Impact of the parameterization of soil hydrological properties on APEX model performance

Dr. Lima, Edberto Moura, Böning Kristin, Bano Mehdi-Schulz

University of Natural Resources & Life Sciences, Vienna
(BOKU)Department of Water-Atmosphere-Environment

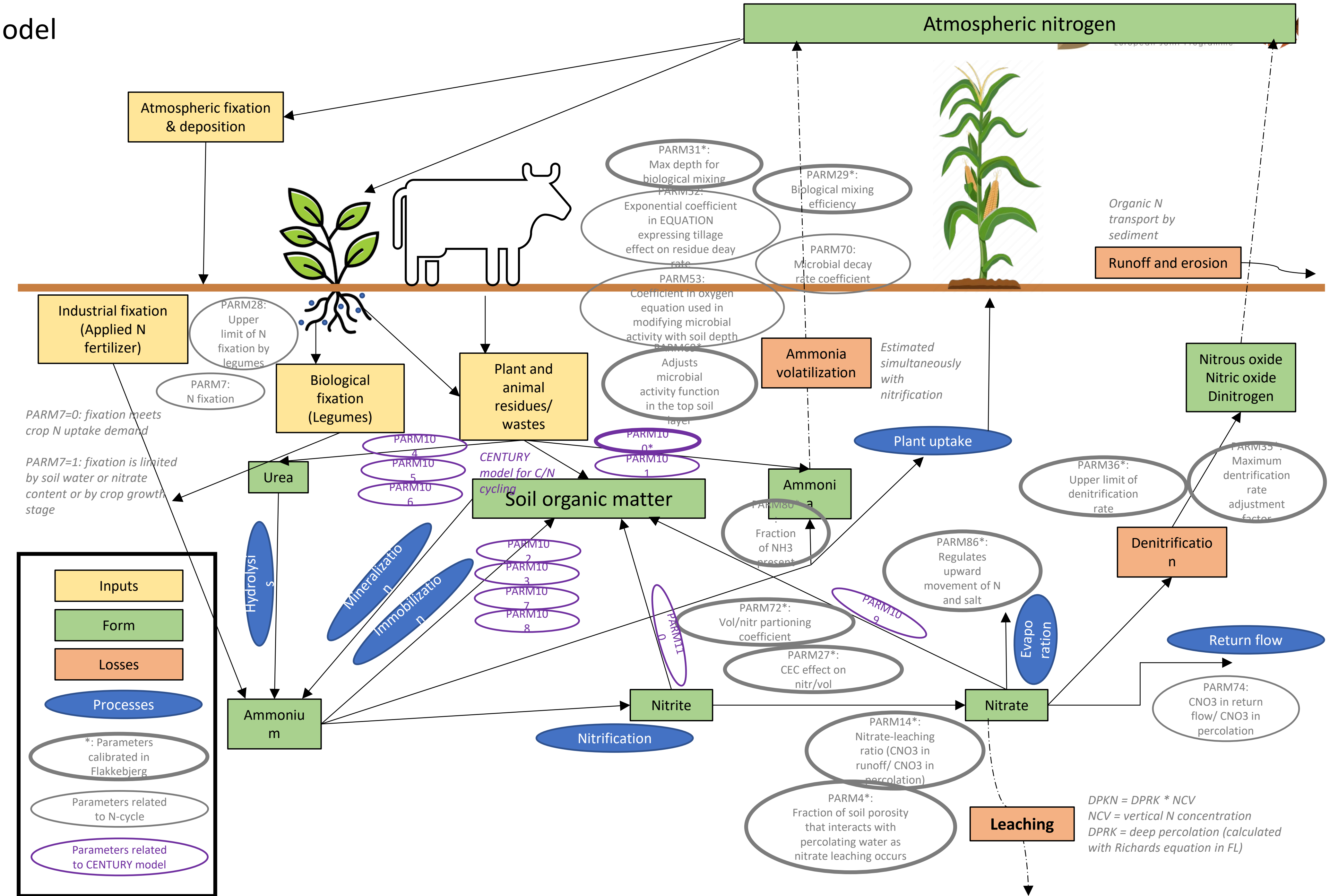
Introduction

- **Agriculture & Environmental Services**
  - Supports crop production, pollution control, nutrient recycling, and climate regulation.
  - Soil health and land management impact environmental sustainability.
- **Conventional Tillage (CT) Systems**
  - Used in 87% of agricultural lands (Kassam et al., 2018).
  - Linked to soil degradation, erosion, and reduced water quality.
- **Conservation Agriculture (CA)**
  - Based on minimal soil disturbance (no-till), permanent soil cover, and crop diversification.
  - Improves soil health, organic carbon, and resilience to climate change.

