RuFaS: Soil and Crop

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U.S. Dairy Forage Research Center
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Systems
Forage
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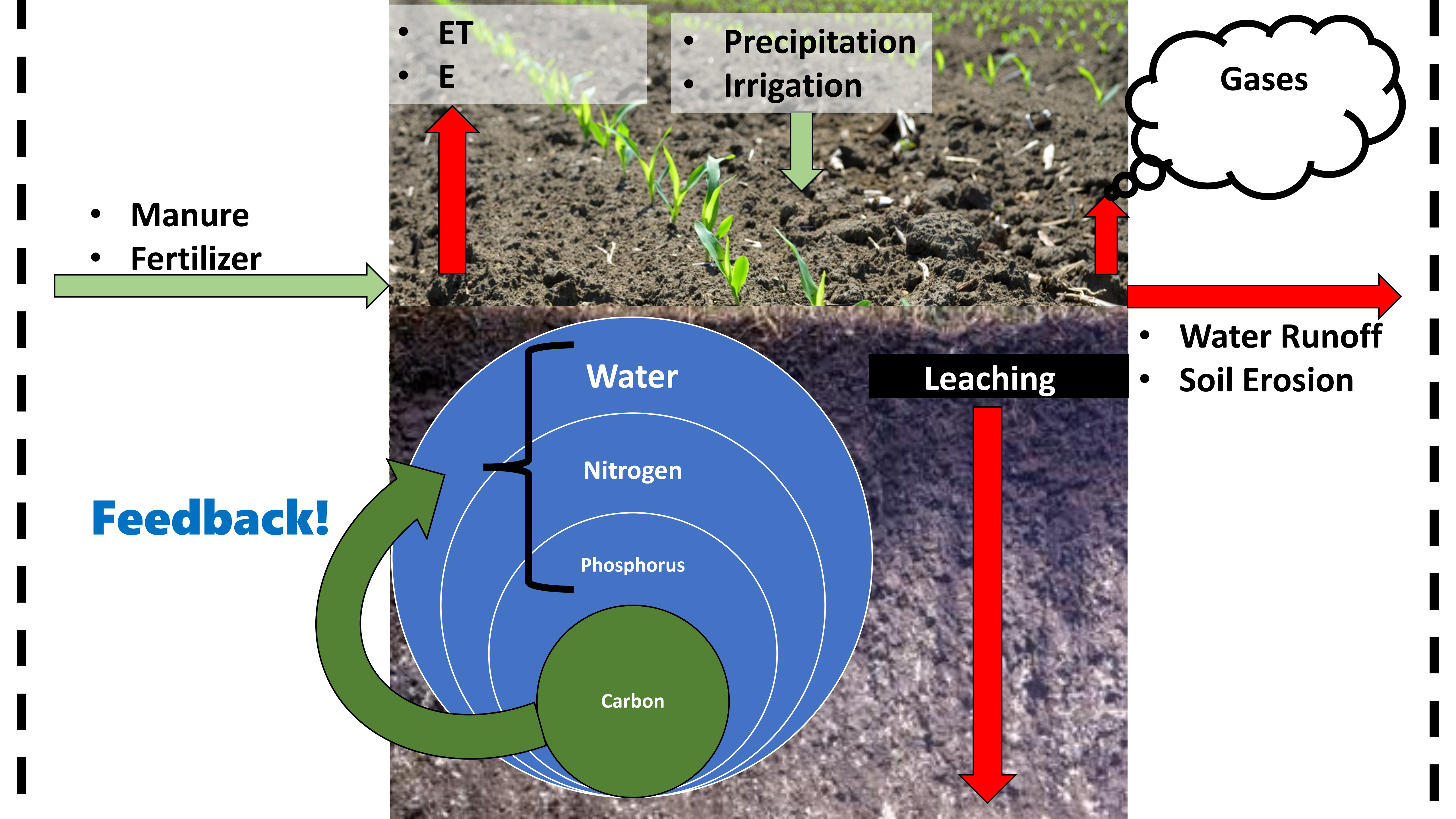
Presentation Outline

- **Manure Module Overview**
- **Soil and Crop Overview**
  - Models used in Soil and Crop
  - Summer Goals/Milestones
- **Data**
- **Calibrations**:
  - Manure and Crop System 1: Kimberly, Idaho
    - Management functionality
    - Grasses, root, and tubers
  - Manure, Crop and Forage System 2: Columbia, Wisconsin
    - Fertilizer functionality
- **Carbon Sub-model**
  - 100 year extreme conditions test
- **Mass Balance**
- **Next Steps**
- **Feed Storage Overview**

Manure Module Output: Manure (kg/ha)

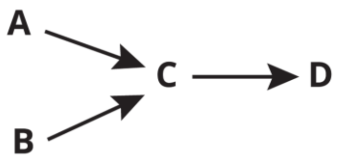


ET
E
Precipitation
Irrigation
Gases
Manure
Fertilizer
Water Runoff
Soil Erosion
Leaching
Water
Nitrogen
Phosphorus
Carbon
Feedback!

"Structure Drives Behavior"

Event Oriented Thinking

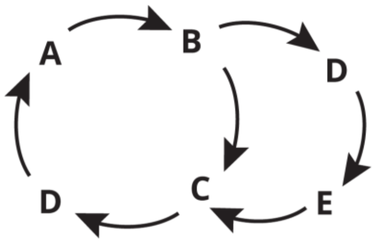
Thinks in straight lines



In event oriented thinking everything can be explained by causal chains of events. From this perspective the **root causes** are the events starting the chains of cause and effect, such as A and B.

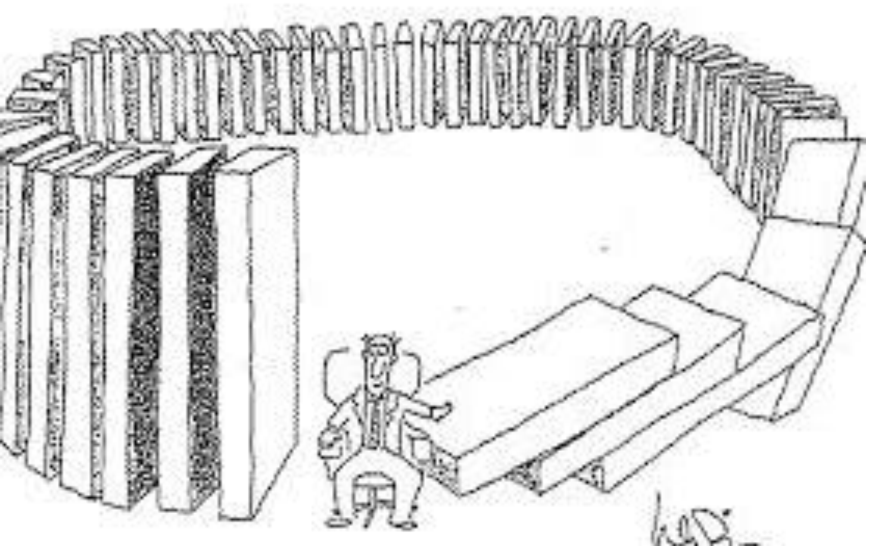
Systems Thinking

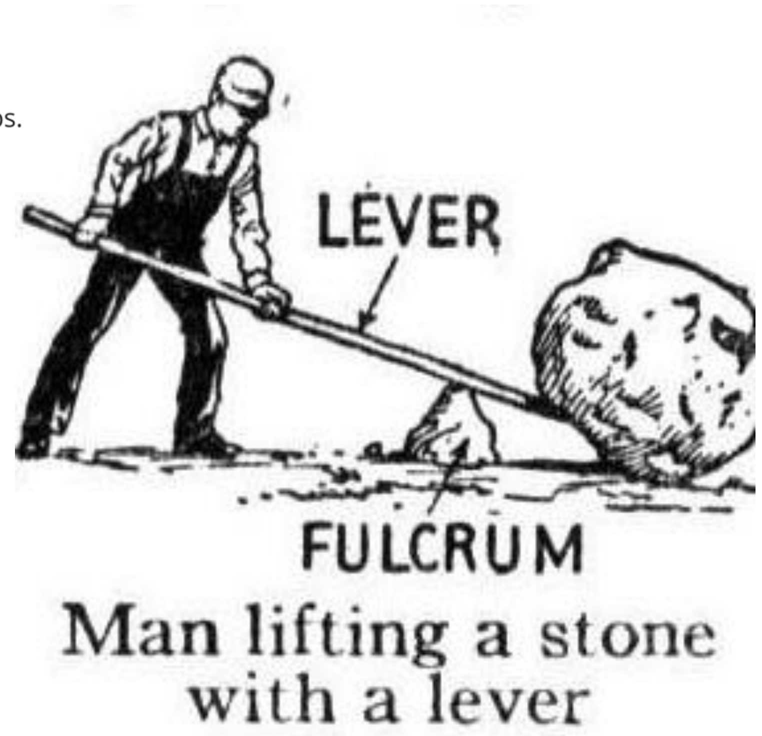
Thinks in loop structure



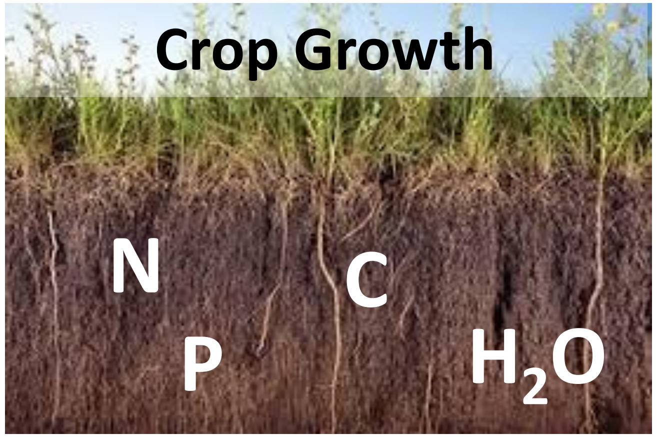
In systems thinking a system's behavior emerges from the structure of its feedback loops. **Root causes** are not individual nodes. They are the forces emerging from particular feedback loops.

Created by Thwink.org

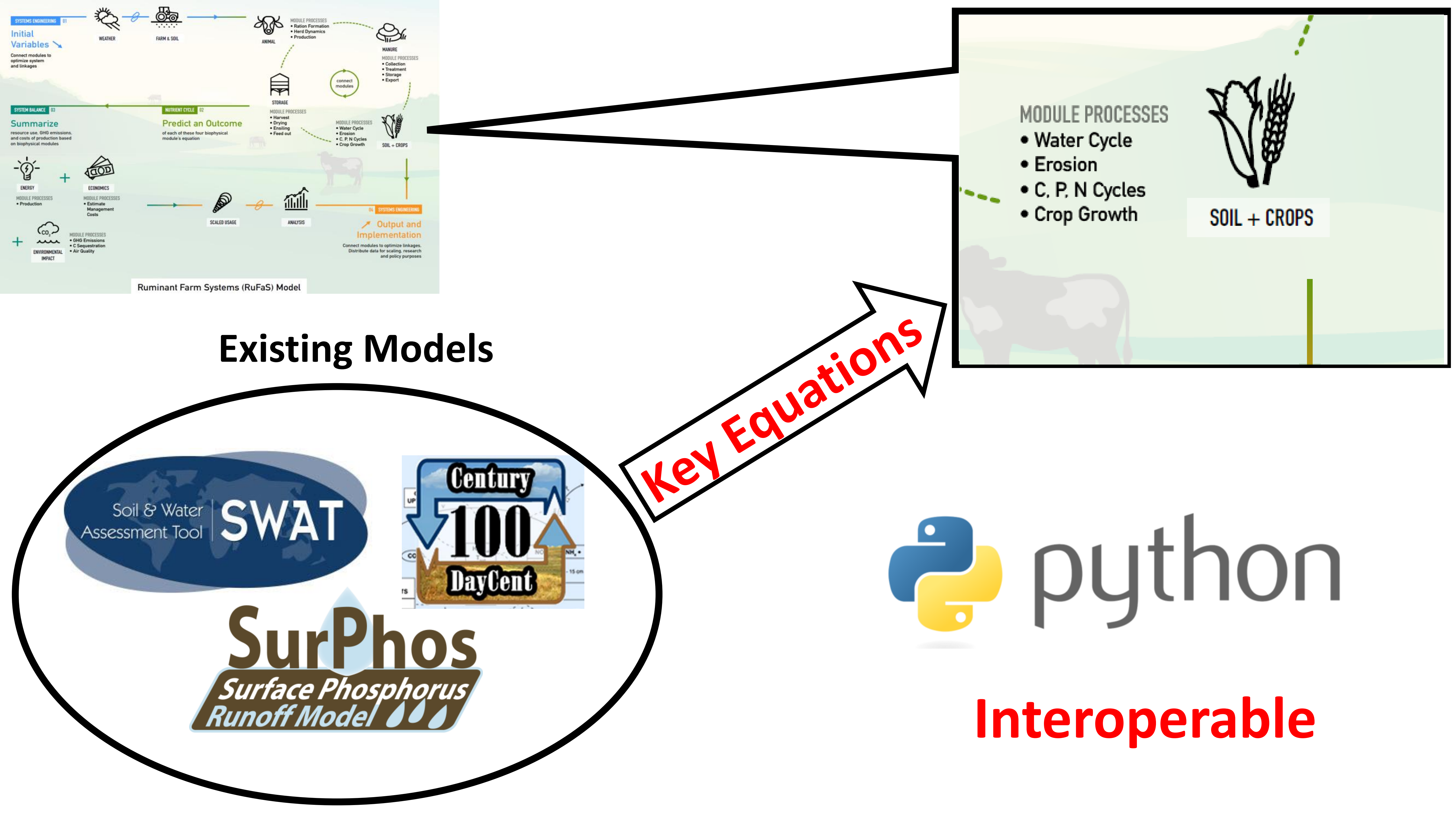




Modeled Processes



Carbon Sequestration



SYSTEMS ENGINEERING 01
Initial Variables
Connect modules to optimize system and linkages
WEATHER
FARM & SOIL
ANIMAL
MODULE PROCESSES
• Ration Formation
• Herd Dynamics
• Production
MANURE
MODULE PROCESSES
• Collection
• Treatment
• Storage
• Export
connect modules
STORAGE
MODULE PROCESSES
• Harvest
• Drying
• Ensiling
• Feed out
SYSTEM BALANCE 03
Summarize
resource use, GHG emissions, and costs of production based on biophysical modules
NUTRIENT CYCLE 02
Predict an Outcome
of each of these four biophysical module's equation
MODULE PROCESSES
• Water Cycle
• Erosion
• C, P, N Cycles
• Crop Growth
SOIL + CROPS
ENERGY
MODULE PROCESSES
• Production
ECONOMICS
MODULE PROCESSES
• Estimate Management Costs
SCALED USAGE
ANALYSIS
SYSTEMS ENGINEERING 04
Output and Implementation
Connect modules to optimize linkages. Distribute data for scaling, research and policy purposes
ENVIRONMENTAL IMPACT
MODULE PROCESSES
• GHG Emissions
• C Sequestration
• Air Quality
Ruminant Farm Systems (RuFaS) Model
MODULE PROCESSES
• Water Cycle
• Erosion
• C, P, N Cycles
• Crop Growth
SOIL + CROPS
Existing Models
Soil & Water Assessment Tool
SWAT
Century
100
DayCent
SurPhos
Surface Phosphorus Runoff Model
Key Equations
python
Interoperable

