nitrogen surface losses
- Phosphorus surface losses
- Nitrogen volatilization

Reporting is focused on annual average (or average growing season) values over 30-year simulation.

Also report change in soil organic matter and change in bulk density from start to end of simulations.

Can report on inter-annual variability.

Modeling Results: Farm-PREP Example Assessments



Take-aways: Our goal

Increased adoption of agricultural management practices that enhance and/or maintain healthy soils, reduce greenhouse gas emissions and sequester carbon, reduce nutrient and pesticide losses, and meet the agronomic needs of farmers through customized scenario analysis.

Source: Drilled cover crops in Waterford VT (https://vermontbiz.com/news/2023/january/05/vermont-pay-performance-program-application-now-open-farms).

Take aways: Where are we?

We established a robust global APEX calibration for modeling multiple processes and output metrics on agricultural fields VT

Trends in environmental responses to management practice changes align with our expected behavior across a broad range of metrics

Tillage and nutrient inputs are a primary driver across most metrics, but land use and other practices/factors also have an impact

Our updated APEX modeling approach and calibration are implemented in Farm-PREP, providing a more holistic quantification of the environmental benefits to changes in farm management

Source: https://cedarcirclefarm.org/tips/entry/no-till-agriculture

Take aways: Future work and opportunities

Continue to work with Vermont Agency of Agriculture on Pay for Performance 2.0

- Improve comparison tool for even better communication of outcomes and decision support
- Additional outreach and training
- Continue to evaluate APEX modeling for greenhouse gases and working lands (e.g. forest)

Alternative baselines (relative field vulnerability, or other)

Build climate change scenarios into the tool

Customization and additions … for pesticides, national scale, user workflows, ‘talking’ to other tools, …

FARMP'REP

VPFP
FARMP'REP
A FARM P-REDUCTION PLANNER

Acknowledgements

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Questions?

For more information contact:

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