Introduction

- **Hydrological Models (Physically-Based Models)**
  - Simulate soil, crop, and environmental dynamics.
  - Useful for comparing land management strategies (e.g., tillage vs. no-till).
- **Applications & Challenges**
  - Requires extensive field data (weather, soil properties, and management practices).
  - Costly field experiments and limited data availability pose challenges.
  - Commonly used models include APEX to assess soil, water, nutrient dynamics, and climate impacts.
- **Challenges**
  - Requires extensive field data (weather, soil properties, management).
  - Field experiments are costly, and data availability is limited.
- **APEX Model Overview**
  - Designed to simulate small watersheds and field-scale areas.
  - Includes nine components: weather, hydrology, soil temperature, tillage, and more.
- **Applications of APEX**
  - Analyze effects of management practices on water, soil, and nutrient dynamics.
  - Calibration and validation with field data are crucial for accuracy.

APEX model



Atmospheric nitrogen
Atmospheric fixation & deposition
Industrial fixation (Applied N fertilizer)
PARM28: Upper limit of N fixation by legumes
PARM7: N fixation
PARM7=0: fixation meets crop N uptake demand
PARM7=1: fixation is limited by soil water or nitrate content or by crop growth stage
Biological fixation (Legumes)
Plant and animal residues/ wastes
PARM31*: Max depth for biological mixing
PARM32: Exponential coefficient in EQUATION expressing tillage effect on residue deay rate
PARM53: Coefficient in oxygen equation used in modifying microbial activity with soil depth
PARM69*: Adjusts microbial activity function in the top soil layer
PARM29*: Biological mixing efficiency
PARM70: Microbial decay rate coefficient
Organic N transport by sediment
Runoff and erosion
Ammonia volatilization
Estimated simultaneously with nitrification
Nitrous oxide Nitric oxide Dinitrogen
Plant uptake
PARM104
PARM105
PARM106
PARM100*
PARM101
CENTURY model for C/N cycling
Urea
Soil organic matter
Ammonia
PARM80*: Fraction of NH3 present
PARM36*: Upper limit of denitrification rate
PARM35*: Maximum dentrification rate adjustment factor
Denitrification
Hydrolysis
Mineralization
Immobilization
PARM102
PARM103
PARM107
PARM108
PARM110
PARM72*: Vol/nitr partioning coefficient
PARM27*: CEC effect on nitr/vol
PARM109
PARM86*: Regulates upward movement of N and salt
Evaporation
Return flow
PARM74: CNO3 in return flow/ CNO3 in percolation
Ammonium
Nitrite
Nitrate
Nitrification
PARM14*: Nitrate-leaching ratio (CNO3 in runoff/ CNO3 in percolation)
PARM4*: Fraction of soil porosity that interacts with percolating water as nitrate leaching occurs
Leaching
DPKN = DPRK * NCV
NCV = vertical N concentration
DPRK = deep percolation (calculated with Richards equation in FL)
Inputs
Form
Losses
Processes
*: Parameters calibrated in Flakkebjerg
Parameters related to N-cycle
Parameters related to CENTURY model

Objective

The aim of this study is to assess the impact of soil hydraulic input parameters on simulations crop yield and model performance under conventional tillage and no-till systems.

To achieve this aim, the following research questions are stated:

1. Can the soil hydraulic parameters estimated with pedotransfer functions (PTFs) replace extensive field soil sampling.
2. Can the required data alone lead to a good model performance for both tillage systems?
3. How big is the variation between the model with PTFs on the simulated crop yields?

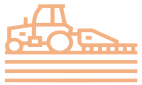
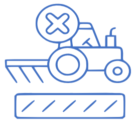
Methodology - Experimental Site