Crop and Soil Module: Timeline

April	May	June	July	August
1. Prepare simplistic carbon model 2. Identify grass growth parameters 3. Complete data requests	1. Input simplistic carbon model 2. Input grass parameters	1. Input refined code in RuFaS 2. Identify problems	1. Finalize code 2. Finalize documentation	

Crop and Soil Module: Milestones

April → May → June → July → August

1. Data collection
2. Agile project management

1. Develop RuFaS Carbon Model
2. Model testing

1. Add management functionality: Manure, fertilizer, tillage

1. Annual and perennial grasses
2. Functionality of “Fields”
3. Connection between animal management
4. manure storage, and soil via field management
5. Connection between crop and feed storage
6. Model calibration (3X)
7. **Document**

Data Collection

1. Ron Alverson
2. Dakota Lakes

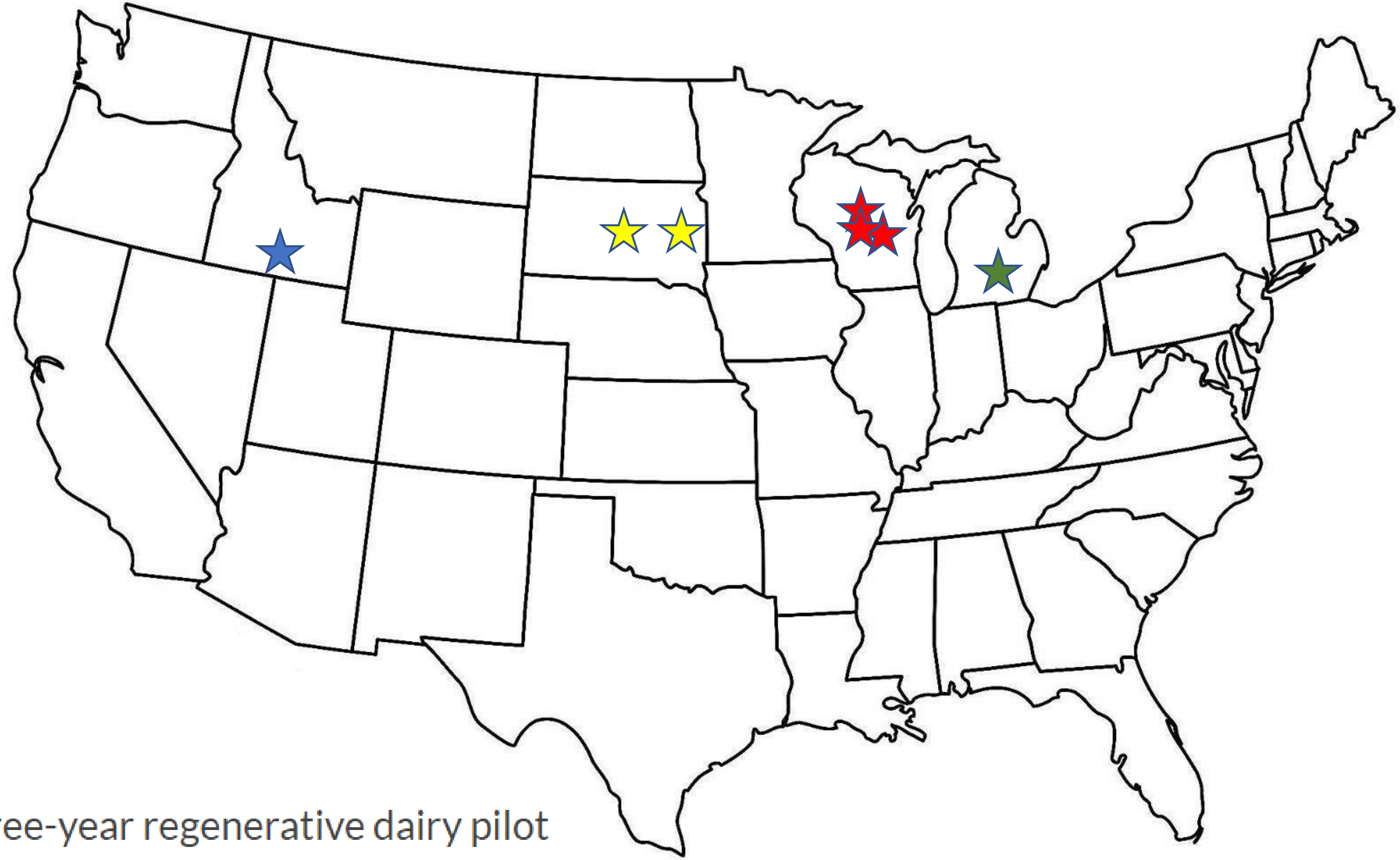
1. Lakeland Agricultural Complex (LAC)
2. UW Arlington Ag. Research Station ARL
3. Prairie du Sac (Vadas)

1. USDA-ARS NORTWEST (3X)

Future Datasets

JUN 16, 2020

General Mills launches three-year regenerative dairy pilot in Michigan in partnership with Foremost Farms and Understanding Ag



Calibration Sites

- 1. USDA-ARS Northwest (3X) LTGHG
- 2. UW Arlington Ag. Research Station **ARL**

Calibration Ticket*

- Documentation of calibration data by model branch ID on ***Git Hub***
- Reproducibility
- Model Transparency
- Publication

Kimberly Idaho Calibration: Yield, N, P, C

Spring Wheat (2013)

Potatoes (2014)

Spring Barley (2015)

Sugar Beets (2016)

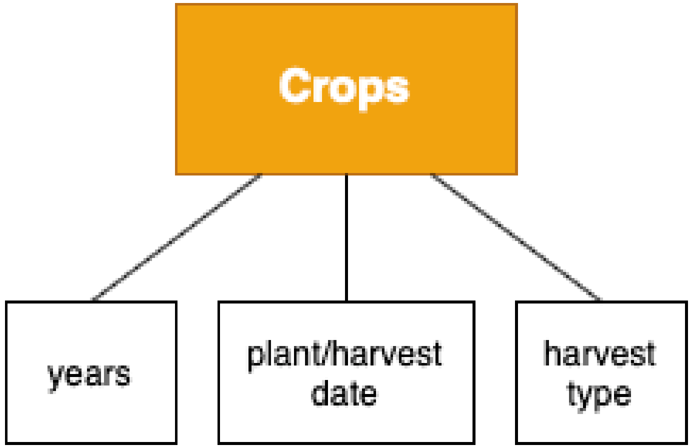
Treatments:

1. **No fertilizer**
2. **Synthetic fertilizer**
3. **18 mg ha -1 Manure**
4. **36 Mg ha-1 Manure**
5. **52 Mg ha-1 Manure**

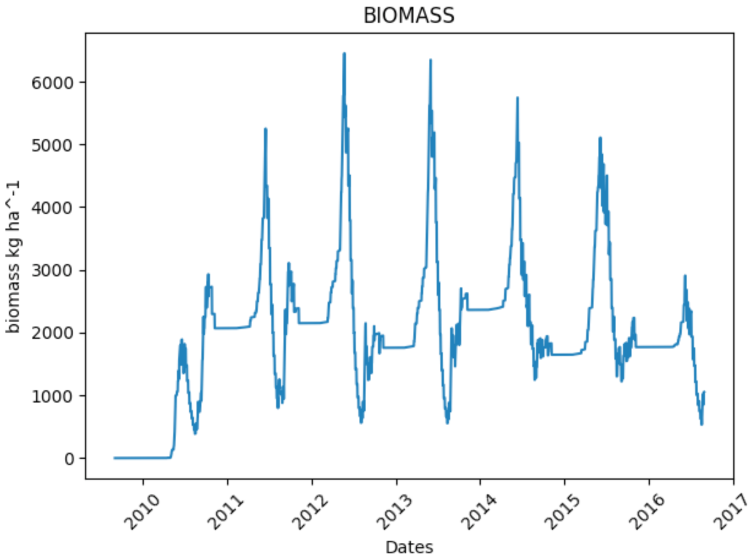
(Leytem et al., 2019)

Old and New Crops

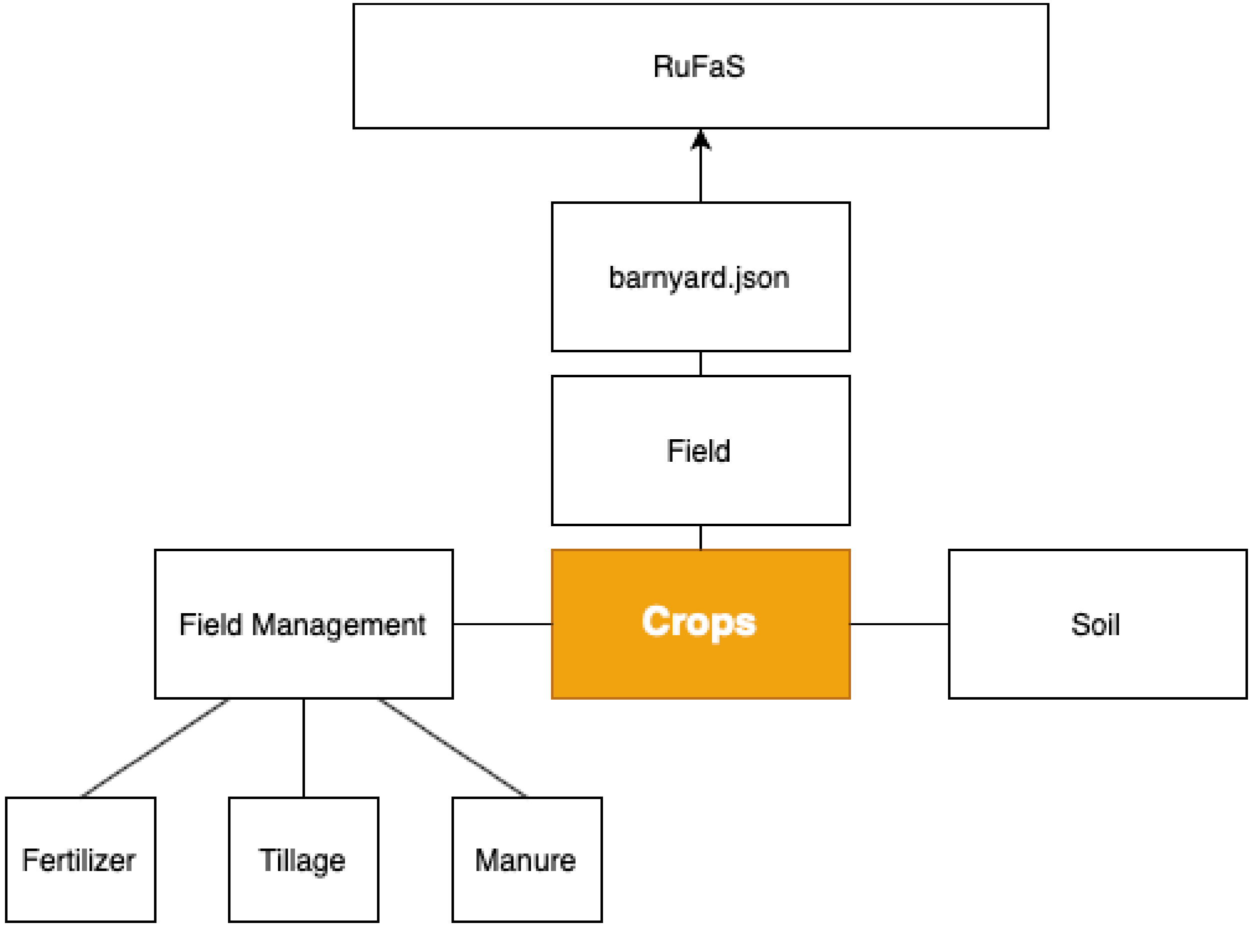
- Main crop types are annual and perennial
  - **Old crops**: Corn, Alfalfa, Soybean
  - **New crops**: Tall Fescue, Spring Barley, Sugar Beets, Spring Wheat, Potato




```json
{
    "latitude": 43.332708,

    "crops": {
        "tall_fescue": {
            "grow_years": [2009],
            "repeat": 1,
            "planting_date": 121,
            "harvest_date": 319,
            "harvest_type": "optimal"
        }
    }
}
```

