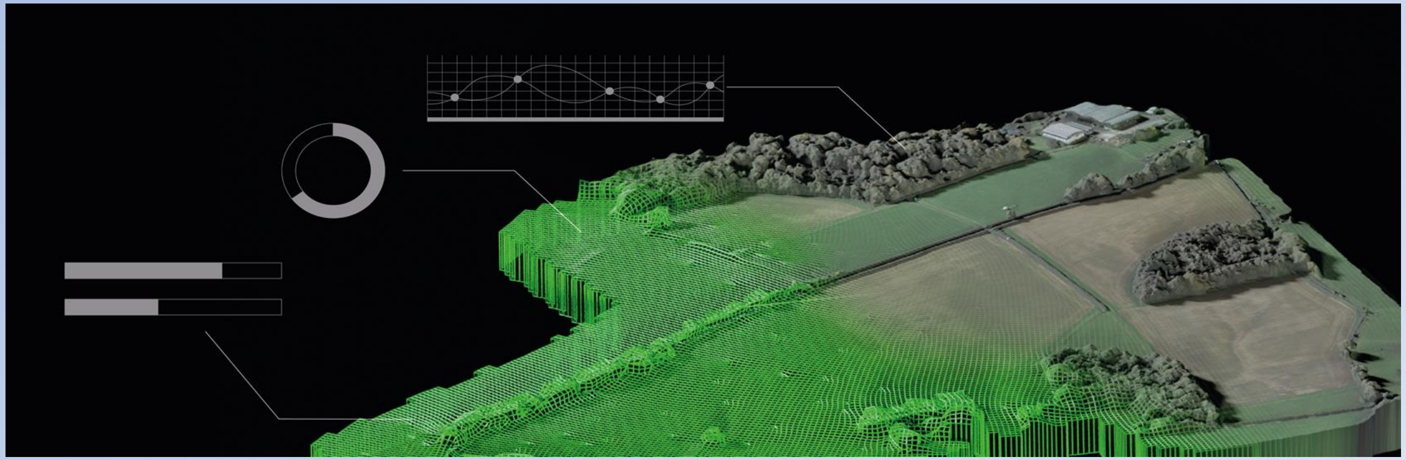
Digital Twins at the Farm-scale: implementation challenges for the North Wyke Farm Platform

Wageningen Workshop

Paul Harris

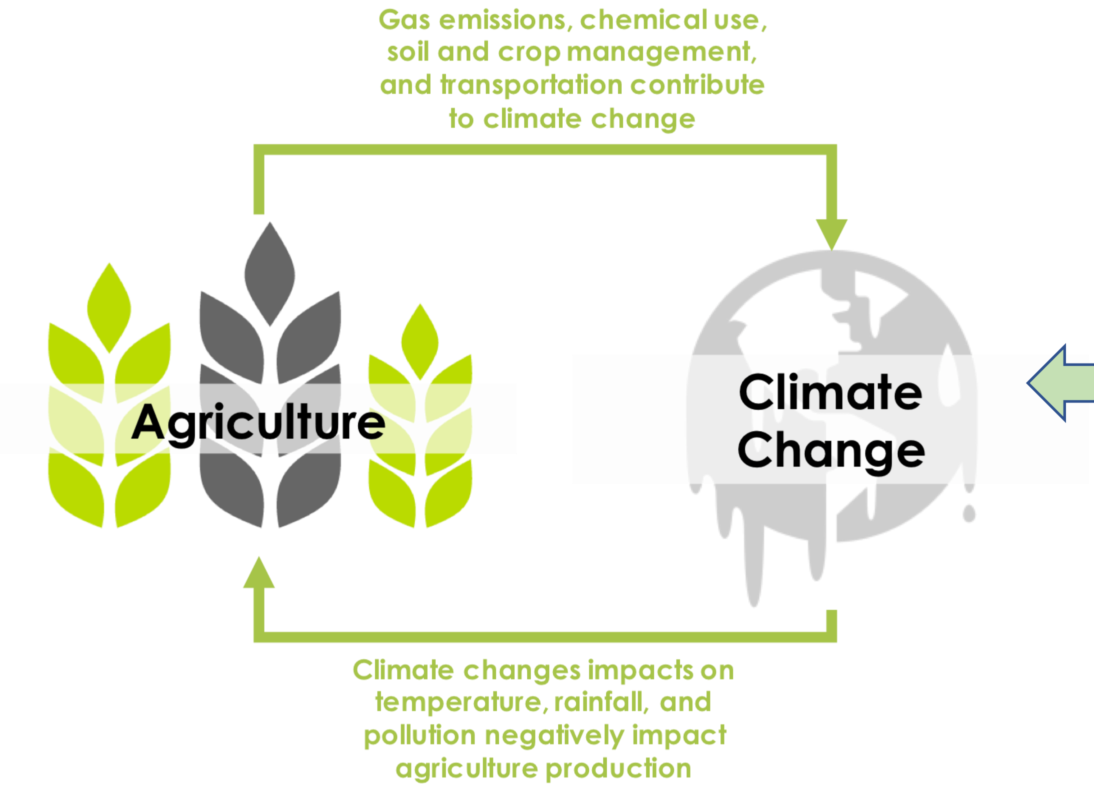
Rothamsted Research

December 13th / 14th 2022

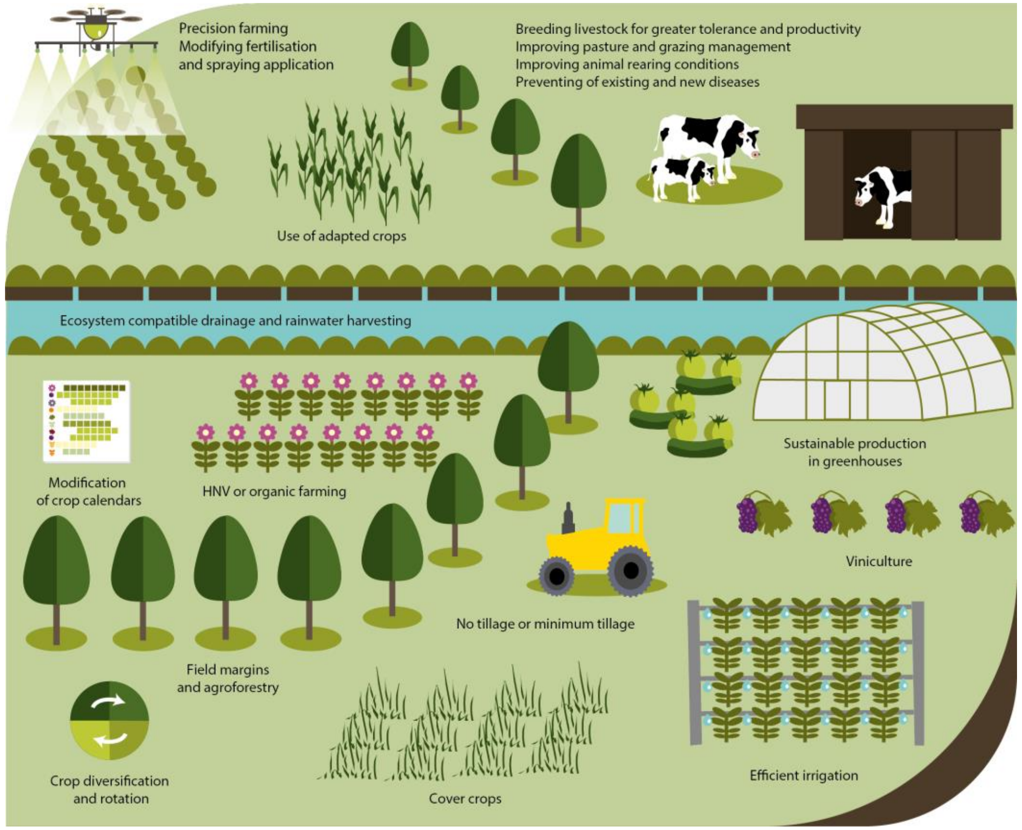


Agricultural challenges in the context of climate change

Contributions and Impacts



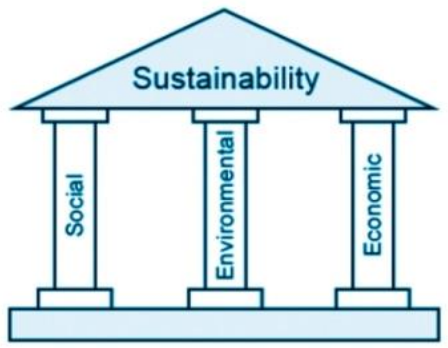
Mitigations and Interventions

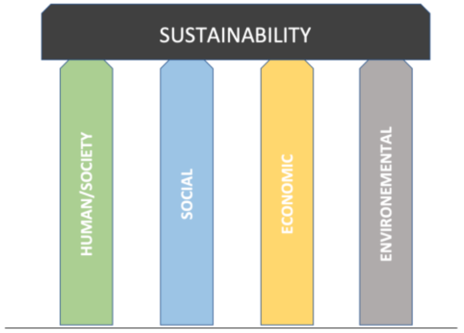


https://digital.hbs.edu/platform-rctom/submission/can-vertical-farming-reduce-agricultures-impact-on-climate-change/

https://www.eea.europa.eu/highlights/climate-change-threatens-future-of

Sustainable Farming versus Resilient Farming

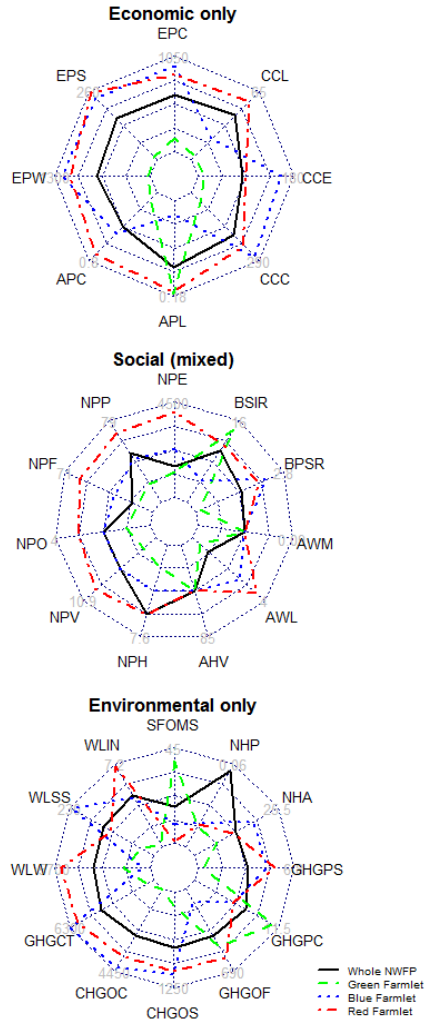


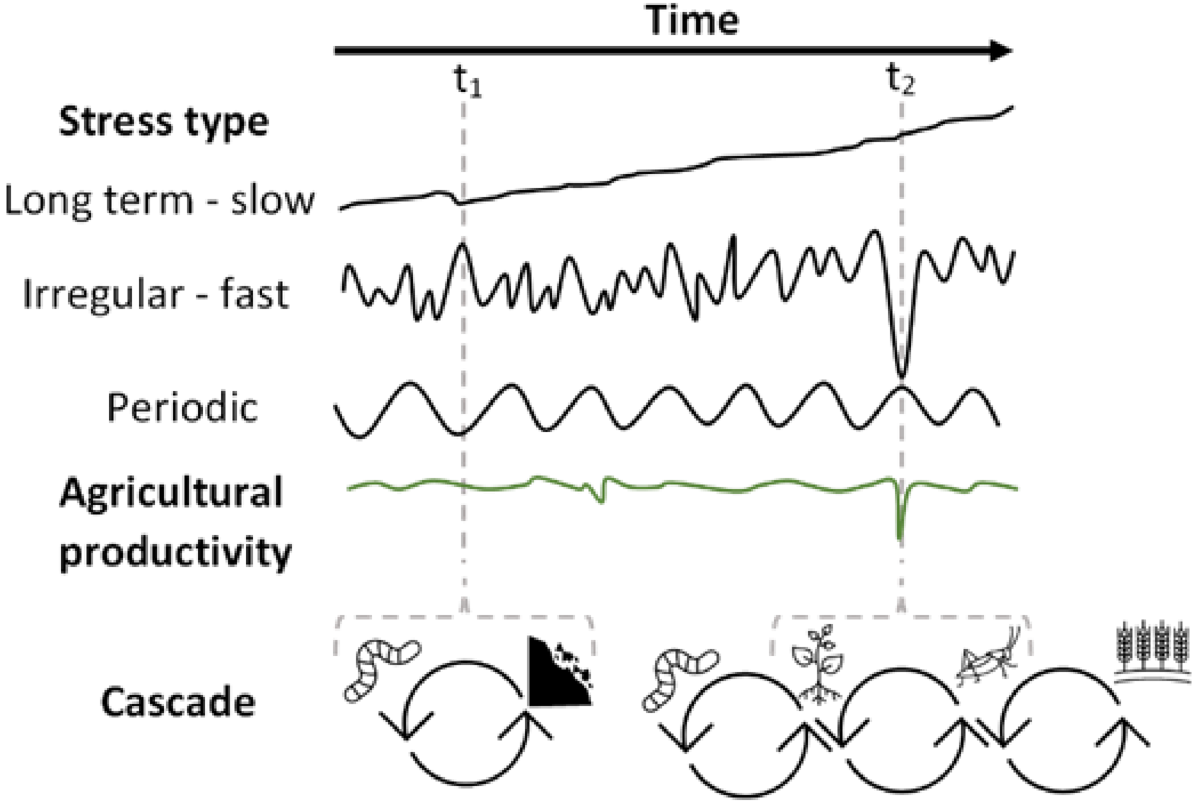


Balancing & Trade-offs

Requires data / metrics

Multi-dimensional with weights



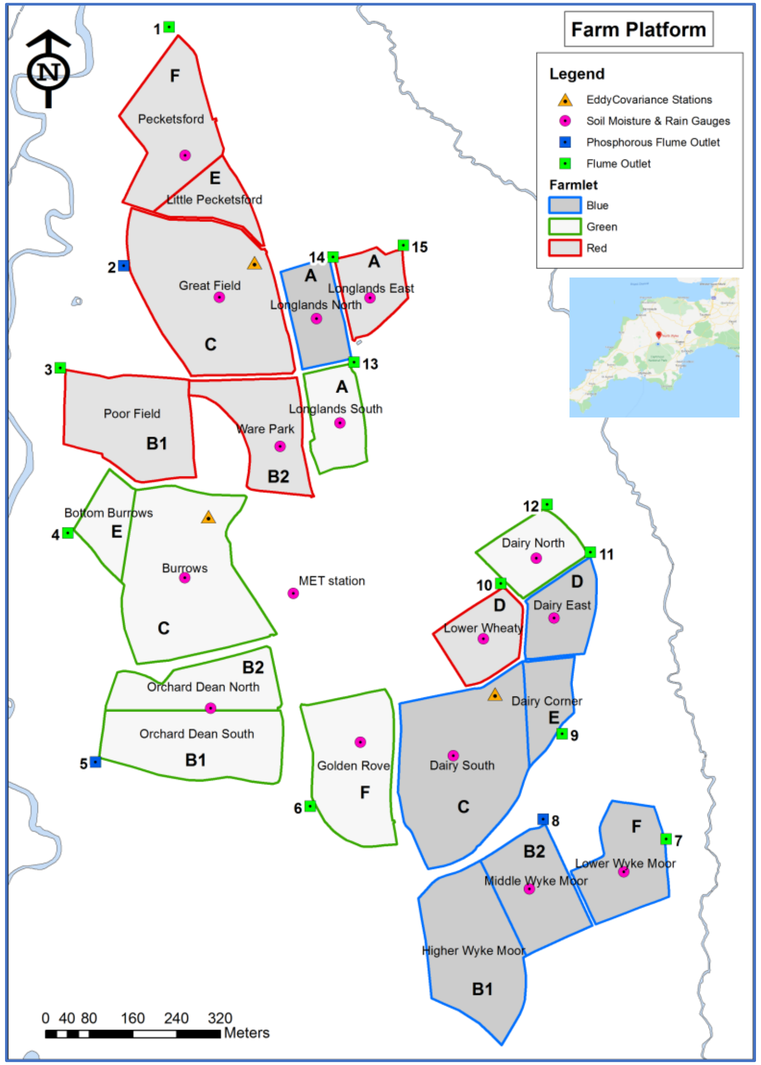


Need Farming to be resilient to single & compound stresses

Need to detect signs of collapse / critical slowing down

Experiments and monitoring platforms

North Wyke Farm Platform (NWFP) est. 2010*

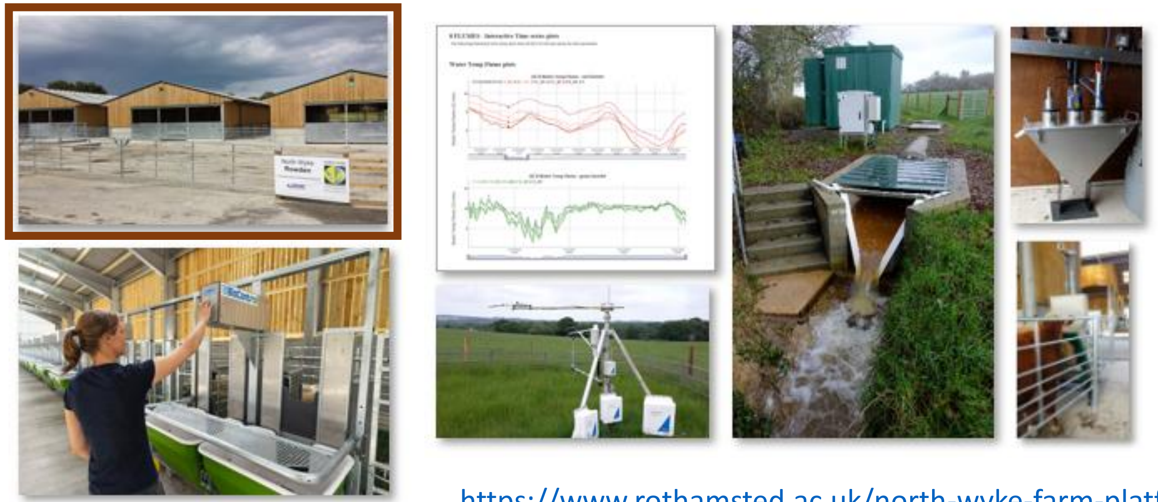


A 4-farm systems scale experiment:

"To help identify sustainable, resilient, net zero land management strategies that optimise the transfer of essential nutrients from soil to crops and livestock to food; thereby simultaneously contributing to a healthy diet and cleaner natural environment."