Study Site

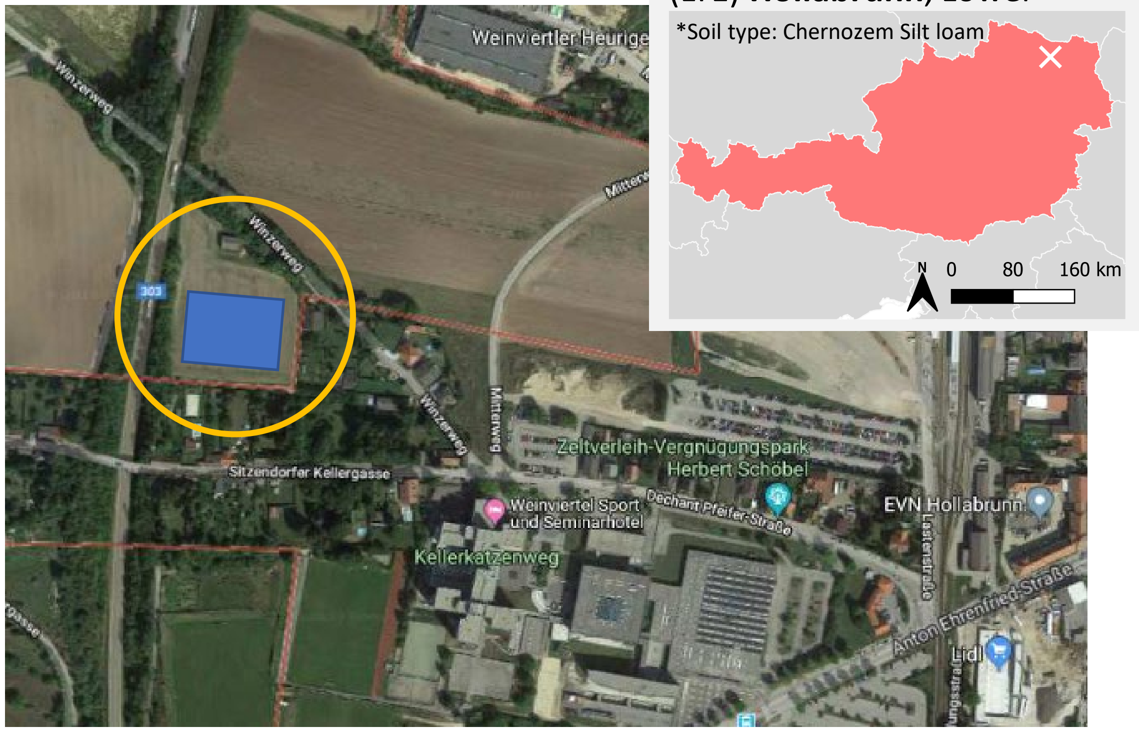
Long-Term Field Experiment (LTE) in Hollabrunn, Lower Austria

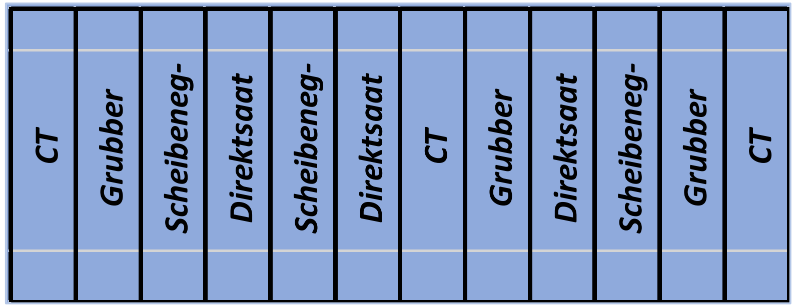
- Semi-arid Pannonian climate (precipitation: 493 mm/year)
- Soil: Calcareous Chernozem, loamy silt

Tillage Treatments

- Conventional Tillage (CT): Moldboard plow, rotary harrow 
- No-Till (NT): Direct seeder 

Long-Term Field Experiment (LTE) **Hollabrunn**, Lower





Methodology - Data Collection

Data Collection & Model Inputs

Soil Sampling (April 2023)

Bulk density, particle size, water retention, and hydraulic conductivity measured (e.i. Field Capacity (FC), Wilting Point (WP), Saturation (SAT))

APEX Model Setup

Potential Evapotranspiration Equation: Hargreaves

Richards-based soil Water Percolation Method

10-year warm-up (1996-2023)

Input data: weather, soil, field operations (crop cycles from 2003-2023)

Methodology – Input soil data

Soil Hydraulic Properties & Pedotransfer Functions (PTFs)

Soil Hydraulic Properties for Model Input

- Field Capacity (FC),
- Wilting Point (WP),
- Saturation (SAT)

Pedotransfer Functions (PTFs)

- Used when measured values are unavailable
- Test impact of PTF-based estimations on crop yields simulation.

Variable	Variable
Z	Depth from the soil surface to the bottom of the layer (m)
BD	Bulk Density (t/m3)
SAN	Sand Content
SIL	Silt Content
PH	Soil pH.
WOC	Organic carbon concentration (%)

Predictor variables	**FC**	**UW**	**SATC**	**Model**
USSAND+USSILT+USCLAY+DEPTH_M	PTF01	PTF01	PTF01	PTF01.01.01
USSAND+USSILT+USCLAY+DEPTH_M+OC	PTF02	PTF02	PTF02	PTF02.02.02
USSAND+USSILT+USCLAY+DEPTH_M+BD	PTF01	PTF01	PTF01	PTF01.01.01
USSAND+USSILT+USCLAY+DEPTH_M+PH_H2O	PTF01	PTF01	PTF01	PTF01.01.01
USSAND+USSILT+USCLAY+DEPTH_M+OC+BD	PTF02	PTF02	PTF02	PTF02.02.02
USSAND+USSILT+USCLAY+DEPTH_M+OC+PH_H2O	PTF02	PTF02	PTF02	PTF02.02.02
USSAND+USSILT+USCLAY+DEPTH_M+BD+PH_H2O	PTF03	PTF01	PTF05	PTF03.05.01
USSAND+USSILT+USCLAY+DEPTH_M+OC+BD+PH_H2O	PTF02	PTF07	PTF02	PTF02.02.07