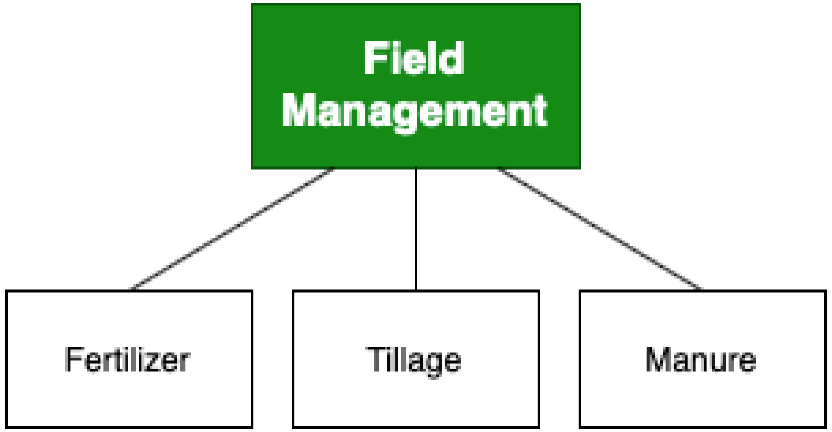
Moving towards database functionality




```json
    "farm":
    {
        "fields": {
            "field_1": {
                "soil": "barnyard_soil.json",
                "crop": "tall_fescue_rotation.json",
                "field_management": "barnyard_field_management.json"
            }
        },
        "animal": "barnyard_animal.json",
        "feed": "panke_buisse_feed.json"
    }
}
```

New Management Structure

- Old Method:
  - Individual specification
- New Method:
  - Working towards database implementation



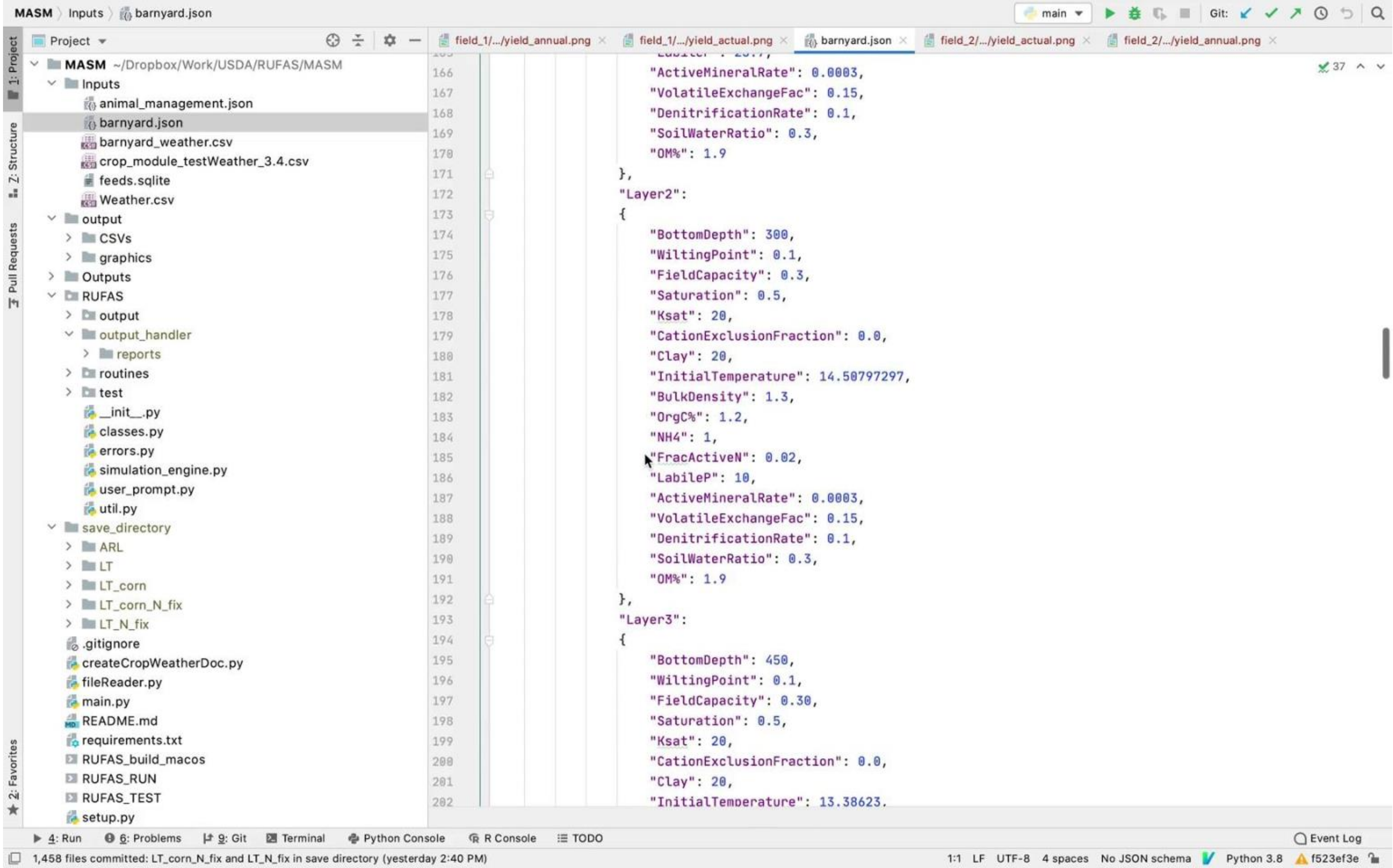

```
    "tillage":
    {
        "rotation_years": [],
        "repeat": 0,

        "year": [],
        "day": [],
        "perc_incorporated": [],
        "perc_mixed": [],
        "depth": []
    }
}
```

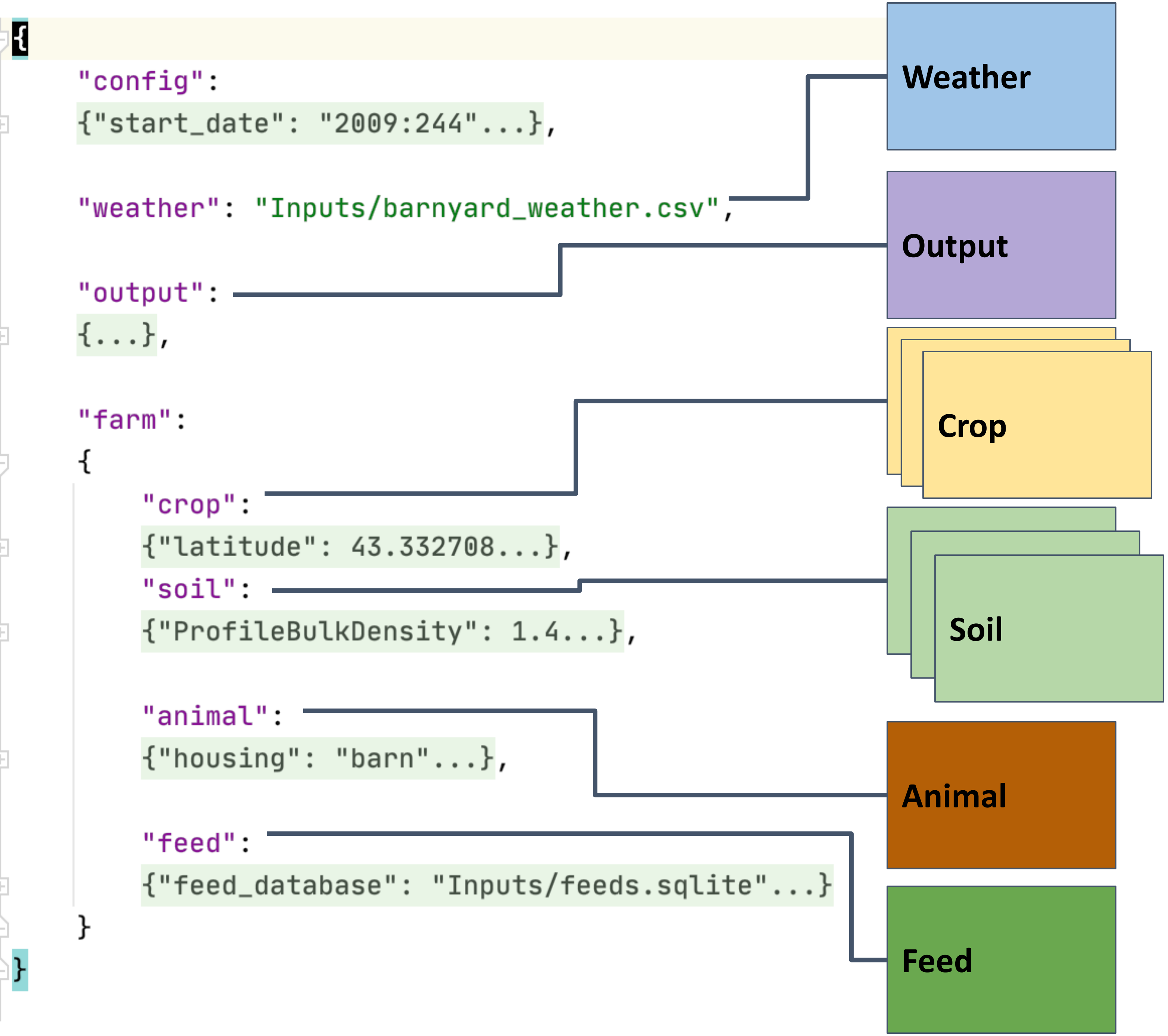
Old tillage application

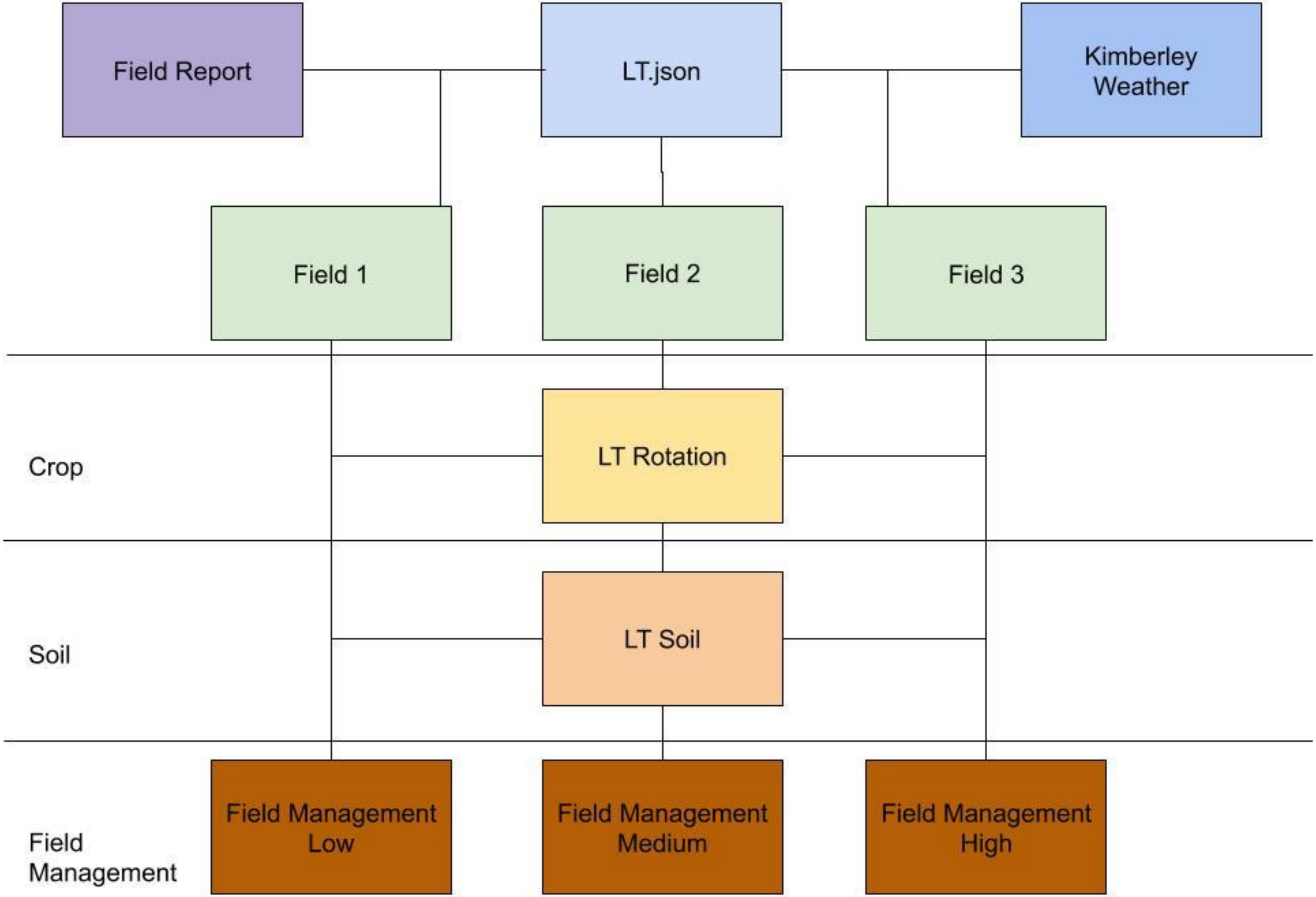
Specifying tillage_type considers variables:
•perc_mixed
•depth

```
    "tillage":
    {
        "rotation_years": [2009],
        "repeat": 1,

        "tillage_type": "DUCKFTC",
        "year": [],
        "day": []
    }
}
```

