RuFaS
Ruminant Farm Systems Model

The Next Generation of Whole Farm Modeling

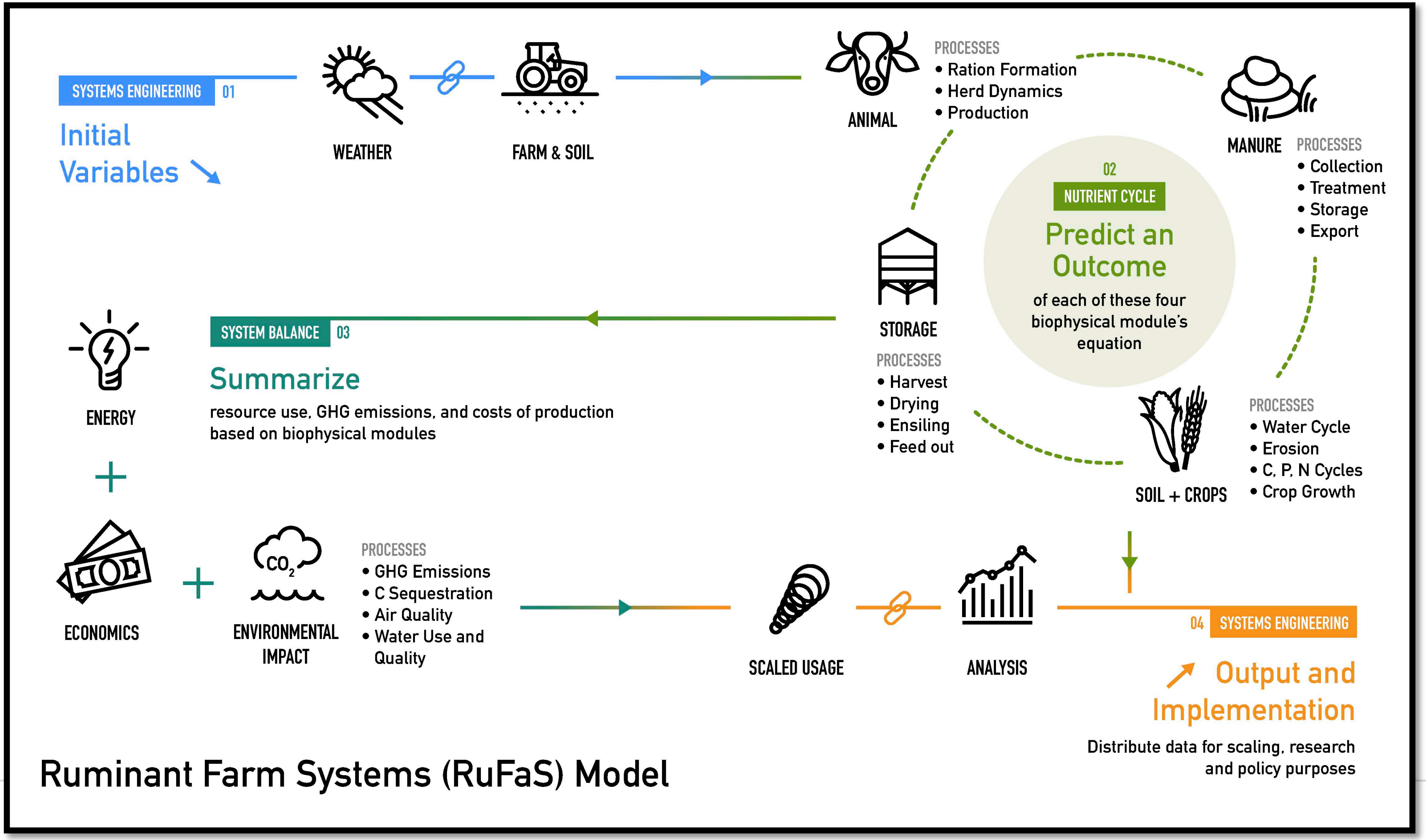
May 2022 Update

What is RuFaS?

A Next-Generation, Whole-Farm, Dairy Sustainability Simulation Model

- Simulates dairy farm production and environmental impact
- Identifies ways to improve efficiency and sustainability
- Has a range of applications, from a research tool for scientists to a decision-aid tool for the dairy industry
- Coding emphasizes transparency and accessibility to ensure model flexibility, clarity, adaptability, and persistence

How Does RuFaS Work?



RuFaS Goals

- Interoperable
- Documented
- Open Source
- Sustainable

Evolution

2017

Formalized vision and established principles for RuFaS development

2018

Computer simulation structure established, and first lines of code written

Submitted first federal proposal

Expanded collaborators to include Cornell

2019

First paper published

Formalized documentation and version control methods

Submitted first successful Federal proposal

2020

Formalized Industry Advisory Council

Connected nutrient cycle in biophysical model

2021

Published 2 manuscripts on Animal Module

Hired first Professional Software Engineer

2022

Initiated contract with FARM-ES

RuFaS Team

★ Team Members

ANIMAL

MANURE

SOIL + CROPS

ENERGY

ECONOMICS

Participatory Modeling

- Involves stakeholders in all parts of the model development
  - 2020: Stakeholder Advisory Council
- Creates a shared understanding of the system, the problem and the solutions
- Increases stakeholder ownership of the research outcomes

Two Development Foci

<u>Adding/Testing Functionality</u>

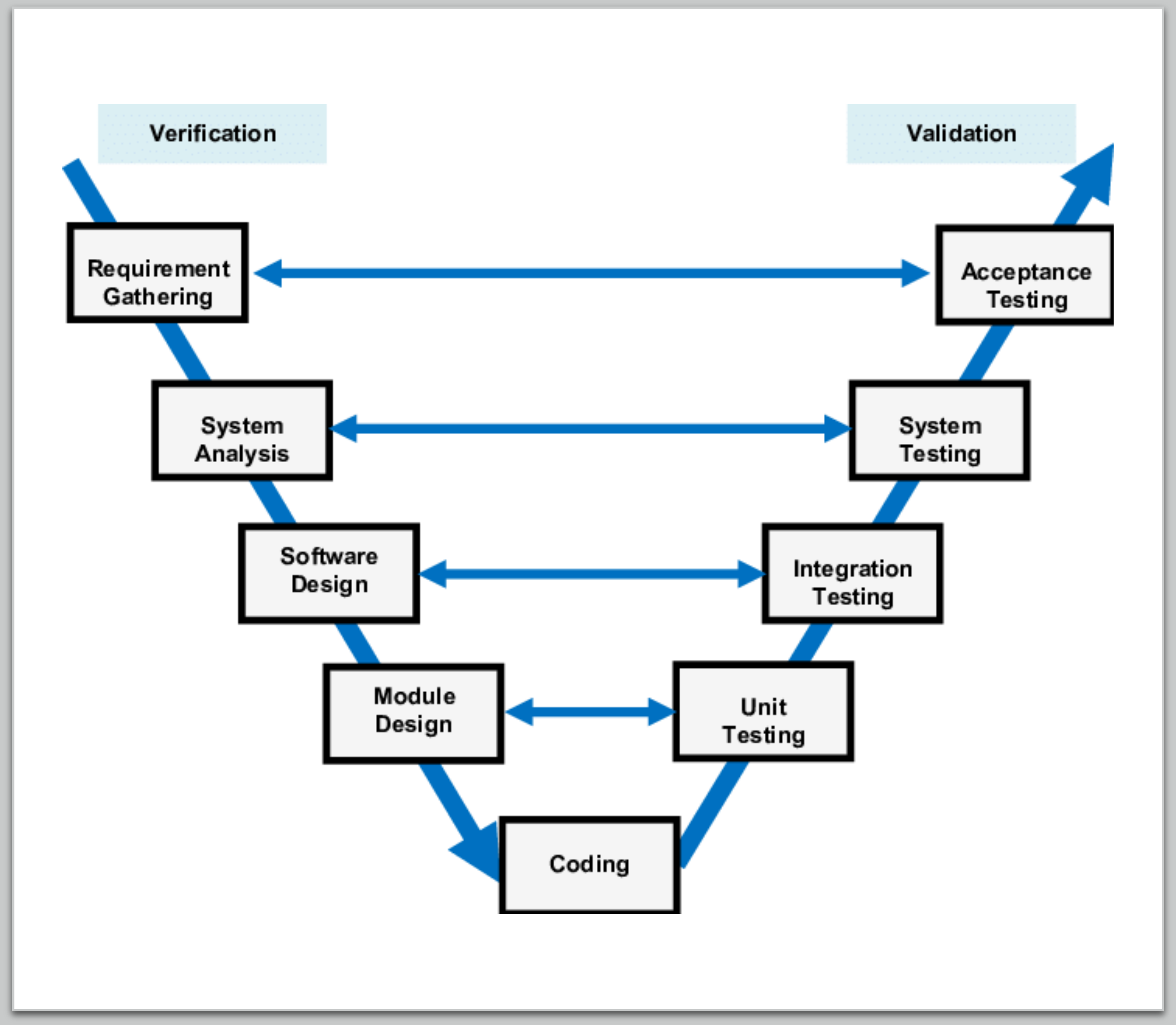
- Additional Management Practices
- Input / output methods
- Sensitivity Analyses
- Precision & Accuracy Evaluation

<u>Improving Code Clarity</u>

- Automated testing – Unit tests!
- Refactoring large functions
- Sphinx documentation

Unit Testing

- Unit tests isolate a section of code and verify its correctness.
- Purpose is to validate that each unit of the software code performs as expected.
- Ensures that individual components of the system are working correctly at the most granular level.



Sphinx Documentation

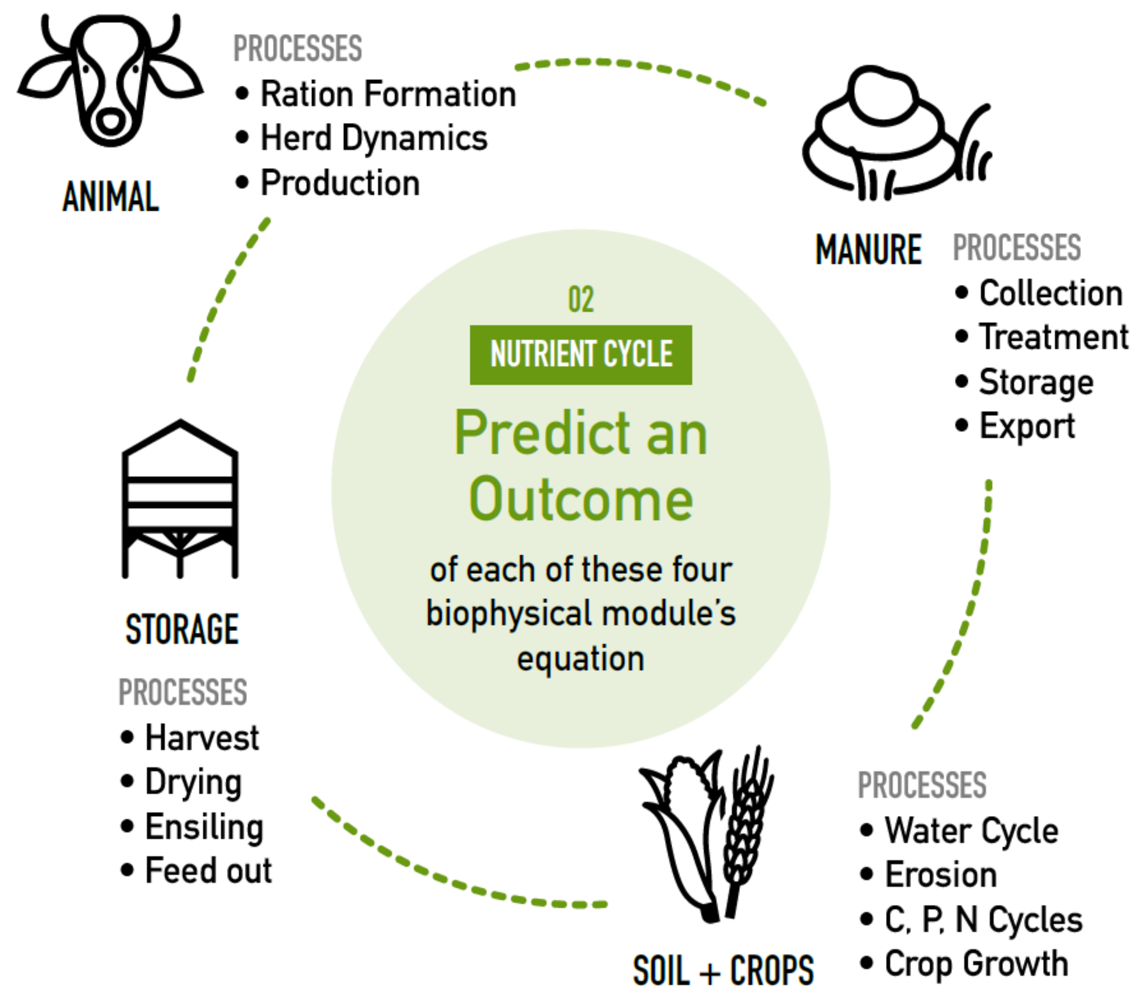
- Sphinx is a tool that makes it easy to create intelligent and beautiful documentation.

- Works based on docstrings and has many great features for writing technical documentation including:
  - Webpages
  - PDFs
  - Cross references code with documentation automatically

```python
def p_comp(animals):
    """
    Args:
        animals: the list of animals for which the P composition should be
            calculated
    Returns:
        p_comp: the P composition of @animals
    """

    if len(animals) == 0:
        return 0
    else:
        total_bw = 0
        total_p_animal = 0
        for animal in animals:
            total_bw += animal.body_weight
            total_p_animal += animal.p_animal
        return total_p_animal / total_bw
```

Biophysical Model Progress



Soil & Crop: Version 1 Functionality

SOIL + CROPS

Management

- Tillage: from conventional to no-till
- Soil amendment: manure and fertilizer from broadcast to injection
- Flexible planting and harvest dates

Crops

- Corn (grain or silage)
- Alfalfa
- Grass
- Soybeans
- Wheat
- Rye
- Triticale
- Cover & Double Cropping

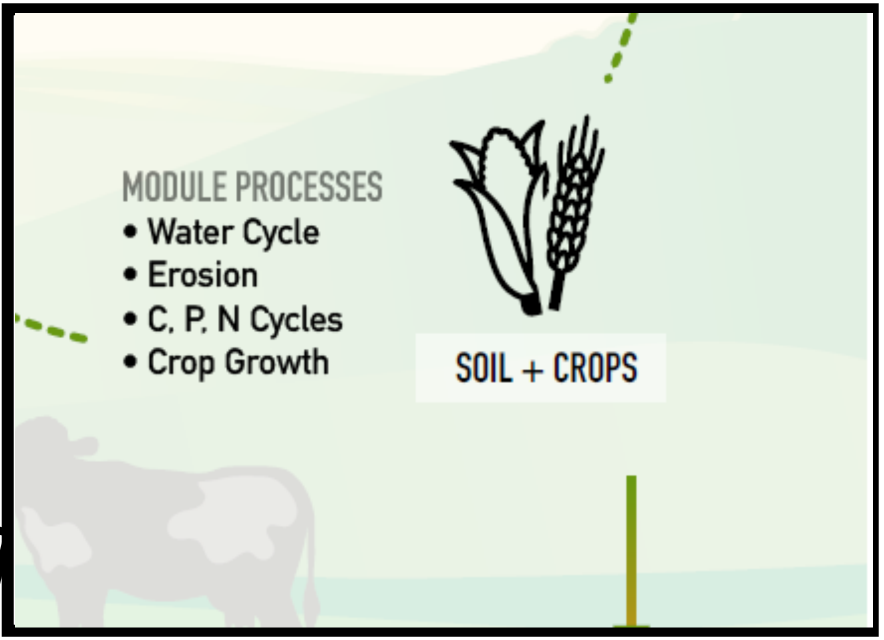
Outputs

- Emissions: N_2O, CH_4, NH_3, CO_2
- Leaching and Runoff: N & P
- Water use
- Soil C stocks and changes
- Crop yields

Soil + Crop Status

- All functionality for v1 are in the Python repo
  - Double cropping functionality still in development
- Currently in model evaluation and testing phase
  - Soil erosion and P runoff manuscript in prep
- DFRC postdoc will join in June to initiate sensitivity analysis