Periodic system (land use) changes - currently consists of two pasture-based livestock (cattle/sheep) systems, one arable system and one housed (cattle) system

Each system is heavily monitored to provide mixed resolution data on soils, crops, livestock, biodiversity, water/gaseous emissions, farm management and weather



3 farms consisting of 15 hydrologically-isolated sub-catchments & 20/21 fields

Housing for cattle & sheep

Data open & freely available

https://www.rothamsted.ac.uk/north-wyke-farm-platform

* Supported by BBSRC, CIEL (Centre for innovation and Excellence in Livestock) & NERC

Outdoor Farms: Linked Data for Systems Science

Operations: Field & Grazing Management plus livestock / crop performance

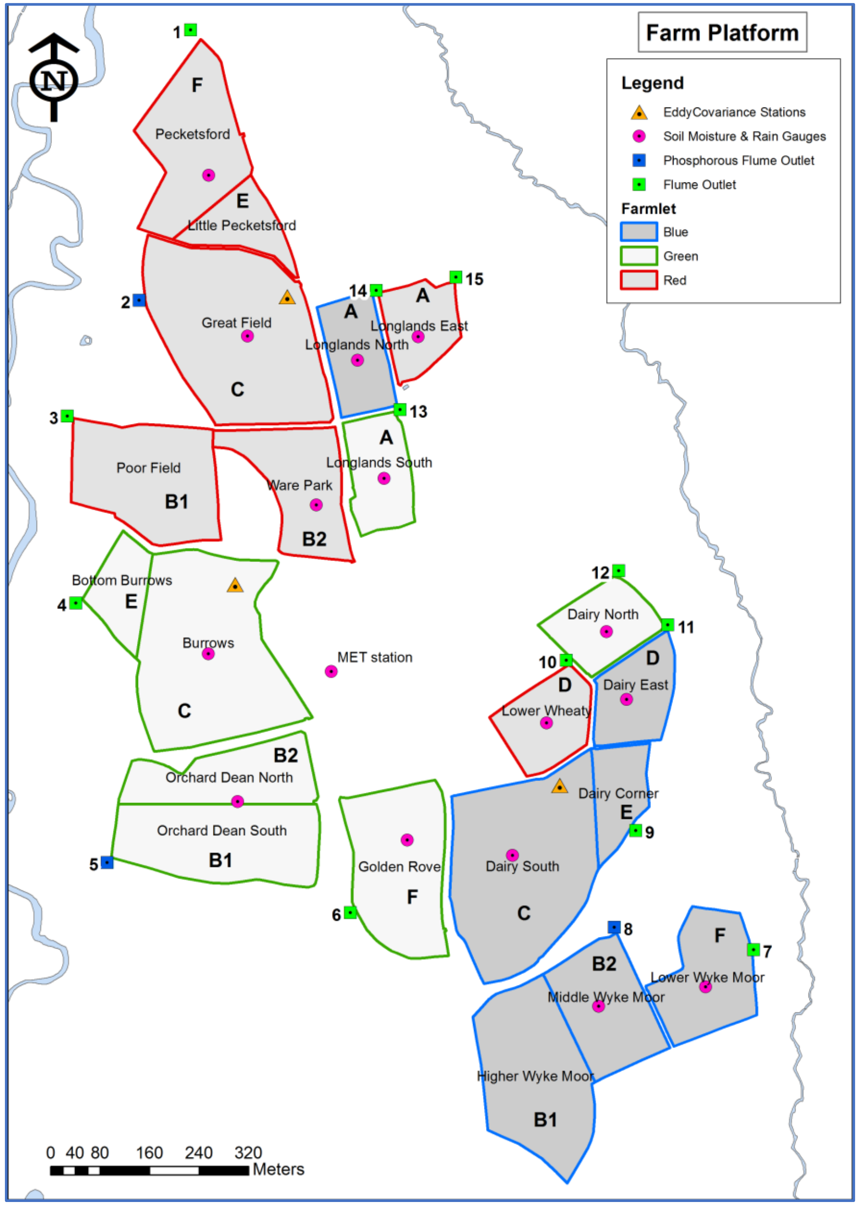
Green & Blue farms (Field):
Beef and sheep - continuously stocked
following sward mass guidelines
- •75 ewes and their lambs per farmlet
- •30 yearling beef cattle per farmlet

Up to 200 kg N fertiliser per ha
P/K/pH maintained at recommended index
First silage cut (late May/early June)
Second silage cut (August)
FYM applied to silage aftermaths

Green & Blue farms (Grazing):
Herbage mass maintained within target ranges throughout season
The area grazed varies but the number of stock stay the same
All excess areas are cut for silage
So productivity = silage made
Coupled with LWG and Condition Scores for Livestock performance

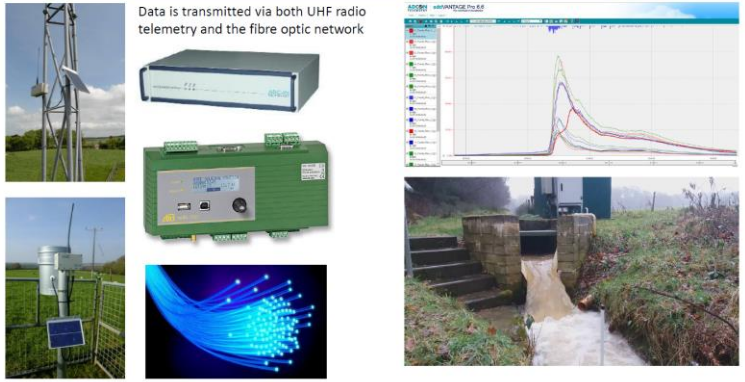
Red farm (Arable):
First wheat harvest 2020 plus assessment of its quality

Mixed resolution data on all inputs, outputs (productivity, emissions, losses, etc.) and events.



Instrumentation: Telemetry & fibre optics for water data

Data is transmitted via both UHF radio telemetry and the fibre optic network



Open Data Release

Operations: Field Surveys

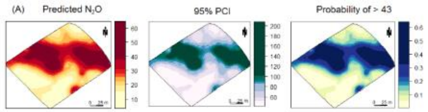
Intermittent 'High Resolution' Field Surveys since 2012 (on 25 m grid) – for within-field variation

Quarterly Low Resolution Surveys since 2018 (bulked and un-bulked "W") – for field-to-field variation

Resource hungry – often done by MSc students as part of dissertation project

Surveys for soils macro- & micro-nutrients, plant nutrients, botanical composition, soil bugs…

FP experiments (data not currently released): Many single field studies including those for soil physics, GHGs…



Instrumentation: GHG Measurements

3 x Chambers Systems
Each with 12 chambers
Spot measurement of CO_2, N_2O, CH_4 Flux

3 x Eddy Covariance Towers
Landscape scale measurements of CO_2, N_2O, CH_4 Flux

GreenFeed systems
CH_4 Emissions from cattle & sheep
Used in cattle & sheep housed facilities

Open data collections with IoT data – 76+ million measurements & counting…

Category & Resolution	Core collections (open)	Limited collections (mixture of open/closed)
Management Events - farm level	Grazing & arable management; field events (e.g. fertilizer apps.; silage cuts); housed management	*Farm economics (tractor hours, fuel use etc.)*
Crop performance - Periodic (weekly & coarser) - field level	Grass forage, silage & wheat/oats quality (nutrients & mass), silage cuts (mass)	*Take-all & fungi presence; platemeter (Grasscheck GB)*
Livestock performance - 4-weekly - individual level	Liveweight gain & condition scores	*Livestock health & welfare (incl. animal-based sensors); carcass quality (abattoir); carcass imagery. Within-field livestock movement & behaviour*
Water emissions - 15-minute - catchment level	Water run-off & chemistry (flumes)	*Storm sampling sediment / nutrients & microbiology*
Soil moisture - 15-minute - field level (15 of 21)	Soil moisture, temperature & rainfall (field centroid)	*COSMOS Soil Moisture (one field only & open via CEH)*
MET - 15-minute - platform level	MET data (single site co-located with MO site)	
GHG emissions - 30-minute (plume footprint) 3 fields only	Eddy Covariance GHG emissions (CO_2 & CH_4)	*Other GHGs; field chambers (N_2O, CO_2, CH_4); direct livestock emissions (SF_6 tracers for CH_4); Greenfeed housed (CO_2 & CH_4)**
Field surveys - Seasonal (quarterly) within-field & field level surveys	Soil / plant micro- & macro-nutrients; soil physics; soil fauna; grass flora biodiversity	*Co-located ECN collections*
Remote Sensing		*Forage Harvester, Drone & Satellite & ground reference**

12 years of data across 3 farms

Consisting of 15 hydrologically-isolated catchments and 21 fields

Housed facilities for cattle & sheep

Data portal & website:

https://nwfp.rothamsted.ac.uk/

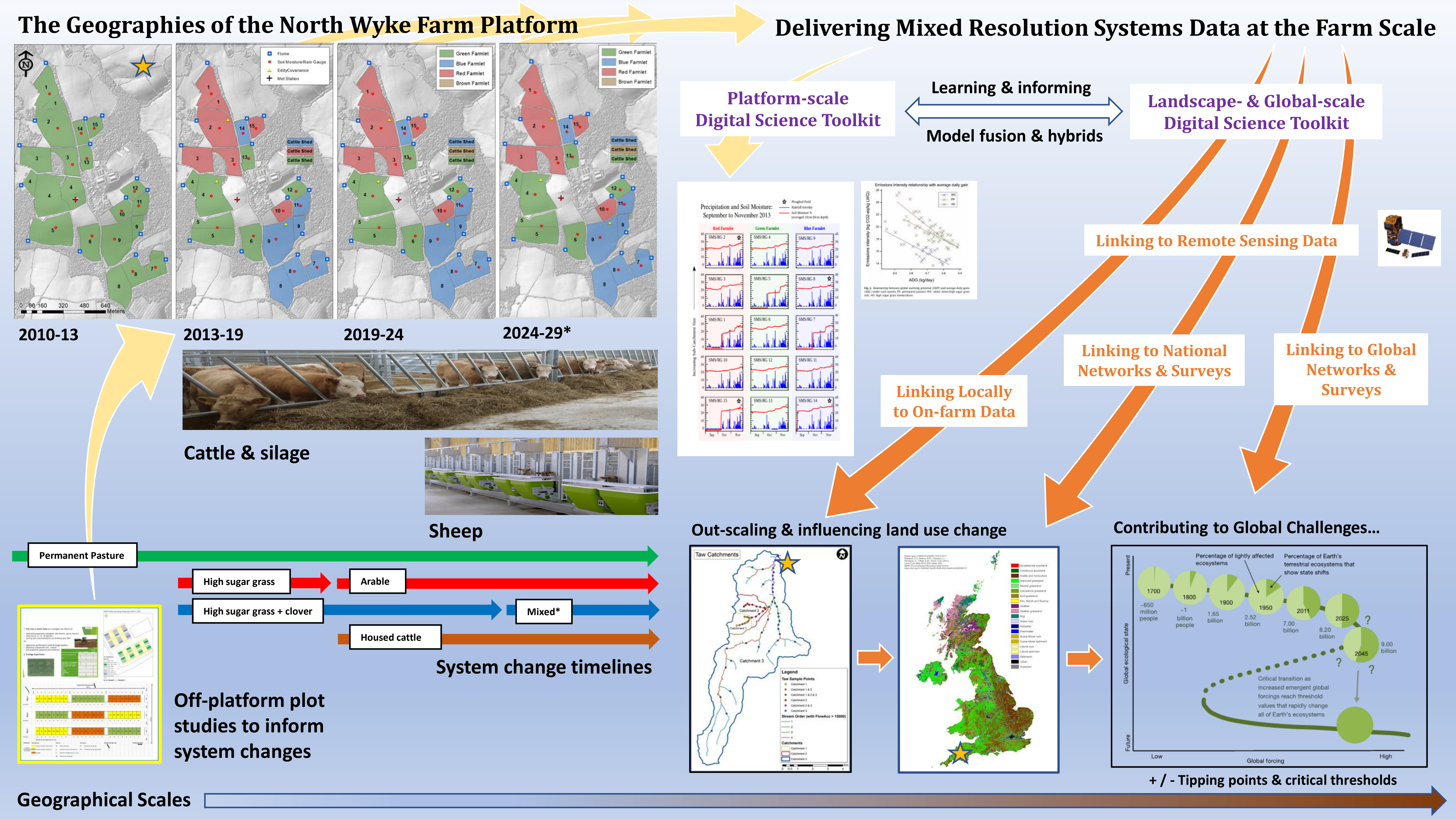
https://www.rothamsted.ac.uk/north-wyke-farm-platform

Many from campaign data from 140+ FP experiments

i.e. from use of the FP as a facility (external / internal)

- Due for core data release through Data Portal

❑ IoT data to the cloud


The Geographies of the North Wyke Farm Platform
Delivering Mixed Resolution Systems Data at the Farm Scale
Green Farmlet
Blue Farmlet
Red Farmlet
Brown Farmlet
Cattle Shed
2010-13
2013-19
2019-24
2024-29*
Cattle & silage
Sheep
Platform-scale Digital Science Toolkit
Learning & informing
Model fusion & hybrids
Landscape- & Global-scale Digital Science Toolkit
Linking to Remote Sensing Data
Linking Locally to On-farm Data
Linking to National Networks & Surveys
Linking to Global Networks & Surveys
Precipitation and Soil Moisture: September to November 2013
Red Farmlet
Green Farmlet
Blue Farmlet
Emissions intensity relationship with average daily gain
ADG (kg/day)
Permanent Pasture
High sugar grass
Arable
High sugar grass + clover
Mixed*
Housed cattle
System change timelines
Off-platform plot studies to inform system changes
Out-scaling & influencing land use change
Taw Catchments
Catchment 1
Catchment 2
Catchment 3
Legend
Contributing to Global Challenges…
Percentage of lightly affected ecosystems
Percentage of Earth's terrestrial ecosystems that show state shifts
1700
1800
1900
1950
2011
2025
2045
~650 million people
~1 billion people
1.65 billion
2.52 billion
7.00 billion
8.20 billion
9.00 billion
Present
Future
Global ecological state
Low
Global forcing
High
Critical transition as increased emergent global forcings reach threshold values that rapidly change all of Earth's ecosystems
+ / - Tipping points & critical thresholds
Geographical Scales