Methodology - Experimental Site

Calibration & Validation Process

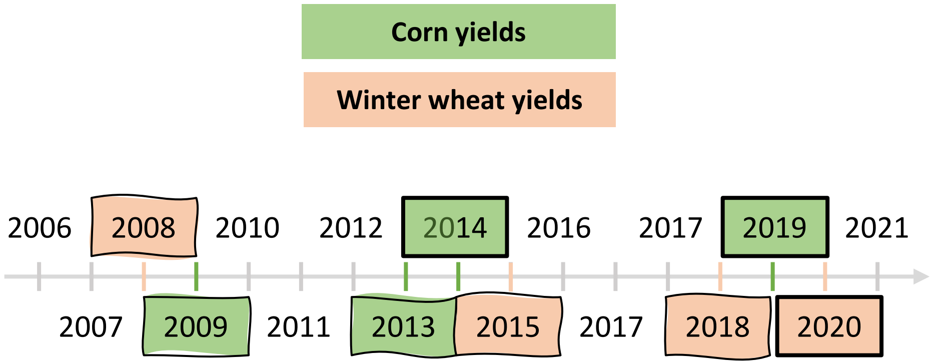
Model Calibration

- Calibrated yields on Block A
- Sensitivity analysis to identify key parameters for yield
- Calibration performed on yield data for maize and winter wheat

Validation

- Yields on blocks B and C to validate
- Evaluating the influence of PTFs on model accuracy

Parameter	Definition
PARM23	Hargreaves PET equation coefficient
PARM34	Hargreaves PET equation exponent
PARM26	Fraction of maturity at spring growth initiation
WA	Biomass-Energy Ratio
HI	Harvest Index
TOP	Optimal Temperature for Plant Growth
TBS	Minimum Temperature for Plant Growth
DMLA	Maximum Potential Leaf Area Index
DLAI	Fraction of Growing Season When Leaf Area Declines



Methodology - Analysis of Interaction Effects: PTF and Tillage System on Crop Yields

Examine the interaction between soil hydraulic properties and tillage systems on yields of CORN and WWHT.

Method:

Utilized a generalized linear mixed-effects model (GLMM) to evaluate the relationship between yields (response) and predictors (soil properties & tillage).

Random intercepts for tillage systems were included to account for treatment variation.

Model:

Yields ~ Model*(1 | Treatment)

Robust Estimation:

Used the robustlmm R package for model fitting.

Ensures reliable estimates in the presence of potential data contamination by applying random effects contamination models.

Results: APEX Calibration and Performance

The initial setup lead to 21 optimal, non-unique sets of crop parameters were identified across various crops and tillage systems.
Using a shared set of crop parameters for all treatments led to inconsistent performance, particularly in validation.
Reduced accuracy for CORN yields under non-tillage systems highlights sensitivity to soil and crop input conditions.

Table 4: Model performance statistics for crop yields under different treatments and blocks.

Crop	Treatment	Block[1]	RSME		KGE	
			Min	Max	Min	Max
WWHT	IST	A	1.04	1.12	0.50	0.58
	NTS	A	0.85	0.97	0.45	0.57
	IST	B	0.97	1.05	0.49	0.53
	NTS	B	0.79	0.92	0.50	0.64
	IST	C	0.81	0.92	0.53	0.64
	NTS	C	0.95	1.07	0.46	0.59
CORN	IST	A	1.05	1.17	0.63	0.70
	NTS	A	0.93	1.10	0.49	0.55
	IST	B	0.83	1.12	0.39	0.82
	NTS	B	0.91	1.37	-0.55	-0.33
	IST	C	0.74	1.19	0.61	0.78
	NTS	C	1.03	1.37	0.07	0.17