Crop and Soil Approach



Key Equations

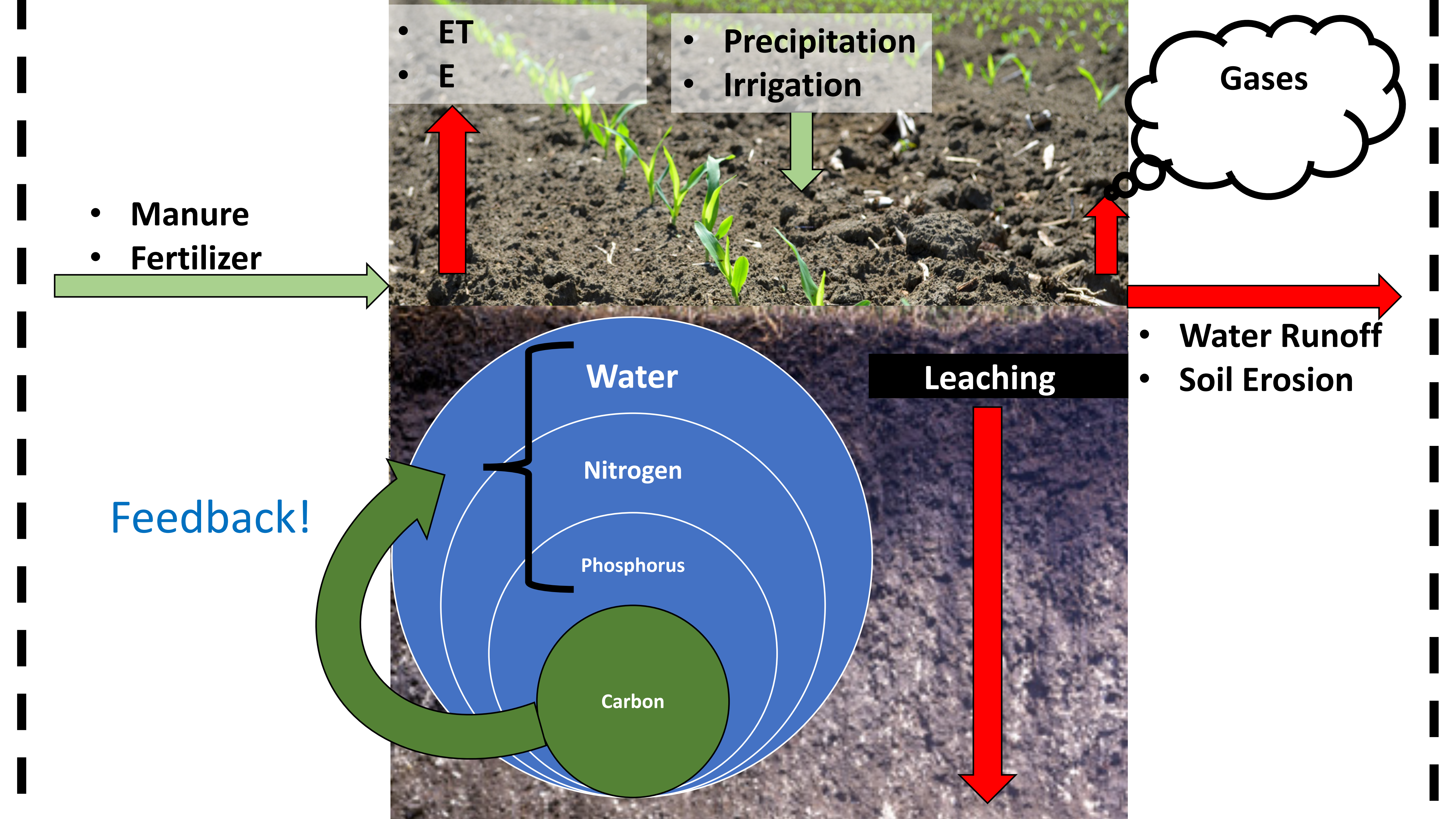
Existing Models

Soil & Water Assessment Tool SWAT

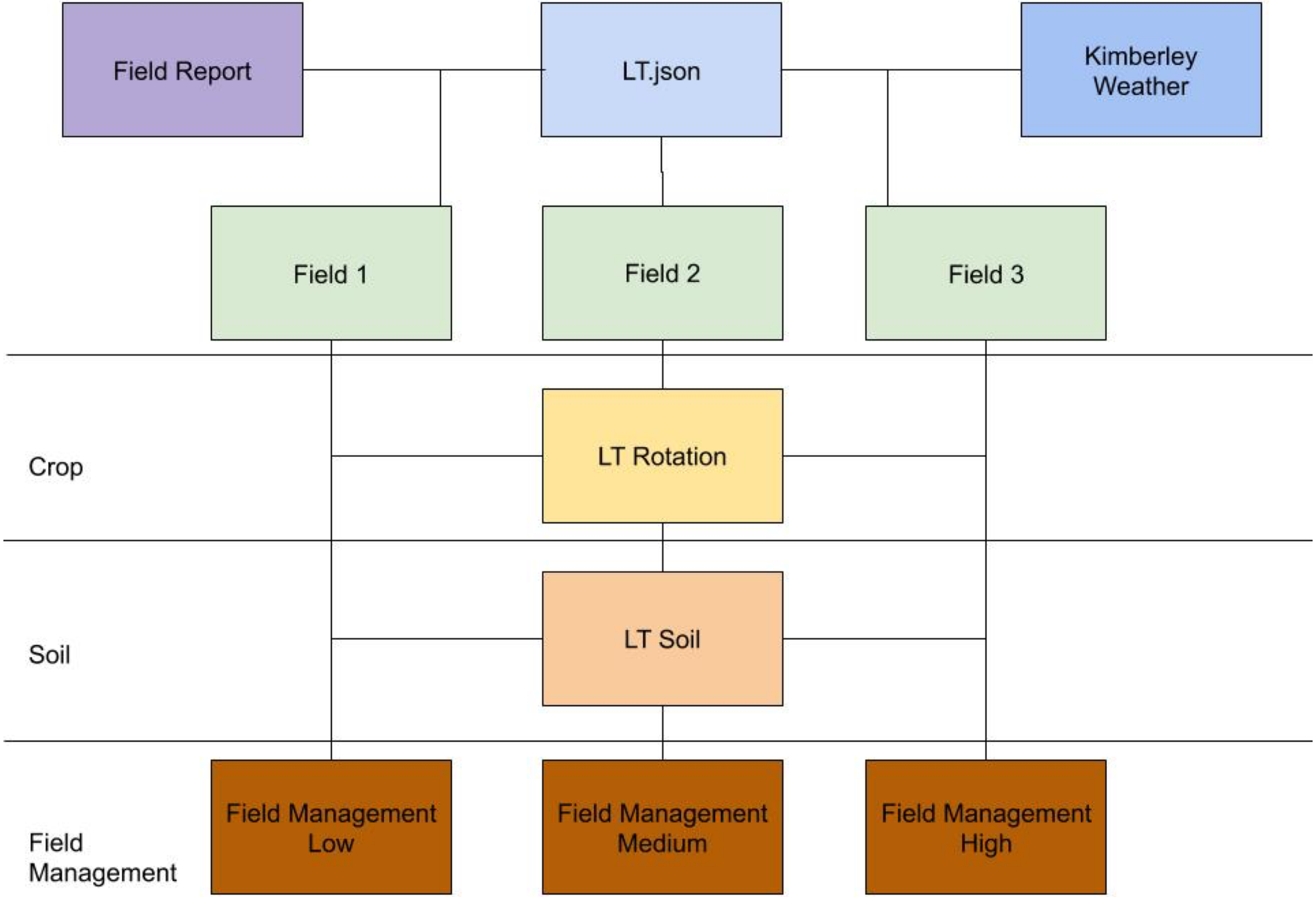
Century 100 DayCent

SurPhos Surface Phosphorus Runoff Model

python



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


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

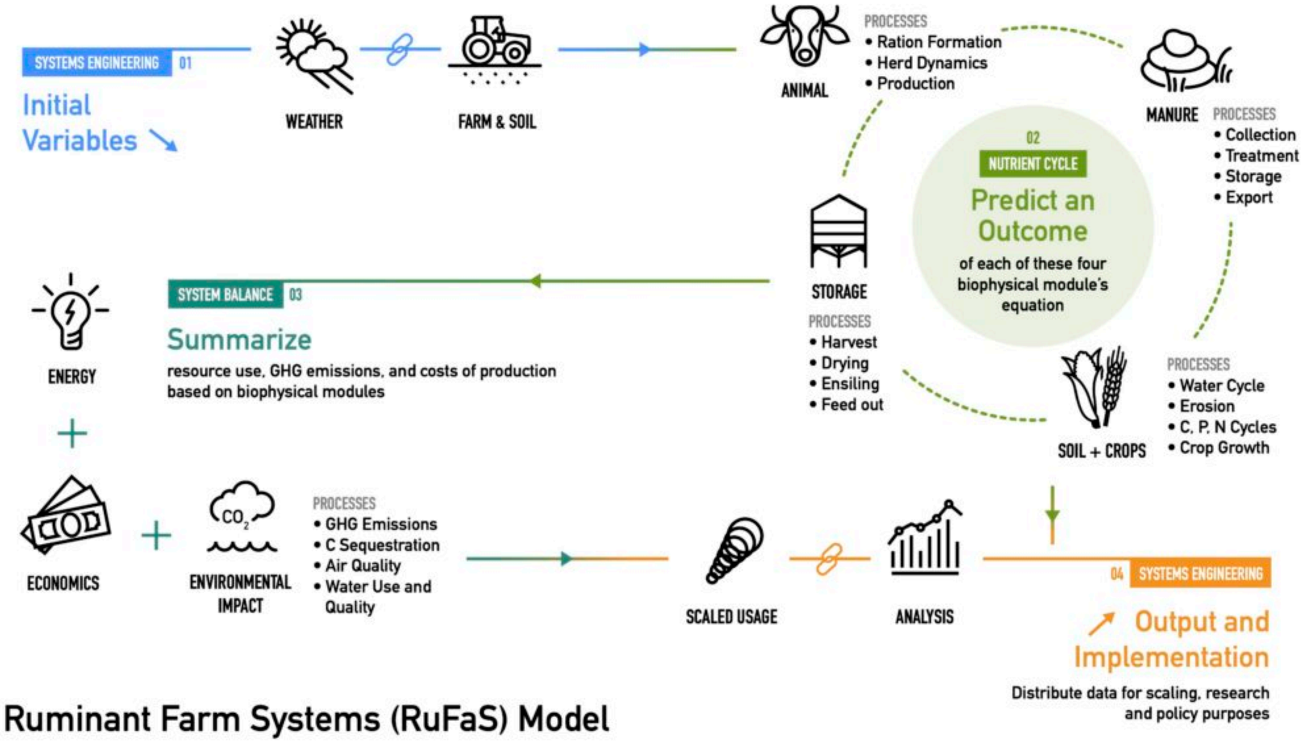
RUFAS scenarios discussion

Tadeu Eder da Silva – UW-Madison

Hector Menendez - SDSU

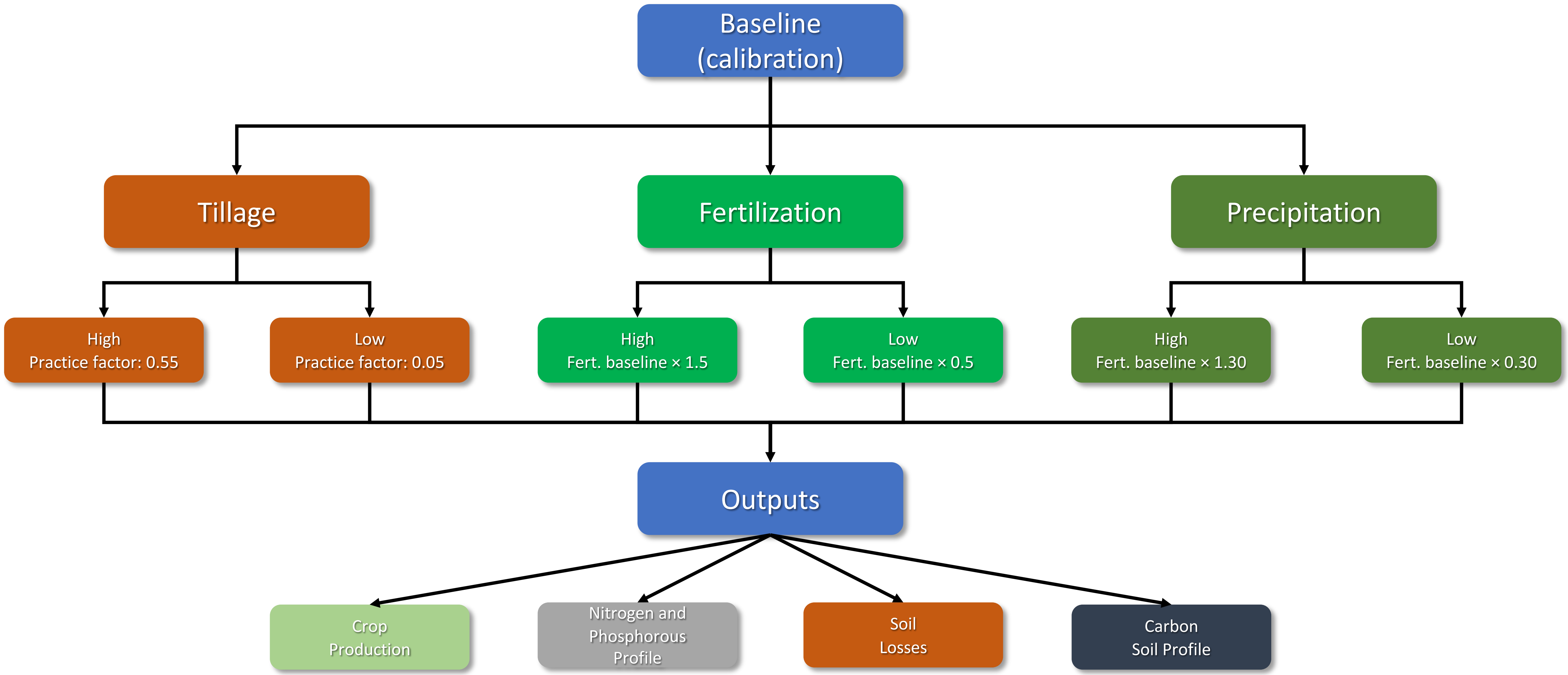
Kristan Reed – Cornell University

Victor Cabrera – UW-Madison

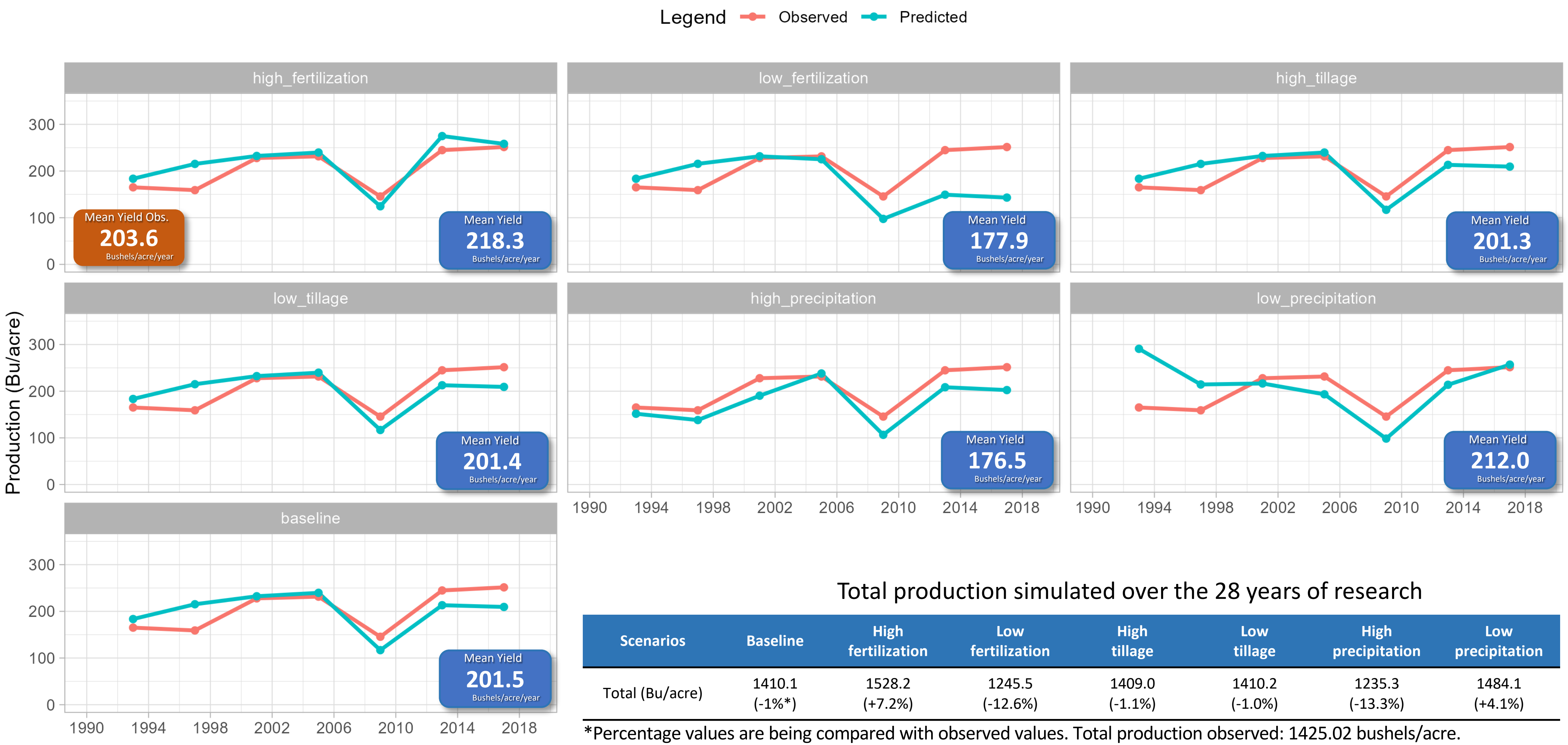


Ruminant Farm Systems (RuFaS) Model

Scenario Development



Results – Corn Production

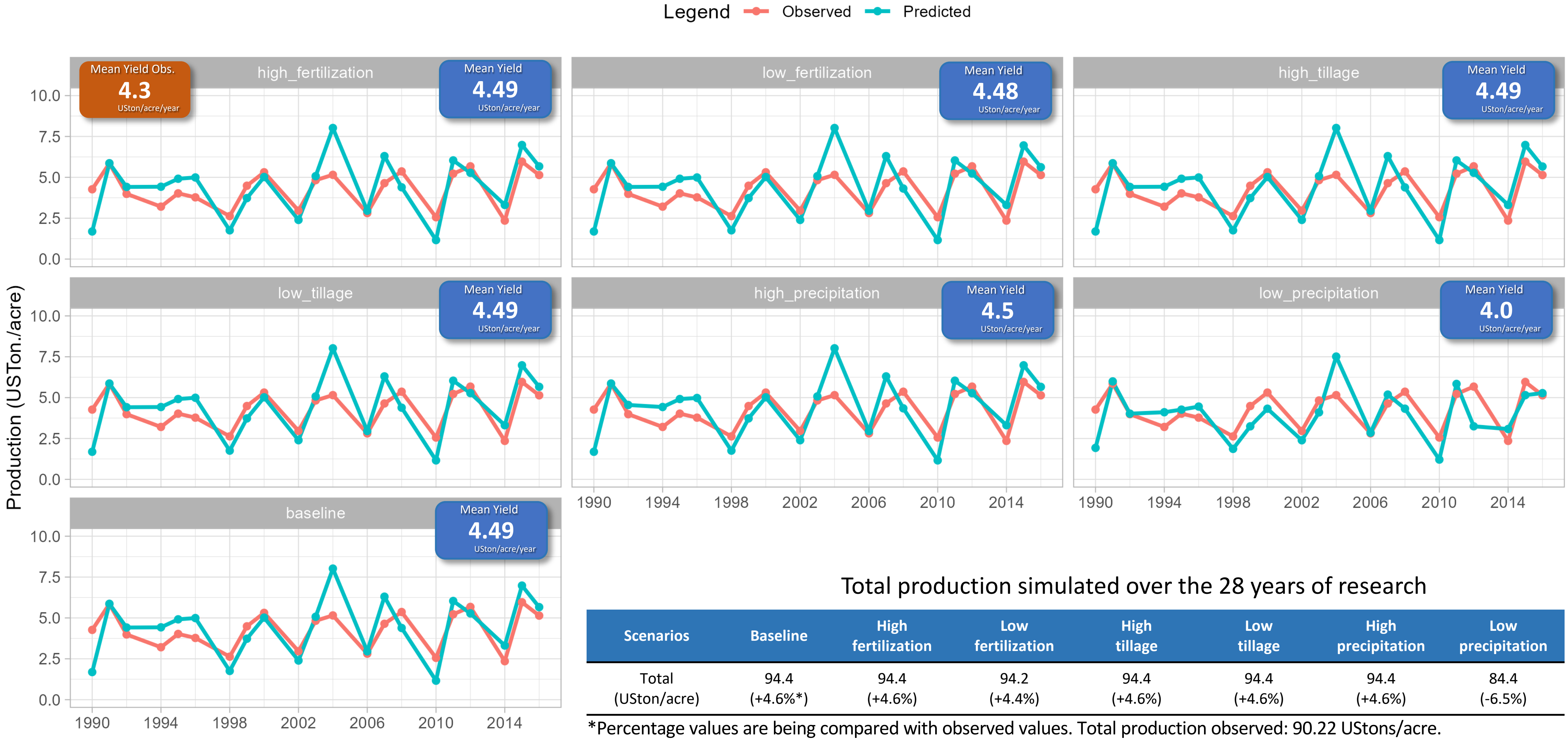


Total production simulated over the 28 years of research

Scenarios	Baseline	High fertilization	Low fertilization	High tillage	Low tillage	High precipitation	Low precipitation
Total (Bu/acre)	1410.1 (-1%*)	1528.2 (+7.2%)	1245.5 (-12.6%)	1409.0 (-1.1%)	1410.2 (-1.0%)	1235.3 (-13.3%)	1484.1 (+4.1%)

*Percentage values are being compared with observed values. Total production observed: 1425.02 bushels/acre.