Increasing value of the data with increasing publications

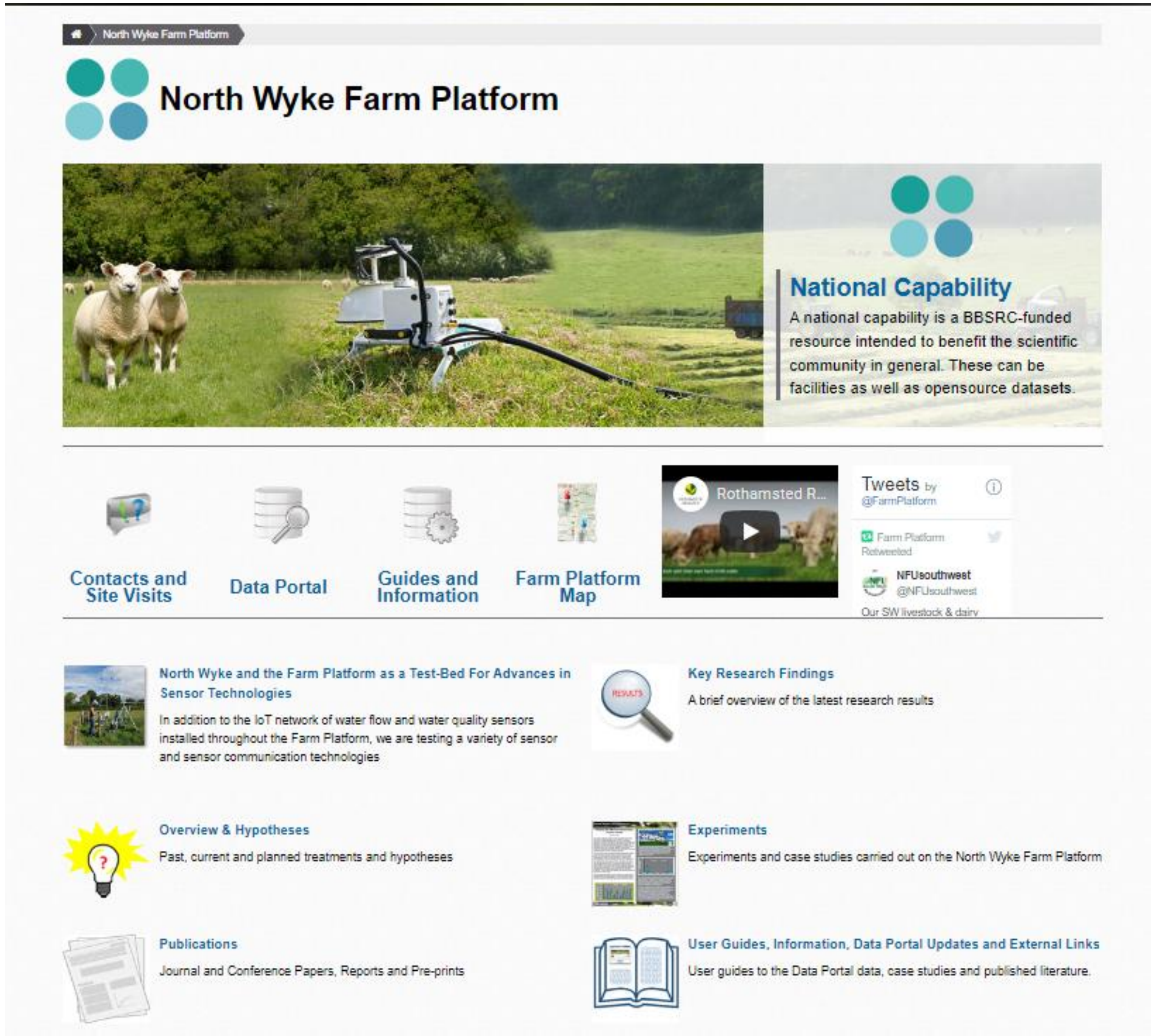
- **To date: 50+ publications directly** using FP data:
- **Many collections reaching maturity** (as 12 years in)
- **Plenty of questions remain un-answered**
- **Plenty of (sub- &) main hypotheses remain un-tested**
- **Opportunities for re-analysis with alternative tools**
- **Wealth of supplementary info & tools**

http://resources.rothamsted.ac.uk/north-wyke-farm-platform/publications

http://resources.rothamsted.ac.uk/north-wyke-farm-platform/overview-hypotheses

https://nwfp.rothamsted.ac.uk/

https://www.rothamsted.ac.uk/north-wyke-farm-platform



Serving internal and external use

North Wyke Farm Platform > North Wyke and the Far...

North Wyke and the Farm Platform as a Test-Bed For Advances in Sensor Technologies

In addition to the IoT network of water flow and water quality sensors installed throughout the Farm Platform, we are testing a variety of sensor and sensor communication technologies. Some that provide data at a local data collection level and those that can be fully integrated using various communication approaches such as Low Power, Wide Area (LPWA) networking using the LoRaWAN protocol or Narrow Band. Some examples of these sensor deployments are given below.

For further details or enquiries on using North Wyke and the Farm Platform to test sensors, please contact Paul Harris (paul.harris@rothamsted.ac.uk) or Jane Hawkins (jane.hawkins@rothamsted.ac.uk).

http://resources.rothamsted.ac.uk/north-wyke-farm-platform/north-wyke-and-farm-platform-test-bed-advances-sensor-technologies

New collections for 2023 to 2028 & enhanced digital workflows:

- **Remote Sensing** (forage harvester, drone, satellite plus ground-reference)
- Enhanced **biodiversity** sensing for improved ecosystem characterisation
- Enhanced **soil moisture** (60 sensors across 20 fields) for improved data assimilation in Digital Twin for Resilience
- **GHG Eddy Covariance** sensors: 3rd CH_4 (plus release of N_2O data)
- **Livestock-based:** (a) cattle genomics & phenotypes; (b) cattle welfare assessment; & (c) cattle meat quality

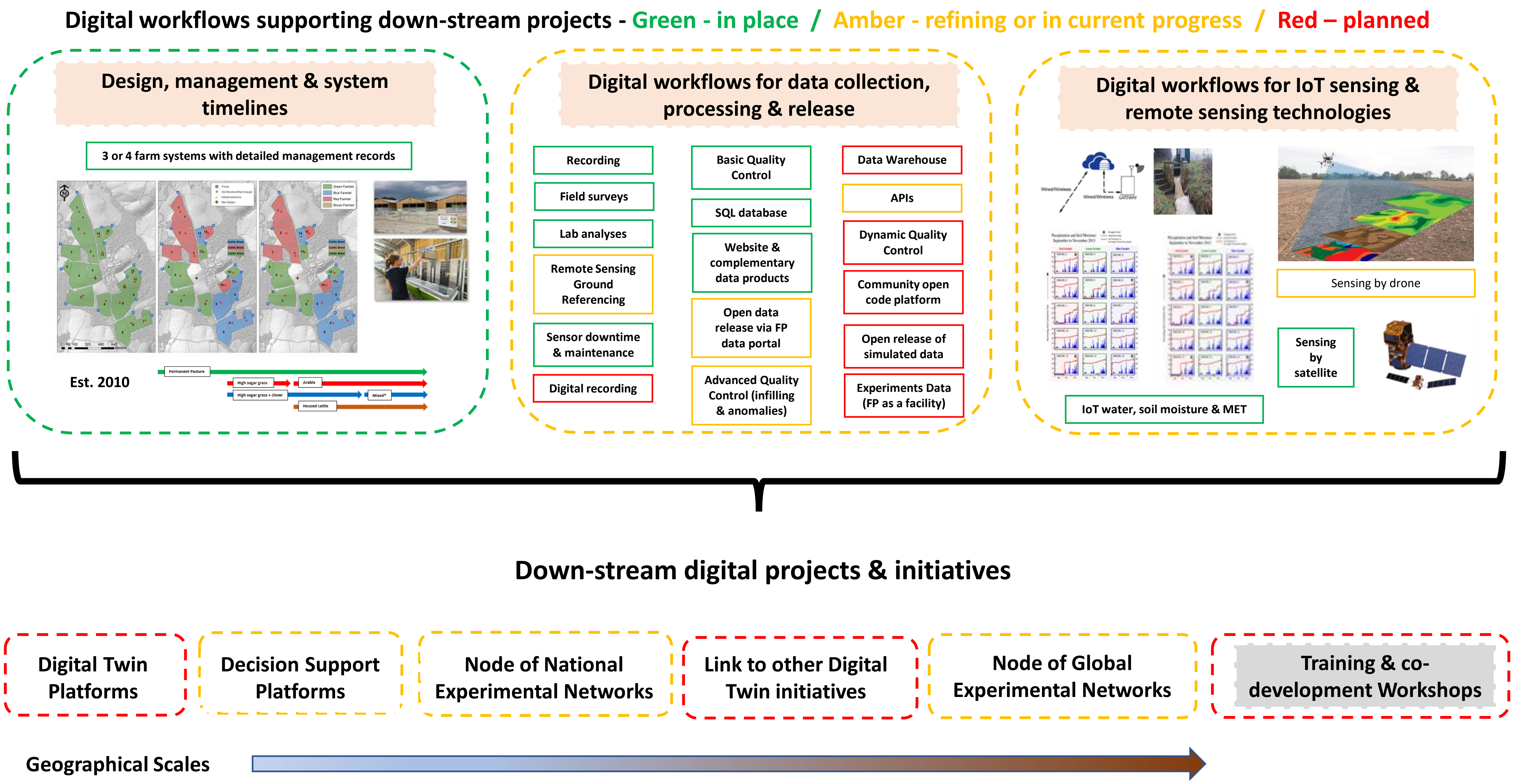
Type-1 and Type-2 datasets with differing digital workflows

Type-1 Collection	Spatial or Operational unit	Temporal Frequency	Start	New	Type-2 Collection	Spatial or Operational unit	Temporal Frequency	Start	New
Grazing & arable farm management activities (e.g., fertilizer apps, ploughing)	Farm-scale	Variable	2011	No	Livestock (cattle) welfare (behaviour & health)	Individual animal	Weekly	2019	Yes
Housed livestock management activities	Farm-scale	Variable	2011	No	Bio-acoustic monitoring for biodiversity (birds, insects, bats)	Farm-scale	Continuous	2023	Yes
Livestock performance (liveweight gain, condition scores)	Individual animal	2- to 4-weekly	2010	No	Citizen science app for wildlife sightings	Farm-scale	Intermittent	2022	No
Livestock performance (sales & carcase data)	Individual animal	End of life	2010	No	Eddy Covariance GHG (CH_4 & CO_2 from soil, plant & livestock).	Sited in 3 of 20 platform fields (CH_4 measured in 2 fields only)	30-minute	2017	No
Livestock (cattle) performance (fat scanning)	Individual animal	2-scans per lifetime	2023	Yes	Eddy Covariance GHG (CH_4 & N_2O from soil, plant & livestock)	Addition of third CH_4 & single N_2O sensors	30-minute	2025	Yes
Livestock (cattle) genomics & phenotypes	Individual animal	1-sample per lifetime	2018	Yes	Housed Greenfeed GHG (CH_4 & CO_2 from cattle)	Farm-scale (individual animal)	Variable	2017	No
Grazing crop quantity (silage cuts); RS ground reference	Field-scale	2-cuts per grazing season	2011	No	Housed Greenfeed GHG (CH_4 & CO_2 from sheep)	Farm-scale (individual animal)	Variable	2022	No
'GrassCheckGB' extension; Un-grazed grass growth; RS ground reference	Off-platform ('Top Burrows' Met site)	Weekly	2018	No	Coordinated RS from Drone & Satellite with links to Forage Harvester	Within-field scale	Variable	2024	Yes
RS ground reference for ecosystem provisioning & plant communities	Field-scale	2-weekly	2024	Yes	Water flow, physics and chemistry	Catchment-scale	15-minute	2012	No
Grazing crop quality (forage)	Field-scale	2-weekly	2015	No	Water flow, physics and chemistry (enhanced for Total C, N & P)	Catchment-scale	15-minute	2022	No
Grazing crop quality (silage)	Farm-scale via Clamp / Bale	2-weekly	2015	No	Soil Moisture and Temperature (existing)	Field-scale (1 in 15 of 20 fields)	15-minute	2011	No
Arable crop quantity & quality (wheat, oats, beans)	Field-scale	Annual Harvest	2020	No	Soil Moisture and Temperature (enhanced)	Field-scale (3 in 20 of 20 fields)	15-minute	2024	Yes
Fine-scale field surveys (soils & herbage nutrients, soil insects, vegetation)	Within-field level	Annual but intermittent	2012	No	Rainfall	Field-scale (1 in 15 of 20 fields)	15-minute	2011	No
Coarse-scale field surveys (soil & herbage nutrients)	Field-level (bulked samples)	Quarterly	2018	No	MET data	Off platform (Top Burrows)	15-minute	2011	No
Above-ground biodiversity surveys (vegetation); RS ground reference	Transects across all 3 farms & into field margins / adjacent habitats	Bi-annual	2023	Yes					
Above- & below-ground biodiversity surveys (soil insects)	Sub-terranean traps	Campaign-style	2023	Yes					
Automated Chambers GHG (N_2O, CH_4 & CO_2 from soil & plant).	Campaign deployment for 3 fields at any given time	Sub 10-minute	2013	No					
Sampling for soil retention curves for improved model parameterisation	Transects covering all platform soil classes	One-off campaign	2024	Yes					

Type-1 data have an inherent human element. Type-2 data are either IoT-based or have the potential to be so.

Type-1 data have a strong human element
Type-2 data either IoT or potential to be so

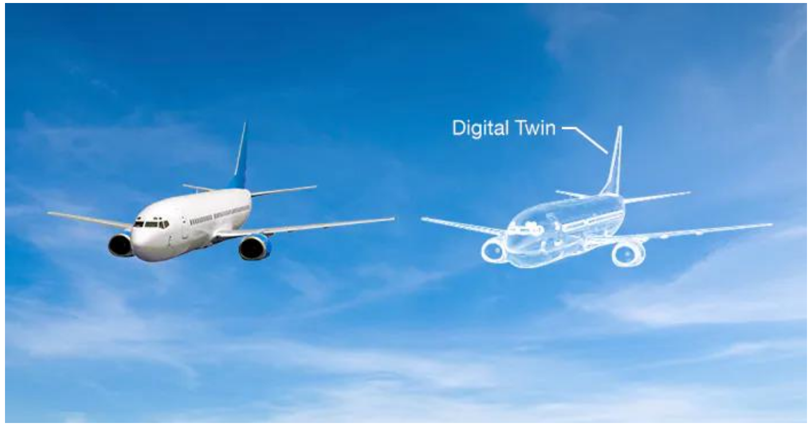
Note new data streams introduced as resources become available

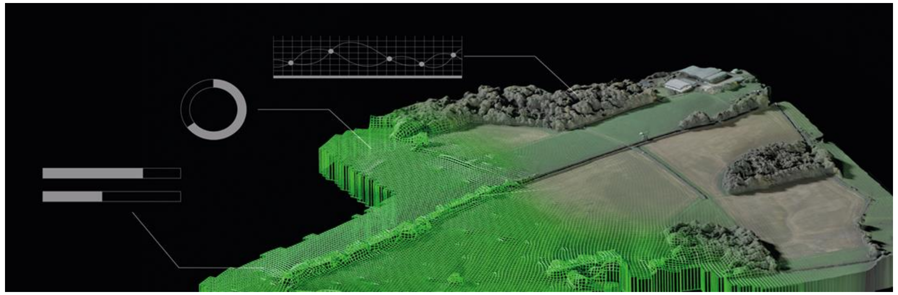


Digital workflows supporting down-stream projects - Green - in place / Amber - refining or in current progress / Red – planned
Design, management & system timelines
3 or 4 farm systems with detailed management records
Est. 2010
Digital workflows for data collection, processing & release
Recording
Field surveys
Lab analyses
Remote Sensing Ground Referencing
Sensor downtime & maintenance
Digital recording
Basic Quality Control
SQL database
Website & complementary data products
Open data release via FP data portal
Advanced Quality Control (infilling & anomalies)
Data Warehouse
APIs
Dynamic Quality Control
Community open code platform
Open release of simulated data
Experiments Data (FP as a facility)
Digital workflows for IoT sensing & remote sensing technologies
Sensing by drone
Sensing by satellite
IoT water, soil moisture & MET
Down-stream digital projects & initiatives
Digital Twin Platforms
Decision Support Platforms
Node of National Experimental Networks
Link to other Digital Twin initiatives
Node of Global Experimental Networks
Training & co-development Workshops
Geographical Scales