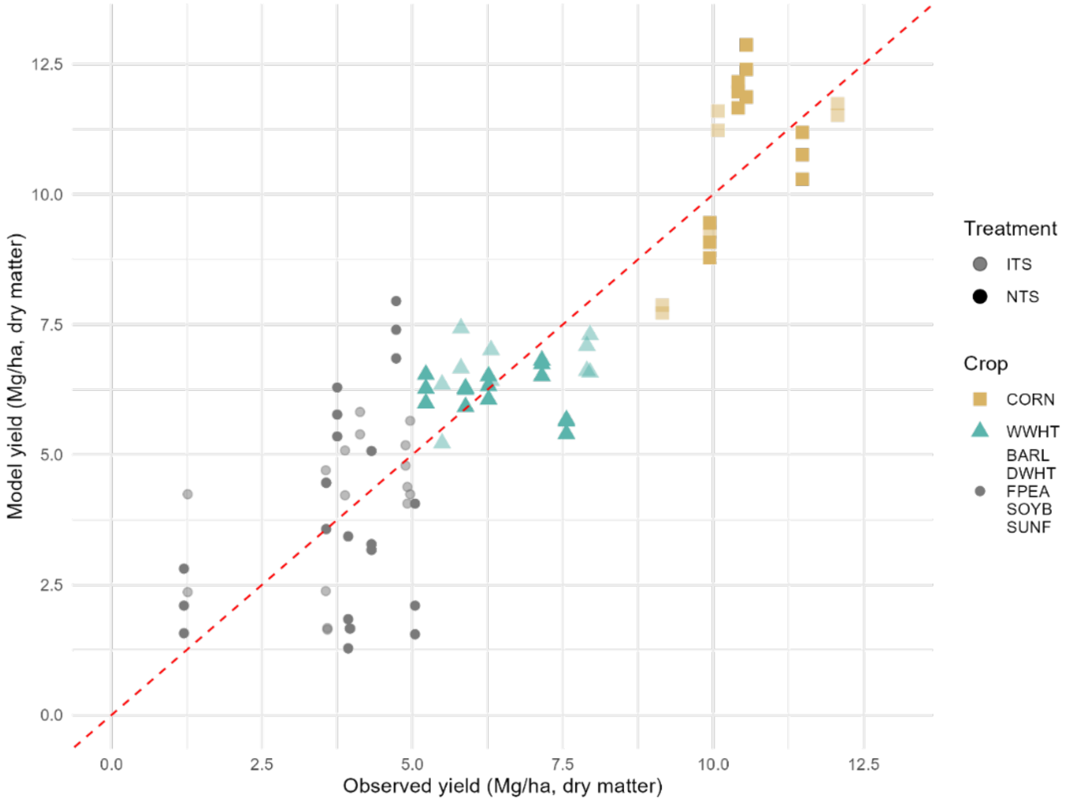


Figure 1: Model yield versus historical LTE-reported (2006-2023) yield for WWHT and CORN under ITS and NTS tillage system.

Results: APEX Calibration and Performance

The best-fit solutions for non-unique crop parameter sets resulted in the following outcomes:

- In the ITS, the simulated average yields for corn and wheat were 10.1 Mg/ha and 6.7 Mg/ha, respectively, with root mean square errors (RMSE) of 1.04 and 1.05.
- In the NTS, the average yields for corn and wheat were 10.8 Mg/ha and 6.2 Mg/ha, respectively, with RMSE values of 0.85 and 0.93.

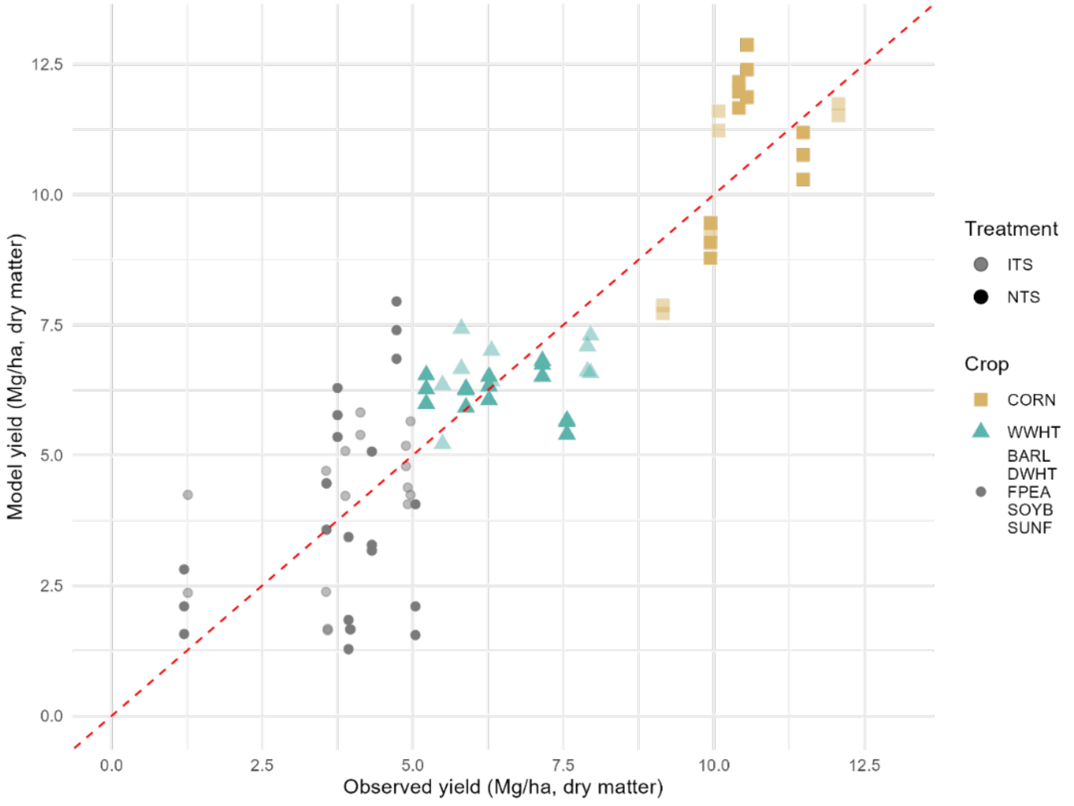


Figure 1: Model yield versus historical LTE-reported (2006-2023) yield for WWHT and CORN under ITS and NTS tillage system.