New tillage application


MASM 〉 Inputs 〉 barnyard.json
main
Git:
Project
field_1/.../yield_annual.png
field_1/.../yield_actual.png
barnyard.json
field_2/.../yield_actual.png
field_2/.../yield_annual.png
MASM ~/Dropbox/Work/USDA/RUFAS/MASM
Inputs
animal_management.json
barnyard.json
barnyard_weather.csv
crop_module_testWeather_3.4.csv
feeds.sqlite
Weather.csv
output
CSVs
graphics
Outputs
RUFAS
output
output_handler
reports
routines
test
__init__.py
classes.py
errors.py
simulation_engine.py
user_prompt.py
util.py
save_directory
ARL
LT
LT_corn
LT_corn_N_fix
LT_N_fix
.gitignore
createCropWeatherDoc.py
fileReader.py
main.py
README.md
requirements.txt
RUFAS_build_macos
RUFAS_RUN
RUFAS_TEST
setup.py
1: Project
7: Structure
Pull Requests
2: Favorites
"ActiveMineralRate": 0.0003,
"VolatileExchangeFac": 0.15,
"DenitrificationRate": 0.1,
"SoilWaterRatio": 0.3,
"OM%": 1.9
},
"Layer2":
{
"BottomDepth": 300,
"WiltingPoint": 0.1,
"FieldCapacity": 0.3,
"Saturation": 0.5,
"Ksat": 20,
"CationExclusionFraction": 0.0,
"Clay": 20,
"InitialTemperature": 14.50797297,
"BulkDensity": 1.3,
"OrgC%": 1.2,
"NH4": 1,
"FracActiveN": 0.02,
"LabileP": 10,
"ActiveMineralRate": 0.0003,
"VolatileExchangeFac": 0.15,
"DenitrificationRate": 0.1,
"SoilWaterRatio": 0.3,
"OM%": 1.9
},
"Layer3":
{
"BottomDepth": 450,
"WiltingPoint": 0.1,
"FieldCapacity": 0.30,
"Saturation": 0.5,
"Ksat": 20,
"CationExclusionFraction": 0.0,
"Clay": 20,
"InitialTemperature": 13.38623,
4: Run
6: Problems
9: Git
Terminal
Python Console
R Console
TODO
Event Log
1,458 files committed: LT_corn_N_fix and LT_N_fix in save directory (yesterday 2:40 PM)
1:1 LF UTF-8 4 spaces No JSON schema Python 3.8 f523ef3e

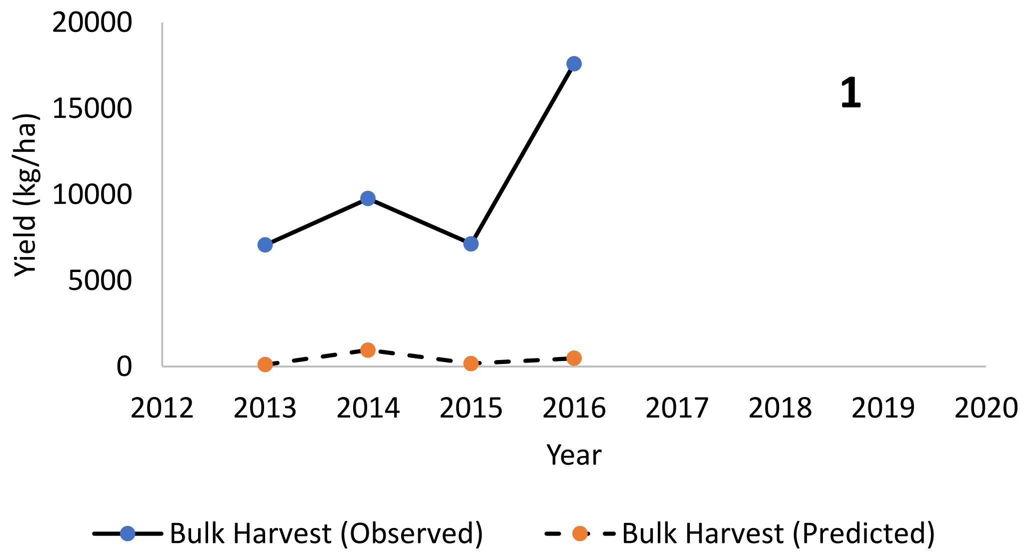

{
"config":
{"start_date": "2009:244"...},
"weather": "Inputs/barnyard_weather.csv",
"output":
{...},
"farm":
{
"crop":
{"latitude": 43.332708...},
"soil":
{"ProfileBulkDensity": 1.4...},
"animal":
{"housing": "barn"...},
"feed":
{"feed_database": "Inputs/feeds.sqlite"...}
}
}
Weather
Output
Crop
Soil
Animal
Feed

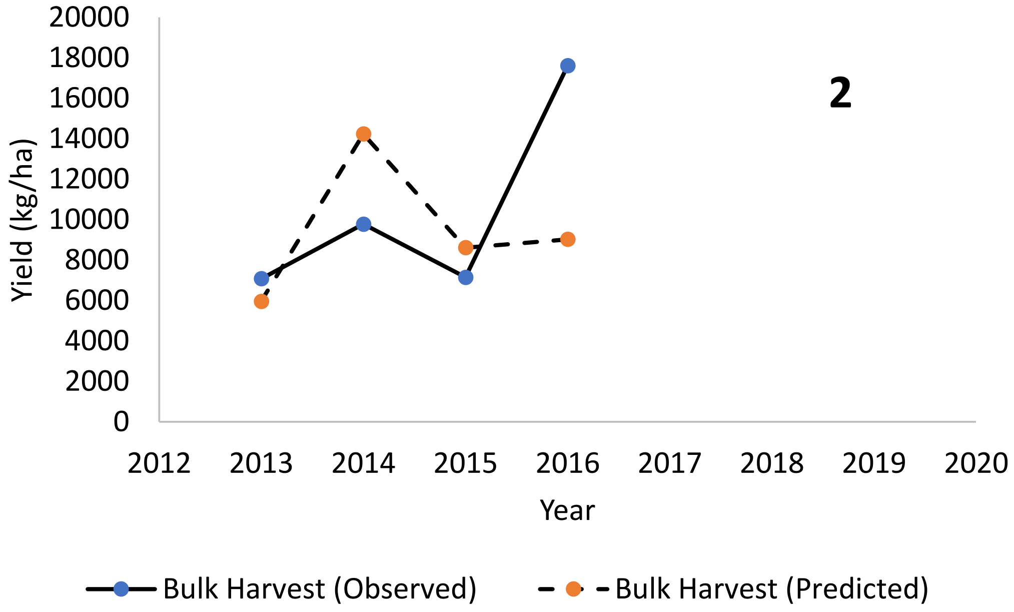

Field Report
LT.json
Kimberley Weather
Field 1
Field 2
Field 3
Crop
LT Rotation
Soil
LT Soil
Field Management
Field Management Low
Field Management Medium
Field Management High

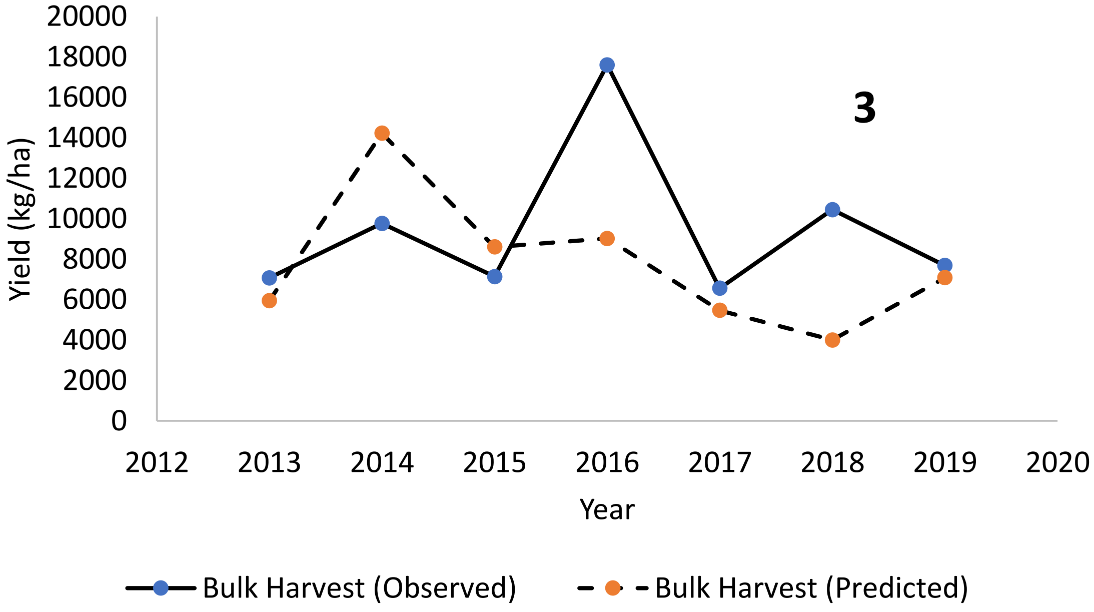
```json
{
    "config":
    {
        "start_date" : "1980:1",
        "end_date" : "2019:365",
        "csv_dir": "output/CSVs/",
        "graphic_dir": "output/graphics/",
        "run_tests": false
    },

    "weather": "LT_weather.csv",

    "output": "field_report.json",

    "farm":
    {
        "fields": {
            "field_1": {
                "soil": "LT_soil.json",
                "crop": "LT_rotation.json",
                "field_management": "LT_field_management_1.json"
            },
            "field_2": {
                "soil": "LT_soil.json",
                "crop": "LT_rotation.json",
                "field_management": "LT_field_management_2.json"
            },
            "field_3": {
                "soil": "LT_soil.json",
                "crop": "LT_rotation.json",
                "field_management": "LT_field_management_3.json"
            }
        },
        "animal": "barnyard_animal.json",
        "feed": "panke_buisse_feed.json"
    }
}
```


```json
"farm":
{
    "fields": {
        "field_1": {
            "soil": "LT_soil.json",
            "crop": "LT_rotation.json",
            "field_management": "LT_field_management_1.json
        },
        "field_2": {
            "soil": "LT_soil.json",
            "crop": "LT_rotation.json",
            "field_management": "LT_field_management_2.json
        },
        "field_3": {
            "soil": "LT_soil.json",
            "crop": "LT_rotation.json",
            "field_management": "LT_field_management_3.json
        }
    },
    "animal": "barnyard_animal.json",
    "feed": "panke_buisse_feed.json"
}
```