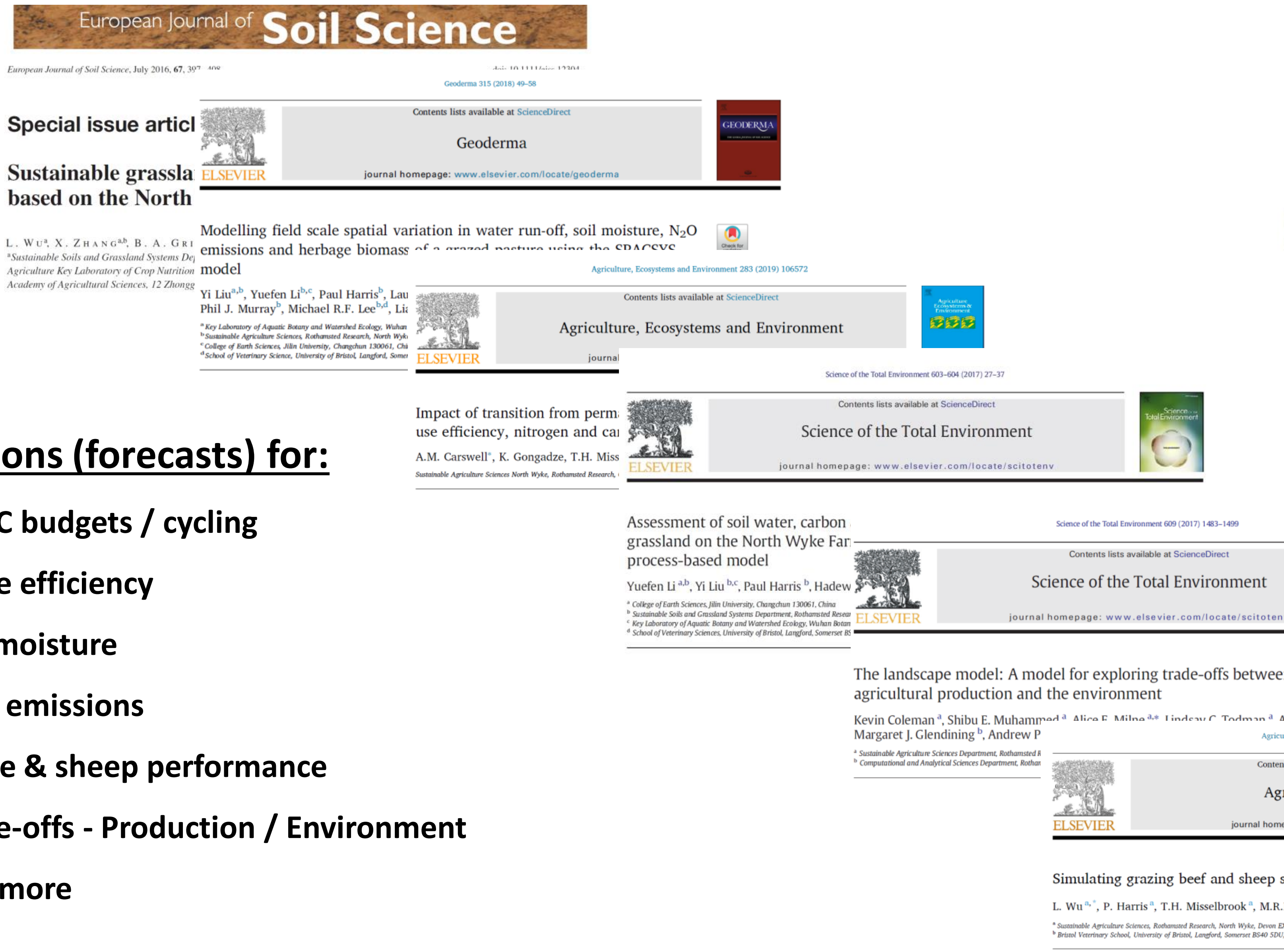
What is a Digital Twin?

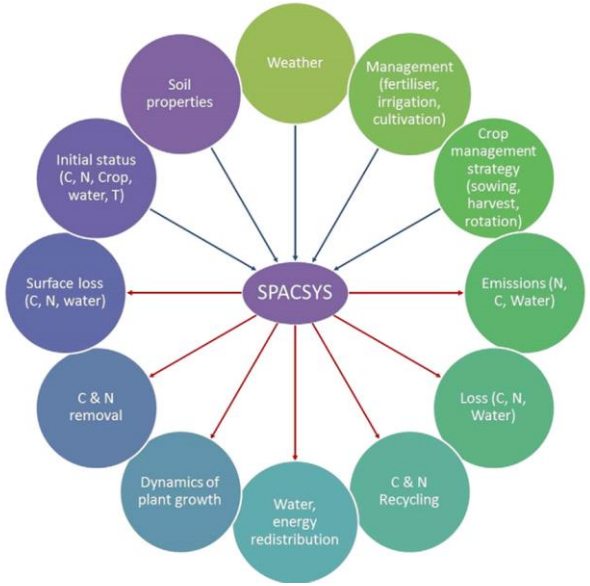
- A digital twin is a virtual representation of a real-world object or system.
- Digital twins typically use:
  - a hybrid approach where models (process-based, statistical / machine learning) are coupled in some manner;
  - and are dynamically refined (updated) with real-time IoT sensor data.
- Interactive analysis and visualization, enable new insights and discovery.
- Digital Twins generate 'what if' scenarios that allow scales of decisions making from research to policy.





Forecasting: History of Process-based Model (PBM) development for systems science

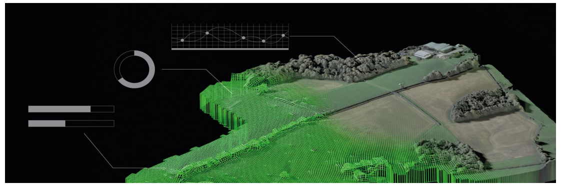




Simulations (forecasts) for:

- ❑ N & C budgets / cycling
- ❑ N use efficiency
- ❑ Soil moisture
- ❑ GHG emissions
- ❑ Cattle & sheep performance
- ❑ Trade-offs - Production / Environment
- ❑ And more

Can we create a Digital Twin for the Farm Platform?

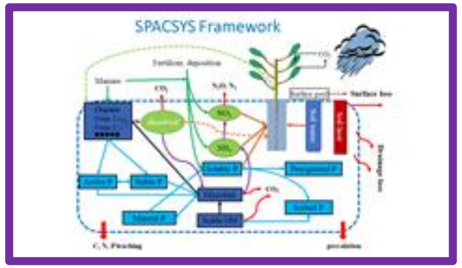


<u>Overview:</u>

- Dynamic virtual (& visual) representation of a real system that has multiple stages of its life cycle
- Will generate multiple future (& historic) simulations (possibilities) of the same system
- Similar to a Decision Support Tool BUT has much better capture of error & uncertainty

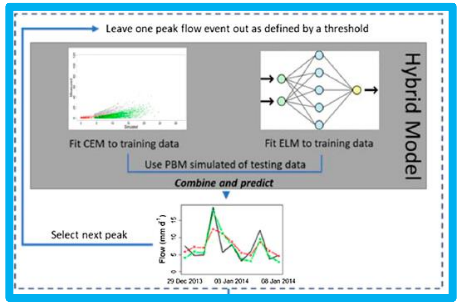
<u>Key components of a Digital Twin:</u>

- Enable ‘dynamic’ updating of simulations via IoT sensor data (scale of updating key)
- Process-based models (PBM) provide the core simulations of the system (& used in ensemble)
- PBMs coupled with statistical / machine learning – to better capture error & uncertainty

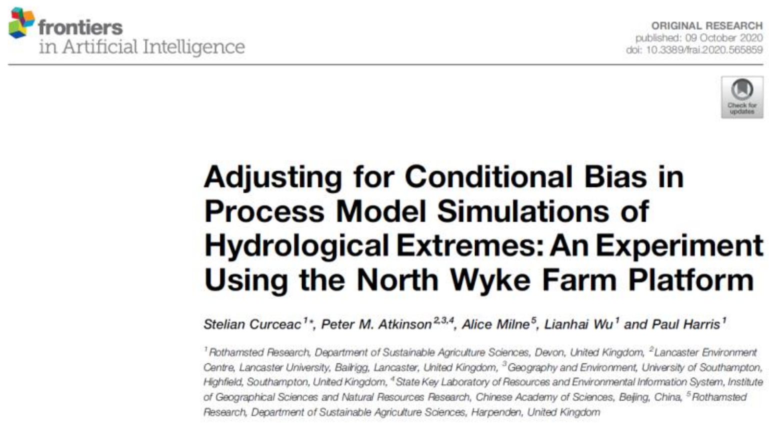


<u>A FP Digital Twin can answer ‘what if’ questions (e.g., resilience in the context of climate change):</u>

- “What if we had consecutive droughts, or increased instances of extreme rainfall?”
- “What if pests and diseases become more prevalent (and in combination with above)?”



Hybrid models – e.g., for water extremes


frontiers in Artificial Intelligence

ORIGINAL RESEARCH
published: 09 October 2020
doi: 10.3389/frai.2020.565859

Check for updates

Adjusting for Conditional Bias in Process Model Simulations of Hydrological Extremes: An Experiment Using the North Wyke Farm Platform

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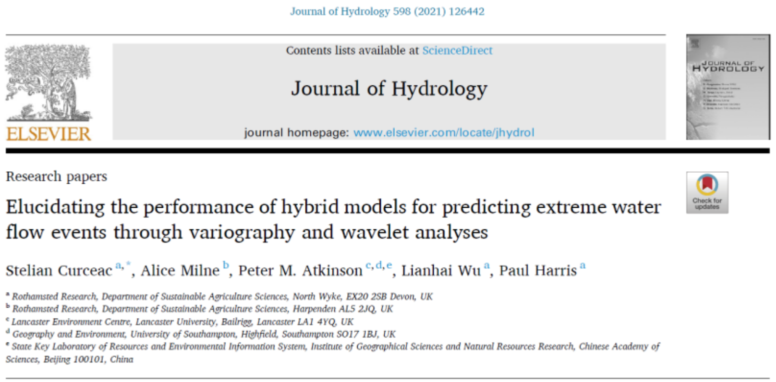
Journal of Hydrology 598 (2021) 126442

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

ELSEVIER

Research papers

Elucidating the performance of hybrid models for predicting extreme water flow events through variography and wavelet analyses

Check for updates

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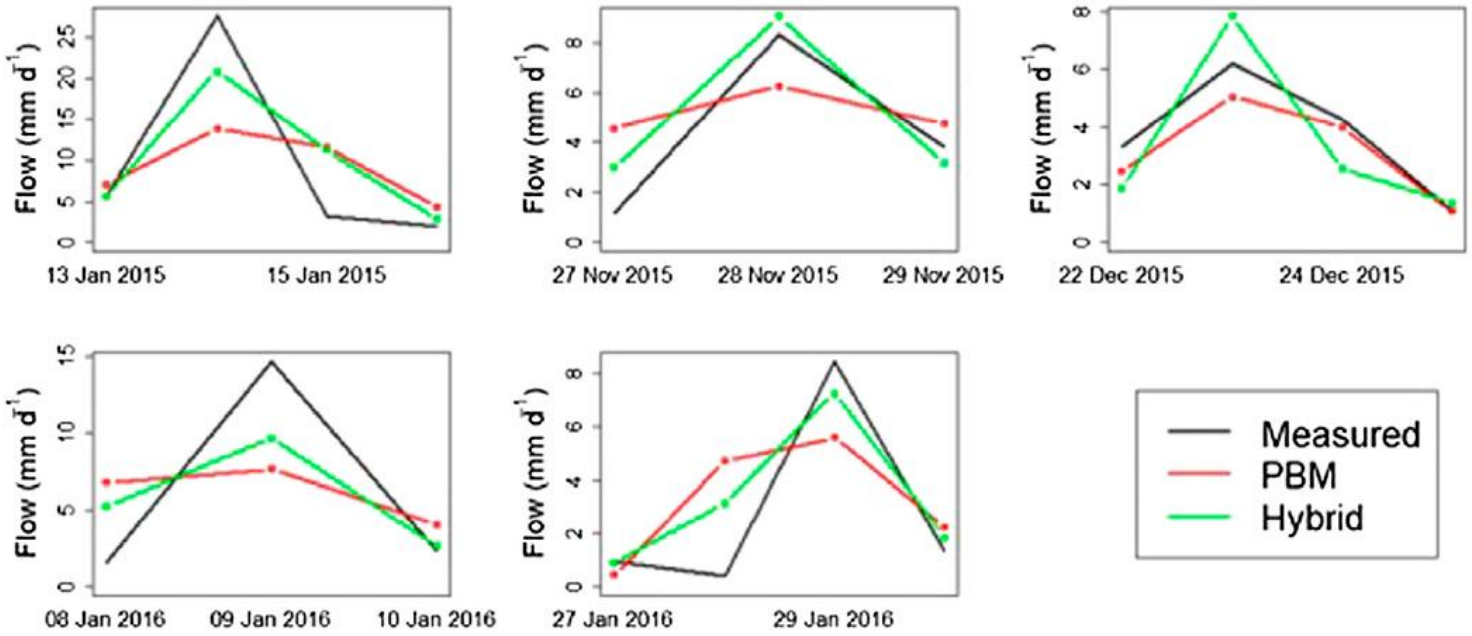
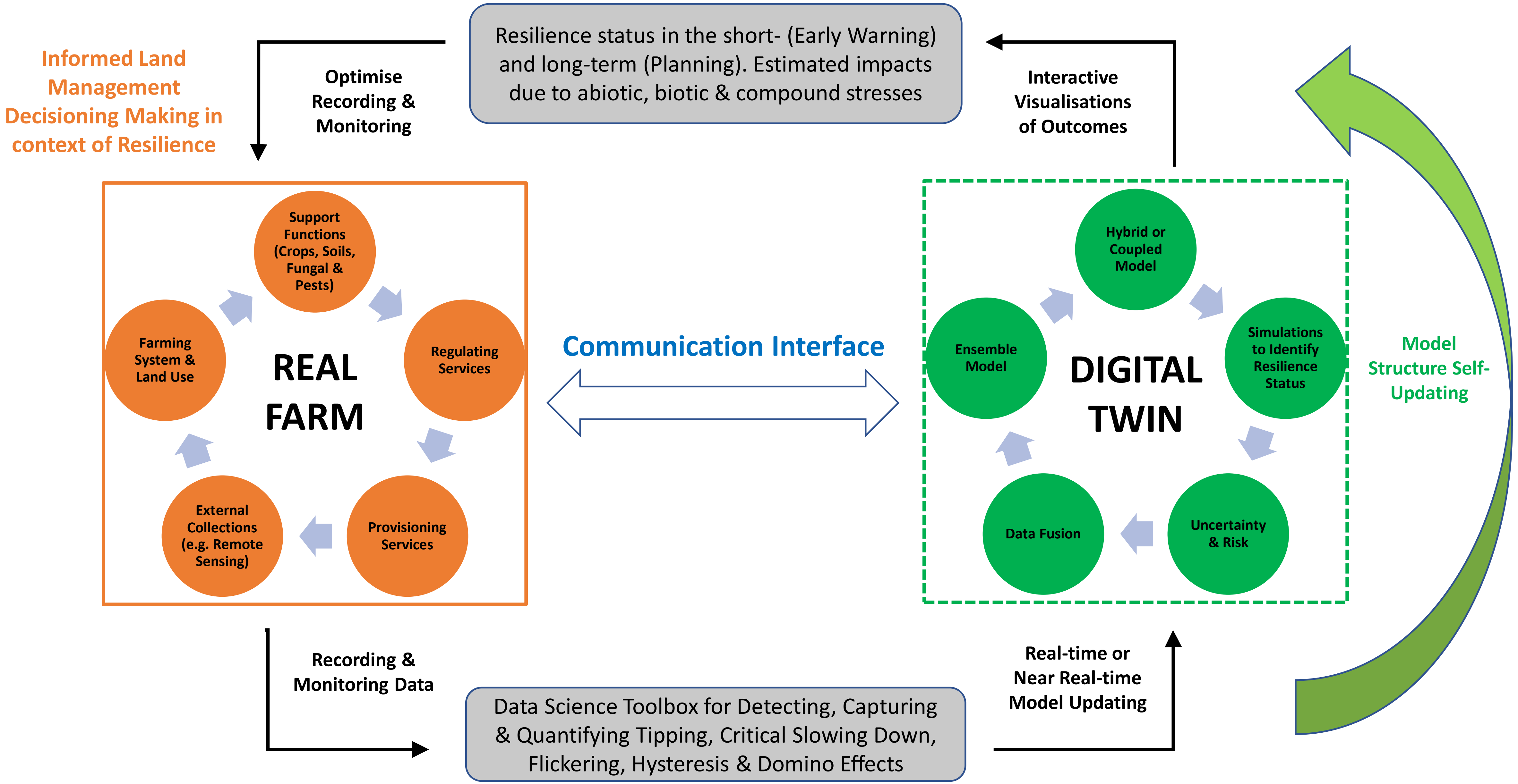