Results: APEX performance with PTFs

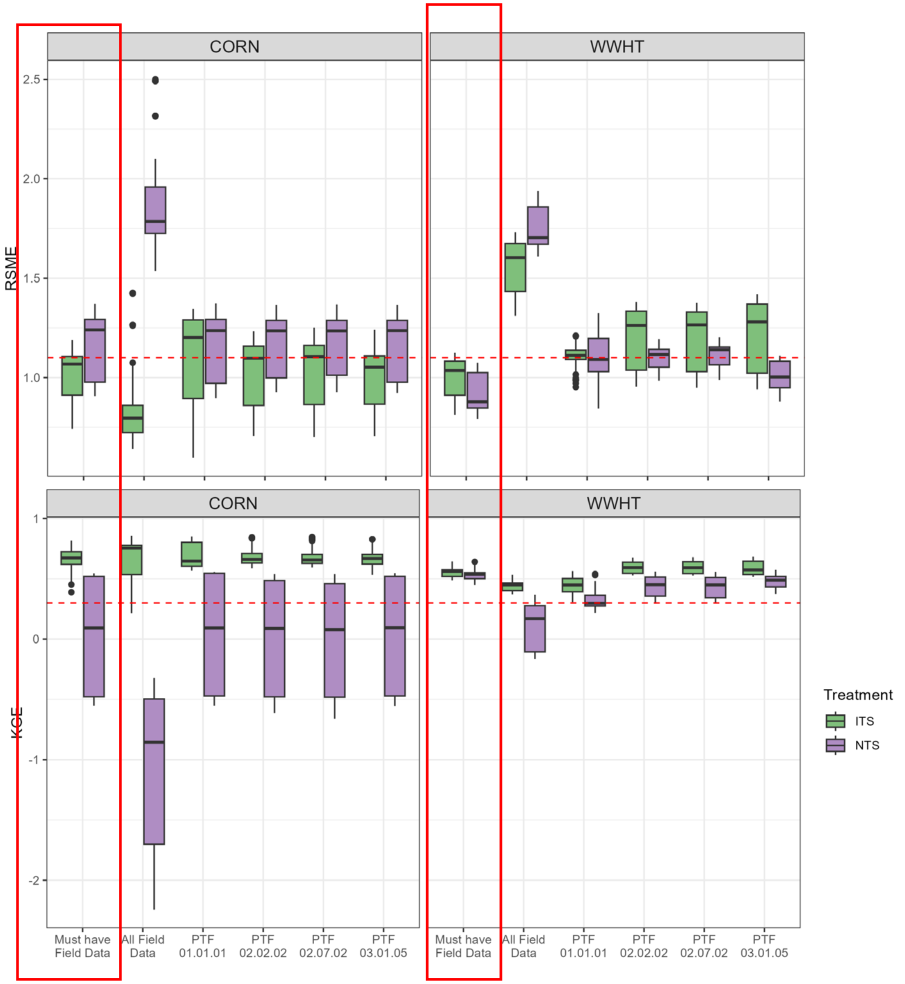


Figure 2: Comparison of performance criteria between model simulations. The horizontal red slash line shows optimal value of performance criteria.

To evaluate the impact of PTFs model parameters on Yields simulation, values for the RSME and KGE performance criteria were compared between the 21 optimal non-unique sets of crop parameters selected across different crops and tillage systems.

Model setup with soil data derive from an extensive soil sampling poorly performed for CORN under non-till system.

Results: Estat. effects of PTFs and tillage on Yields

Effects on WWHT Yields

- **Baseline Intercept**:
- **Measured Data**: Decreased yields by 0.752.
- **PTF Models**:
    - PTF02.02.02: Decreased yields by 0.267.
    - PTF02.07.02: Decreased yields by 0.288.
    - PTF03.01.05: Decreased yields by 0.209.
    - PTF01.01.01: Increased yields by 0.286.
- **Tillage System**: No significant effect on WWHT yields.