Preliminary Results



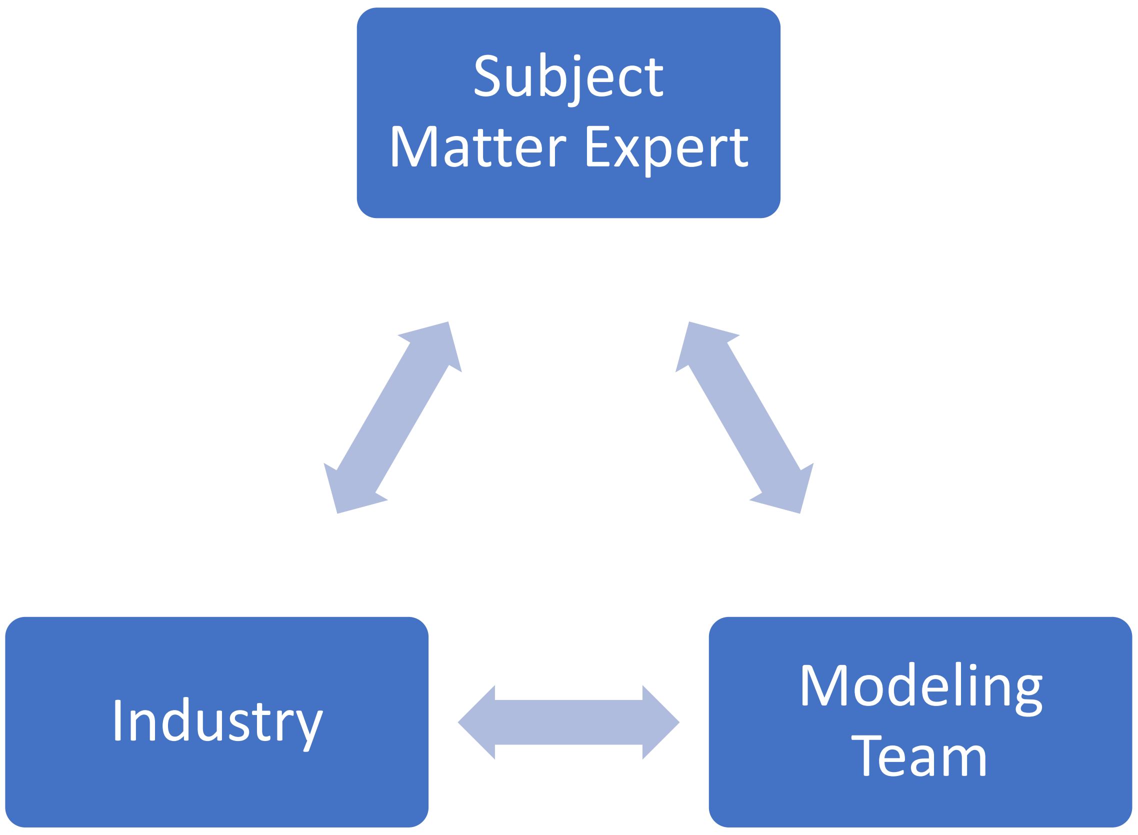




Nutrients and Triangulation

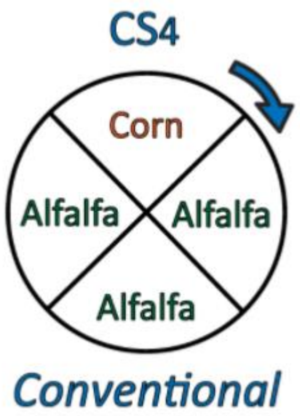
Calibration

- Runoff and Erosion
- Soil N
- Soil P
- Soil C



Columbia Wisconsin Calibration: Yield, P

DAIRY FORAGE SYSTEMS

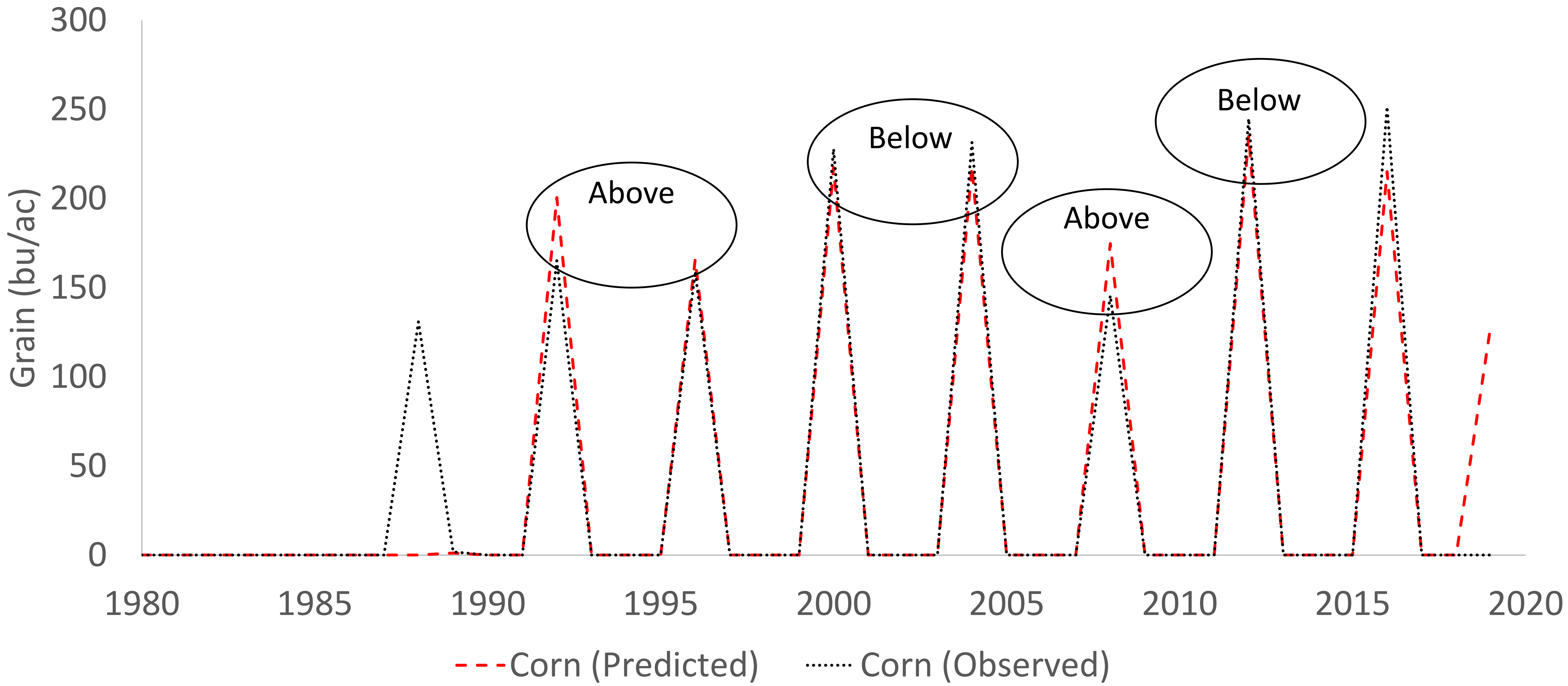


WISCONSIN INTEGRATED CROPPING SYSTEMS TRIAL
COLLEGE OF AGRICULTURAL & LIFE SCIENCES

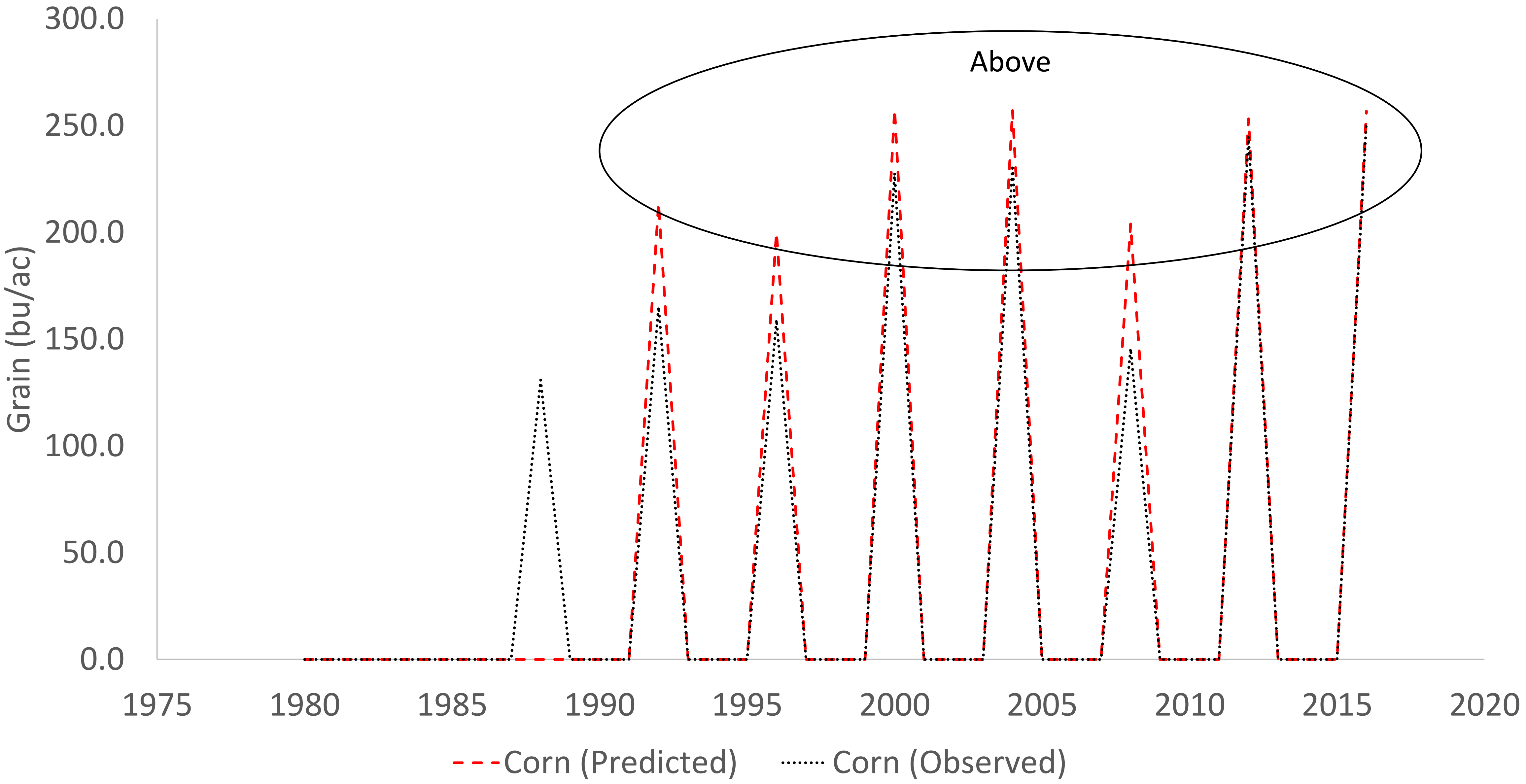
1980 → 2018




Preliminary Results



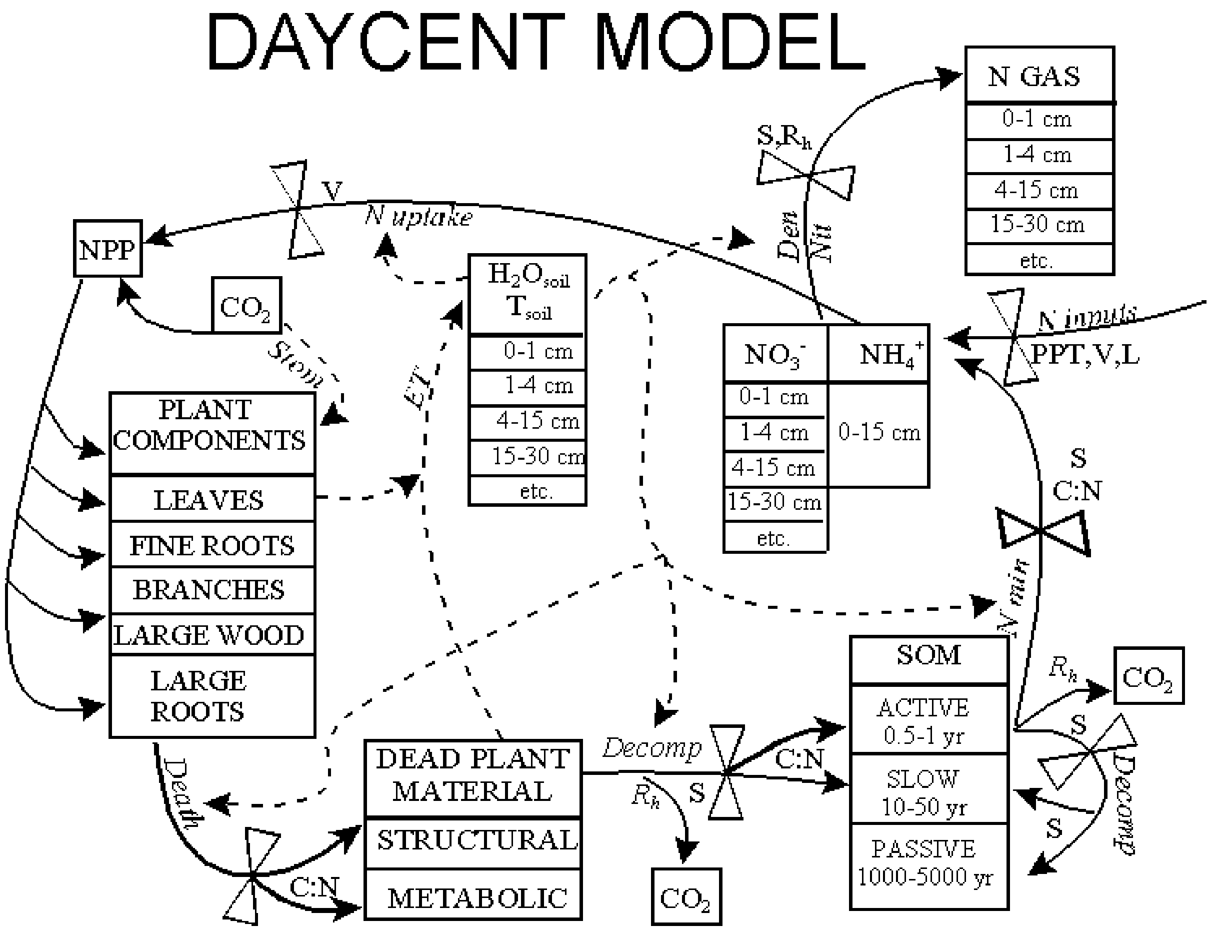
Management Inputs



RuFaS Carbon Model

Use <u>key equations</u> from the Century and DayCent Models to:

1. Estimate soil carbon
2. Capture carbon flux
3. Provide <u>feedback</u> regarding soil health



= C, N flows

= Feedbacks, information flows

= Control on process

H_2O_{soil} = Soil water content

T_{soil} = Soil temperature

S = Soil texture

C:N = Carbon:Nitrogen ratio of material

V = Vegetation type

SOM = Soil Organic Matter

L = Land use

R_h = Heterotrophic respiration

N GAS = N_2O, NO_X, N_2

Processes designated by *italics*

Stom = Stomatal conductance

Death = Plant component death

Decomp = Decomposition

N inputs = N Fixation, N deposition, N fertilization

Nit = Nitrification

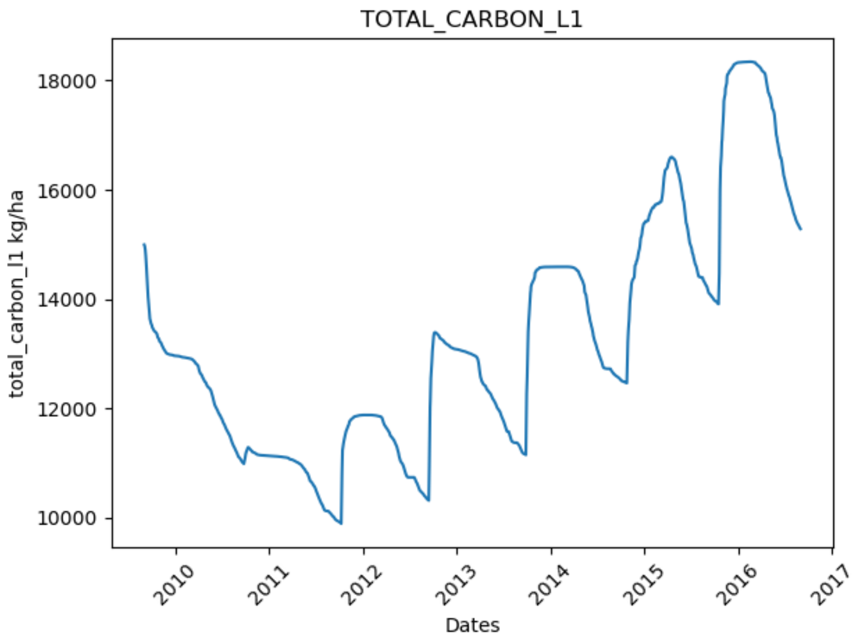
Den = Denitrification

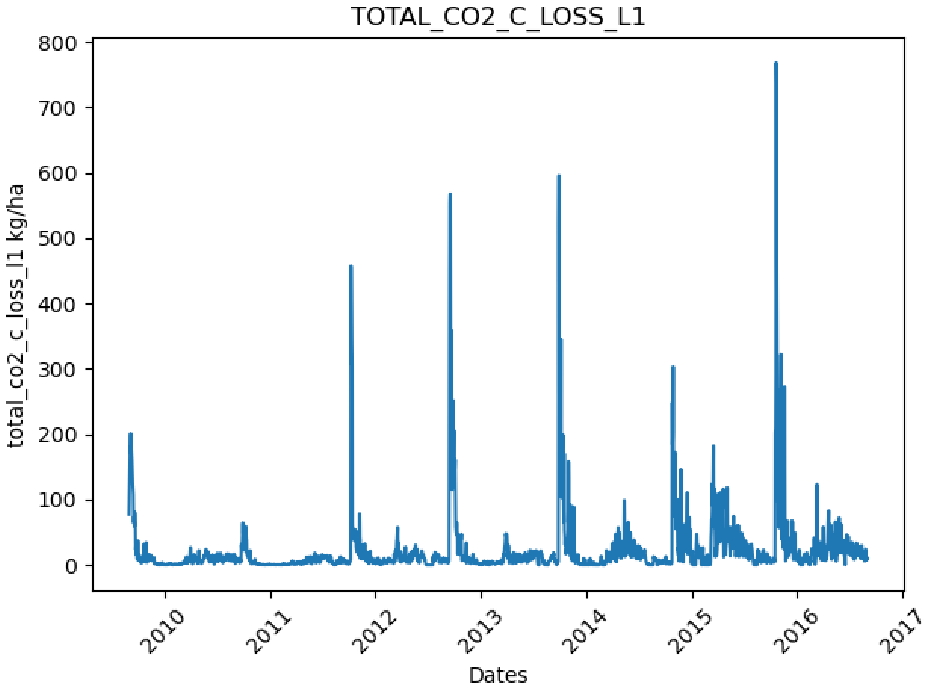
N min = N mineralization

ET = Evapotranspiration

RuFaS Carbon Model

- **Functionality**
- **Inputs** and **outputs** for the carbon model

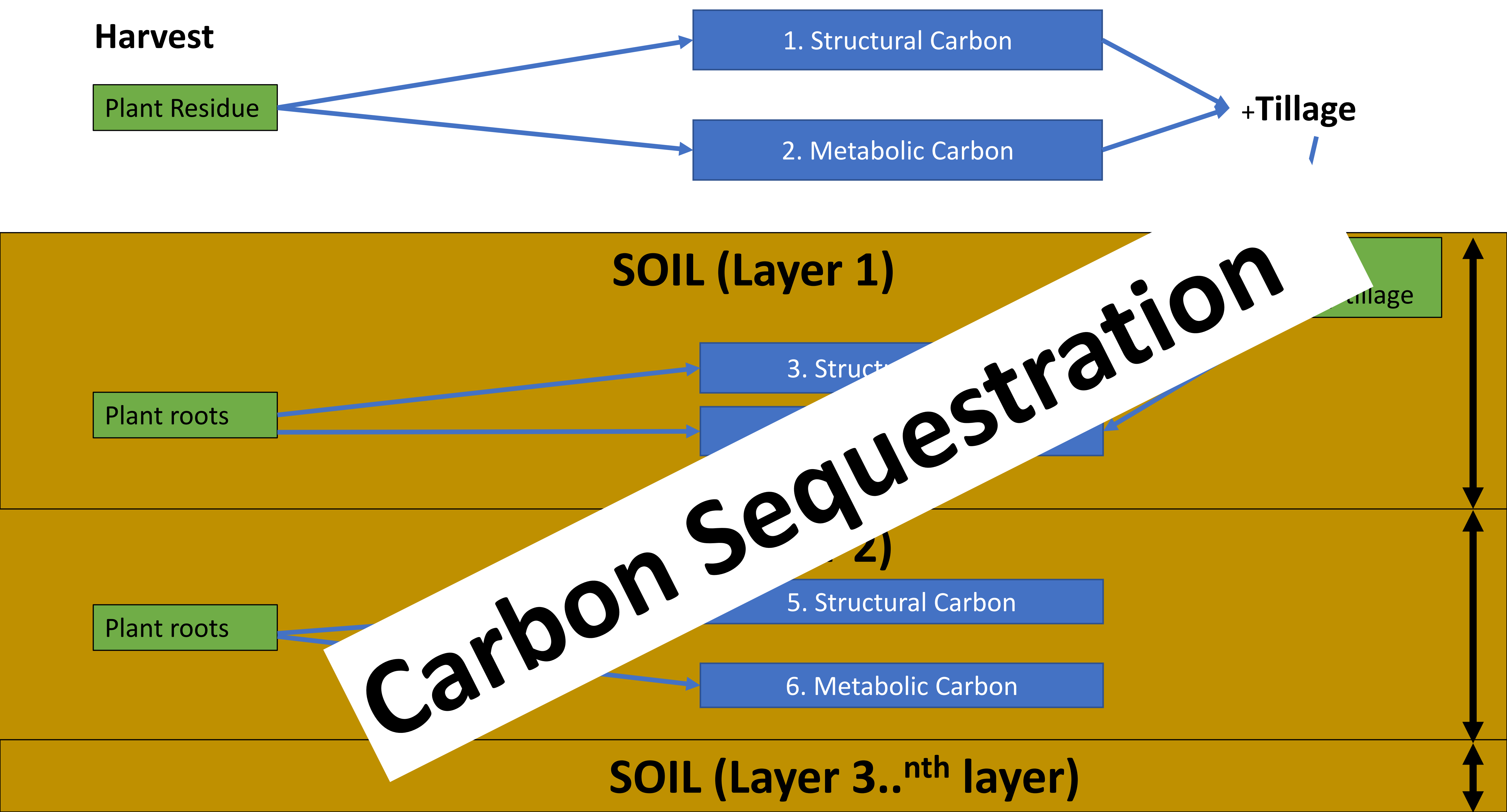




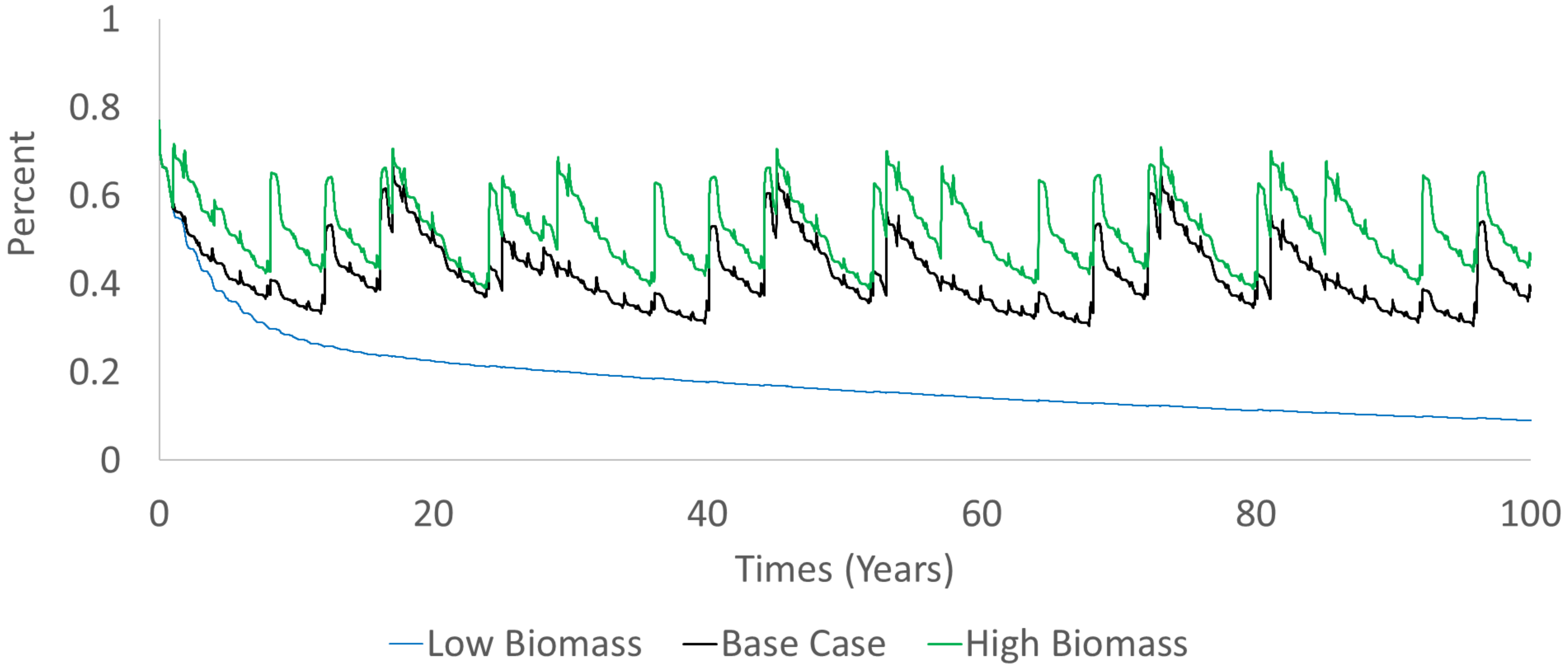
RuFaS Carbon Model

- Evaluation
- Advancement of the model

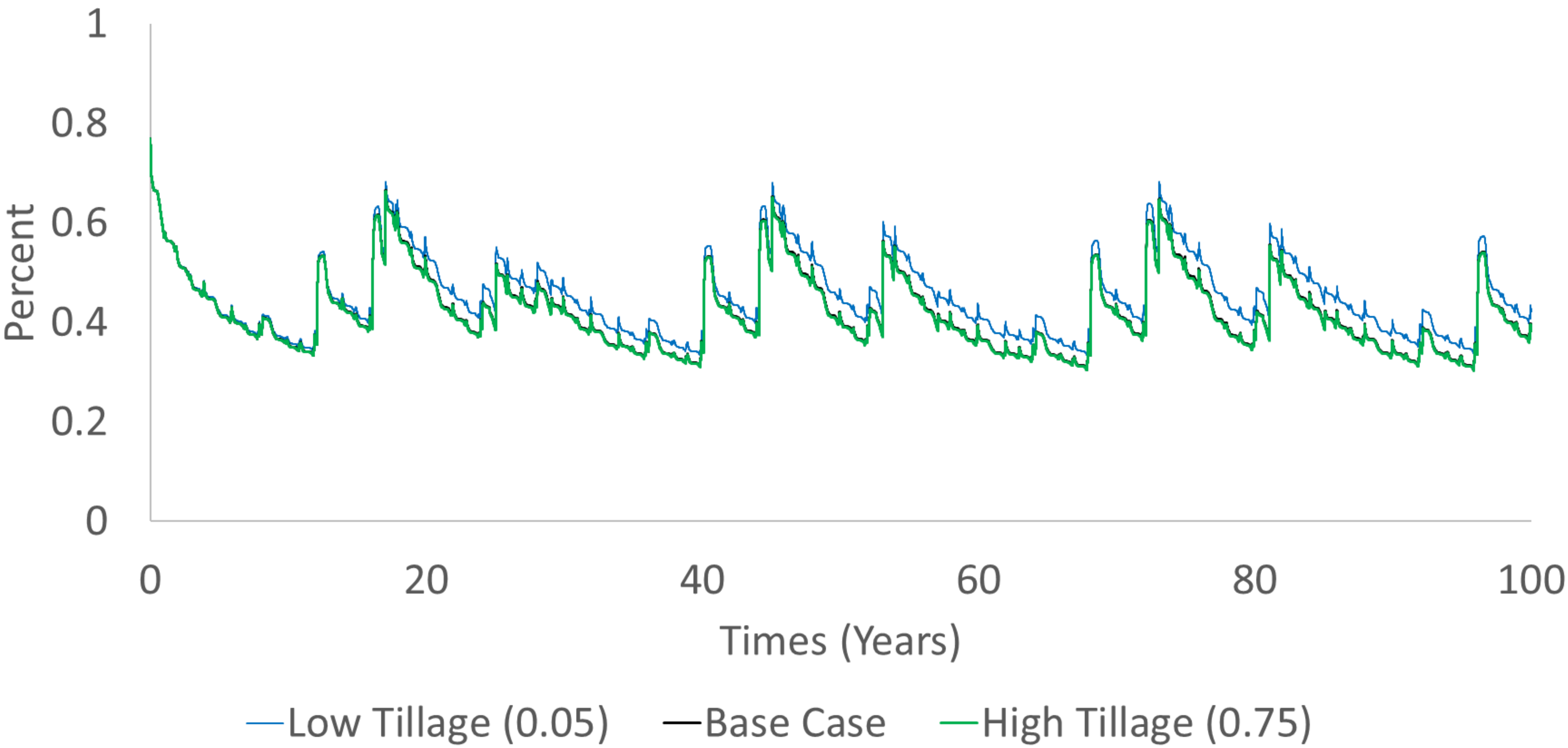
```
T_d = max(0.0, (teff_2 + (teff_3 / math.pi) * math.atan(math.pi * teff_4 * (
        weather.T_avg[time.year - 1][time.day - 1] - teff_1))) / normalizer)

soil.T_d = T_d

for layer in soil.soil_layers:
    base_1 = (layer.water_fac - b) / (a - b)
    base_2 = (layer.water_fac - c) / (a - c)
    M_d = (base_1 ** e1) * (base_2 ** e2)
    layer.M_d = M_d

    # above ground metabolic residue
    layer.metabolic_AG_to_C_active = metabolic_AG_active_decomp * layer.M_d * soil.T_d * layer.metabolic_AG

    metabolic_AG_to_BG = layer.metabolic_AG * layer.fr_tillage

    d_metabolic_AG = soil.residue_DM_harvest * metabolic_AG_frac - (
            (layer.metabolic_AG_to_C_active - metabolic_AG_to_BG) + metabolic_AG_to_BG)

    layer.metabolic_AG += d_metabolic_AG

    # above ground structural residue
    K1 = 0.076
    struct_AG_decomp = K1 * math.exp(-3) * (1 - metabolic_AG_frac)

    layer.struct_AG_to_C_active = struct_AG_decomp * layer.M_d * soil.T_d * layer.structural_AG
    layer.struct_AG_to_C_slow = struct_AG_decomp * layer.M_d * soil.T_d * layer.structural_AG

    struct_AG_to_BG = layer.structural_AG * layer.fr_tillage

    d_structural_AG = ((soil.residue_DM_harvest * (1 - metabolic_AG_frac)) - struct_AG_to_BG) - \
                      (layer.struct_AG_to_C_active + layer.struct_AG_to_C_slow)

    layer.structural_AG += d_structural_AG
```