3-model coupled hybrid:
- ❖ **PBM**
- ❖ **Statistical extreme-value model**
- ❖ **Machine Learning extreme-value model**

The Architecture of a Farm-scale Digital Twin for Capturing System Resilience



Challenges for Digital Twin Implementation & co-development opportunities

Challenges:

A. Ever-present challenges of design, measurement, relevance & implementation

B. Ensuring generic digital building blocks for any down-stream digital project

C. IoT measurement is still in its infancy – many systems-scale processes cannot be measured this way

D. Only ‘part or component’ Digital Twins are currently possible (& may always be so)

E. Resourcing core digital skillsets (e.g., software engineering)

Open for business:

- Co-development with academia & industry key for FP Digital Twins (e.g. analytical tools; sensor tech.)
- Co-development for any ‘digital’ FP project (e.g. for LCA; water emissions; GHG emissions)
- Co-development for any ‘non-digital’ (core science) FP project (e.g. biodiversity; below-ground focus; NUE)

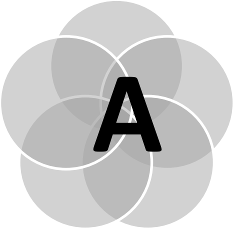
‘A to B’ Digitalisation of a ‘open’ Farm-scale Experiment: from Data Capture to Digital Platforms

1. Farm-scale Data Capture

Field Collections & Laboratory Analysis

In-situ, mobile & autonomous sensing

Management & other contextual Data



Remote Sensing

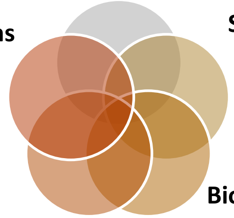
External Data

4. Fundamental Systems Science

Water emissions

GHG emissions

Soils (biology, chemistry & physics)



Crops & livestock

Biodiversity & Ecology

7. Up-skilling & Ensuring Longevity

Management Buy-in

Mentoring, Training & Best Practice

In-house Research Awards

Sabbaticals & Placements

Culture Change

2. Data Systems & Architecture

Scalability, High Performance & Cloud Computing

Data processing & QC

APIs & Data Communication

Databases & platforms

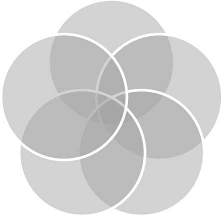
Software Engineering

5. Regular Review & Revision

Cost Benefit Analysis for each component

Resource Costs

Prevailing Policy



Zeitgeist & Blue Sky

Scientific Literature & Debate

8. Stakeholder Co-development

Industry & Academia Sensor Engineering

Academia with Digital Excellence

Agriculture Industries

Environmental Organisations

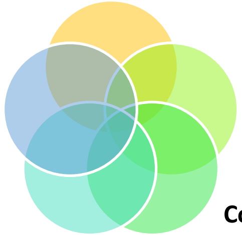
Policy & Government

3. Serving the (Digital) Community

FAIR data

FAIR code

Documentation & Metadata



Metrics of Use

Community coding (Github; Galaxy)

6. Data Science for Current Status

Design & Re-design

Statistical Inference & Uncertainty

Matching Process & Data Scale

Machine & Deep Learning

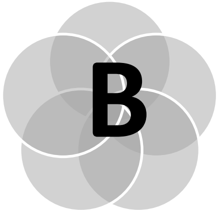
Optimisation & Evaluation

9. Digital Platforms for Forecasting

Decision Support & Risk

Model simulation – internal & external calls

Digital Twins & Risk



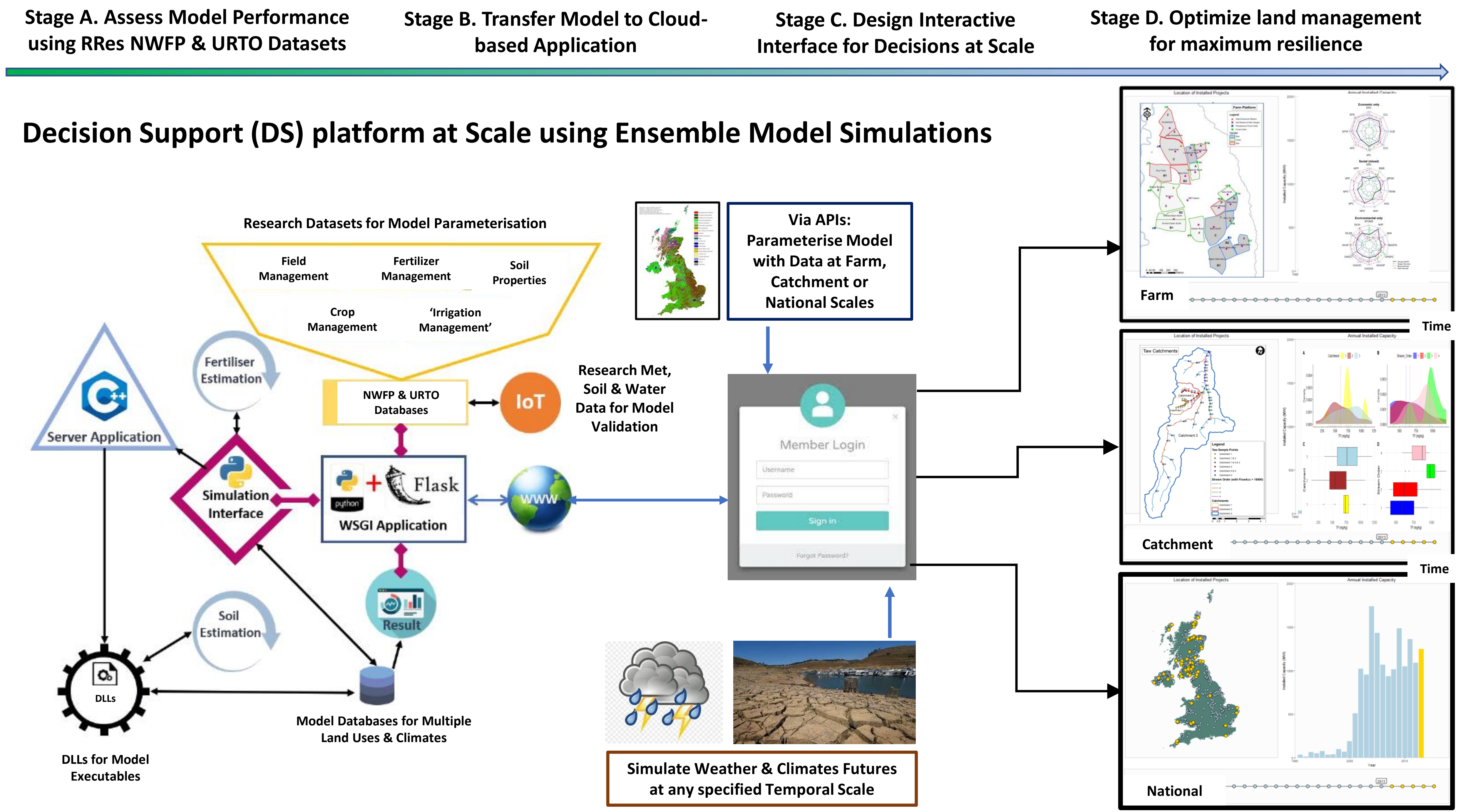
Back- & fore-casting

Hybrids & Ensemble models

ROTHAMSTED RESEARCH

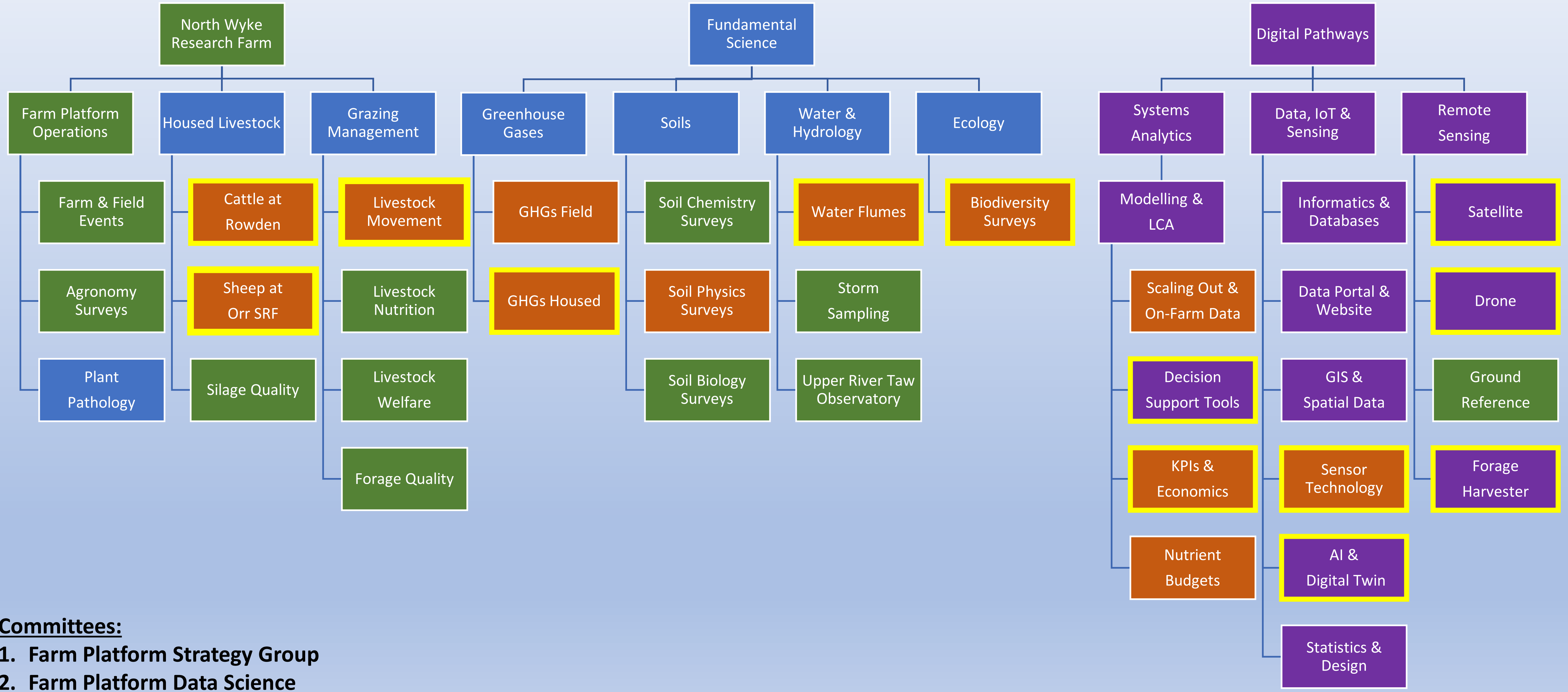
Thank you

Extra Slides


Stage A. Assess Model Performance using RRes NWFP & URTO Datasets
Stage B. Transfer Model to Cloud-based Application
Stage C. Design Interactive Interface for Decisions at Scale
Stage D. Optimize land management for maximum resilience
Decision Support (DS) platform at Scale using Ensemble Model Simulations
Research Datasets for Model Parameterisation
Field Management
Fertilizer Management
Soil Properties
Crop Management
'Irrigation Management'
Server Application
Fertiliser Estimation
NWFP & URTO Databases
IoT
Research Met, Soil & Water Data for Model Validation
Simulation Interface
python
Flask
WSGI Application
WWW
Result
Soil Estimation
DLLs
DLLs for Model Executables
Model Databases for Multiple Land Uses & Climates
Via APIs: Parameterise Model with Data at Farm, Catchment or National Scales
Member Login
Username
Password
Sign in
Forgot Password?
Simulate Weather & Climates Futures at any specified Temporal Scale
Location of Installed Projects
Annual Installed Capacity
Farm
Time
Catchment
Time
National

North Wyke Farm Platform Organogram (circa 2022)

Colour key:
Agroecostem Science
Digital Science
Data Collection
Data Collection with Digital Science
Agri-tech Industry

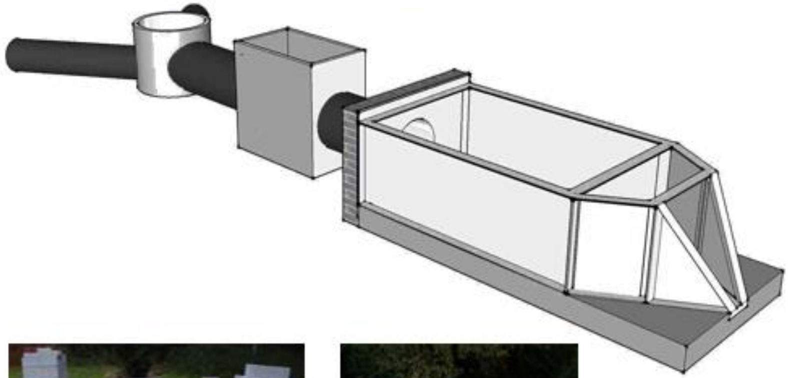


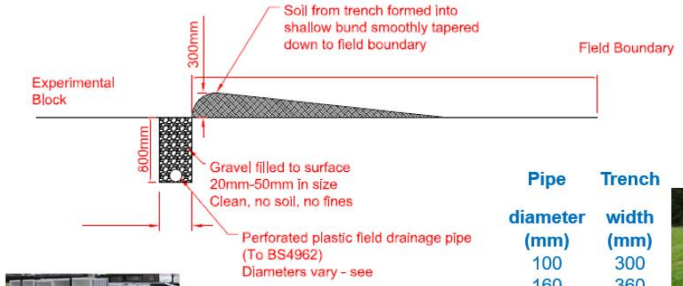
Committees:

1. **Farm Platform Strategy Group**
2. **Farm Platform Data Science**
3. **Farm Platform Management Committee**

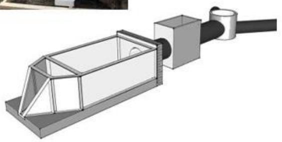
Set-up circa 2010: Construction of Drains & H-flumes for 15 catchments

9.2 km French drains
5056 tonnes 20-50mm stone
5.2 km mains electricity cable
5.2 km blown fibre optic cable





15 flumes
8 @ 1'6" (450mm)
6 @ 2'0" (600mm)
1 @ 2'6" (750mm)



Pipe diameter (mm)	Trench width (mm)
100	300
160	360
200	400
225	425
300	500
375	575
400	600
450	650

Current PhD opportunities:

SWBio DTP

UKRI Biotechnology and Biological Sciences Research Council

Informing a Farm-scale Digital Twin: Designing an effective data collection strategy

Supervisory team:
Rothamsted supervisor: Prof Paul Harris (Rothamsted Research)
Academic supervisor: Prof Richard Brazier (University of Exeter)
Mr Andrew Mead (Rothamsted Research), Prof Helen Metcalfe (Rothamsted Research), Prof Simon Willcock (Rothamsted Research), Prof Chris Baker (Rothamsted Research)

Host institution: Rothamsted Research (North Wyke)
Submit applications for this project to University of Exeter

https://www.swbio.ac.uk/bioscience-for-sustainable-agriculture-and-food/

Agroecosystems in a Climate Crisis: Using Big Data to understand the Out of the Ordinary

Rothamsted Research > Research Projects

Dr P Harris, Dr S Willcock   Wednesday, January 11, 2023

Competition Funded PhD Project (Students Worldwide)

Harpenden | United Kingdom | Data Analysis | Ecology | Environmental Biology | Environmental Geography | Plant Biology

About the Project

Agroecosystems produce food but also deliver both benefits and disbenefits for the environment, including water and air quality. Climate change forecasts

Envision

> About the Project

Institution website

Add to shortlist

https://www.envision-dtp.org/

Outline

1. Challenges of global agriculture
2. The North Wyke Farm Platform: 12 years of systems-scale measurement
3. Resources & Outputs
4. Challenges & Lessons Learned
5. Moving towards a more Digital Platform (NWFP v2.0)
6. The Architecture of a Farm-scale Digital Twin
7. Working with us & community co-development

Globally unique experiments (NBRIs) at Rothamsted

- Long-Term Experiments (LTEs): 1843- Harpenden
- Rothamsted Insect Survey (RIS): 1964- UK-wide
- North Wyke Farm Platform (NWFP): 2010- North Wyke

Promotion of:

- ❑ Research & Collaboration
- ❑ Knowledge Exchange & Communication
- ❑ Training

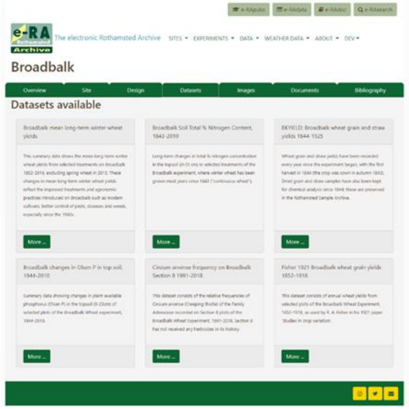
Data freely available

NWFP open for use as a facility

Long Term Experiments (LTEs) est. 1843

Biotechnology and Biological Sciences Research Council

The electronic Rothamsted Archive (e-RA) – a source of freely available data for research



- Recent paper (Poulton et al, 2018) based on LTE soil carbon data was the 2nd most downloaded paper in Global Change Biology for 2018-19.