Results – Alfalfa Production

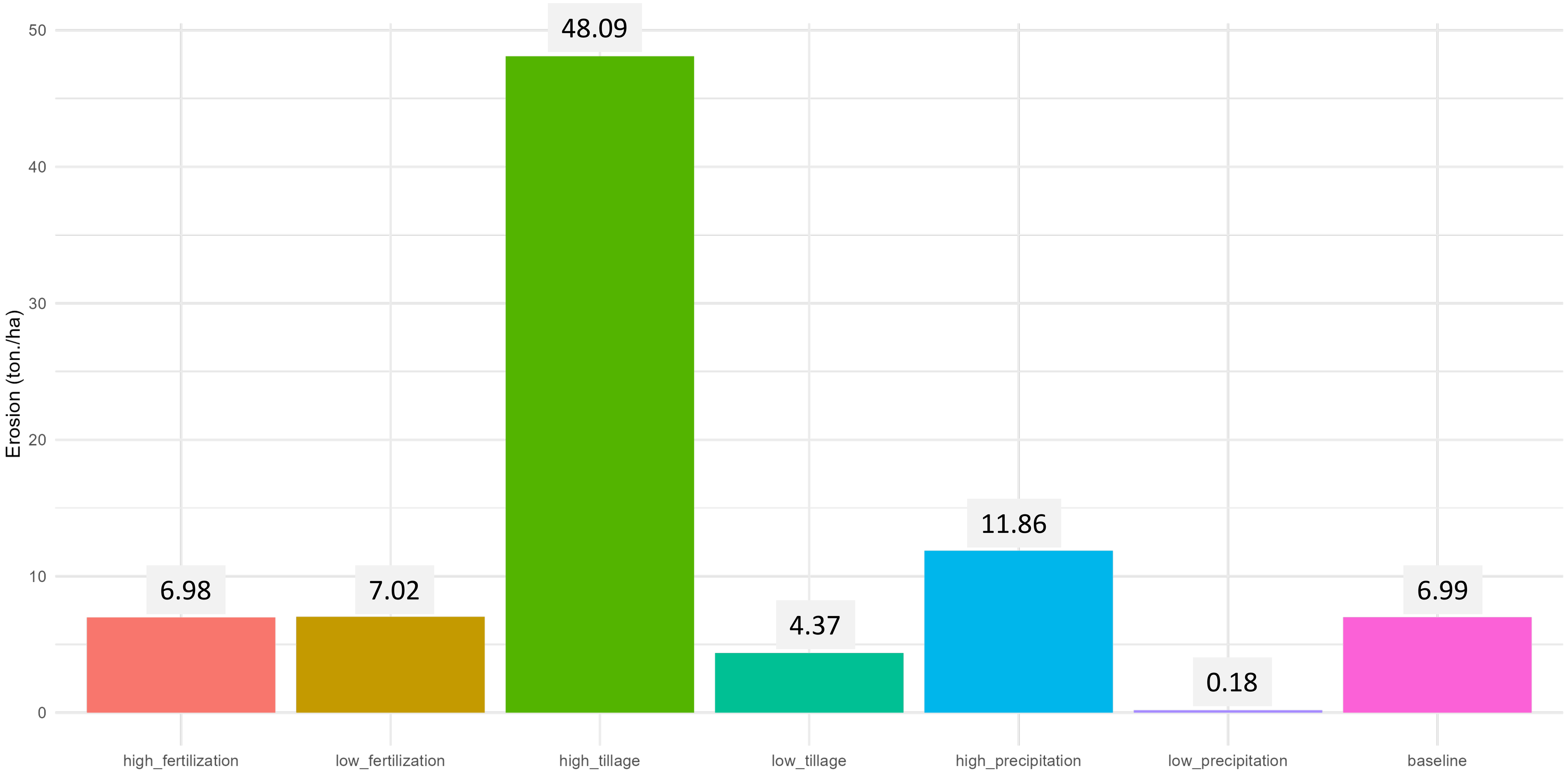


Total production simulated over the 28 years of research

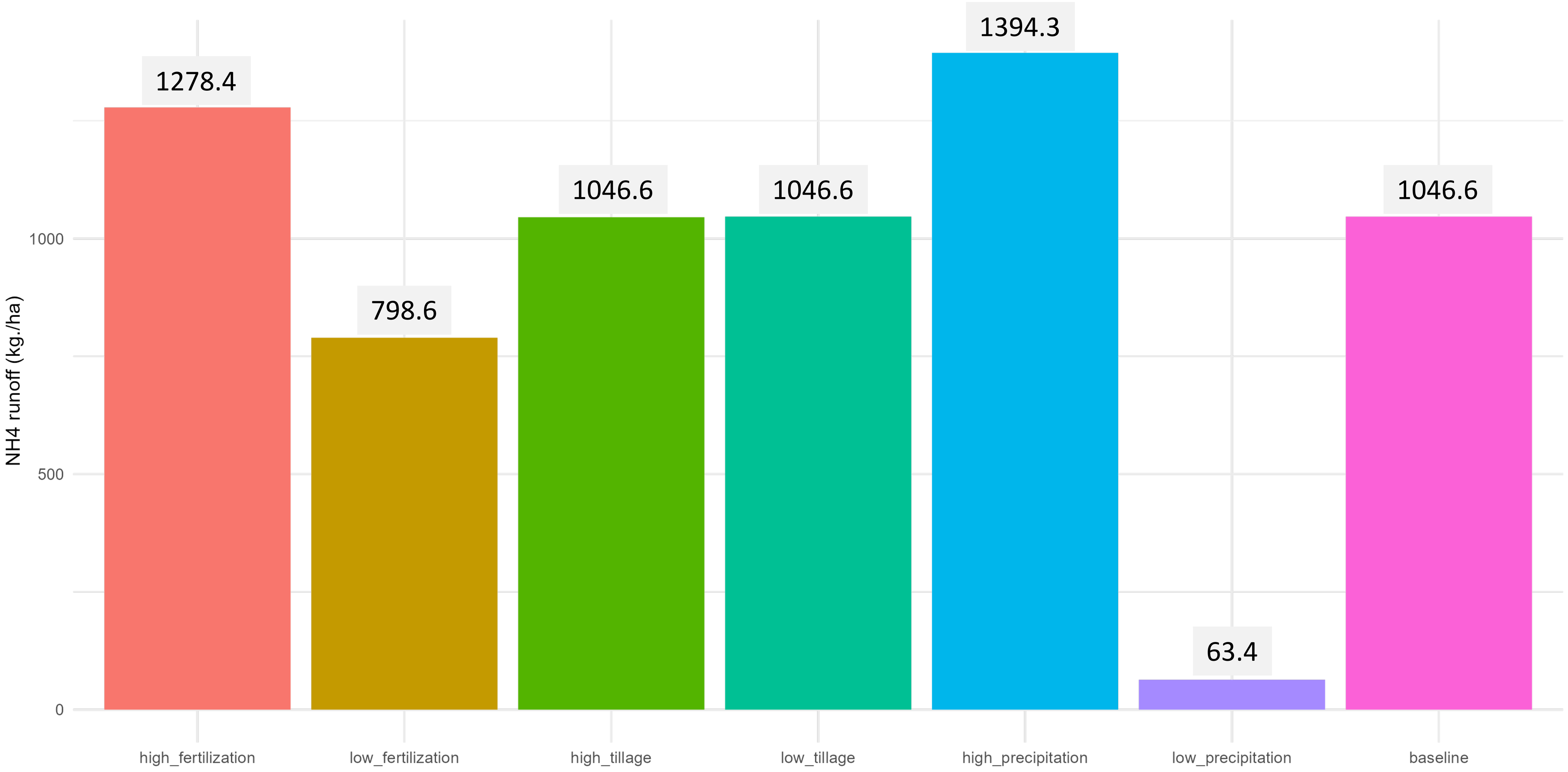
Scenarios	Baseline	High fertilization	Low fertilization	High tillage	Low tillage	High precipitation	Low precipitation
Total (USton/acre)	94.4 (+4.6%*)	94.4 (+4.6%)	94.2 (+4.4%)	94.4 (+4.6%)	94.4 (+4.6%)	94.4 (+4.6%)	84.4 (-6.5%)

*Percentage values are being compared with observed values. Total production observed: 90.22 UStons/acre.

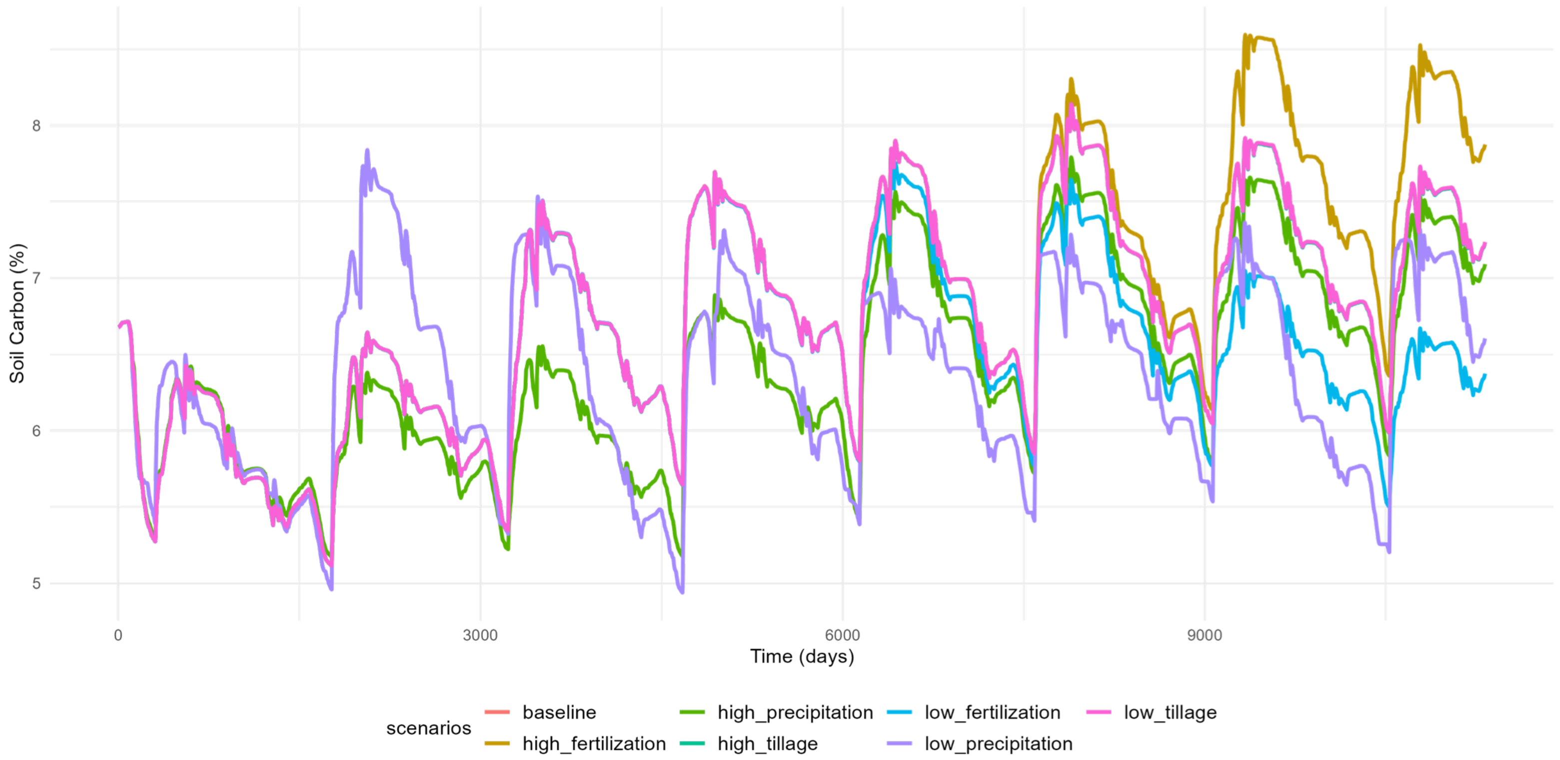
Results – Soil Erosion



Results – NH_4 Runoff

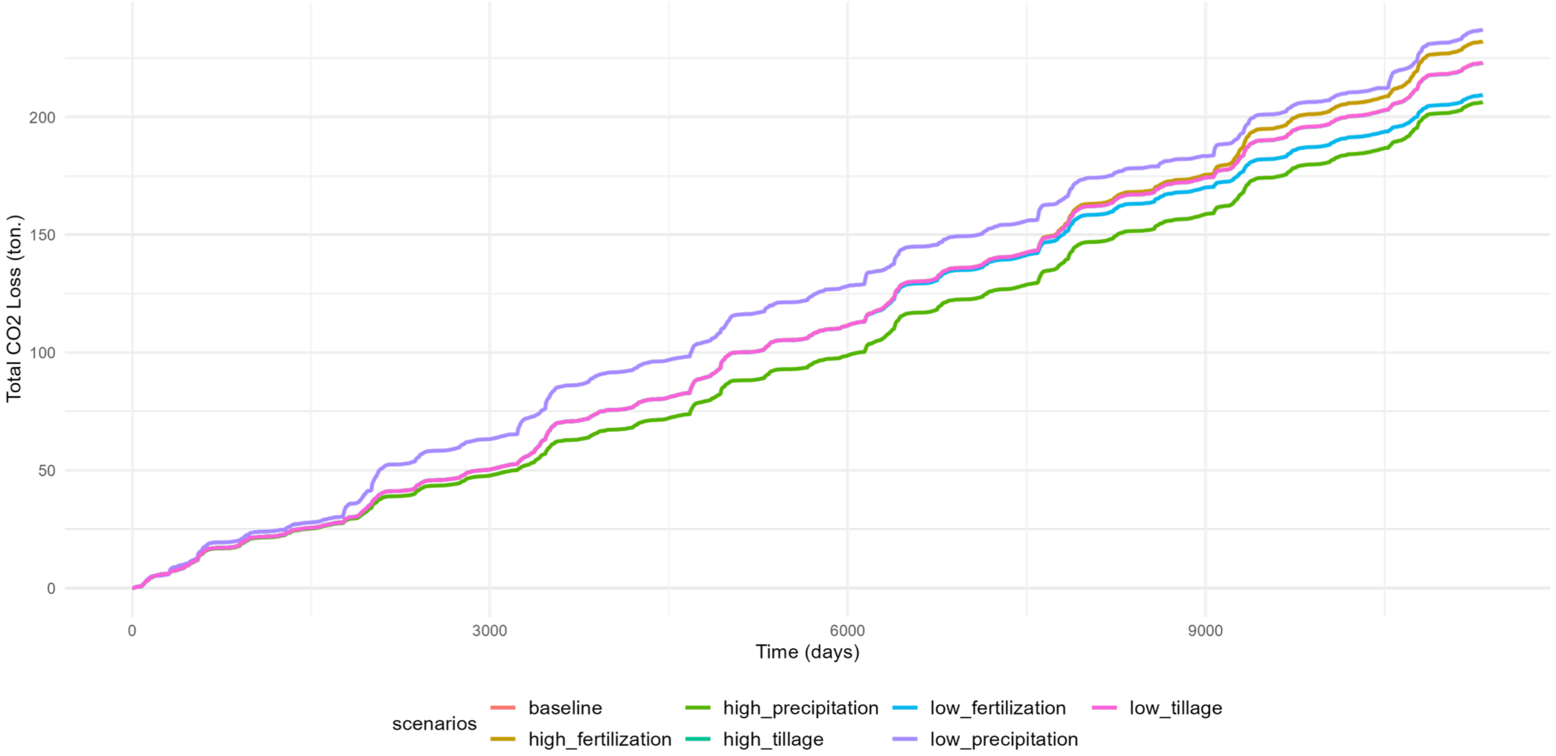


Results – Soil Carbon Content



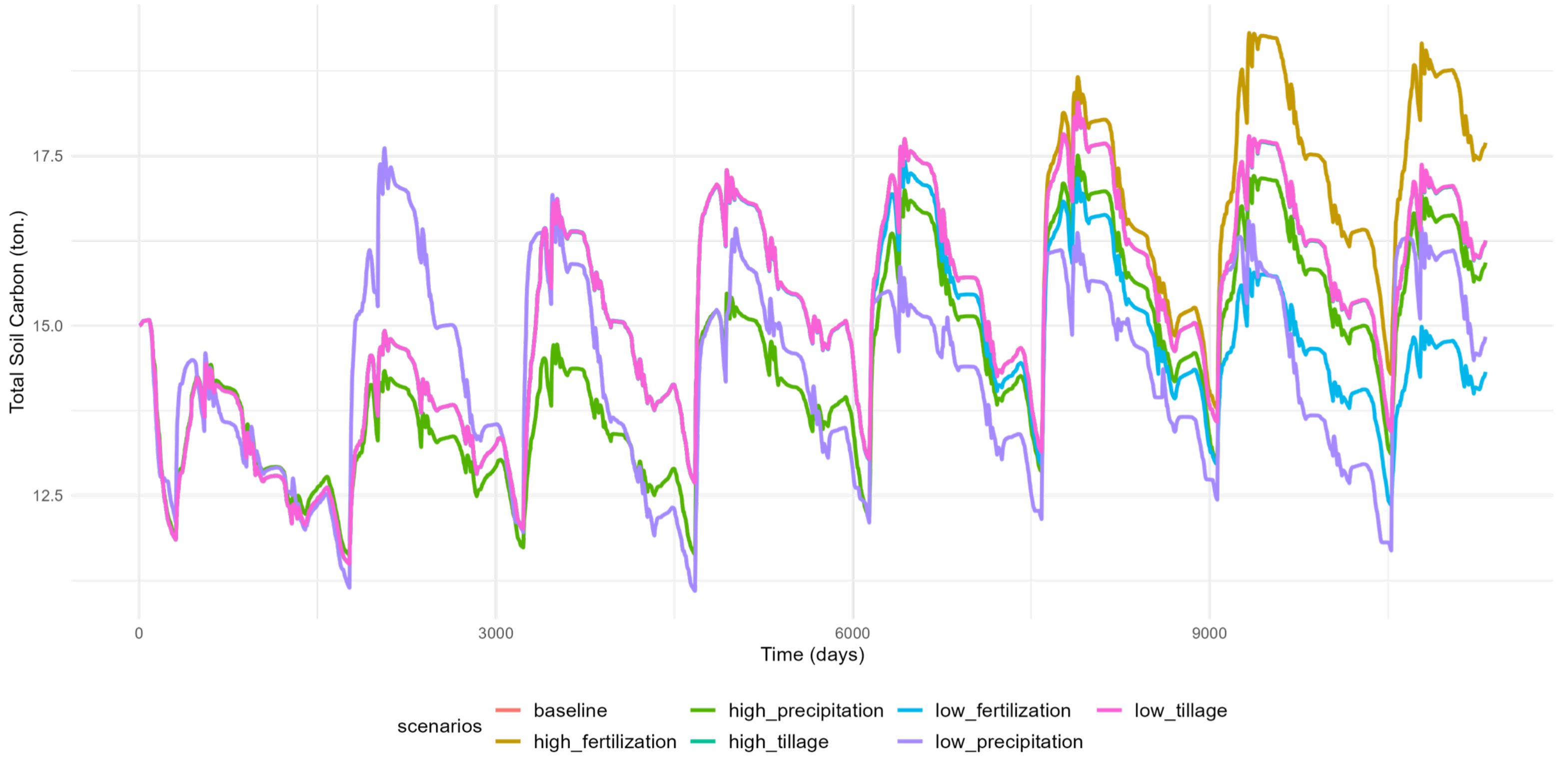
Scenarios	Mean Soil C (%)	Min. Soil C (%)	Max. Soil C (%)
Baseline	6.73	5.12	8.14
High Fertilization	6.87	5.12	8.59
Low Fertilization	6.51	5.12	7.75
High Tillage	6.73	5.12	8.14
Low Tillage	6.73	5.12	8.14
High Precipitation	6.44	5.12	8.59
Low Precipitation	6.37	4.94	7.84