Harvest
Plant Residue
1. Structural Carbon
2. Metabolic Carbon
+Tillage
SOIL (Layer 1)
Tillage
Plant roots
3. Struct
Carbon Sequestration
2)
Plant roots
5. Structural Carbon
6. Metabolic Carbon
SOIL (Layer 3..nth layer)

Extreme Conditions Test: 100 Year Run, Biomass



Extreme Conditions Test: 100 Year Run, Tillage



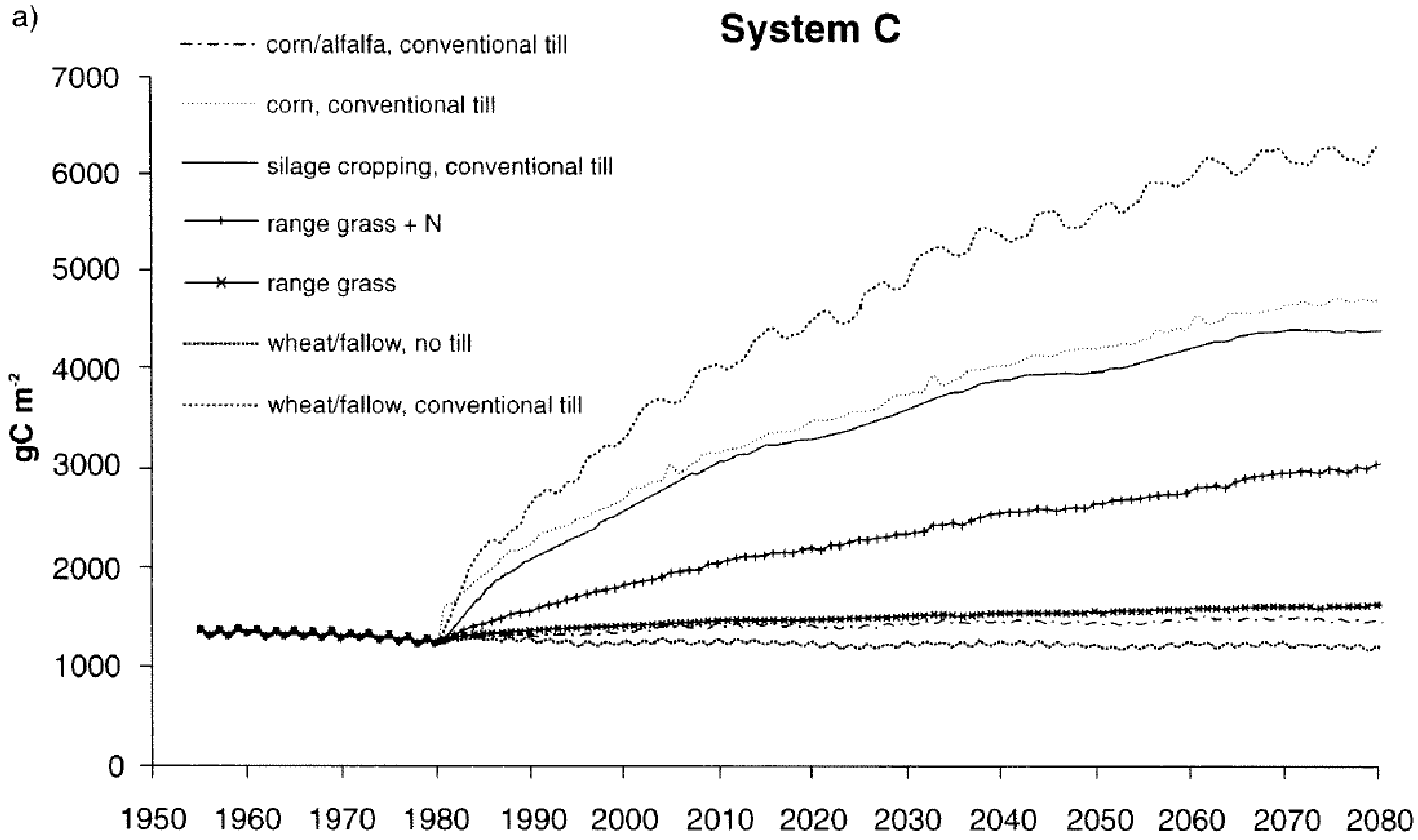
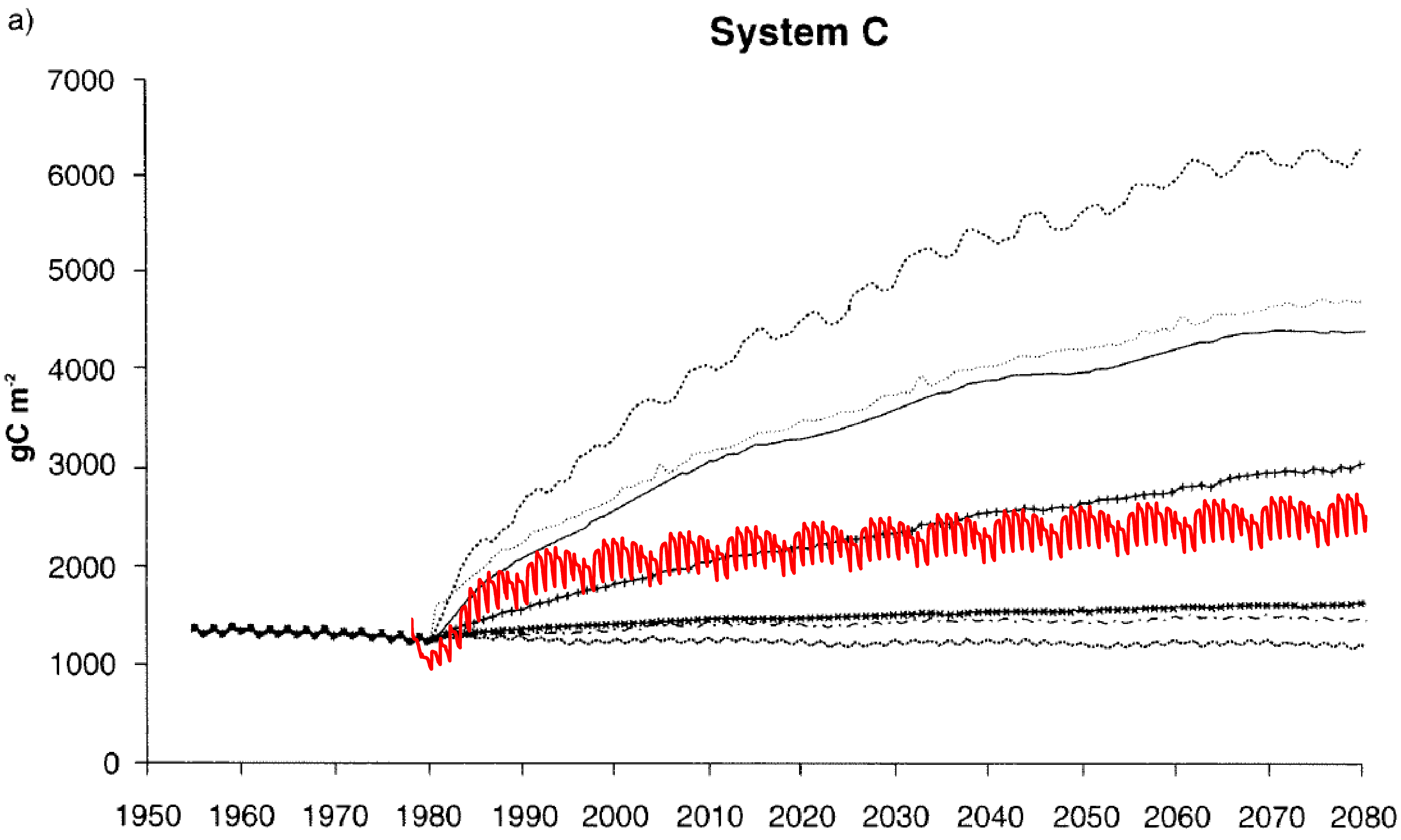


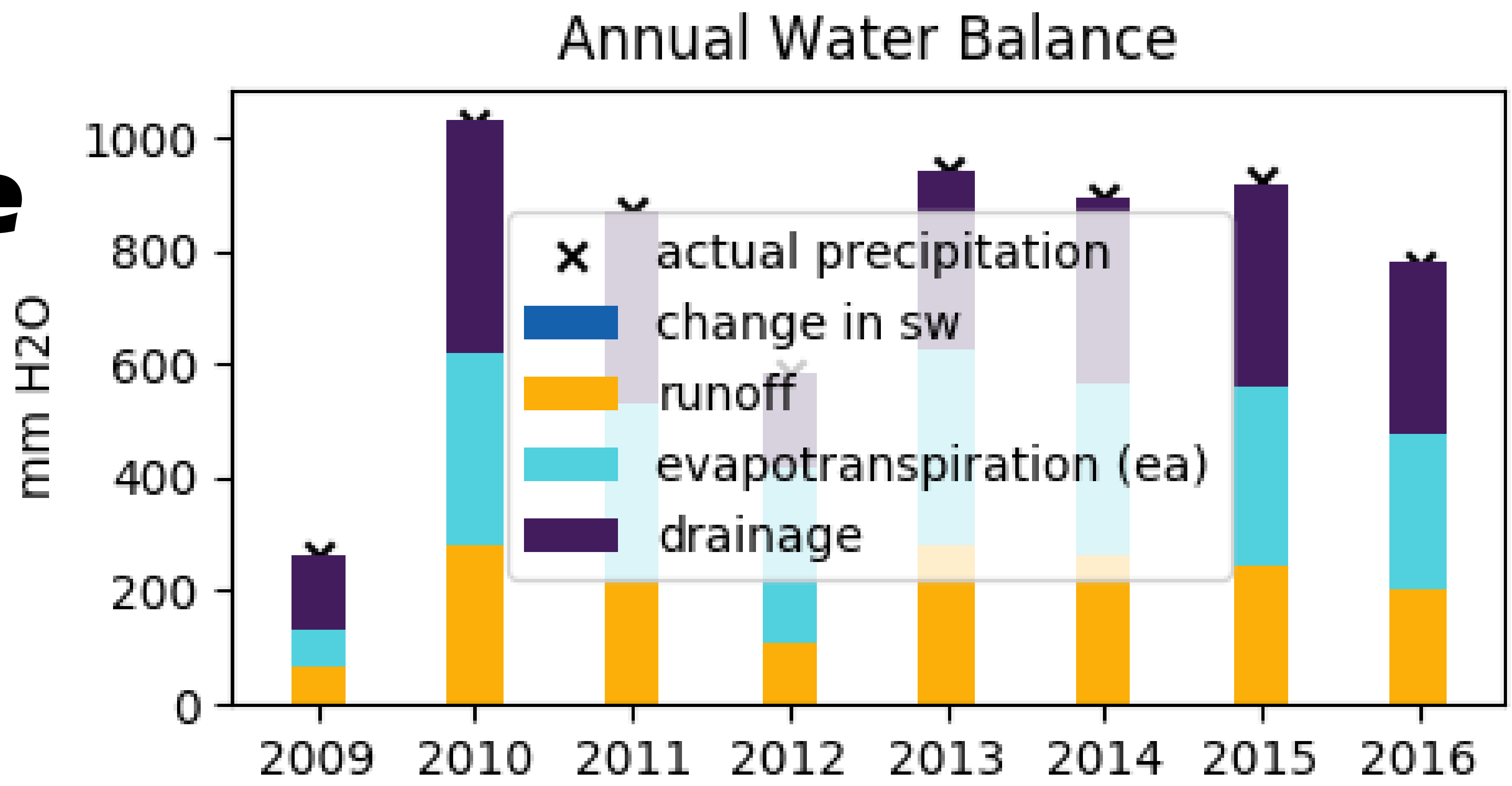
Figure 8.7 Simulated yearly changes in system C (soil C + litter C + surface organic matter C) (a); cumulative yearly N_2O emissions (b); and cumulative yearly NO_3^- leaching (c) for a Great Plains soil under conventional till winter wheat/fallow rotations and six alternative land use scenarios.