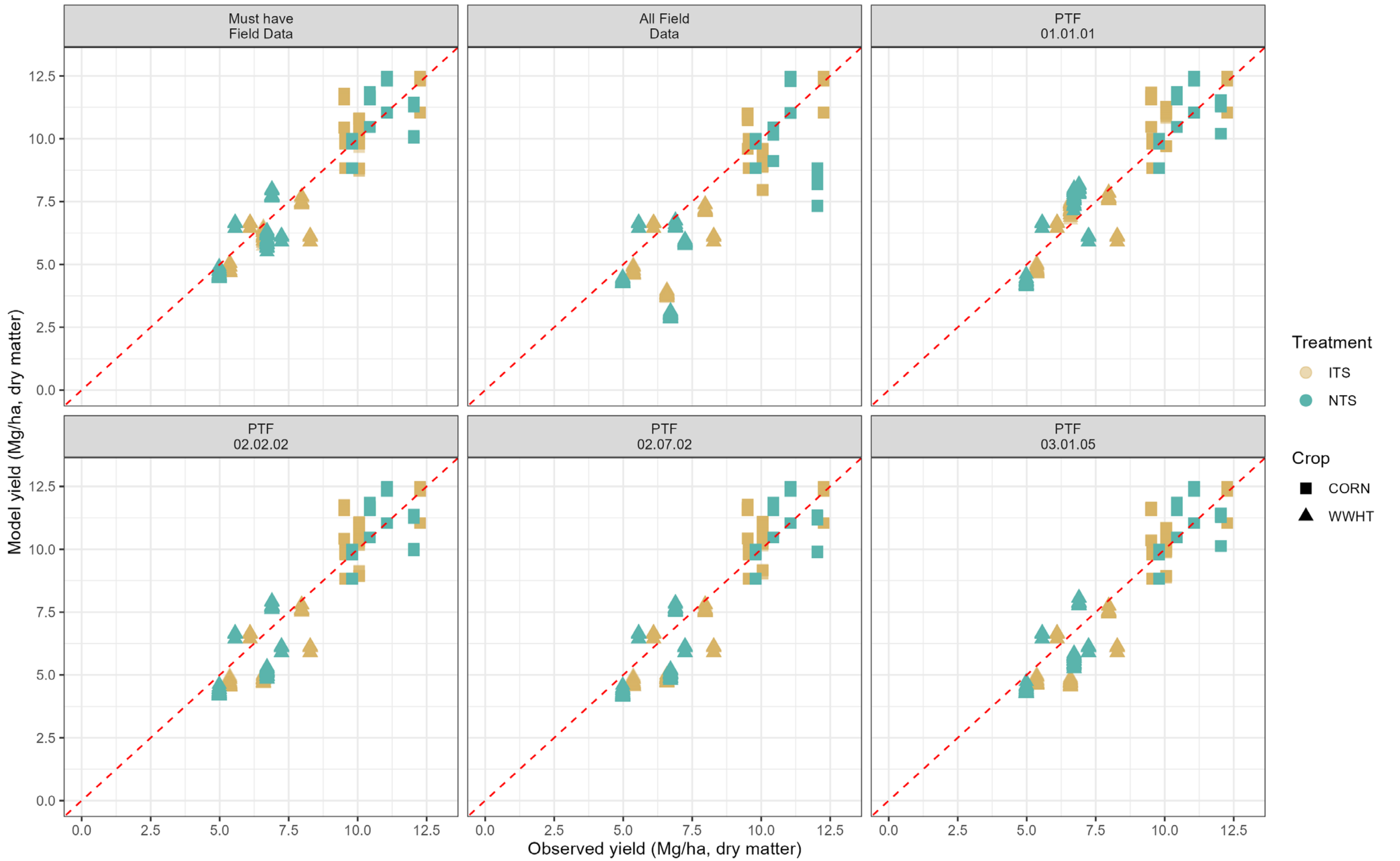


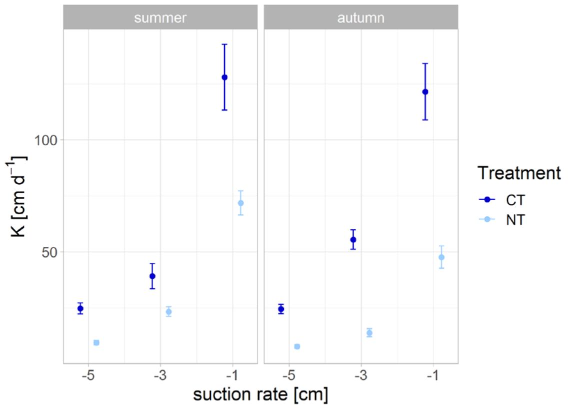
Figure 2: Model yield versus historical LTE-reported (2006-2023) yield for WWHT and CORN under ITS and NTS tillage system.