Results – Total CO_2 Loss



Scenarios	Total CO_2 Loss (Ton.)	Dif. Baseline (Ton.)
Baseline	1238574	-
High Fertilization	1253327	14753 (+1.2%)
Low Fertilization	1210362	-28212 (-2,27%)
High Tillage	1238214	-360 (-0.03%)
Low Tillage	1238603	29 (+0.002%)
High Precipitation	1128100	-110474 (-8.9%)
Low Precipitation	1366575	128001 (+10.3%)

Results – Total Soil Carbon



Scenarios	Total Soil C (Ton.)	Dif. Baseline (Ton.)
Baseline	171210.8	-
High Fertilization	174620.8	3410 (+1.2%)
Low Fertilization	165639.6	-5571.2 (-2,27%)
High Tillage	171169.5	-41.3 (-0.02%)
Low Tillage	171214.1	3.3 (+0.002%)
High Precipitation	163720.5	-7490.3 (-4.4%)
Low Precipitation	162177.0	-9033.8 (-5.3%)

Feed: Version 1 Functionality

STORAGE

Management

- Silage and Hay
- Storage separation by forage quality
- Inventory tracking
- Biomass loss during harvest, storage, and feedout
- Different feeds available to each animal group

Forage Composition Changes

- Dry matter content
- Total N and Non-protein N

Outputs

- CO_2 losses during harvest, storage and feedout
- Biomass left on field
- Spoilage/losses from storage and feedout
- Daily forage inventory

Feed Storage Status

- Basic, empirical silage and hay storage functionality
  - Nutrient losses
  - Inventory management
- Have pseudocode for dynamic silage storage
- Connection to ration formulation needs improvement

Animal: Version 1 Functionality

ANIMAL

Management

- Housing: Tie stall, freestall, drylot
- Reproduction: estrus detection, TAI, Re-synch
- Pens: variable number, size, stocking density and grouping methods
- Breeds: Holsteins and Jerseys

Diets

- Diets: 30-70% farm grown forage
- Purchased feed and by products
- Enteric methane mitigation supplements
- Least cost diet formulation

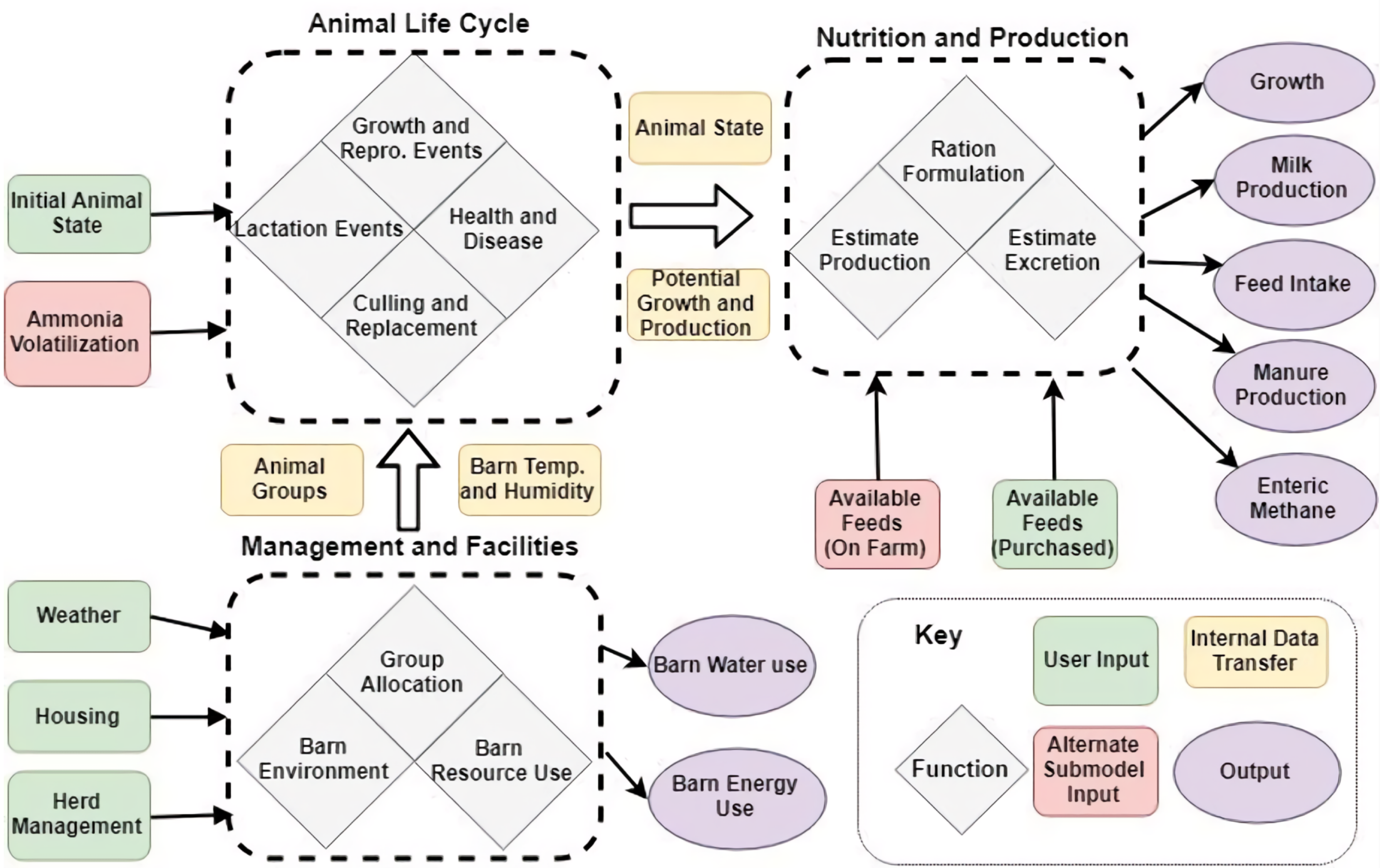
Outputs

- Herd demographics
- Milk and meat production
- Enteric Methane production
- Embedded feed emissions
- Manure production and composition
- Energy, feed and water use

Animal Module Status

- Most functionality exists and some has been tested
- Remaining functionality:
  - Dry lot housing
  - Enteric Methane supplements
  - Update to new NASEM requirements?
- Sensitivity analysis has started with life-cycle sub-module
- Ration formulation evaluation is a top priority

Animal Module Approach



Animal life cycle sub-model

Components of simulation

Lactation curve

Reproduction programs

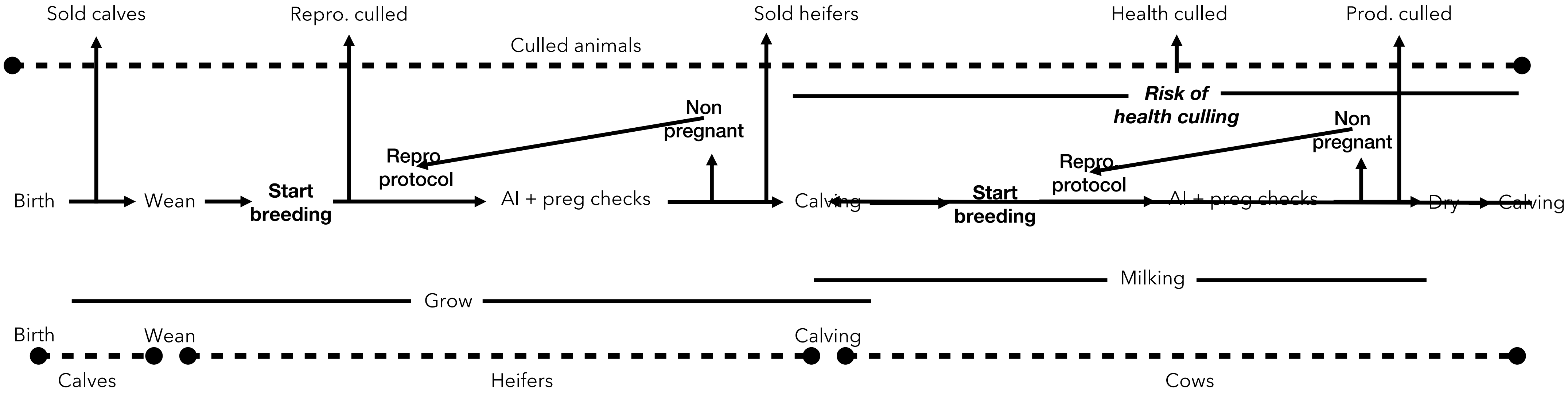
Culling events

Bodyweight change

Animal life cycle sub-model

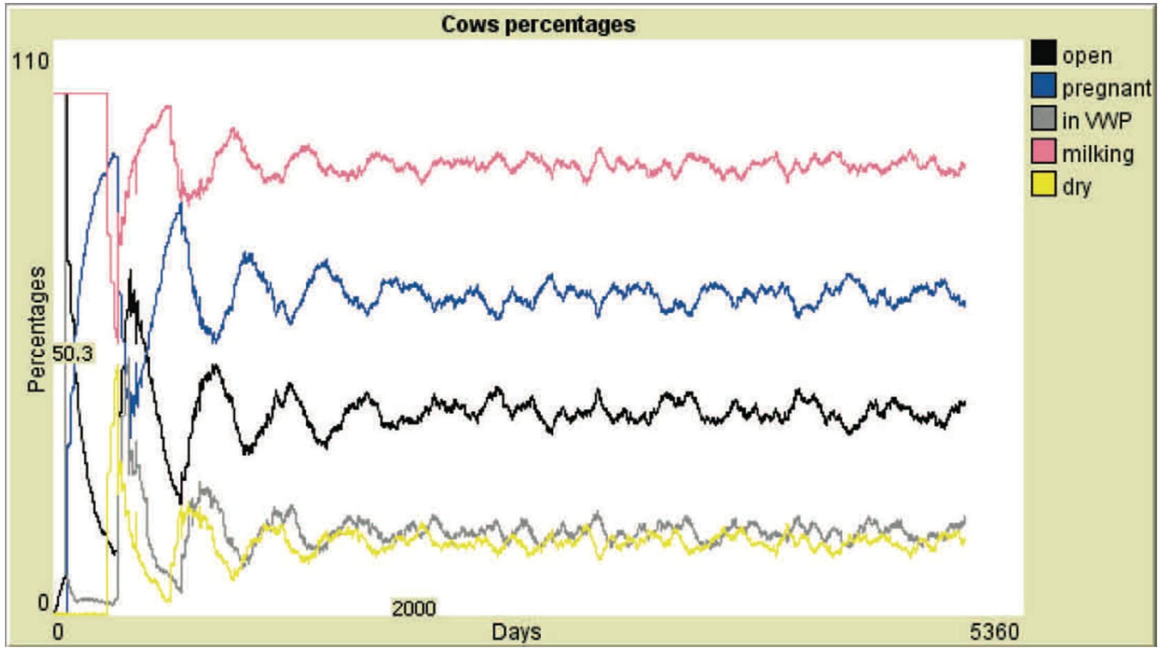
Individual animal life story

Calves	Heifers I	Heifers II	Heifers III	Cow	Culled
Birth - wean	Wean - breed	Breed - replacement	Close to calving	Start lactating	After culling
0 - 60	60 - 400	400 - replacement	to 1st calving	Calved - cull	Culled - sell