Del Grosso et al., 2001


a)
System C
gC m⁻²
7000
6000
5000
4000
3000
2000
1000
0
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080

Mass Balance

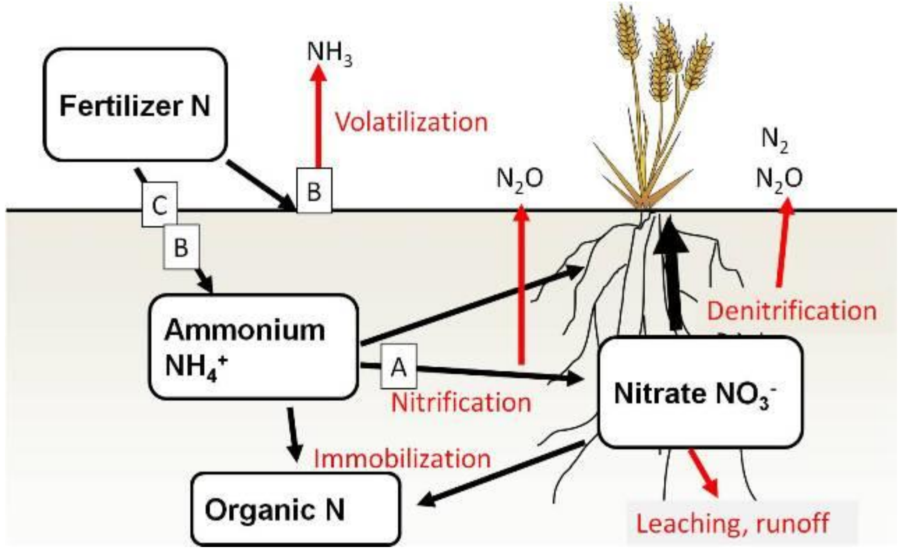
- Proof of concept



change in sw	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
runoff	66.818	278.896	212.814	107.757	278.567	260.217	242.497	201.575
evapotranspiration (ea)	63.775	341.663	320.428	306.986	349.254	306.022	321.112	276.39
drainage	131.368	408.787	336.087	167.887	315.168	326.134	355.133	300.499
actual precipitation	262.89	1027.43	872.49	582.168	941.07	892.048	922.528	774.192
calculated water	262.89	1027.43	872.49	582.168	941.07	892.048	922.528	774.192
difference	0.0	-0.0	-0.0	0.0	0.0	0.0	0.0	-0.0

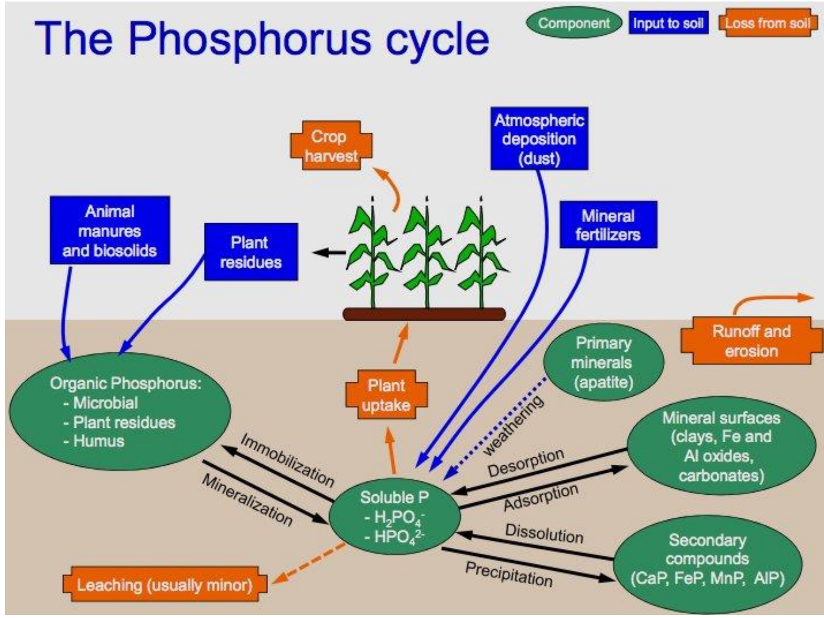
Mass Balance: Nitrogen

Inflow	Stock or Pool	Outflow
Manure Fertilizer Residue Roots	NH_4^+ NO_3^- Organic Nitrogen Active Nitrogen Stable Nitrogen Fresh Nitrogen	Leaching Runoff Erosion Nitrification Volatilization Denitrification Plant Uptake



Mass Balance: Phosphorus

Inflow	Stock or Pool	Outflow
Manure Fertilizer Residue Roots	Labile Inorganic P Active Inorganic P Stable Inorganic P	Runoff Erosion Leaching Plant Uptake



VADAS ET AL.: A MODEL FOR MANURE PHOSPHORUS RUNOFF LOSS

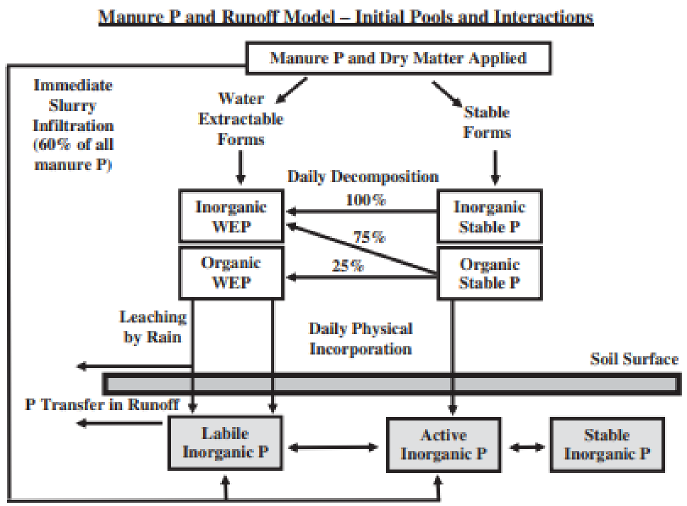
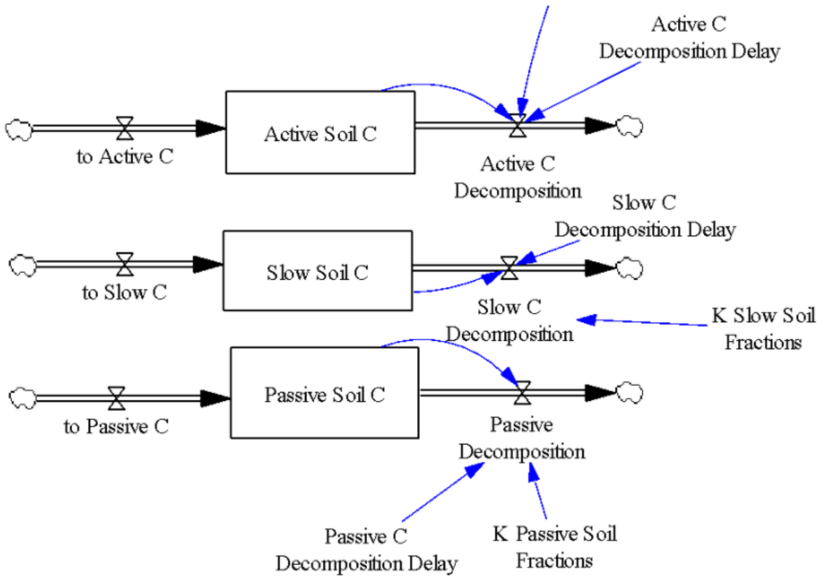


Fig. 1. Schematic depiction of manure and soil P pools, and pathways of P transformation between the pools.

Mass Balance: Carbon

Inflow	Stock or Pool	Outflow
Residue Roots Manure	Structural Metabolic Active Passive Slow	CO_2



Next Step: Add Complexity

Functionality

Continuous Cover

- Corn, Winter Wheat, Corn

Next Steps

September | October | November | December | January

- **Integrate** Carbon and Manure "branches" to RuFaS Master
- **Complete Calibrations**
  - Idaho
  - Wisconsin
- **Functionality:** Develop Continuous Cropping
- **Write** Publication (s)

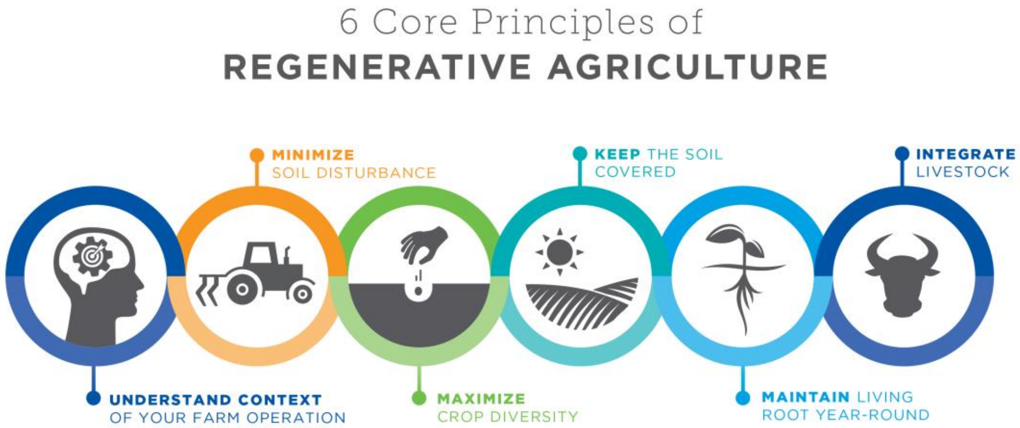
- **Mass Balances (**P, N, C, H_2O)
  - Idaho (Leytem)
  - Wisconsin (Sandford)
  - Prairie du Sac (Vadas)
- **Functionality:** Grazing
- **Develop** multispecies cropping in the same field

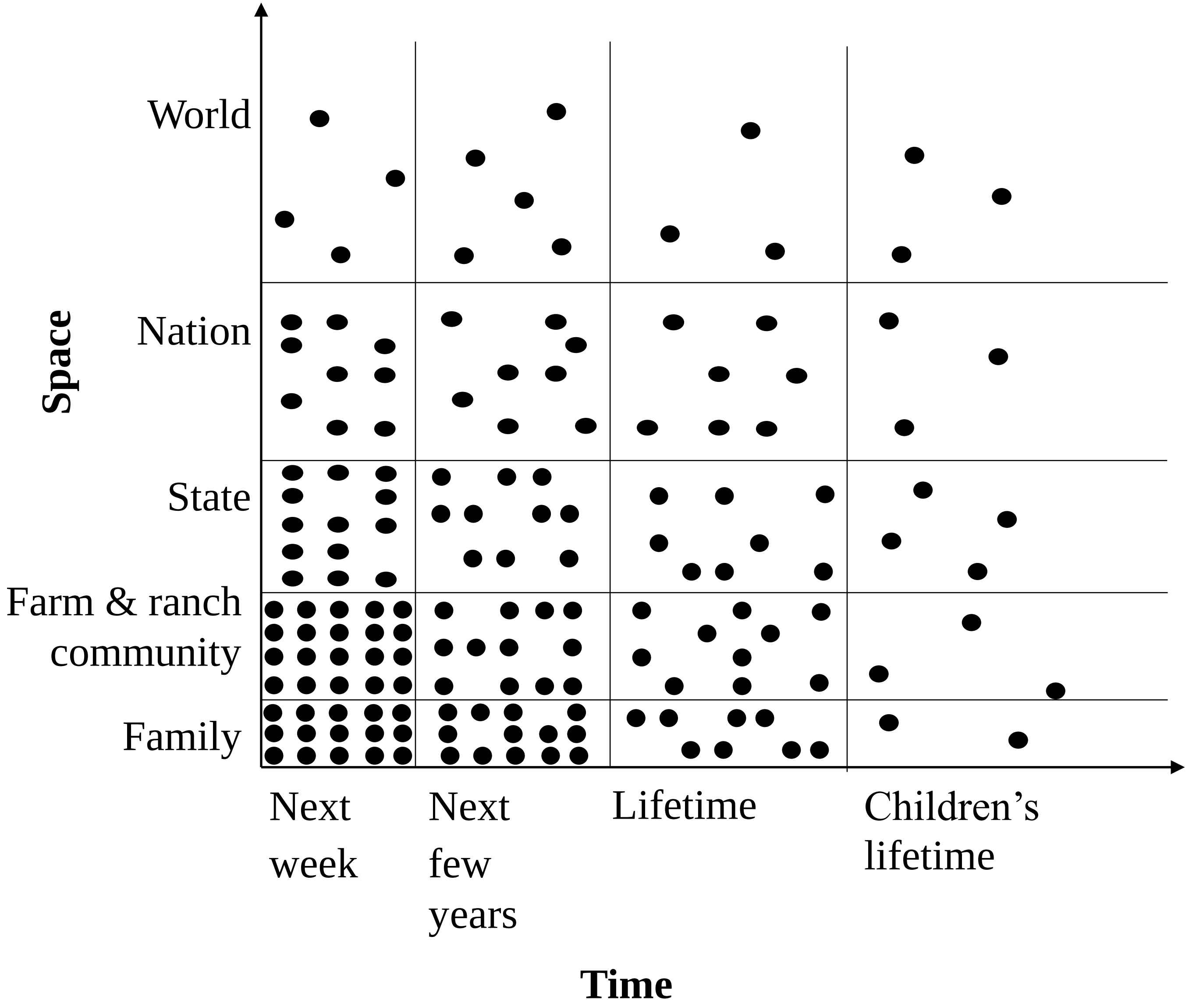
Integration of initial grazing into crop and soil.
Functionality: AMP grazing

Model Evaluation
Policy Design and Analysis

Document, document, document…

Agriculture Decision Paradigm





Adapted from Meadows et al., 1972

Next Steps: RuFaS and General Mills

1. Improve understanding and management of regenerative agriculture

2. Cover crop, multi-species mixes, livestock integration data

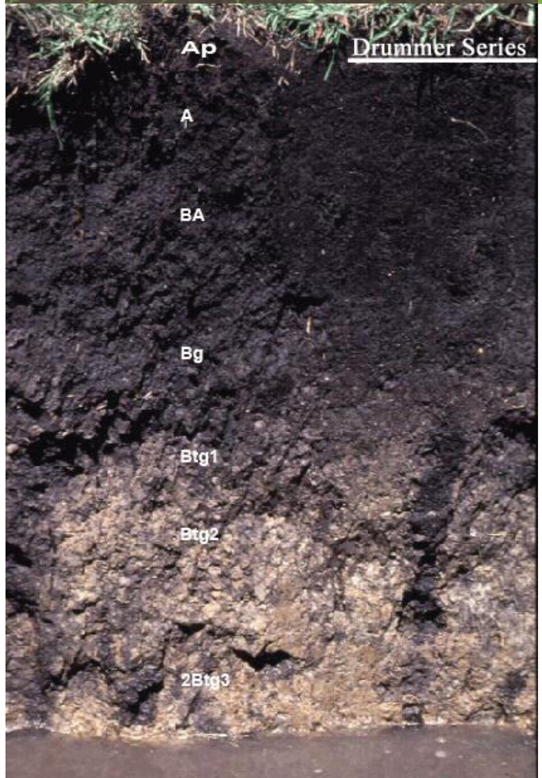
3. Decision Support Tools

4. Stakeholder Use

Questions?

Manure Module Output: Manure (kg/ha)

Soil and Crop Module



Soil and Crop Output: Yield

Feed Storage