Effects of PTFs and tillage on Yields

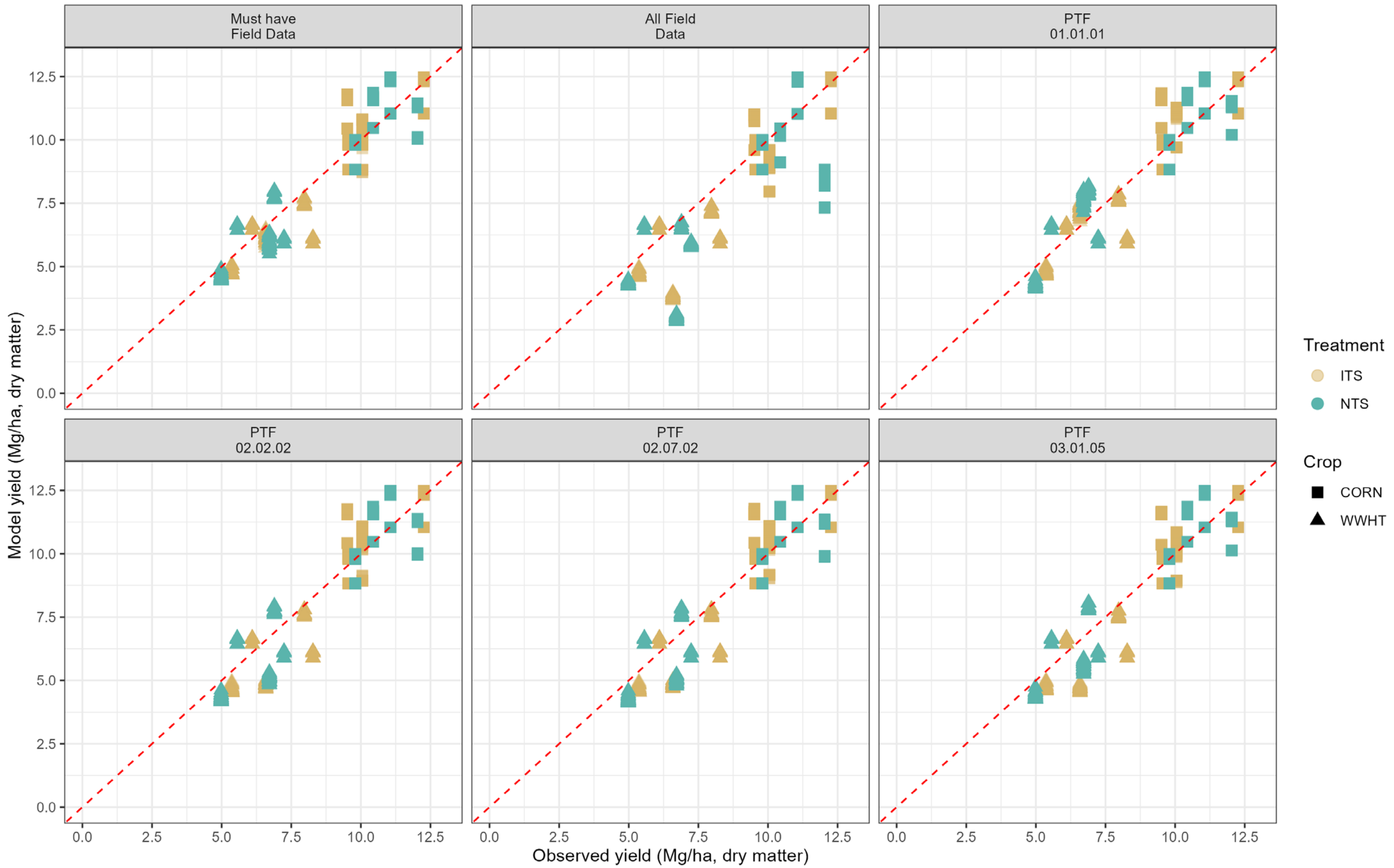
Effects on CORN Yields

- **Baseline Intercept**: 11.2 Mg/ha .
- **Measured Data**: Decreased yields by 0.8 Mg/ha
- **PTF Models**:
  - PTF01.01.01: Increased yields by 0.089.
  - PTF02.02.02: Increased yields by 0.029.
  - PTF02.07.02: Increased yields by 0.027.
  - PTF03.01.05: Negligible effect.
- **Tillage System**: Weak sig. impact (variance: 0.004925).

Measured in Hollabrunn



Measured KSAT
3 times higher than
PTFs in NCT.



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Conclusion

PTFs vs. Measured Values

Soil hydraulic properties significantly impact APEX simulations.

PTFs can introduce uncertainty, particularly in no-till (NT) systems (KAST).

Key Findings

Accurate soil hydraulic data enhances model performance, improving yield and environmental predictions.

PTFs are useful but can increase uncertainty, especially in NT systems.

Proper parameterization is crucial for reliable simulations.

On going Research

Investigate the impact of extreme climate scenarios on tillage systems and model accuracy.

Acknowledgments & Questions

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https://ejpsoil.eu/soil-research/eom4soil/into-dialogue/soilx

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