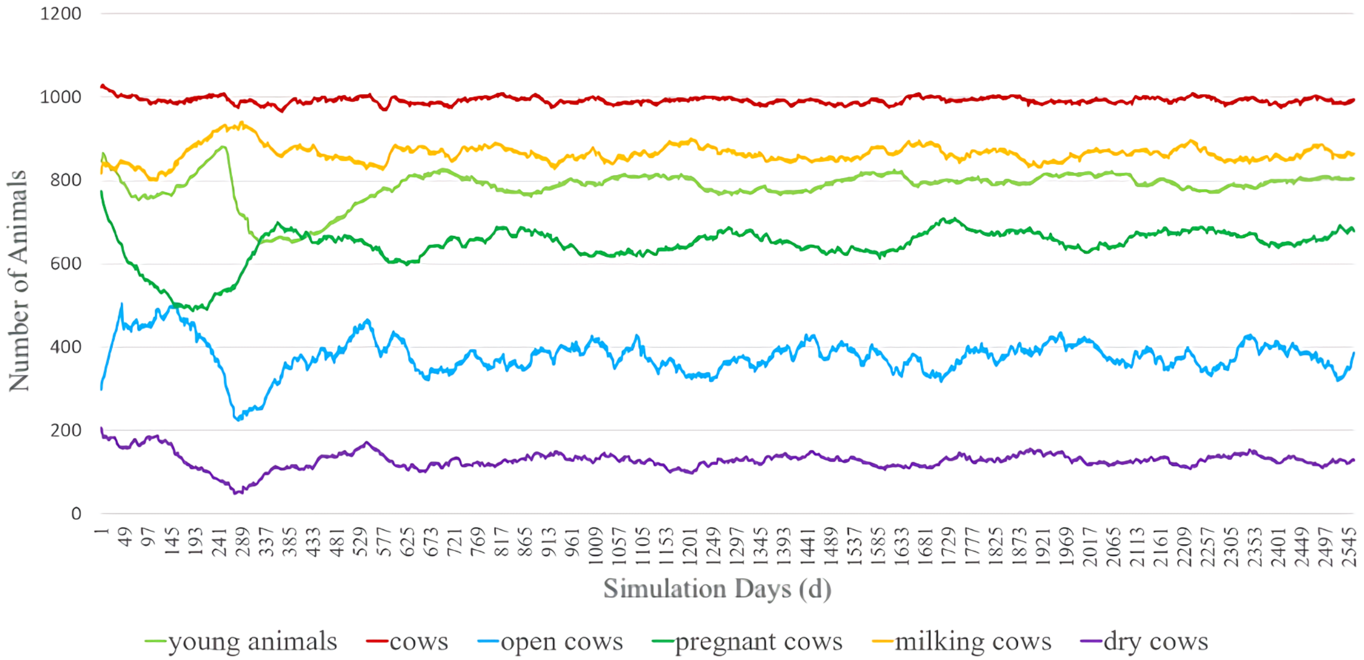
Animal life cycle submodel

Herd simulation steady state — 1000 adult cow herd



Steady state reached around 3000 d,

Galvão et al., 2013



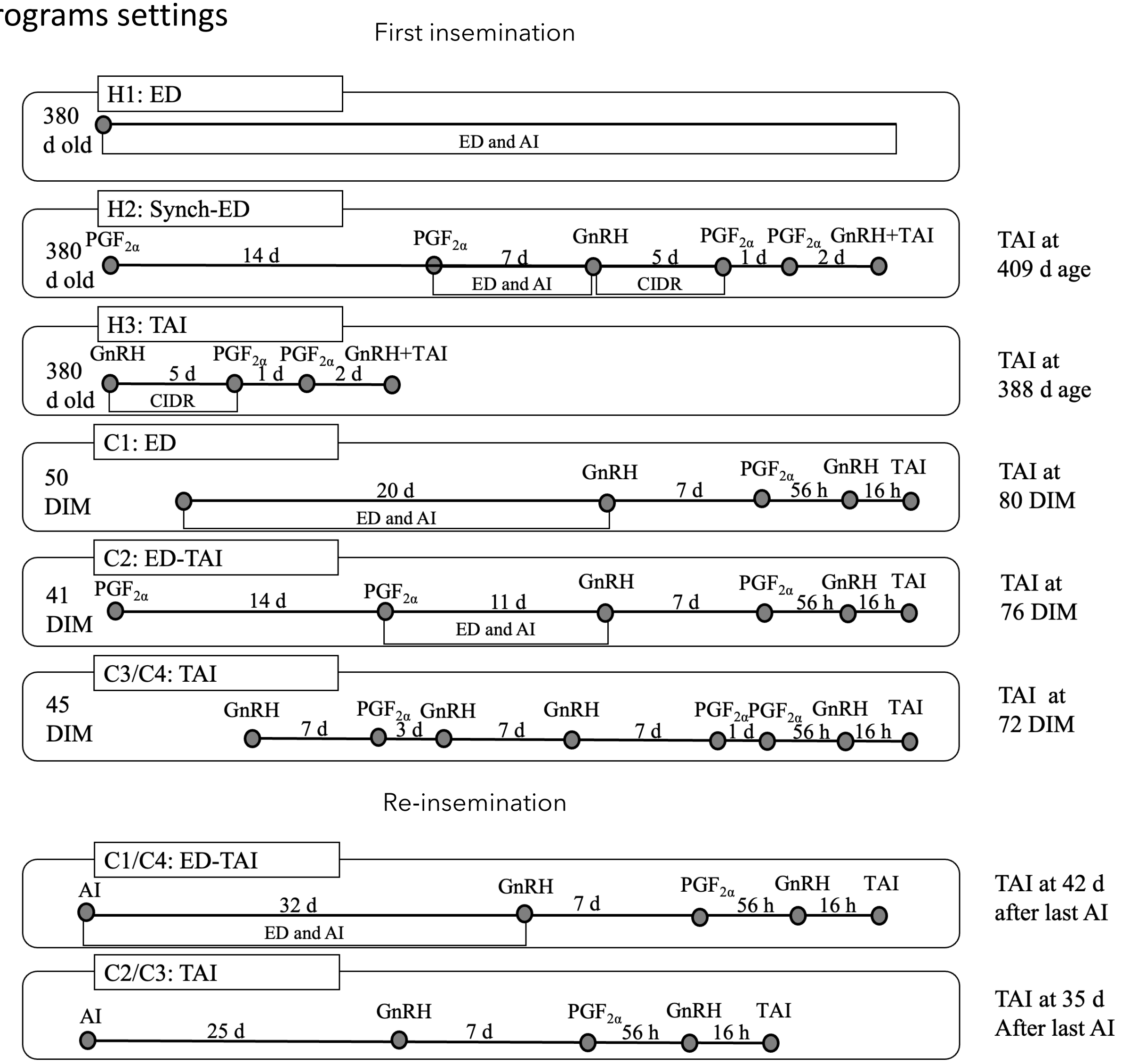
Steady state reached around 700 d,

Example from RuFaS

Case study - combine cow and heifer repro programs

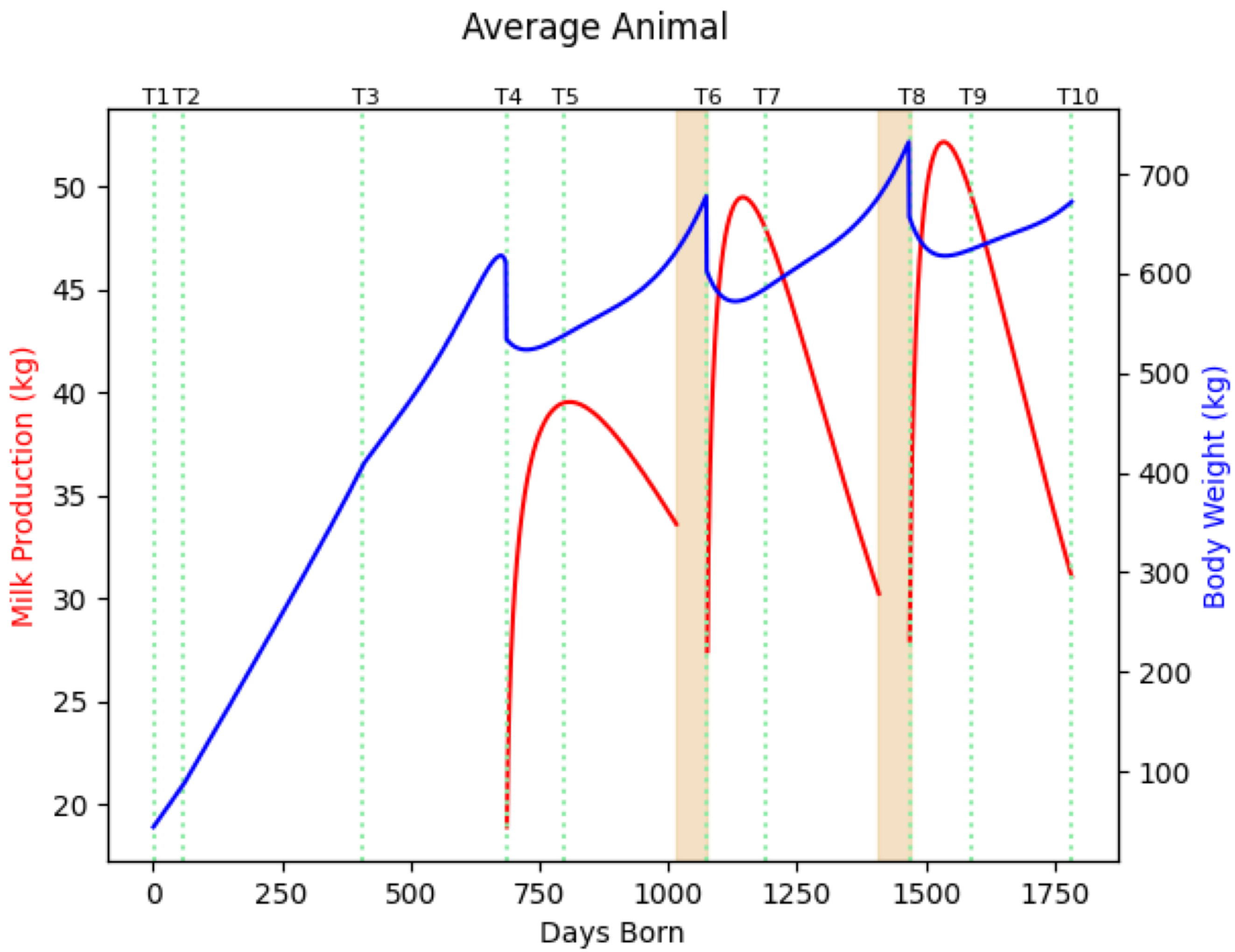
Reproductive programs settings

	Strategy	Program	Settings for simulations: SR[2] (%)	First insemination P/AI (%)	Re-inseminations, P/AI (%)	
Heifer nulliparous						Start age (d)
H1	ED	ED	60	60		380
H2	Synch-ED	$PGF_{2\alpha}$- $PGF_{2\alpha}$ - finish with TAI	70 100	60 50	ED, 60	380
H3	TAI	GnRH-CIDR- $PGF_{2\alpha}$- $PGF_{2\alpha}$ -GnRH+TAI	100	60		380
Cow primiparous[3]						VWP(DIM)
C1	ED	ED + Ovsynch	60 100	50 40	ED + Ovsynch, 45, 45	50
C2	ED-TAI	Synch-ED + Ovsynch	60 100	50 50	Ovsynch, 45	55
C3	TAI	Double-Ovsynch + $PGF_{2\alpha}$	100	60	Ovsynch, 45	72
C4	TAI-ED	Double-Ovsynch + $PGF_{2\alpha}$	100	60	ED + Ovsynch, 45, 45	72



Repro case study

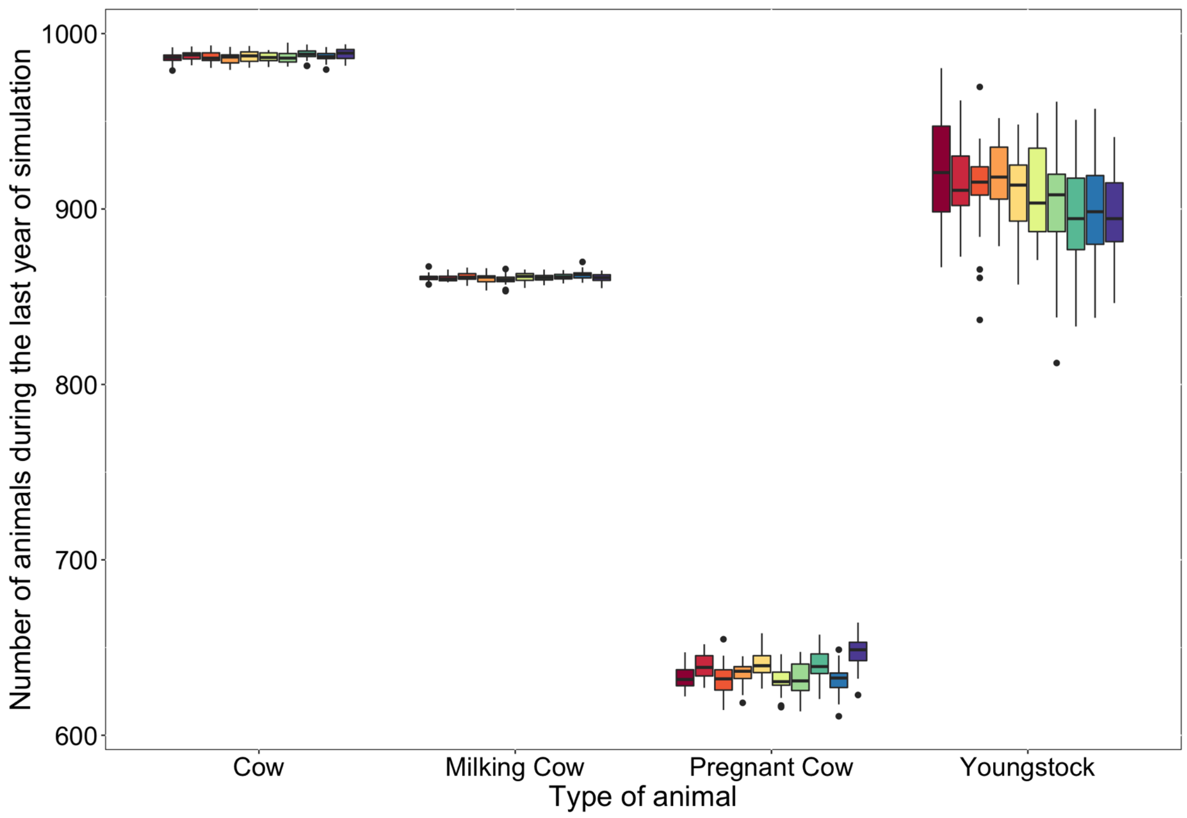
Average animal from one reproduction scenario

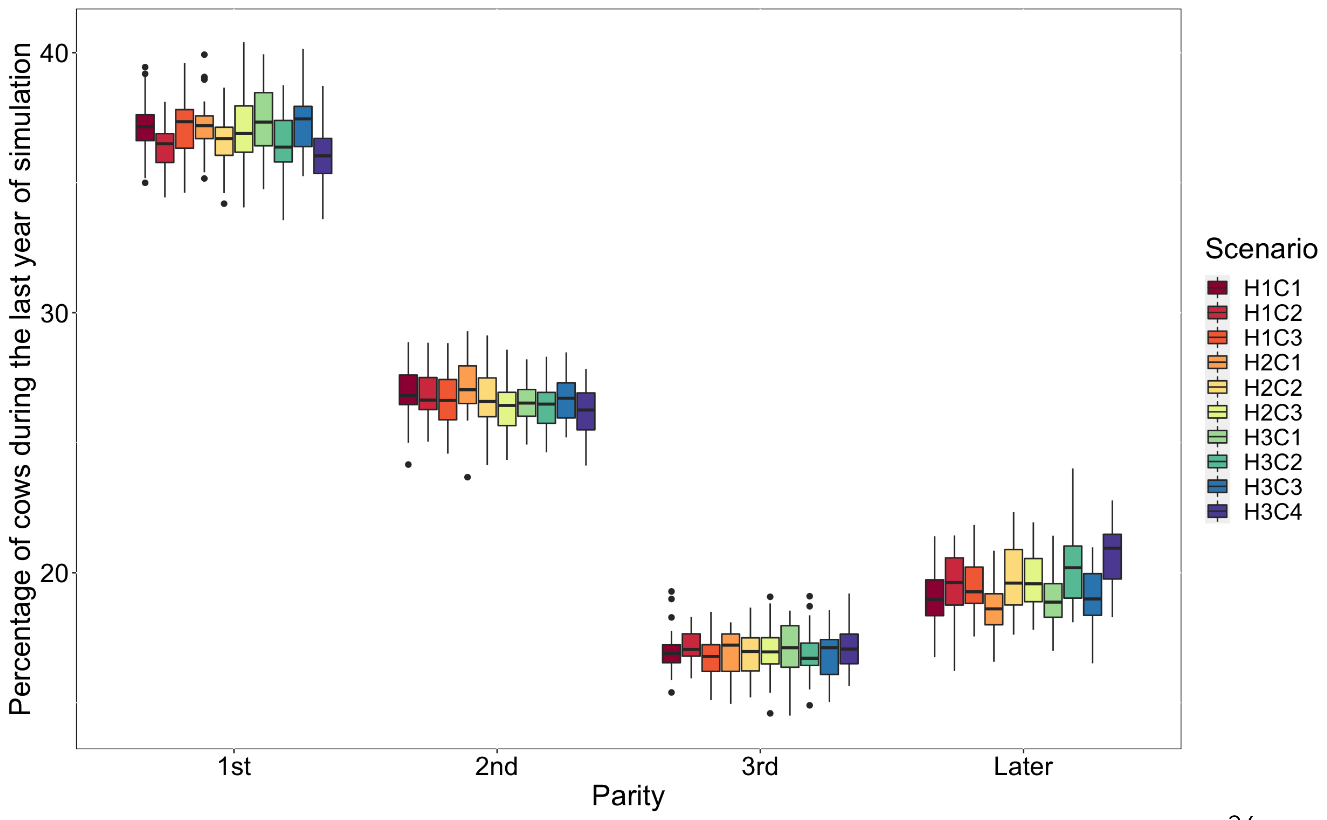


Time	Average age at
T1	Birth
T2	Wean
T3	Heifer pregnant
T4	1st Calving
T5	Cow pregnant
T6	2nd Calve
T7	Cow pregnant
T8	3rd Calve
T9	Cow pregnant
T10	Culled as a cow

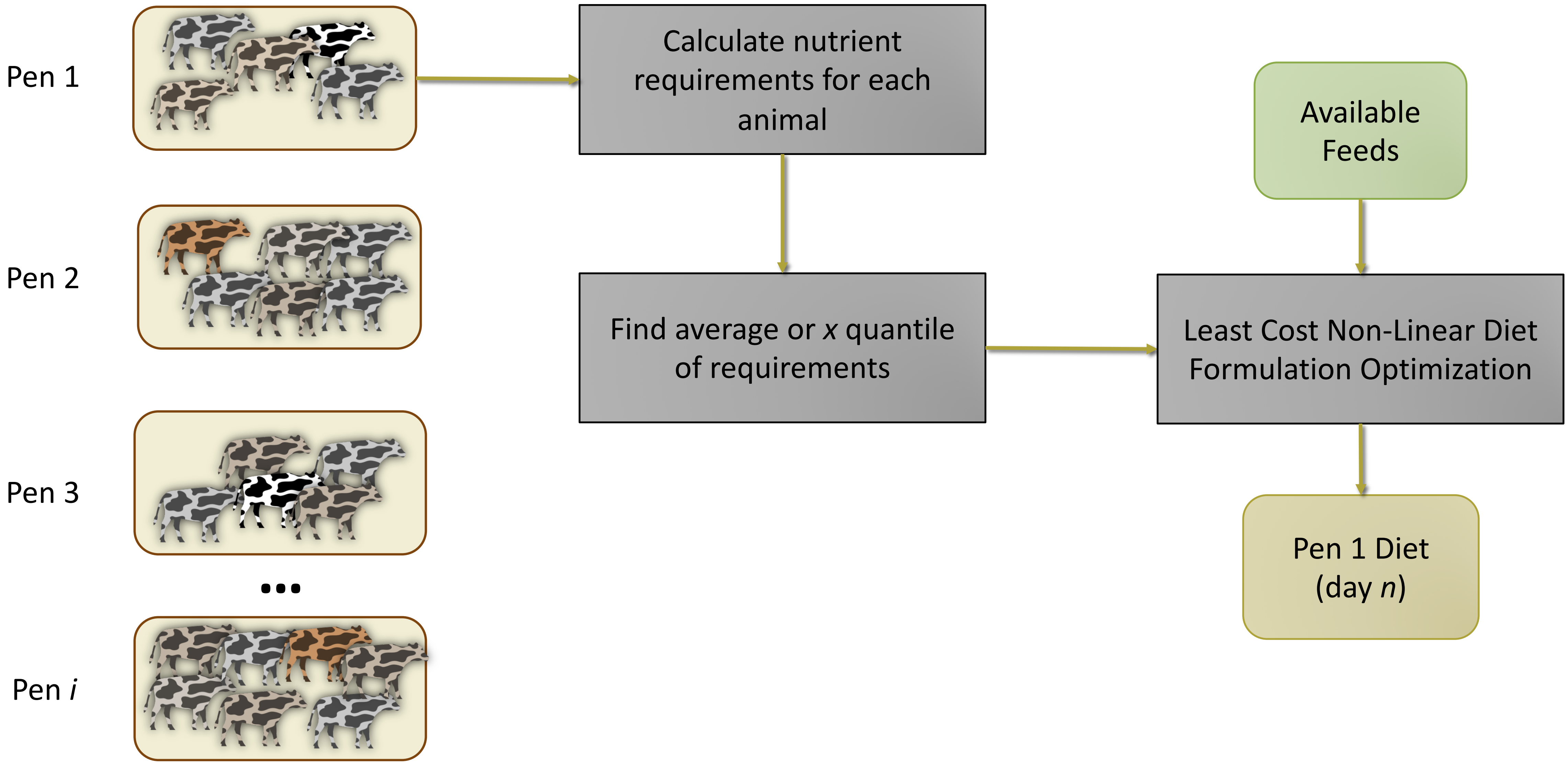
Reproduction program case study — Results

Box-and-whisker plot (median, first and third percentiles, range) of studied reproductive programs





Animal Grouping and Diet Formulation



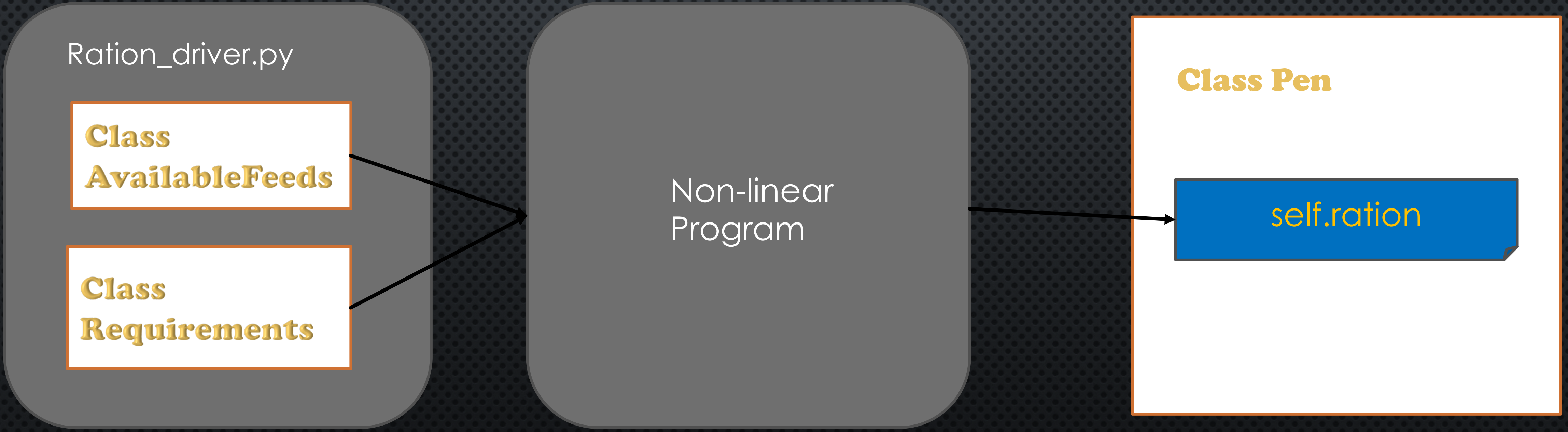
Happens on an interval set by the user (i.e. 1x/week; 1x/month)