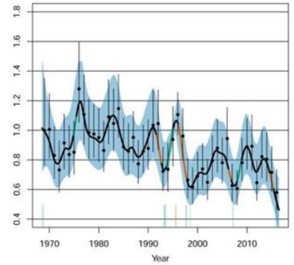
POULTON, P. R., JOHNSTON, A. E., MACDONALD, A. J., WHITE, R. AND POWLSON, D. S. (2018) "Major limitations to achieving "4 per 1000" increases in soil organic carbon stock in temperate regions: evidence from long-term experiments at Rothamsted Research, UK.", Global Change Biology, 24, 2563-2584. http://doi.org/101111/gcb.14066.

Perryman, S. A. M. et al. (2018) The electronic Rothamsted Archive (e-RA), an online resource for data from Rothamsted's long-term experiments. *Sci Data* 5:180072 doi: 10.1038/sdata.2018.72

Rothamsted Insect Survey (RIS) est. 1964

Biotechnology and Biological Sciences Research Council

- ❑ Running two trap networks since 1964
- ❑ Data on aphids, moths & other migrating insects
- ❑ Most comprehensive standardised long-term data on insects in the World



- Recent **Insect Declines report for Parliamentary Office of Science & Technology (POST)**, led by Baroness Young.
- Recent study summarising **aphid and moth trends since 1969** – data made available for download via RRes repository
- Supporting scientists to exploit the RIS archive in which 100 million insects are stored since 1974 – e.g. genomic surveillance with **Oxford University,** insect eDNA with **Queen Mary,** DNA degradation with **Newcastle University**
- Track record of **advances in Data Science** https://insectsurvey.com.

North Wyke: history & site

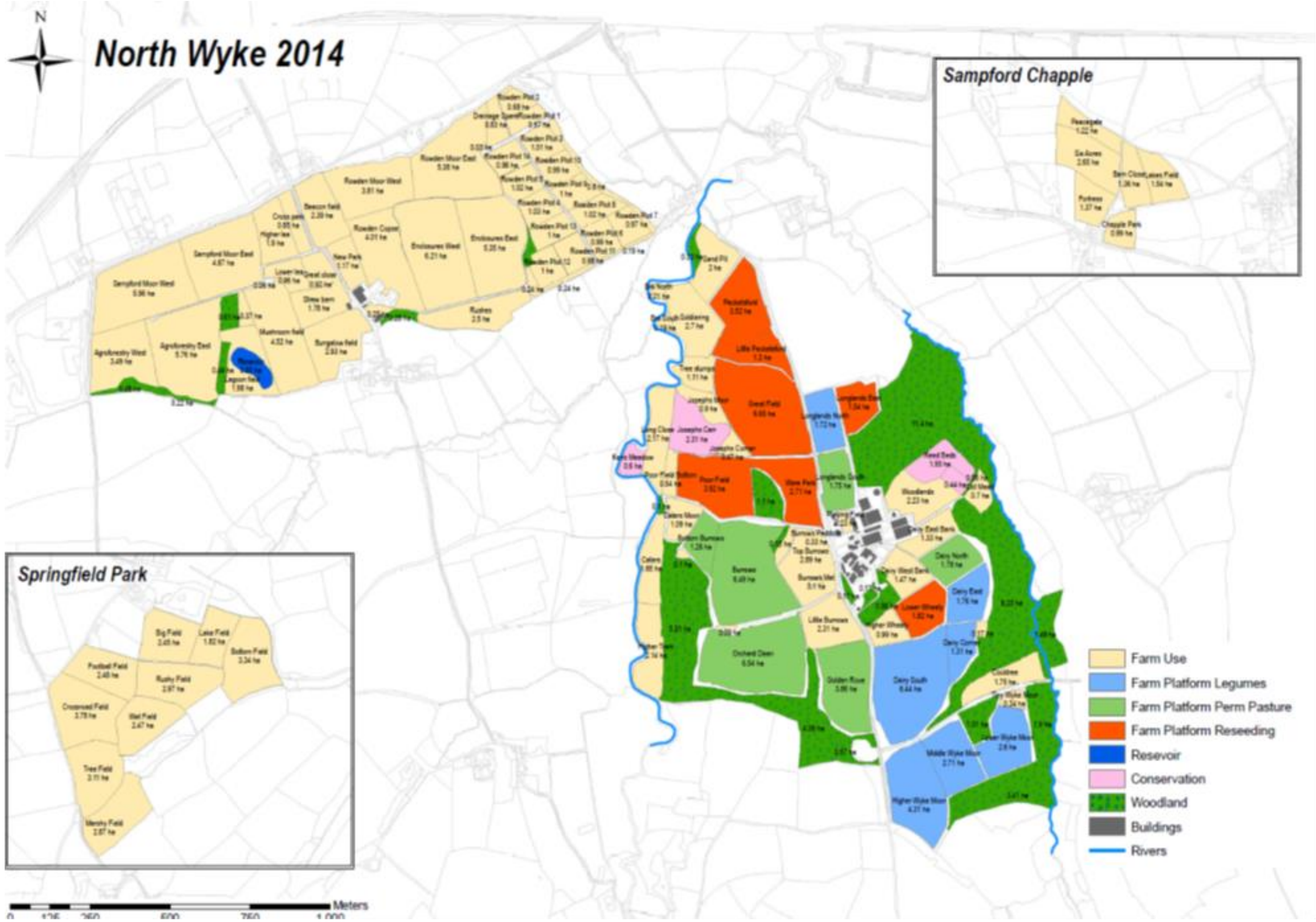
1955 – Fisons Fertiliser Research Station
1981 – Grassland Research Institute (Hurley) Permanent Pasture Department
1992 – Expansion as part of IGER
2009 – Integrated into Rothamsted Research

Dept. of Net Zero & Resilient Farming

Funding:
BBSRC, NERC, Defra, EU, Levy Boards, Industry

Main Experiments:

- Farm platform;
- Rowden drainage plots; Agroforestry fields;
- Buffers plots; Cell-grazing



+ Whidden Down site (2018)

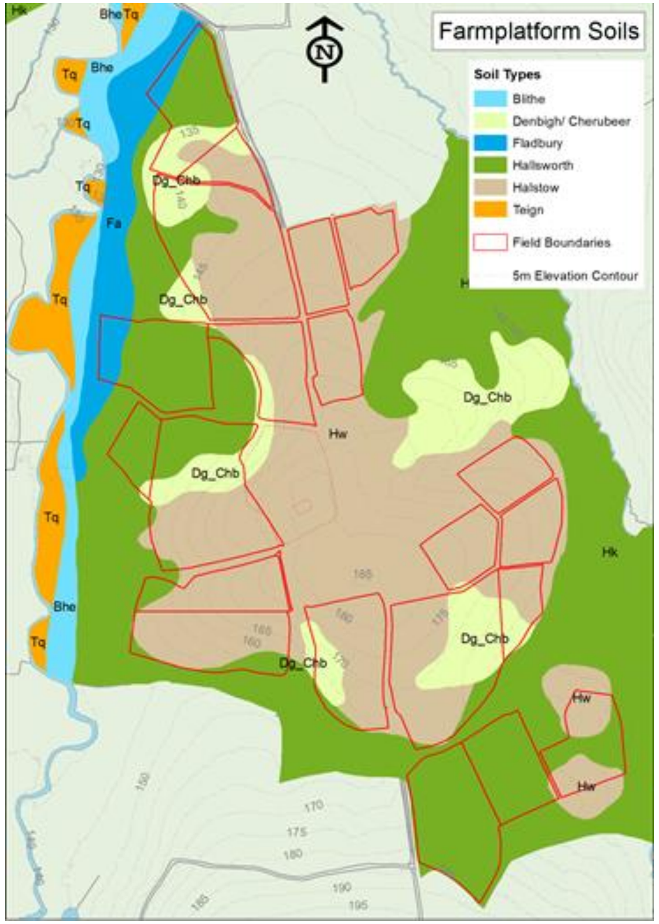
Set-up circa 2010: Soils & Topography

Halstow & Hallsworth Soil Series

Topsoil: Slightly stony clay or clay loam

Subsoil: Slowly permeable prominently mottled stony clay

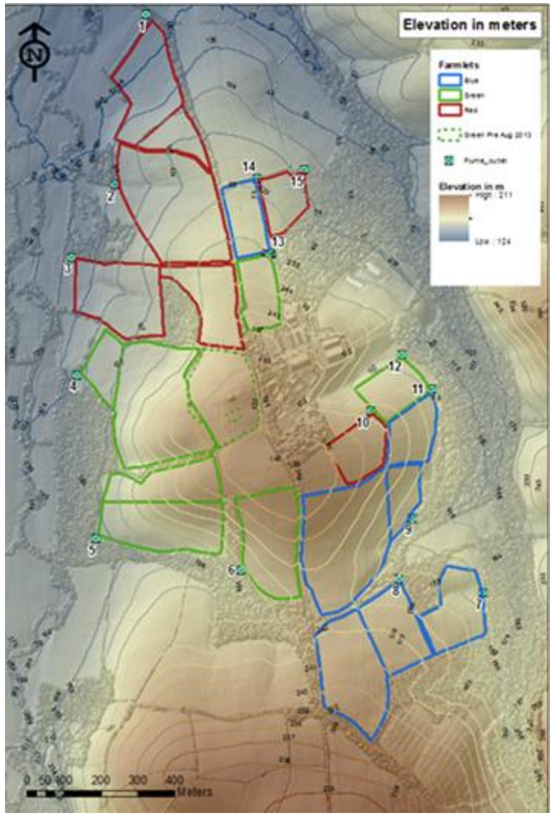
Allows the hydrological isolation for each catchment

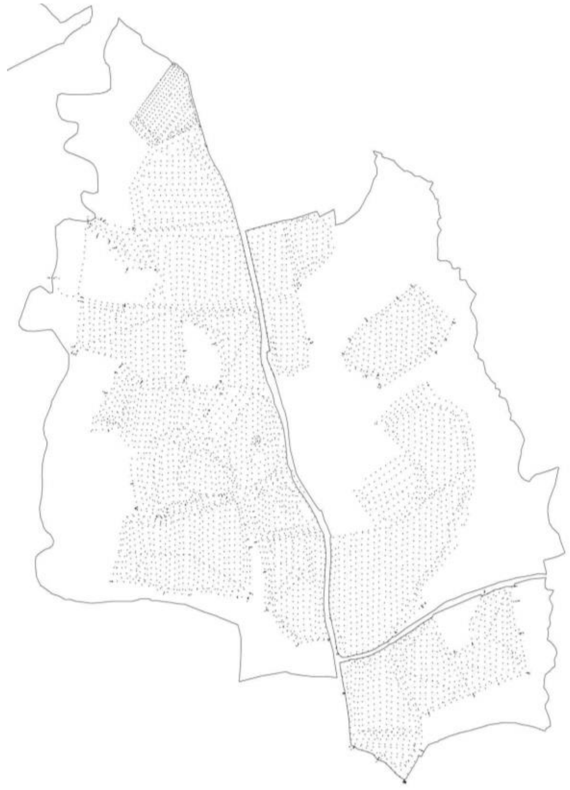


Detailed GPS survey

DEM helped inform the layout of the fields and location of the drains to capture the run-off.

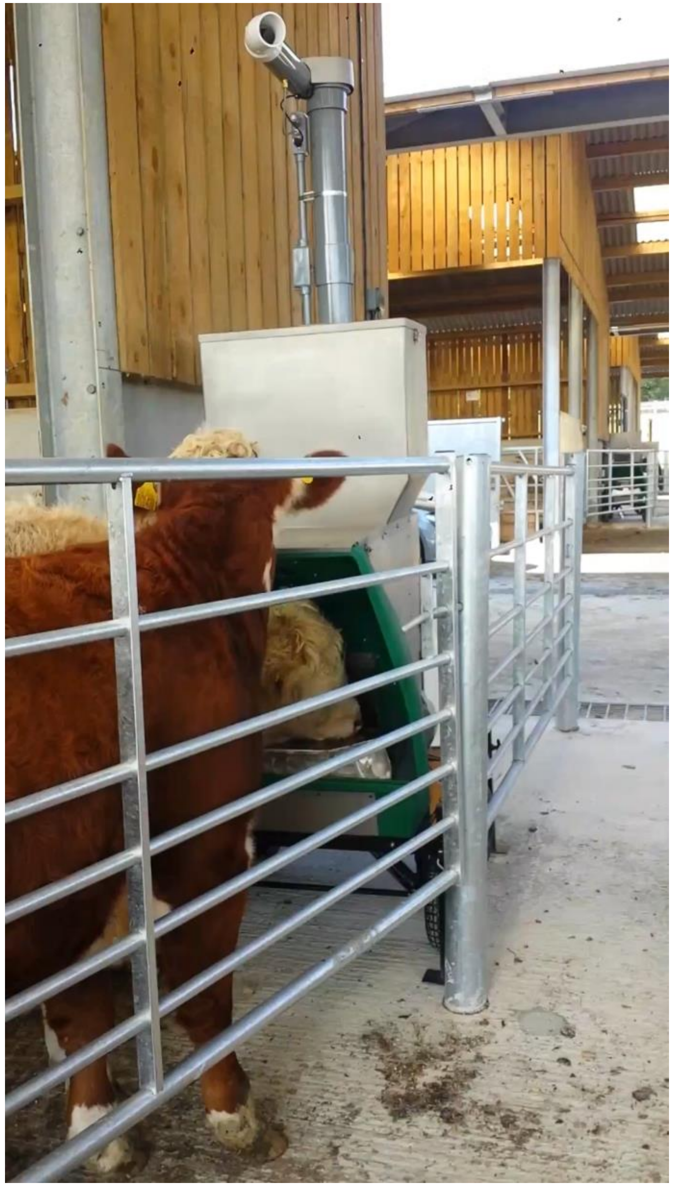
Used to inform the layout. The location of ditches to isolate the 15 sub-catchments and locate the flumes





Each farm broadly similar in terms of catchment sizes, topography & soil type

Water & Gaseous Emissions



Set-up & Baseline

European Journal of Soil Science

European Journal of Soil Science, July 2016, **67**, 374–385 doi: 10.1111/ejss.12350

Special issue article

The North Wyke Farm Platform: effect of temperate grassland farming systems on soil moisture contents, runoff and associated water quality dynamics

R. J. Orr[a], P. J. Murray[a], C. J. Eyles[b], M. S. A. Blackwell[a], L. M. Cardenas[a], A. L. Collins[a], J. A. J. Dungait[a], K. W. T. Goulding[c], B. A. Griffith[a], S. J. Gurr[a,b], P. Harris[a], J. M. B. Hawkins[a], T. H. Misselbrook[a], C. Rawlings[c], A. Shepherd[a], H. Sint[a], T. Takahashi[a,e], K. N. Tozer[d], A.P. Whitmore[c], L. Wu[a] & M. R. F. Lee[a,e]

[a]*Rothamsted Research, North Wyke, Okehampton, EX20 2SB Devon, UK,* [b]*College of Life and Environmental Sciences, University of Exeter, Exeter, EX4 4RJ Devon, UK,* [c]*Rothamsted Research, Sustainable Soils and Grassland Systems, Harpenden, AL5 2JQ Hertfordshire, UK,* [d]*AgResearch, Ruakura Research Centre, Farm Systems North, Private Bag 3123, Hamilton 3214, New Zealand, and* [e]*School of Veterinary Sciences, University of Bristol, Langford, BS40 5DU Somerset, UK*

Summary

The North Wyke Farm Platform was established as a United Kingdom national capability for collaborative research, training and knowledge exchange in agro-environmental sciences. Its remit is to research agricultural productivity and ecosystem responses to different management practices for beef and sheep production in lowland grasslands. A system based on permanent pasture was implemented on three 21-ha farmlets to obtain baseline data on hydrology, nutrient cycling and productivity for 2 years. Since then two farmlets have been modified by either (i) planned reseeding with grasses that have been bred for enhanced sugar content or deep-rooting traits or (ii) sowing grass and legume mixtures to reduce nitrogen fertilizer inputs. The quantities of nutrients that enter, cycle within and leave the farmlets were evaluated with data recorded from sensor technologies coupled with more traditional field study methods. We demonstrate the potential of the farm platform approach with a case study in which we investigate the effects of the weather, field topography and farm management activity on surface runoff and associated pollutant or nutrient loss from soil. We have the opportunity to do a full nutrient cycling analysis, taking account of nutrient transformations in soil, and flows to water and losses to air. The NWFP monitoring system is unique in both scale and scope for a managed land-based capability that brings together several technologies that allow the effect of temperate grassland farming systems on soil moisture levels, runoff and associated water quality dynamics to be studied in detail.