Ration Formulation Approach

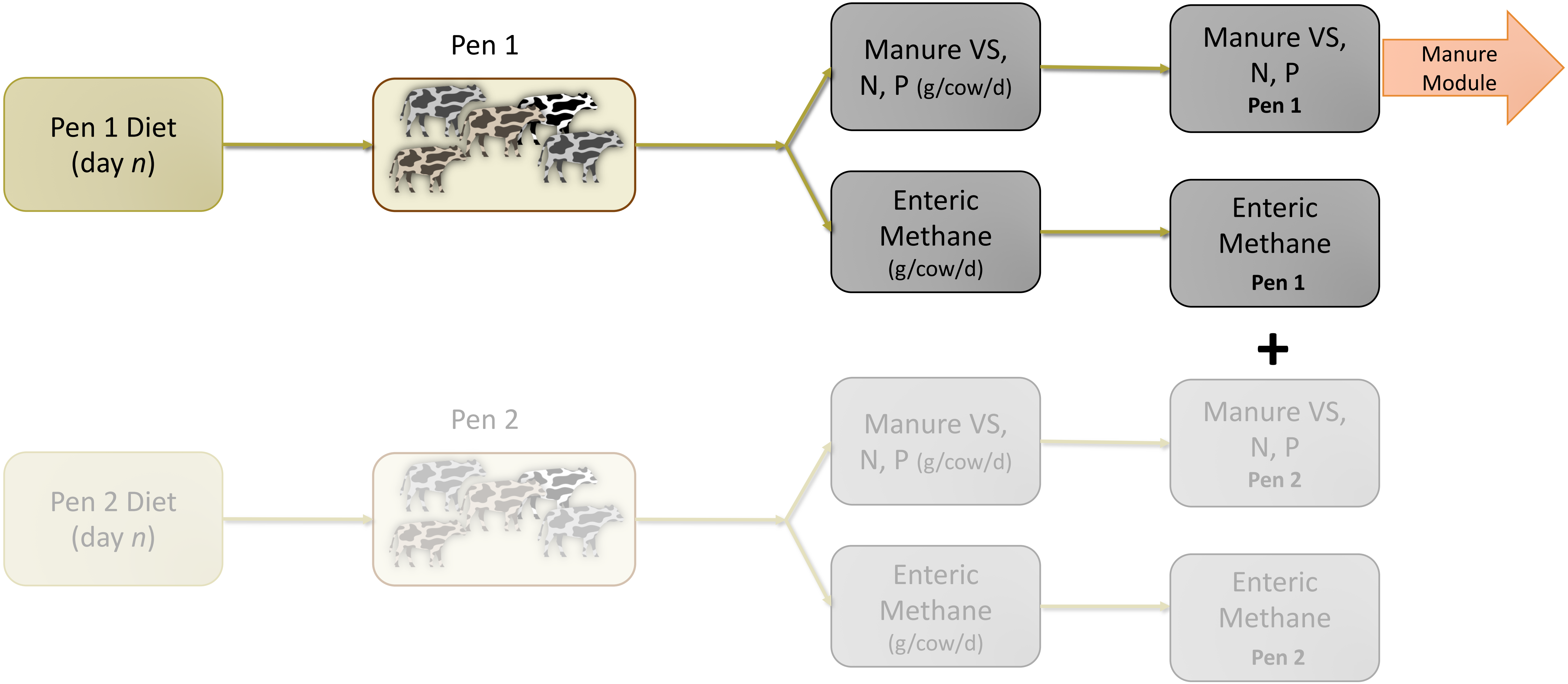
J. Dairy Sci. 105:2180–2189
https://doi.org/10.3168/jds.2021-20817

The application of nonlinear programming on ration formulation for dairy cattle

J. Li,[1] E. Kebreab,[1] Fengqi You,[2] J. G. Fadel,[1] T. L. Hansen,[3] C. VanKerkhove,[4] and K. F. Reed[3]*
[1]Department of Animal Science, University of California, Davis 95616
[2]Robert Frederick Smith School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, NY 14853
[3]Department of Animal Science, Cornell University, Ithaca, NY 14853
[4]School of Operations Research and Information Engineering, Cornell University, Ithaca, NY 14853



Methane and Manure Production



Manure: Version 1 Functionality

MANURE

Management Options

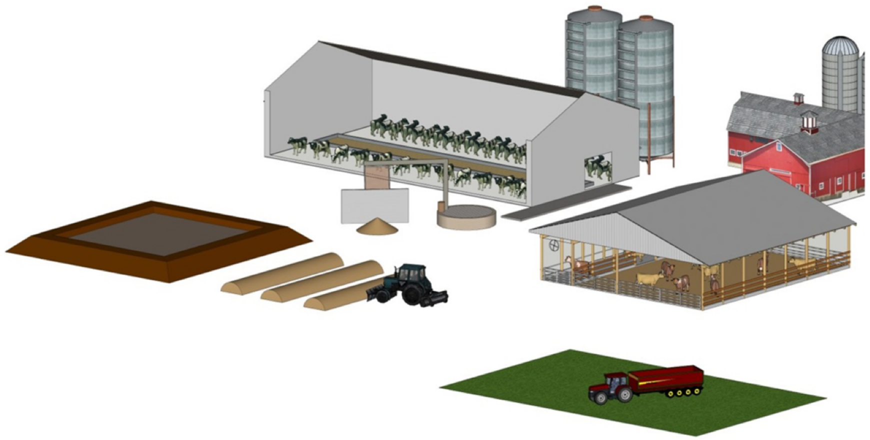
- Bedding: Sand or Organic
- Collection: Scraping or Flushing
- Processing: Solid-liquid separation, Anaerobic Digestion
- Storage: Lagoon, Composting, Bedded-pack, daily spread

Management Systems

- Allocated on a per pen basis
- Any combination of options (within reason)
- Milking parlor manure handled separately

Outputs

- Emissions: N_2O, CH_4, NH_3, CO_2
- Leaching and Runoff: N & P
- Water use
- Energy/Fossil Fuel use
- Soil C stocks and changes
- Crop yields



RufaS: Manure module

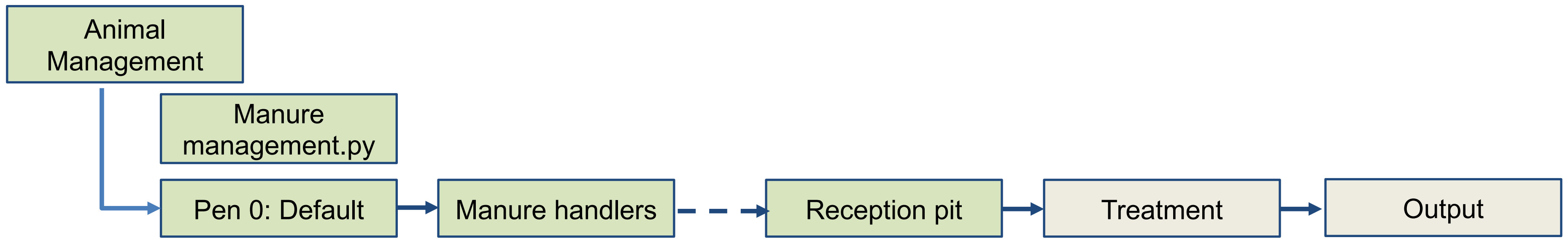
Vempalli S Varma, Loi Pham, Camille Vadas, Sadman Chowdhury, Greg Thoma

Manure Module Status

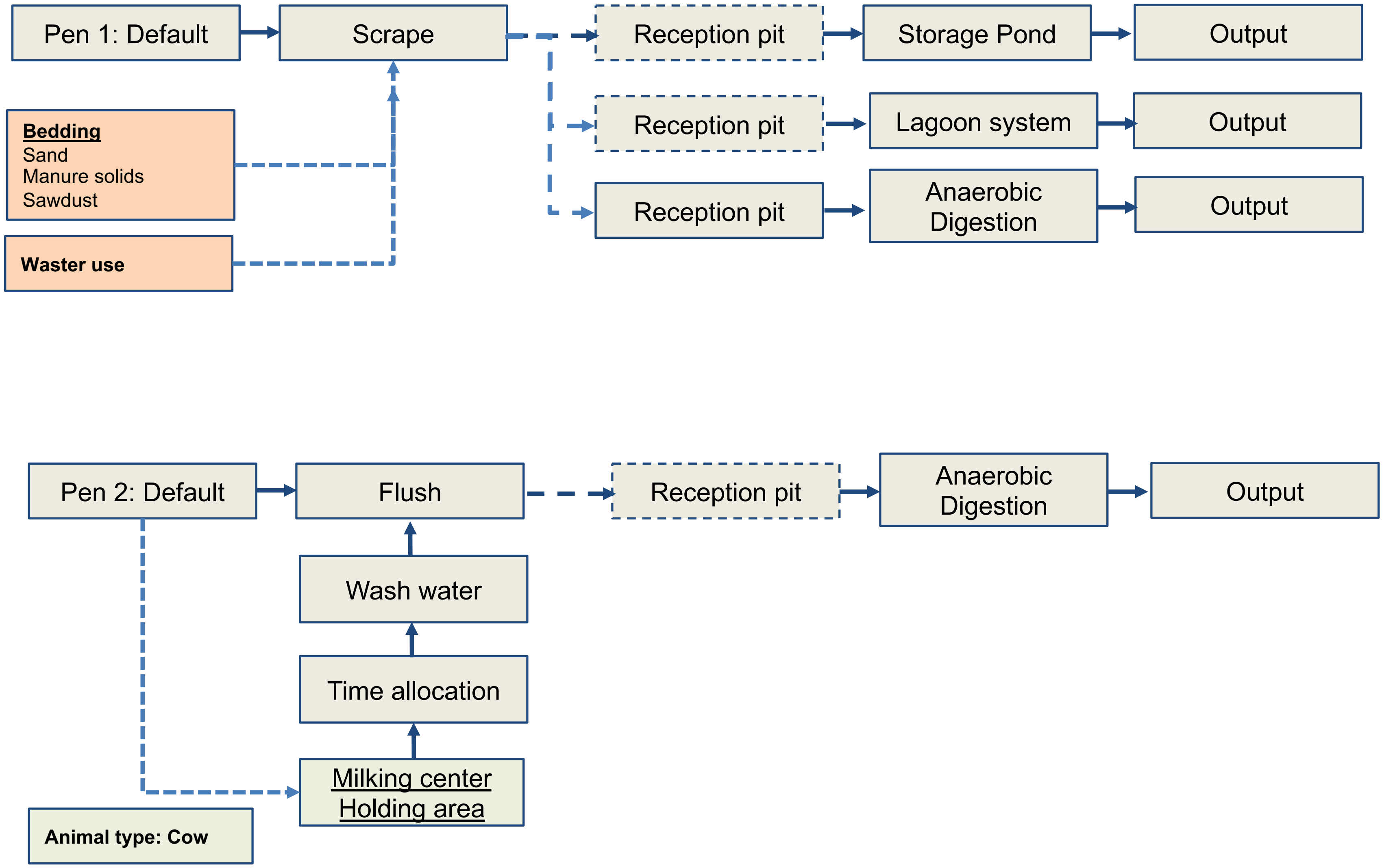
- Pseudocode for all functionality is drafted and being reviewed
- Refactoring the existing code to achieve object orientation
- Testing and evaluation not yet started

Manure Module Approach:

- Management systems are established with one option for each setting:
  - Bedding type: sand, manure solids, sawdust etc.,
  - Manure handlers - Cleaning: flush/scrape (varying water volume)
  - Storage/Treatment – lagoon, pond, solid liquid separation, anaerobic digestion
- We define a pen type and management system are established that can be reused by different pens.



Manure Module Approach:



- Manure from different pens can be combined into the same storage or treatment system objects
- Emissions estimation functions are applied to each object

❖ Manure Module - Timeline

Manure cleaning, handlers, and treatment methods – (May –Aug, 2022)

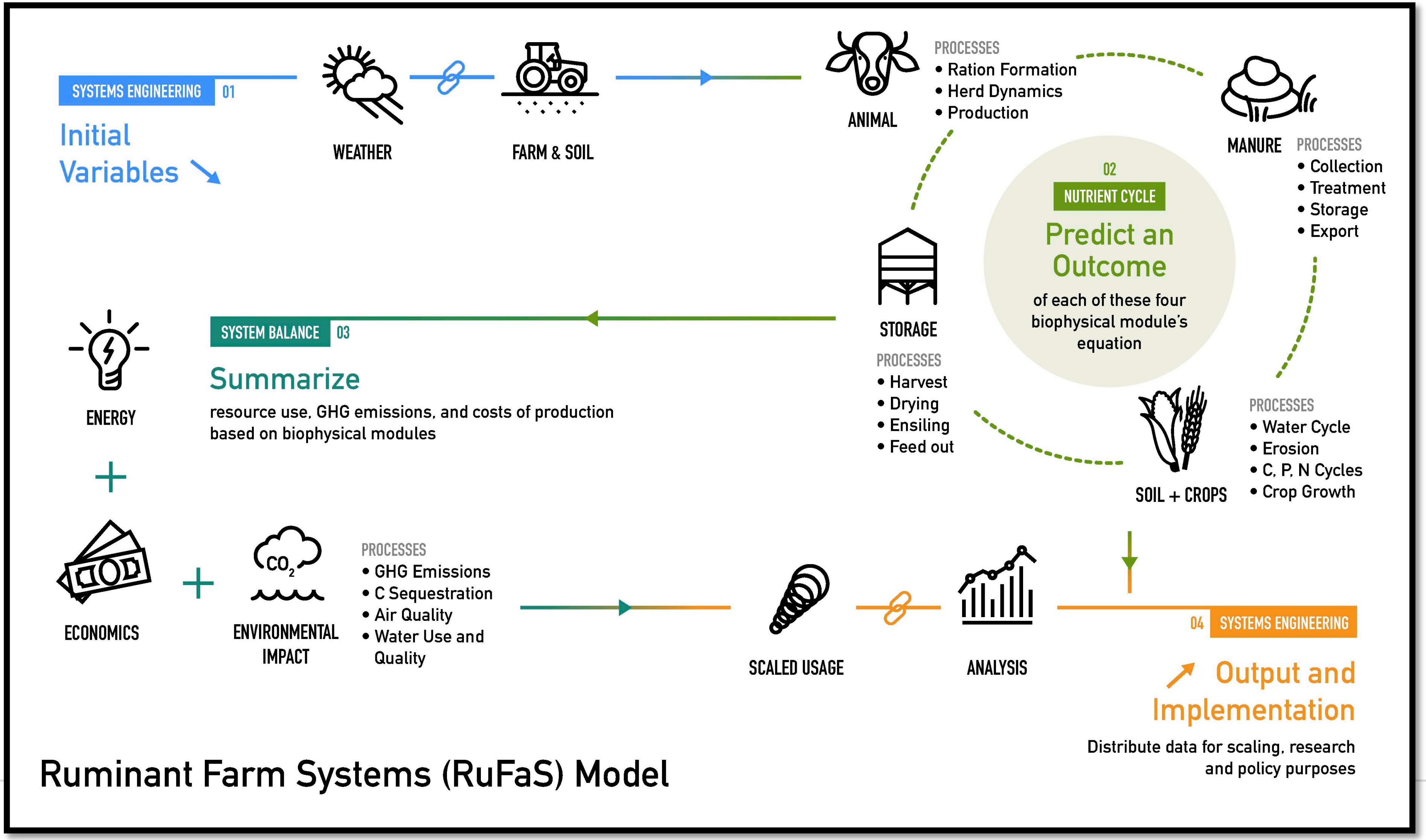
Housing and treatment gas emissions class functions – (July – Oct, 2022)

Parallel Unit testing

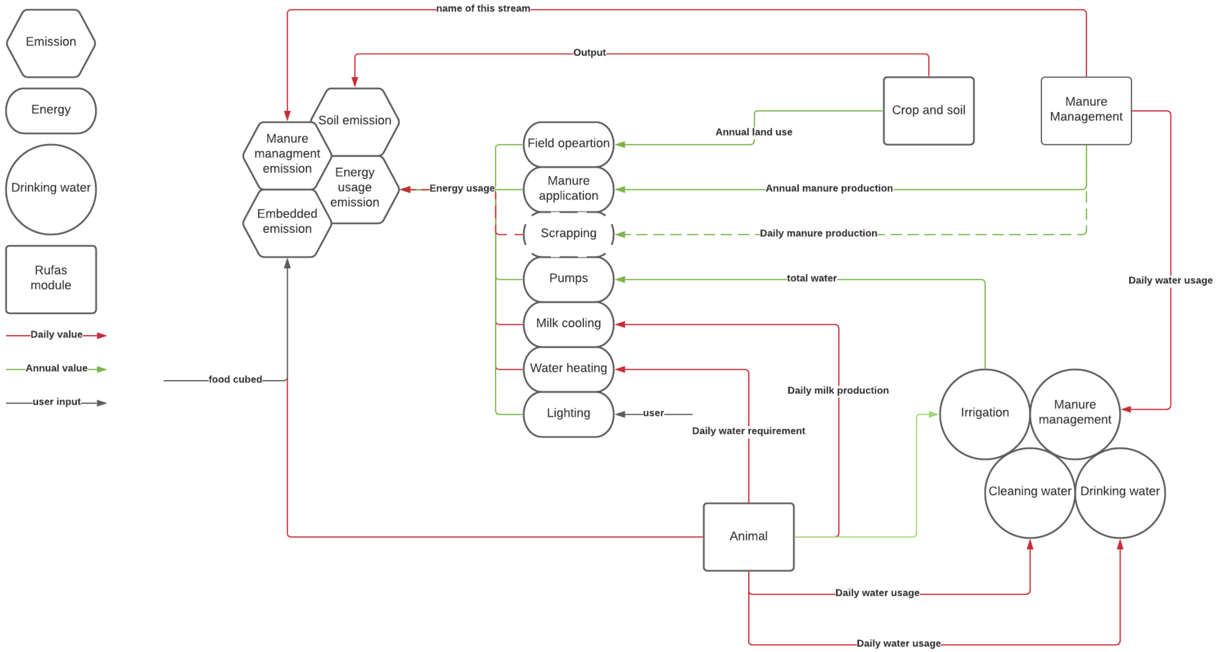
Calibration and Sensitivity analysis (Sep – Nov, 2022)

Develop new treatment methods (Oct – Dec, 2022)

Biophysical Model Outputs Feed Energy



Systems Balance Model Progress



Energy Use: Version 1 Functionality

ENERGY

Management Options

- Manure collection methods
- Field operations
- Barn electricity use
  - Milk cooling
  - Heat abatement
- Water and manure pumps

Energy Production

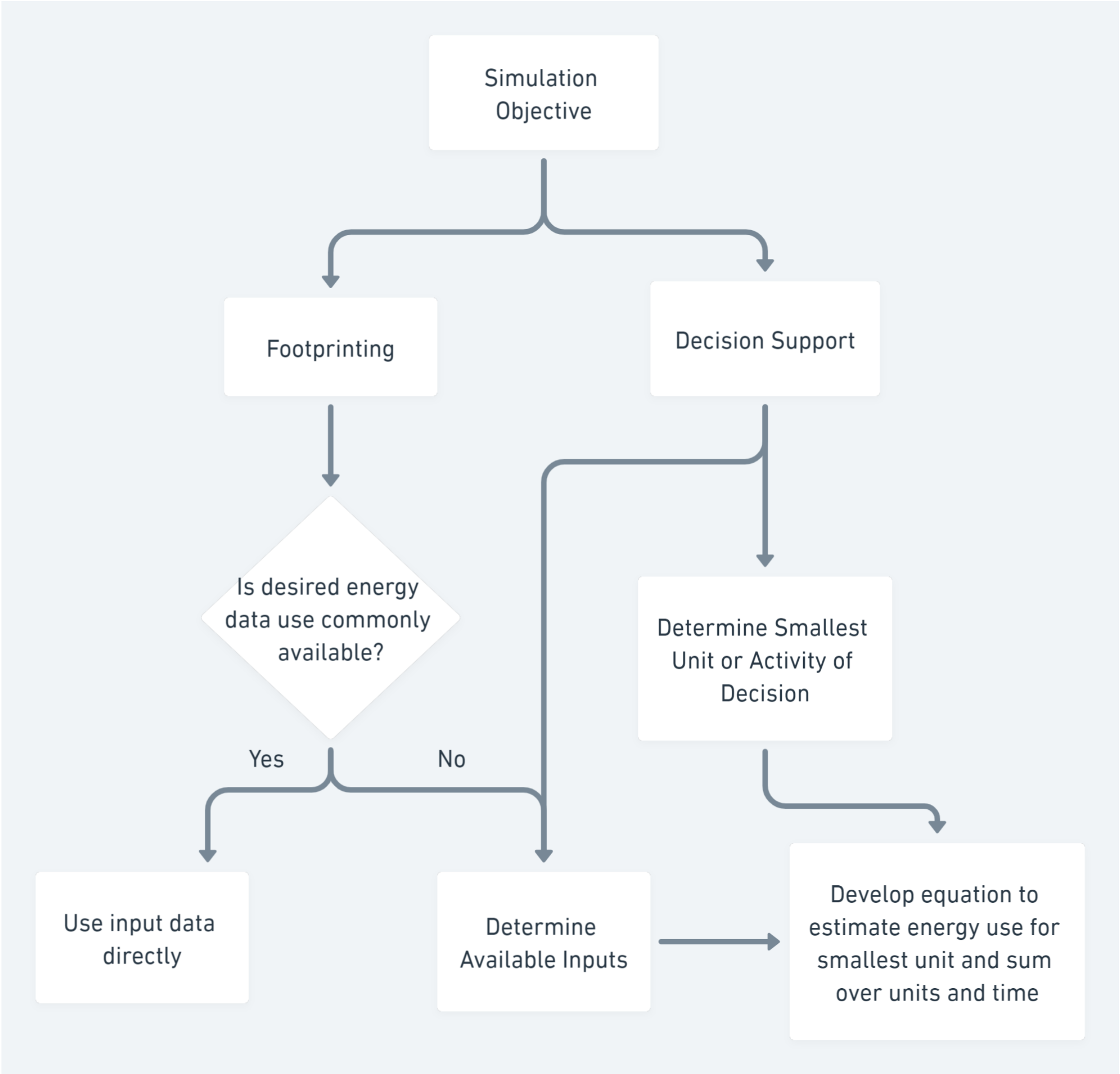
- Anaerobic digestion CH_4 production
- (solar panel electricity production)

Outputs

- Gas and diesel use
- Electricity use
- Electricity or NG production

Energy Use Approach:

- Foot-printing:
  - Use farm data if available
- Decision support:
  - Develop equation for smallest unit of estimation needed to differentiate between management options
- Example:
  - Cow Cooling:
    - Air circulation per unit of area
    - Water use and pressure per cow



Energy Use Approach:

- Foot printing:
  - Use farm data if available
- Decision support:
  - Develop equation for smallest unit of estimation needed to differentiate between management options
- Example:
  - Cow Cooling:
    - Air circulation per unit of area
    - Water use and pressure per cow

$$E_{cow\_evap\_cooling} = \frac{h_{sprayer} \times m_{spraywater}}{pump_{eff}} * n_{session}$$

$$K_{fan\_number} = \left\lceil \frac{L_{pen} \times W_{pen}}{A_{fan}} \right\rceil$$

$$E_{cow\_fan\_cooling} = K_{fan\_number} \times t_{fan\_operation} \times fan_{eff}$$

Pilot Testing Objectives

- Evaluate RuFaS performance with commercial farm data
- Compare performance with extant models
- Develop methodology for baseline foot printing with RuFaS
- Use RuFaS to compare management scenarios for impact on all KPIs
- Train industry, CCE, and NGO collaborators in RuFaS application
- Gather stakeholder input on RuFaS reporting content and format
- Gather stakeholder input on GUI needs

Key Performance Indicators

GHG emissions:
(CO_2-eq/yr ; CO_2-eq/ kg milk; CO_2-eq/ha land; CO_2-eq/animal life span)

Water, P, Energy use
(per kg milk; per ha land)*

N and P runoff
(g/kg milk; kg/ha); N leaching (g/kg milk; kg/ha)

Soil erosion
(kg/ha; kg/kg milk)

Soil Carbon
(% total Carbon; %Active Carbon; %Structural/Slow/Inactive Carbon)*

Feed efficiency
(kg milk/kg total feed; kg milk/ kg purchased feed; kg milk/ kg human-inedible feed)*

Production
(kg milk and meat/year; kg milk and meat/ha; kg milk and meat/cow)*

Management Cost
($/kg milk, $/acre)*

Pilot Testing: Cohort 1

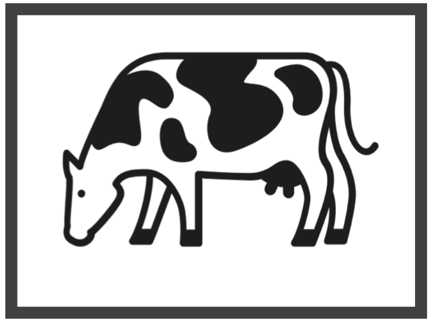
Team Members

Pilot Farms

Experimental Data

Cohort 2 will be larger with more geographic and management diversity

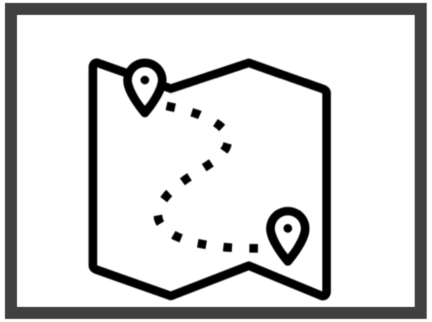
Vision of Success



Created by Rutmer Zijlstra
from Noun Project

Footprinting

Calculate baseline estimates of current farm outputs and environmental outcomes



Created by Aficons
from Noun Project

Planning

Identify management practices that will generate progress towards your sustainability goals

Created by mynamepong
from Noun Project

Implementation

Implement management plan, track progress, strive for continuous improvement

Created by Made x Made
from Noun Project

Impacts

Achieve industry-wide progress towards sustainable dairy production









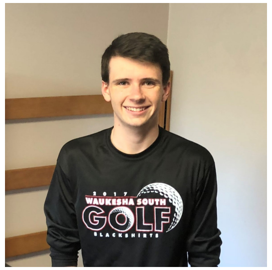








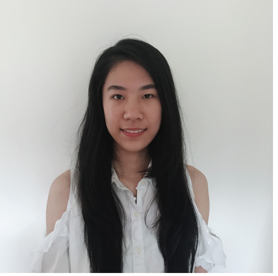














University of Arkansas

Cornell University

Northeast Agribusiness & Feed Alliance (NEAFA)
Advocate · Educate · Collaborate

The Nature Conservancy

UC Davis
University of California

WWF

Wisconsin
University of Wisconsin-Madison

USDA

Innovation Center for U.S. Dairy
Healthy People • Healthy Products • Healthy Planet

General Mills
Making Food People Love

NIFA AWARD # 2020-68014-31466

THANK YOU

RuFaS Informs Decision-Makers

Extension Specialists

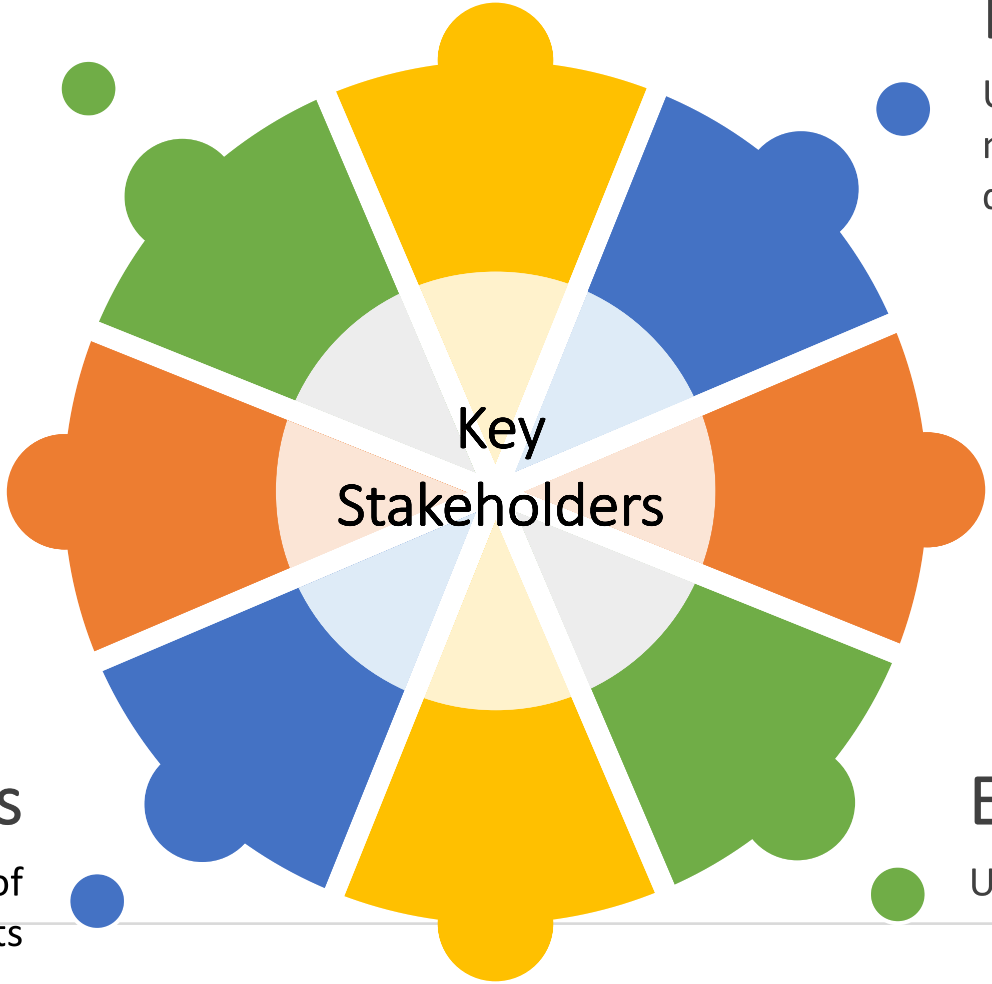
Use RuFaS to compare system impacts of proposed management practices before implementation

CAFO Planners

Use RuFaS to compare proposed management impacts on nutrient management plans before implementation

NGO Project Planners

Use RuFaS to compare system impacts of proposed projects



Farmers and Consultants

Use RuFaS to track progress of different management practices and inform future decisions

Dairy Processors

Use RuFaS to verify that claims meet company standards

Ecosystem Service Markets

Use RuFaS to quantify ecosystem services

Founders

Key Stakeholders

USDA

Cornell University

University of Arkansas

UC Davis University of California

University of South Dakota

Innovation Center for U.S. Dairy – Healthy People • Healthy Products • Healthy Planet