Animal (2018), **12:8**, pp 1766–1776
doi:10.1017/S1751731118000502

animal

Roles of instrumented farm-scale trials in trade-off assessments of pasture-based ruminant production systems

T. Takahashi[1,2†], P. Harris[1], M. S. A. Blackwell[1], L. M. Cardenas[1], A. L. Collins[1], J. A. J. Dungait[1], J. M. B. Hawkins[1], T. H. Misselbrook[1], G. A. McAuliffe[1,2], J. N. McFadzean[1,3], P. J. Murray[1], R. J. Orr[1], M. J. Rivero[1], L. Wu[1] and M. R. F. Lee[1,2]

[1]*Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK;* [2]*University of Bristol, Langford House, Langford, Somerset, BS40 5DU, UK;* [3]*University of Exeter, Stocker Road, Exeter, EX4 4QD, UK*

(Received 22 June 2017; Accepted 16 February 2018; First published online 13 April 2018)

For livestock production systems to play a positive role in global food security, the balance between their benefits and disbenefits to society must be appropriately managed. Based on the evidence provided by field-scale randomised controlled trials around the world, this debate has traditionally centred on the concept of economic-environmental trade-offs, of which existence is theoretically assured when resource allocation is perfect on the farm. Recent research conducted on commercial farms indicates, however, that the economic-environmental nexus is not nearly as straightforward in the real world, with environmental performances of enterprises often positively correlated with their economic profitability. Using high-resolution primary data from the North Wyke Farm Platform, an intensively instrumented farm-scale ruminant research facility located in southwest United Kingdom, this paper proposes a novel, information-driven approach to carry out comprehensive assessments of economic-environmental trade-offs inherent within pasture-based cattle and sheep production systems. The results of a data-mining exercise suggest that a potentially systematic interaction exists between 'soil health', ecological surroundings and livestock grazing, whereby a higher level of soil organic carbon (SOC) stock is associated with a better animal performance and less nutrient losses into watercourses, and a higher stocking density with greater botanical diversity and elevated SOC. We contend that a combination of farming system-wide trials and environmental instrumentation provides an ideal setting for enrolling scientifically sound and biologically informative metrics for agricultural sustainability, through which agricultural producers could obtain guidance to manage soils, water, pasture and livestock in an economically and environmentally acceptable manner. Priority areas for future farm-scale research to ensure long-term sustainability are also discussed.

Keywords: beef systems, sheep systems, instrumented farms, sustainability metrics, whole-farm analysis

Livestock performance

agronomy

MDPI

Article

Livestock Performance for Sheep and Cattle Grazing Lowland Permanent Pasture: Benchmarking Potential of Forage-Based Systems

Robert J. Orr [1], Bruce A. Griffith [1], M. Jordana Rivero [1,*] and Michael R. F. Lee [1,2]

1 Rothamsted Research, Sustainable Agriculture Sciences, North Wyke, Okehampton, Devon EX20 2SB, UK; robert.orr@rothamsted.ac.uk (R.J.O.); bruce.griffith@rothamsted.ac.uk (B.A.G.); michael.lee@rothamsted.ac.uk (M.R.F.L.)
2 University of Bristol, Bristol Veterinary School, Langford, Somerset BS40 5DU, UK
* Correspondence: jordana.rivero-viera@rothamsted.ac.uk; Tel.: +44-1837-512302

Received: 29 January 2019; Accepted: 18 February 2019; Published: 21 February 2019

check for updates

Abstract: Here we describe the livestock performance and baseline productivity over a two-year period, following the establishment of the infrastructure on the North Wyke Farm Platform across its three farmlets (small farms). Lowland permanent pastures were continuously stocked with yearling beef cattle and ewes and their twin lambs for two years in three farmlets. The cattle came into the farmlets as suckler-reared weaned calves at 195 ± 32.6 days old weighing 309 ± 45.0 kg, were housed indoors for 170 days then turned out to graze weighing 391 ± 54.2 kg for 177 days. Therefore, it is suggested for predominantly grass-based systems with minimal supplementary feeding that target live weight gains should be 0.5 kg/day in the first winter, 0.9 kg/day for summer grazing and 0.8 kg/day for cattle housed and finished on silage in a second winter. The sheep performance suggested that lambs weaned at 100 days and weighing 35 kg should finish at 200 days weighing 44 to 45 kg live weight with a killing out percentage of 44%. Good levels of livestock production are possible with grass and forage-based systems using little or no additional supplementary concentrate feeds.

Keywords: sheep; cattle; grazing; permanent pasture; fertiliser; lowland

Animal xxx (xxxx) xxx

Contents lists available at ScienceDirect

Animal
The international journal of animal biosciences

ELSEVIER

Using a lamb's early-life liveweight as a predictor of carcass quality

A.G. Jones [a,b], T. Takahashi [a,b,*], H. Fleming [a], B.A. Griffith [a], P. Harris [a], M.R.F. Lee [a,b]

[a] Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[b] University of Bristol, Bristol Veterinary School, Langford, Somerset, BS40 5DU, UK

A R T I C L E I N F O

Article history:
Received 2 March 2020
Received in revised form 20 July 2020
Accepted 28 July 2020
Available online xxxx

Keywords:
Conformation
Ewe condition
Farm management
Fat class
Sheep systems

A B S T R A C T

The commercial value of lamb carcasses is primarily determined by their weight and quality, with the latter commonly quantified according to muscle coverage and fat depth. The ability to predict these quality scores early in the season could be of substantial value to sheep producers, as this would enable tailored flock management strategies for different groups of animals. Existing methods of carcass quality prediction, however, require either expensive equipment or information immediately before slaughter, leaving them unsuitable as a decision support tool for small to medium-scale enterprises. Using seven-year high-resolution data from the North Wyke Farm Platform, a system-scale grazing trial in Devon, UK, this paper investigates the feasibility of using a lamb's early-life liveweight to predict the carcass quality realised when the animal reaches the target weight. The results of multinomial regression models showed that lambs which were heavier at weaning, at 13 weeks of age, were significantly more likely to have leaner and more muscular carcasses. An economic analysis confirmed that these animals produced significantly more valuable carcasses at slaughter, even after accounting for seasonal variation in lamb price that often favours early finishers. As the majority of heavier-weaned lambs leave the flock before lighter-weaned lambs, an increase in the average weaning weight could also lead to greater pasture availability for ewes in the latter stage of the current season, and thus an enhanced ewe condition and fertility for the next season. All information combined, therefore, a stronger focus on ewes' nutrition before and during lactation was identified as a key to increase system-wide profitability.

LCA & Systems Science (GHG emissions focus)

Journal of Cleaner Production 171 (2018) 1672–1680

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Distributions of emissions intensity for individual beef cattle reared on pasture-based production systems

G.A. McAuliffe [a, b], T. Takahashi [a, b, *], R.J. Orr [a], P. Harris [a], M.R.F. Lee [a, b]

[a] Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[b] University of Bristol, Langford House, Langford, Somerset, BS40 5DU, UK

ARTICLE INFO

Article history:
Received 12 April 2017
Received in revised form
9 October 2017
Accepted 10 October 2017
Available online 12 October 2017

Keywords:
Beef production
Carbon footprint
Grazing systems
High-resolution data
Life Cycle Assessment
Uncertainty analysis

ABSTRACT

Life Cycle Assessment (LCA) of livestock production systems is often based on inventory data for farms typical of a study region. As information on individual animals is often unavailable, livestock data may already be aggregated at the time of inventory analysis, both across individual animals and across seasons. Even though various computational tools exist to consider the effect of genetic and seasonal variabilities in livestock-originated emissions intensity, the degree to which these methods can address the bias suffered by representative animal approaches is not well-understood. Using detailed on-farm data collected on the North Wyke Farm Platform (NWFP) in Devon, UK, this paper proposes a novel approach of life cycle impact assessment that complements the existing LCA methodology. Field data, such as forage quality and animal performance, were measured at high spatial and temporal resolutions and directly transferred into LCA processes. This approach has enabled derivation of emissions intensity for each individual animal and, by extension, its intra-farm distribution, providing a step towards reducing uncertainty related to agricultural production inherent in LCA studies for food. Depending on pasture management strategies, the total emissions intensity estimated by the proposed method was higher than the equivalent value recalculated using a representative animal approach by 0.9–1.7 kg CO_2-eq/kg liveweight gain, or up to 10% of system-wide emissions. This finding suggests that emissions intensity values derived by the latter technique may be underestimated due to insufficient consideration given to poorly performing animals, whose emissions becomes exponentially greater as average daily gain decreases. Strategies to mitigate life-cycle environmental impacts of pasture-based beef productions systems are also discussed.

Agriculture, Ecosystems and Environment 300 (2020) 106978

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Elucidating three-way interactions between soil, pasture and animals that regulate nitrous oxide emissions from temperate grazing systems

G.A. McAuliffe[a], M. López-Aizpún[a,*], M.S.A. Blackwell[a], A. Castellano-Hinojosa[b], T. Darch[a], J. Evans[a], C. Horrocks[a], K. Le Cocq[a], T. Takahashi[a,c], P. Harris[a], M.R.F Lee[a,c], L. Cardenas[a]

[a] Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK
[b] University of Florida, IFAS Southwest Florida Research and Education Center, Immokalee, FL, 34142, USA
[c] University of Bristol, Bristol Veterinary School, Langford, Somerset, BS40 5DU, UK

ARTICLE INFO

Keywords:
Nitrous oxide
Beef cattle
Urine
Dung
Climate change
Denitrification
Nitrification
Soil microbial communities

ABSTRACT

Pasture-based livestock farming contributes considerably to global emissions of nitrous oxide (N_2O), a powerful greenhouse gas approximately 265 times more potent than carbon dioxide. Traditionally, the estimation of N_2O emissions from grasslands is carried out by means of plot-scale experiments, where externally sourced animal excreta are applied to soils to simulate grazing conditions. This approach, however, fails to account for the impact of different sward types on the composition of excreta and thus the functionality of soil microbiomes, creating unrealistic situations that are seldom observed under commercial agriculture. Using three farming systems under contrasting pasture management strategies at the North Wyke Farm Platform, an instrumented ruminant grazing trial in Devon, UK, this study measured N_2O emissions from soils treated with cattle urine and dung collected within each system as well as standard synthetic urine shared across all systems, and compared these values against those from two forms of controls with and without inorganic nitrogen fertiliser applications. Soil microbial activity was regularly monitored through gene abundance to evaluate interactions between sward types, soil amendments, soil microbiomes and, ultimately, N_2O production. Across all systems, N_2O emissions attributable to cattle urine and standard synthetic urine were found to be inconsistent with one another due to discrepancy in nitrogen content. Despite previous findings that grasses with elevated levels of water-soluble carbohydrates tend to generate lower levels of N_2O, the soil under high sugar grass monoculture in this study recorded higher emissions when receiving excreta from cattle fed the same grass. Combined together, our results demonstrate the importance of evaluating environmental impacts of agriculture at a system scale, so that the feedback mechanisms linking soil, pasture, animals and microbiomes are appropriately considered.

Agricultural Policy (sediment loss focus)

Journal of Environmental Management 249 (2019) 109365

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

ELSEVIER

Research article

Field-based determination of controls on runoff and fine sediment generation from lowland grazing livestock fields

S. Pulley*, A.L. Collins

Sustainable Agriculture Sciences, Rothamsted Research, North Wyke, Okehampton, Devon, EX20 2SB, UK

ARTICLE INFO

Keywords:
Erosion
Grassland
Farming
Lowland grazing
Rain splash
Saturation-excess runoff

ABSTRACT

Compared with arable land, there is a paucity of field-based measurements of erosion rates and controls for lowland temperate grassland supporting ruminant agriculture. Despite this evidence gap, reducing diffuse fine sediment pollution from intensively farmed grassland has been recognised as essential for improving compliance with water quality targets. Improved information on erosion rates and controls within intensively managed lowland grazing livestock systems are prerequisites for informing best management practices for soil and water resource conservation.

Accordingly, this study assembled such information using the North Wyke farm platform in south west England where flow, suspended sediment concentration, rainfall and soil moisture are monitored quasi-continuously in 15 hydrologically-isolated (1.54–11.12 ha) catchments. This region of the UK is representative of temperate lowland ruminant grazing landscapes with semi permeable soil drainage.

Catchment area was the major control on both water and sediment flux. When normalised to catchment area, sediment yields were controlled by the erodibility of the catchment's soils. Ploughing for re-seeding of grass swards was the major factor that affected this. Whilst total rainfall had a small effect on sediment yields, slope and the damage of soils by livestock had no significant effects. This finding may be due to the overriding effects of ploughing and re-seeding of some fields during the study period.

Detachment by impacting raindrops mobilised sediment particles across the entire field with diffuse saturation-excess overland flow responsible for their transport. The majority of erosion occurred during the rising limbs of storm events when there is an abundance of easily detached soil particles. Given that erosion and sediment transport are driven mechanistically by processes affecting the entire field areas, a reduction in sediment yield through the implementation of highly spatially-targeted in-field management such as that for feeder ring use, troughs, poached tracks or gateways would likely be very challenging. Instead, stocking density and grazing regime management, as well as carefully planned ploughing and re-seeding will be more beneficial for erosion control.

Environmental Science and Policy 116 (2021) 114–127

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

ELSEVIER

Current advisory interventions for grazing ruminant farming cannot close exceedance of modern background sediment loss – Assessment using an instrumented farm platform and modelled scaling out

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ARTICLE INFO

Keywords:
Soil erosion
Sediment
Ruminant farming
Mitigation

ABSTRACT

Water quality impairment by elevated sediment loss is a pervasive problem for global water resources. Sediment management targets identify exceedance or the sediment loss 'gap' requiring mitigation. In the UK, palaeo-limnological reconstruction of sediment loss during the 100–150 years pre-dating the post-World War II intensification of agriculture, has identified management targets (0.20–0.35 t ha^{-1} yr^{-1}) representing 'modern background sediment delivery to rivers'. To assess exceedance on land for grazing ruminant farming, an integrated approach combined new mechanistic evidence from a heavily-instrumented experimental farm platform and a scaling out framework of modelled commercial grazing ruminant farms in similar environmental settings. Monitoring (2012–2016) on the instrumented farm platform returned sediment loss ranges of 0.11–0.14 t ha^{-1} yr^{-1} and 0.21–0.25 t ha^{-1} yr^{-1} on permanent pasture, compared with between 0.19–0.23 t ha^{-1} yr^{-1} and 0.43–0.50 t ha^{-1} $yr^{-1}$and 0.10–0.13 t ha^{-1} $yr^{-1}$and 0.25–0.30 t ha^{-1} yr^{-1} on pasture with scheduled plough and reseeds. Excess sediment loss existed on all three farm platform treatments but was more extensive on the two treatments with scheduled plough and reseeds. Excessive sediment loss from land used by grazing ruminant farming more strategically across England, was estimated to be up to >0.2 t ha^{-1} yr^{-1}. Modelled scenarios of alternative farming futures, based on either increased uptake of interventions typically recommended by visual farm audits, or interventions selected using new mechanistic understanding for sediment loss from the instrumented farm platform, returned minimum sediment loss reductions. On the farm platform these were 2.1 % (up to 0.007 t ha^{-1} yr^{-1}) and 5.1 % (up to 0.018 t ha^{-1} yr-1). More strategically, these were up to 2.8 % (0.014 t ha^{-1} yr^{-1}) and 4.1 % (0.023 t ha^{-1} yr^{-1}). Conventional on-farm measures will therefore not fully mitigate the sediment loss gap, meaning that more severe land cover change is required.