Wisconsin University of Wisconsin–Madison

The Nature Conservancy

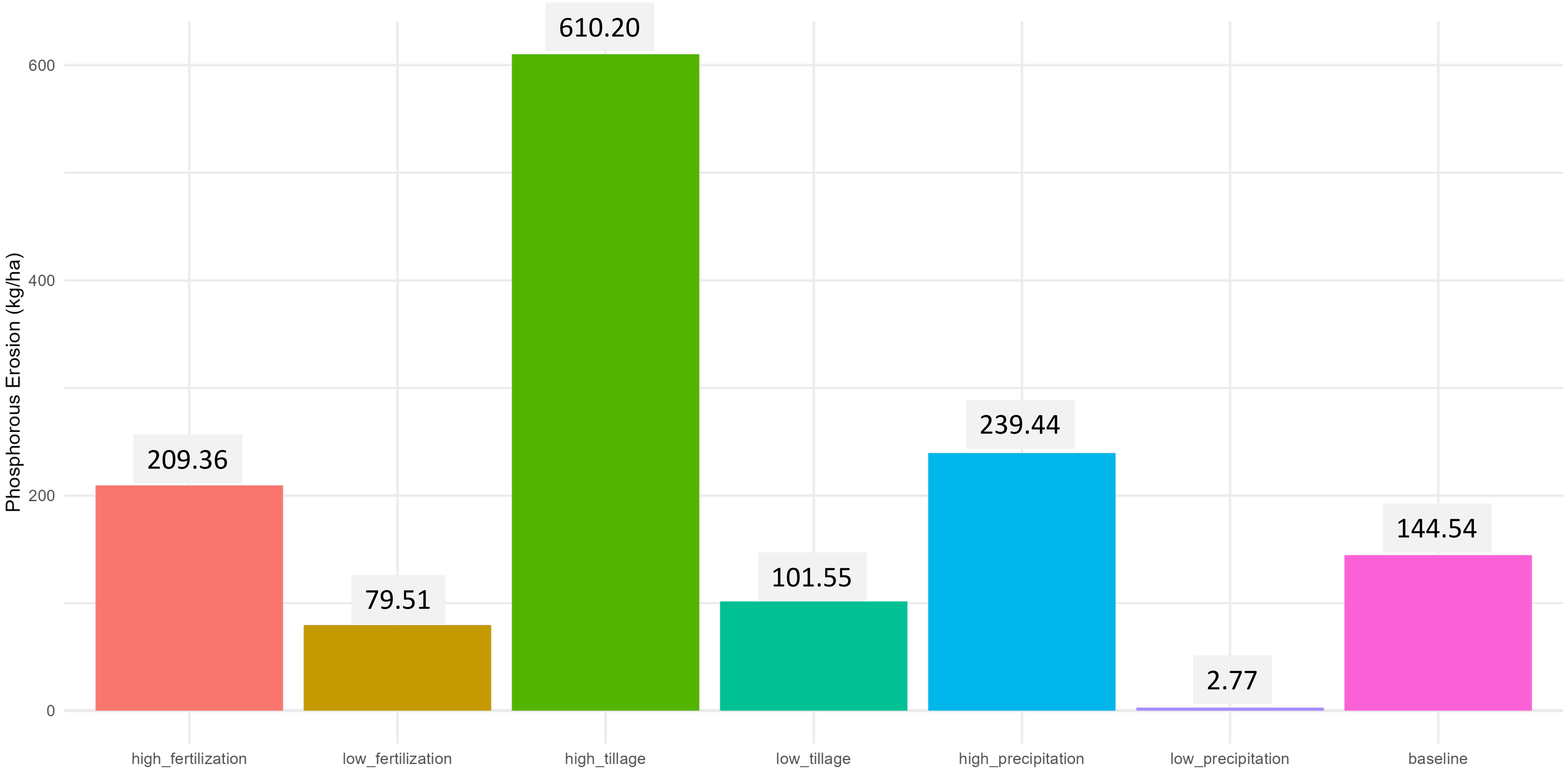
WWF

NEAFA Northeast Agribusiness & Feed Alliance – Advocate · Educate · Collaborate

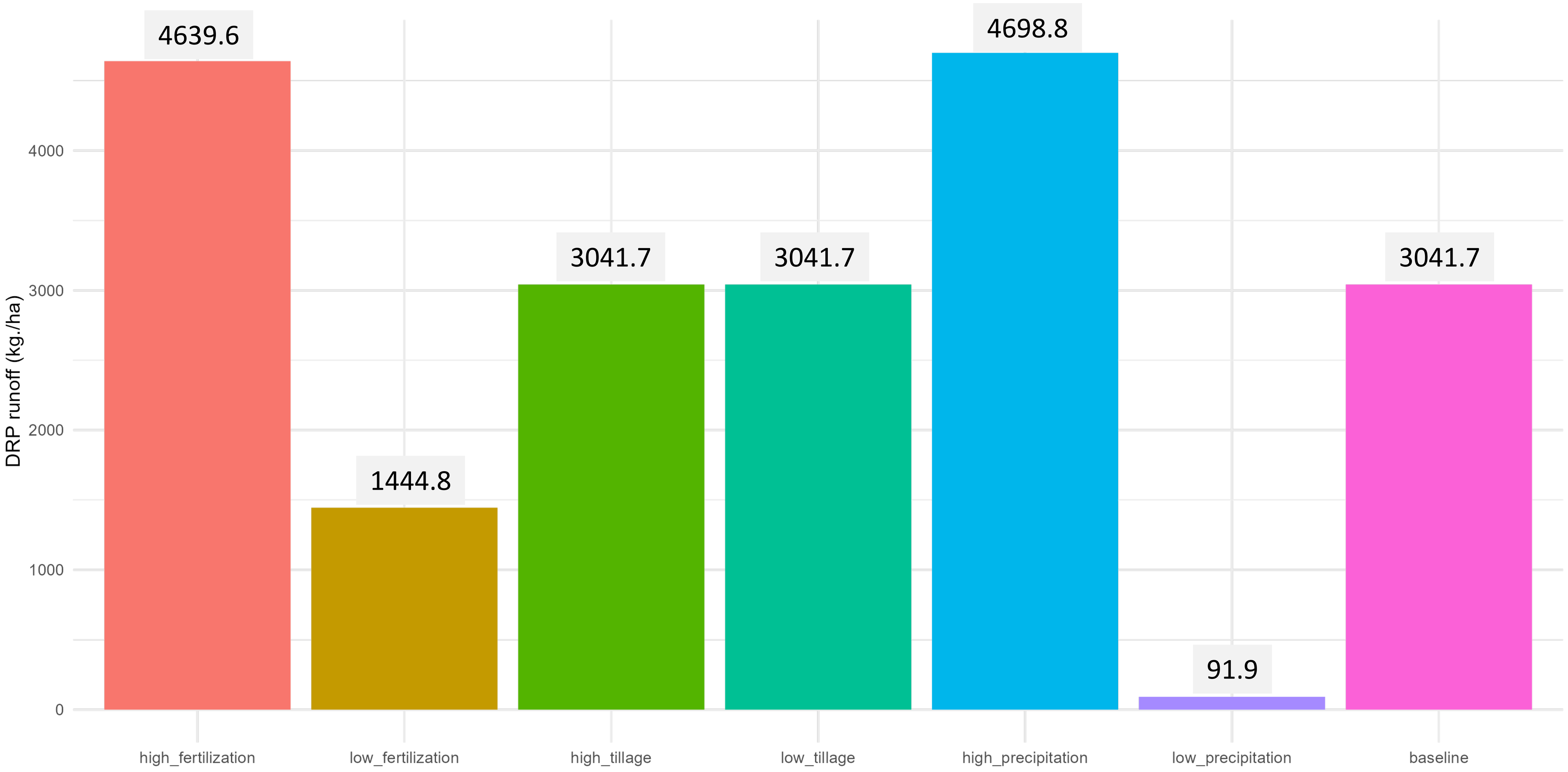
General Mills Making Food People Love

DMI Dairy Management Inc.™

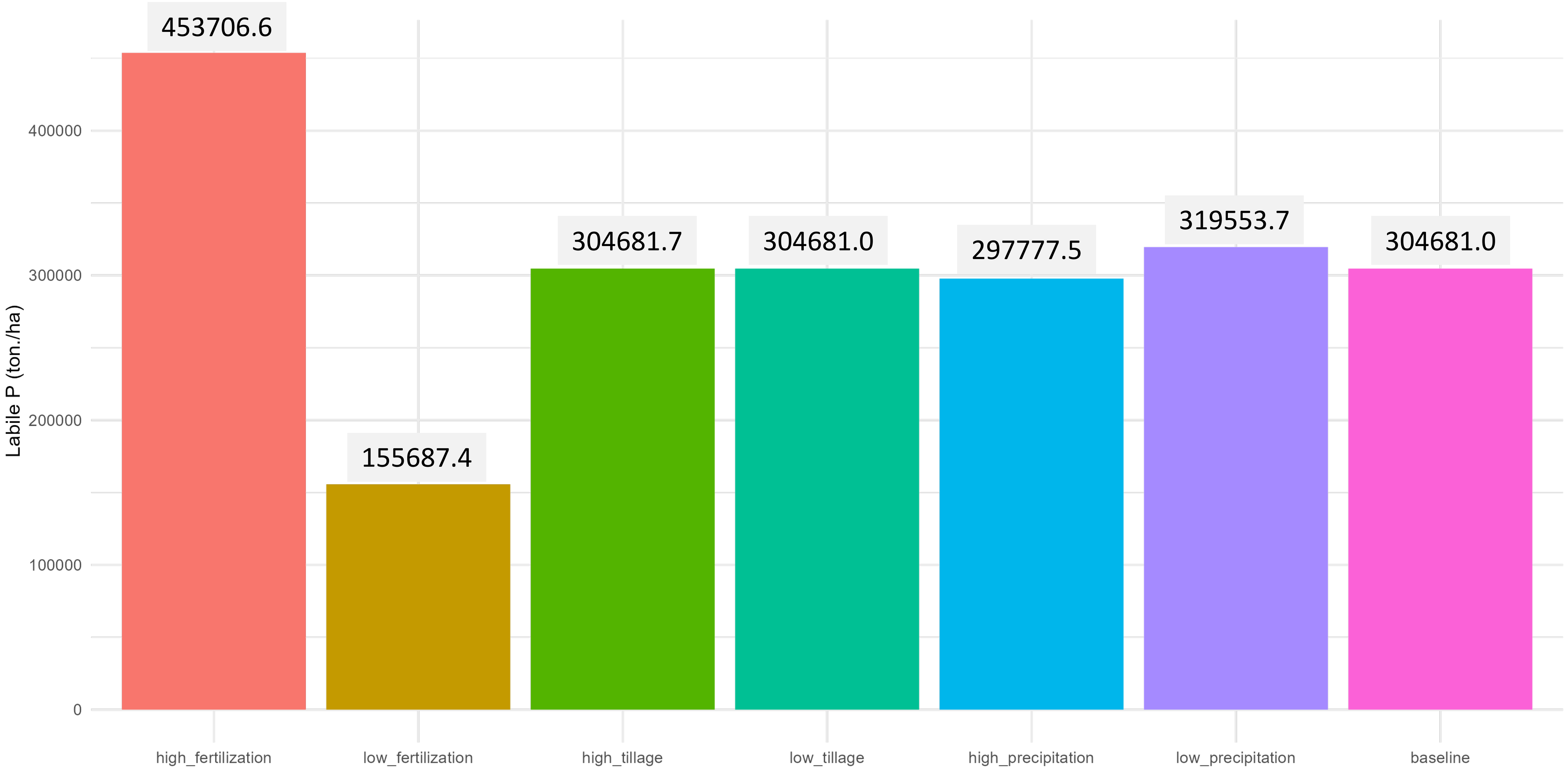
Results – Phosphorous Erosion



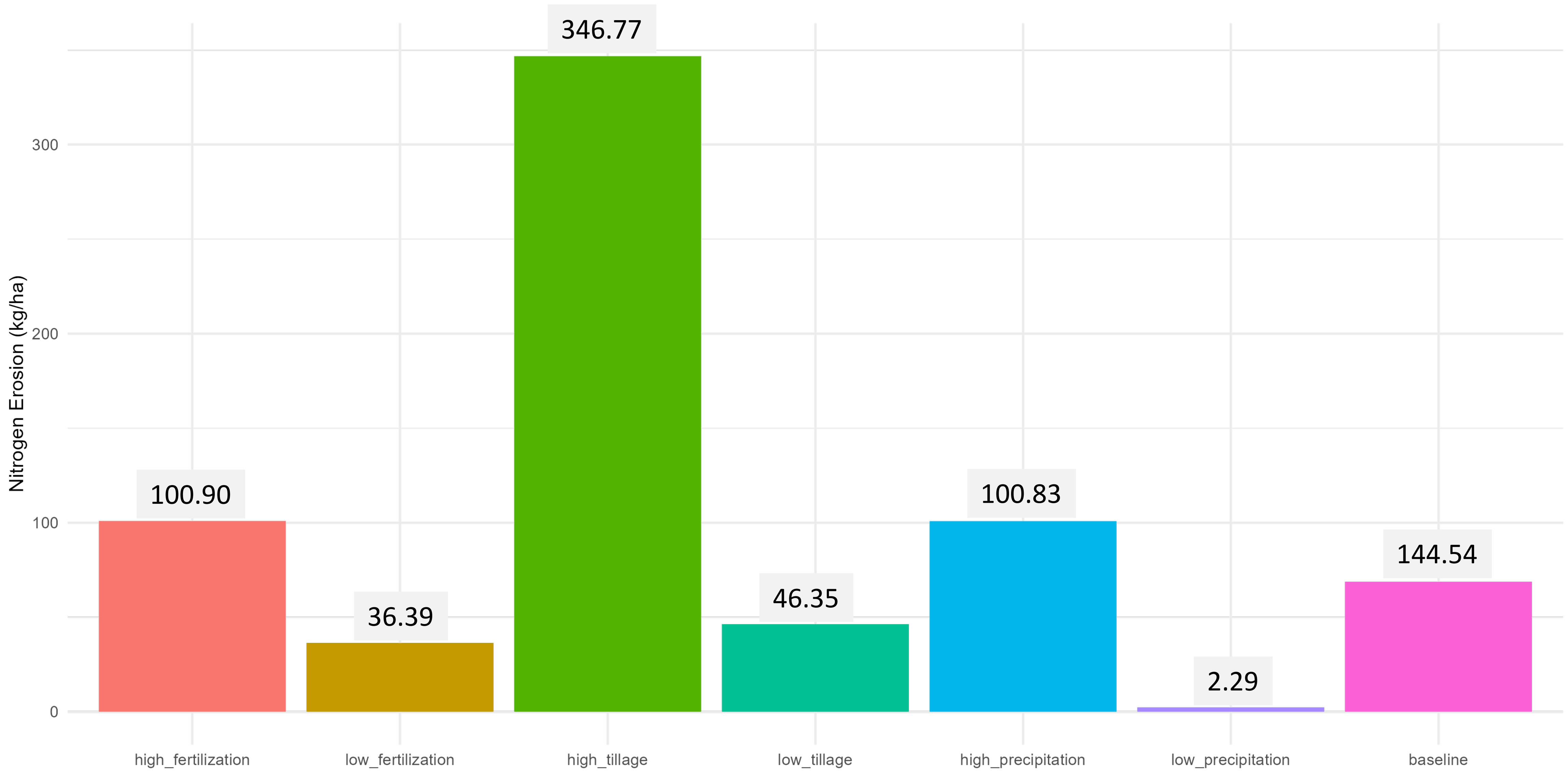
Results – DRP Runoff



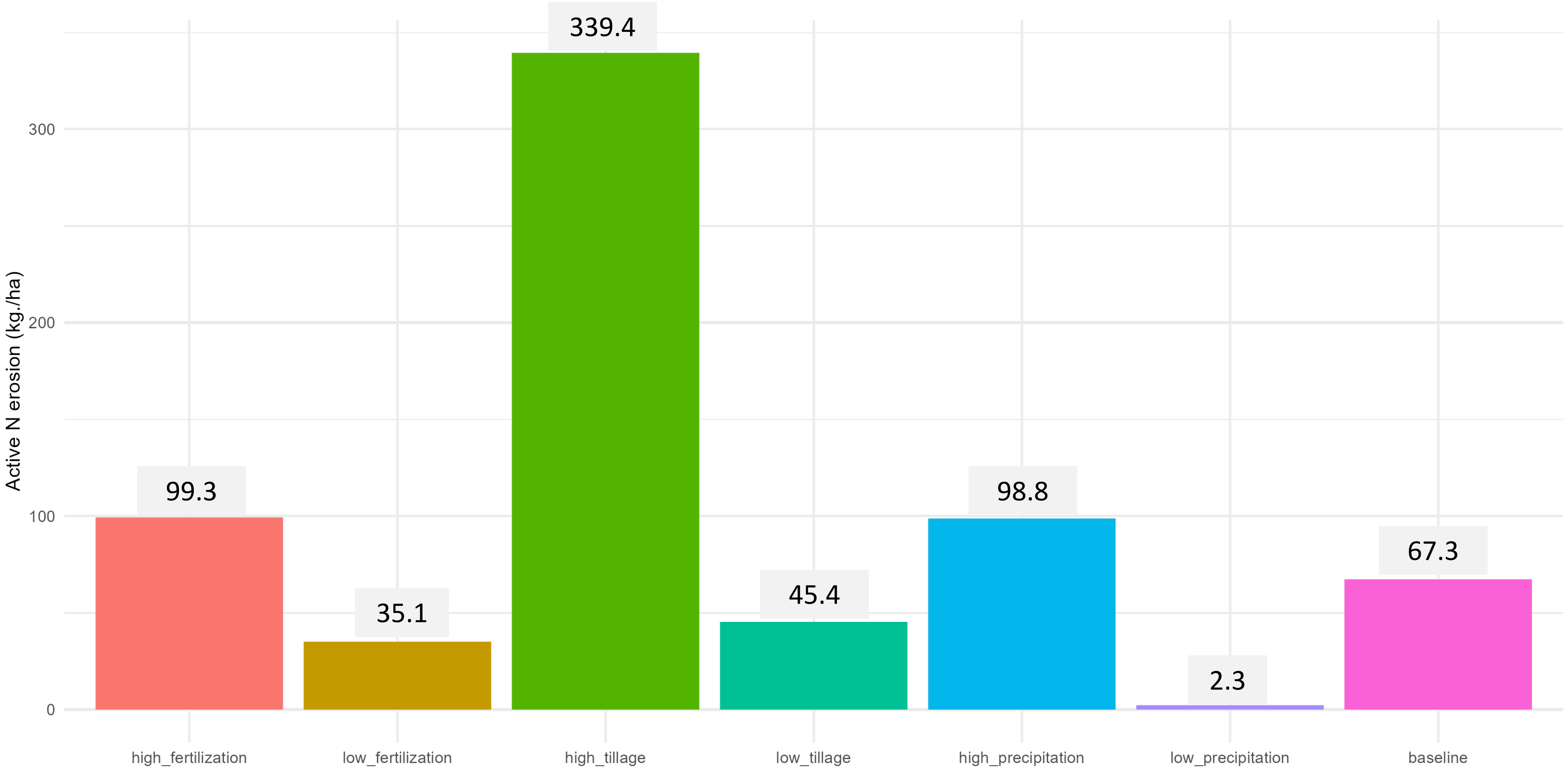
Results – Labile Phosphorous



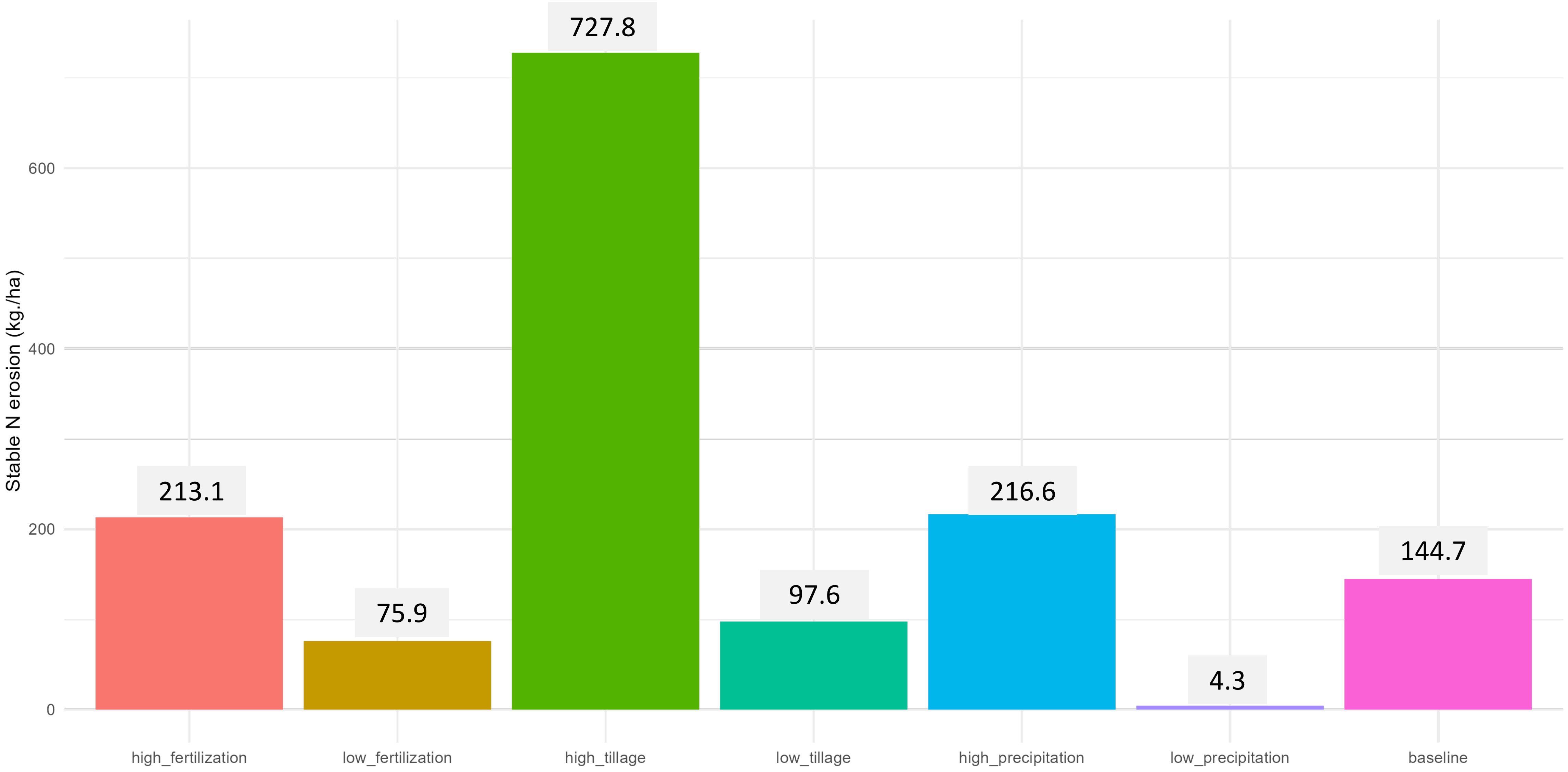
Results – Nitrogen Erosion



Results – Active Nitrogen Erosion

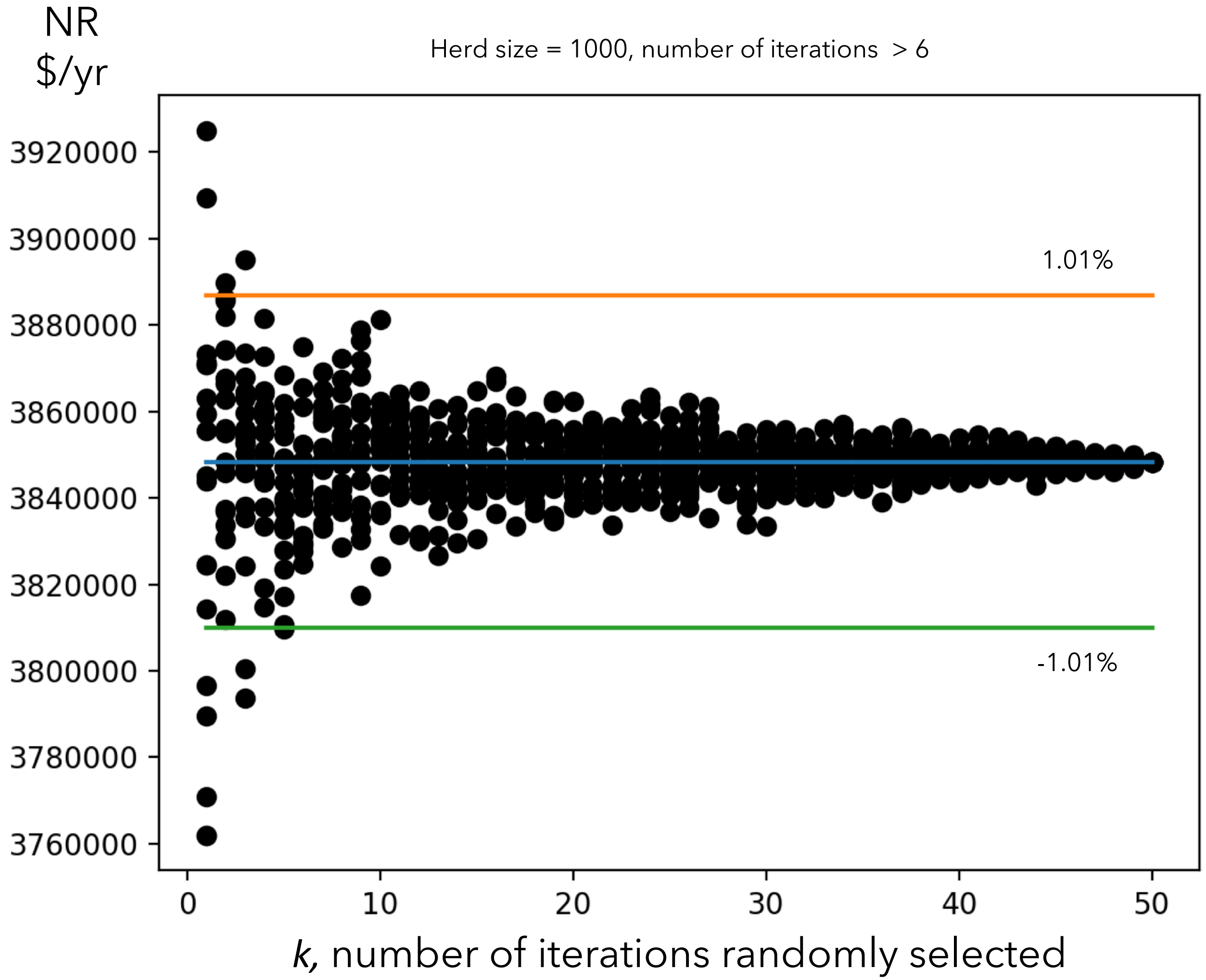


Results – Stable Nitrogen Erosion



Animal life cycle submodel

Herd simulation iterations



To determine the number of replications needed:

1. Calculate the NR for each of the 100 replications
2. Randomly select *k* values of the NR and take the average 20 times where *k* = 1-100
3. Plot the 20 average NR against the value of *k*
4. Plot Horizontal lines for the (i) overall average, (ii) +/- 1% of the overall average
5. The selected value for R is the smallest value of *k* when most of the NR points are within +/- 1% of the mean

Many models are already out there

- Dairy contributions to climate change are widely discussed but difficult to measure.
- Companies and NGOs need tools to quantify dairy farm emissions and help suppliers achieve net zero emissions.
- Existing models do not capture the complex dynamics on dairy farms, so confusion and mistrust has arisen among dairy industry users.

TRUTERRA

CFT

DSSAT

AMTS

Integrated Farm System Model
Version 4.5

USDA / Agricultural Research Service
Pasture Systems and Watershed
Management Research Unit

University Park, Pennsylvania

FARMERS ASSURING FARM RESPONSIBLE MANAGEMENT

FARM Environmental Stewardship
Version 2 Updates

SWAT Soil & Water Assessment Tool

COMET Farm

USDA United States Department of Agriculture
Natural Resources Conservation Service

Colorado State University

Whole Farm and Ranch Carbon and Greenhouse Gas Accounting System.