Model test-bed: Validation

Science of the Total Environment 609 (2017) 1483–1499

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The landscape model: A model for exploring trade-offs between agricultural production and the environment

Kevin Coleman [a], Shibu E. Muhammed [a], Alice E. Milne [a,*], Lindsay C. Todman [a], A. Gordon Dailey [a], Margaret J. Glendining [b], Andrew P. Whitmore [a]

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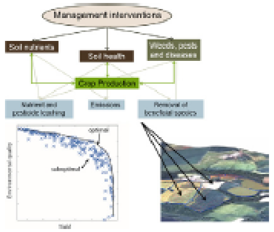
HIGHLIGHTS

- Understanding trade-offs between yield and environment is essential for SI.
- The Landscape Model aids the understanding of crop-soil-water interactions.
- Model validated against 50 years of data from two long-term experiments.
- Model validated against spatially-explicit data from the North Wyke farm platform.
- The model simulated wheat yield, grain N and grain P particularly well.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 14 March 2017
Received in revised form 20 July 2017
Accepted 21 July 2017
Available online 8 August 2017

Editor: D. Barcelo

Keywords:
Modelling
Crops
Soil processes
Nutrient flow
Water movement
Agriculture

ABSTRACT

We describe a model framework that simulates spatial and temporal interactions in agricultural landscapes and that can be used to explore trade-offs between production and environment so helping to determine solutions to the problems of sustainable food production. Here we focus on models of agricultural production, water movement and nutrient flow in a landscape. We validate these models against data from two long-term experiments, (the first a continuous wheat experiment and the other a permanent grass-land experiment) and an experiment where water and nutrient flow are measured from isolated catchments. The model simulated wheat yield (RMSE 20.3–28.6%), grain N (RMSE 21.3–42.5%) and P (RMSE 20.2–29% excluding the nil N plots), and total soil organic carbon particularly well (RMSE 3.1 – 13.8%), the simulations of water flow were also reasonable (RMSE 180.36 and 226.02%). We illustrate the use of our model framework to explore trade-offs between production and nutrient losses.

Agriculture, Ecosystems and Environment 283 (2019) 106572

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Impact of transition from permanent pasture to new swards on the nitrogen use efficiency, nitrogen and carbon budgets of beef and sheep production

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ARTICLE INFO

Keywords:
Balance
Carbon
Grazing
Livestock
Nitrogen use efficiency
Nutrient budgets
Reseed

ABSTRACT

There is currently much debate around the environmental implications of ruminant farming and a need for robust data on nitrogen (N) and carbon (C) fluxes from beef and sheep grazing systems. Here we use data collected from the North Wyke Farm Platform along with the SPACSYS model to examine the N and C budgets and the N use efficiency (NUE) of grassland swards at different stages of establishment. We assessed the transition from permanent pasture (PP) to a high-sugar grass (HSG), and a mixed sward of HSG with white clover (HSGC), identifying data specifically for the reseed (RS) years and the first year following RS (HSG-T and HSGC-T). Dominant fluxes for the N budget were N offtake as cut herbage and via livestock grazing, chemical-N fertiliser and N leaching at 88–280, 15–177, and 36–92 kg N ha^{-1} a^{-1}, respectively. Net primary productivity, soil respiration and C offtake as cut herbage and via livestock grazing at 1.9–15.9, 1.74–12.5, and 0.34–11.7 t C ha^{-1} a^{-1}, respectively, were the major C fluxes. No significant differences were found between the productivity of any of the swards apart from in the RS year of establishment. However, NUE of the livestock production system was significantly greater for the HSGC and HSGC-T swards at 32 and 42% compared to all other swards, associated with the low chemical-N fertiliser inputs to these clover-containing swards. Our findings demonstrate opportunities for improving NUE in grazing systems, but also the importance of setting realistic NUE targets for these systems to provide achievable goals for land-managers.

Model test-bed: Development and with Remote Sensing

frontiers in Artificial Intelligence

ORIGINAL RESEARCH
published: 09 October 2020
doi: 10.3389/frai.2020.565859

Check for updates

Adjusting for Conditional Bias in Process Model Simulations of Hydrological Extremes: An Experiment Using the North Wyke Farm Platform

Stelian Curceac[1]*, *Peter M. Atkinson*[2,3,4], *Alice Milne*[5], *Lianhai Wu*[1] and *Paul Harris*[1]

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Peak flow events can lead to flooding which can have negative impacts on human life and ecosystem services. Therefore, accurate forecasting of such peak flows is important. Physically-based process models are commonly used to simulate water flow, but they often under-predict peak events (i.e., are conditionally biased), undermining their suitability for use in flood forecasting. In this research, we explored methods to increase the accuracy of peak flow simulations from a process-based model by combining the model's output with: a) a semi-parametric conditional extreme model and b) an extreme learning machine model. The proposed 3-model hybrid approach was evaluated using fine temporal resolution water flow data from a sub-catchment of the North Wyke Farm Platform, a grassland research station in south-west England, United Kingdom. The hybrid model was assessed objectively against its simpler constituent models using a jackknife evaluation procedure with several error and agreement indices. The proposed hybrid approach was better able to capture the dynamics of the flow process and, thereby, increase prediction accuracy of the peak flow events.

Keywords: peak flow, conditional extreme model, extreme learning machine, process-based model, hybrid, grassland agriculture

OPEN ACCESS

Edited by:
Gregoire Mariethoz, University of Lausanne, Switzerland

Reviewed by:
Georgia Papacharalampous, National Technical University of Athens, Greece
Tianfang Xu, Arizona State University, United States

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Specialty section:

Agricultural and Forest Meteorology 307 (2021) 108466

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

ELSEVIER

Check for updates

Inferring management and predicting sub-field scale C dynamics in UK grasslands using biogeochemical modelling and satellite-derived leaf area data

Vasileios Myrgiotis [*,a], Paul Harris [b], Andrew Revill [a], Hadewij Sint [b], Mathew Williams [a]

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A R T I C L E I N F O

Keywords:
Grasslands
UK
Carbon
Earth observation
Leaf area index
Model-data fusion

A B S T R A C T

Grasslands, natural and managed, cover a large part of the Earth's surface and play an important role in the global carbon (C) cycle. Human management strongly affects grassland C budgets through grass cutting and removal, varied grazing intensities, and organic matter additions. Thus managed grassland C cycles are highly heterogeneous and challenging to quantify. In this study, we combine a process-based model of the grassland C cycle, validated against field data on C fluxes and pools, with satellite-derived data (Proba-V and Sentinel-2) on leaf area index (LAI) in order to quantify field-scale grassland productivity and C dynamics under climatic and management conditions typical of northwest Europe. Input data on the weekly vegetation canopy anomaly (estimated from Proba-V LAI) and meteorology are used to drive the grassland C model (DALEC-Grass) that is integrated into a Bayesian model-data fusion (MDF) framework. The novelty of the MDF algorithm is that it infers weekly livestock grazing and grass cutting events based on expected canopy growth estimated by the model, and constrained by LAI observations (estimated from Sentinel-2). The MDF approach also resolves observational, parametric, and input uncertainties on C cycling estimates. We analysed four years (2015–2018) of C dynamics at three variably-managed fields of the Rothamsted Research North Wyke Farm Platform (UK). Compared against independent field data, the MDF was able to (i) identify 87.5% of the harvest events that occurred, (ii) accurately predict the annual yields in 83% of the identified harvest years and (iii) reproduce the observed grazing intensity in each field ($r = 0.8$, overlap = 90%). We demonstrate that the fusion of process modelling with earth observations is an effective method for monitoring biomass removals and quantifying management impacts on field-scale C balance, without the need for frequent and laborious ground measurements. This approach can support the delivery of more robust national greenhouse gas (GHG) accounting that takes account of grassland vegetation management.

Challenges – Review of FP publications by process, scale & Data Science tools used

* **45 publications directly** using FP data (http://resources.rothamsted.ac.uk/north-wyke-farm-platform/publications)

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
Number	Year	Authors, Paper & Journal	Management	Livestock/ crop	Soils	Plants	Soil_Bugs	Water	Gases	No_processess	Dimension	No_catch	Period	Sample_years	No_years	Treatment	Unit_scale	Modelling	Statistics	AI	Model	Stat_method	AI_method	Back/fore-cast or up/out-scale
1	2012	Peukert, S., Bol, R., Roberts, W., Macleod, C. J. A., Murray, P. J., Dixon, E. R. and Brazier, R. E. (2012). Understanding spatial variability of soil properties: a key step in establishing field- to farm-scale agro-ecosystem experiments. Rapid Communications in Mass Spectrometry, 26, 20, 2413-2421. (doi:10.1002/rcm.6336).	0	0	1	0	0	0	0	1	Spatial	1	Baseline	2011	1	Red	Within-catchment	0	1	0	No	Geostatistics (ordinary kriging)	No	0
2	2014	Peukert, S., Griffith, B. A., Murray, P. J., Macleod, C. J. A. and Brazier, R. E. (2014). Intensive Management in Grasslands Causes Diffuse Water Pollution at the Farm Scale. Journal of Environmental Quality, 43, 6, 2009-2023. (doi:10.2134/jeq2014.04.0193).	1	0	0	0	0	1	0	2	Spatio-temporal	3	Baseline	2011-2012	2	G-R-B	Catchment	0	1	0	No	Time series regressions; Time series plots; scatterplot regressions	No	0
3	2016	Benefer, C. M., D'Ahmed, K. S., Blackshaw, R. P., Sint, H. M. and Murray, P. J. (2016). The Distribution of Soil Insects across Three Spatial Scales in Agricultural Grassland. Frontiers in Ecology and Evolution, 4, 41. (doi:10.3389/fevo.2016.00041).	1	0	0	0	1	0	0	2	Spatio-temporal	15	Baseline	2012-2013	2	G-R-B	Within-catchment	0	1	0	No	Deviance partitioning & chi-squared tests	No	0
4	2016	Liu, W., Zhang, J., Norris, S. L. and Murray, P. J. (2016). Impact of Grassland Reseeding, Herbicide Spraying and Ploughing on Diversity and Abundance of Soil Arthropods. Frontiers in Plant Science, 7, 1200. (doi:10.3389/fpls.2016.01200).	1	0	1	0	1	0	0	3	Spatio-temporal	4	Trans-1	2013-2014	2	R-B	Within-catchment	0	1	0	No	CCA; PCA	No	0
5	2016	Orr, R. J., Murray, P. J., Eyles, C. J., Blackwell, M. S. A., Cardenas, L. M., Collins, A. L., Dungait, J. A. J., Goulding, K. W. T., Griffith, B. A., Gurr, S. J., Harris, P., Hawkins, J. M. B., Misselbrook, T. H., Rawlings, C., Shepherd, A., Sint, H., Takahashi, T., Tozer, K. N., Whitmore, A. P., Wu, L. and Lee, M. R. F. (2016). The North Wyke Farm Platform: effect of temperate grassland farming systems on soil moisture contents, runoff and associated water quality dynamics. European Journal of Soil Science, 67, 4, 374-385. (doi:10.1111/ejss.12350).	1	0	0	0	0	1	0	2	Spatio-temporal	15	Trans-1	2013	1	G-R-B	Catchment	0	1	0	No	ANOVA; Time Series plots; Scatterplots	No	0
6	2016	Peukert, S., Griffith, B. A., Murray, P. J., Macleod, C. J. A. and Brazier, R. E. (2016). Spatial variation in soil properties and diffuse losses between and within grassland fields with similar short-term management. European Journal of Soil Science, 67, 4, 386-396. (doi:10.1111/ejss.12351).	1	0	1	0	0	1	0	3	Spatio-temporal	3	Baseline	2012-2013	2	G-R-B	Within-catchment	0	1	0	No	Geostatistics (ordinary kriging) & summaries of time series data	No	0

To complete & summarise…

Could we develop specific (bespoke) systems science analytical tools?

Upgrade: Capital grant award (2020) – new water sensors on all 15 catchments

“A step change in compelling evidence on water quality impacts of agricultural best practice”

1. Monitoring the **high resolution quasi-continuous soluble reactive and total phosphorus and total nitrogen losses in runoff** from lowland grazing livestock and cereal farming systems.
2. Assembling the fundamental data for addressing the evidence gap on the impacts of best practice interventions for water quality in lowland grazing livestock and cereal farming systems - major farming systems for the UK.

In summary, 15 water quality sensors to deliver new replicated water quality data which will be publicly available on the free open access platform data portal ((https://nwfp.rothamsted.ac.uk/).

Total award value: £568k

First Wheat Harvest (2020) (Red Farm)

Interesting wheat quality results:

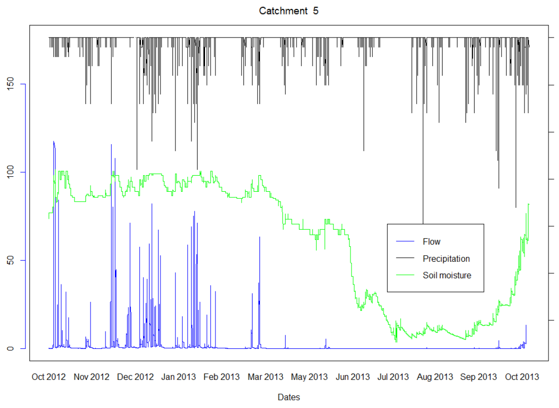
- **Quality high (milling grade) when harvest should have taken place**
- **However poor weather conditions entailed delayed harvest**
- **Resulting on significant lowering of quality (and not milling grade)**

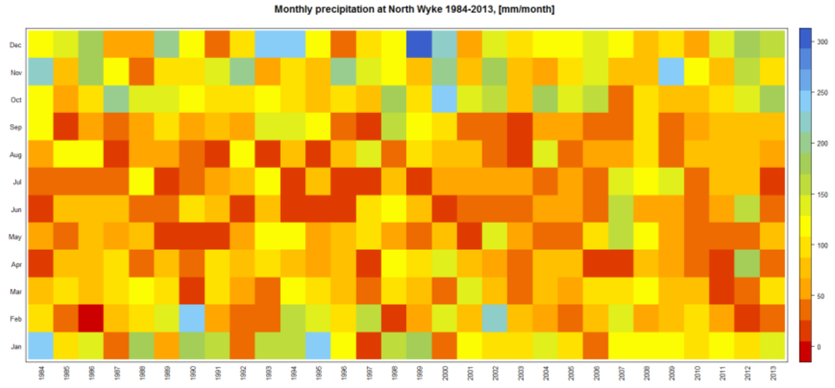
- **Highlights inherent risk of growing wheat in a wet climate**

Sample	Sample date	Field	% Moisture content	Amount of flour for hagburg (g)	Left hagburg falling number	Right hagburg falling number	Mean hagburg falling number
NW 735/60001	10/08/2020	Pecketsford	6.66	6.16	484	475	479
NW 735/60012	10/08/2020	Great field	6.43	6.14	482	429	455
NW 735/60023	11/08/2020	Ware park	6.58	6.15	328	333	330
NW 735/60034	11/08/2020	Poor Field	6.45	6.14	398	408	403
NW 735/60045	11/08/2020	Lower Wheaty	6.84	6.18	444	434	439
NW 735/60056	11/08/2020	Longlands East	6.55	6.15	385	391	388
NW 735/60067	02/09/2020	Pecketsford	8.7	6.37	115	113	114
NW 735/60068	02/09/2020	Great field	8.7	6.37	171	170	170
NW 735/60069	02/09/2020	Ware park	8.7	6.37	130	131	130
NW 735/60070	02/09/2020	Poor Field	8.6	6.36	145	148	146
NW 735/60071	02/09/2020	Lower Wheaty	8.9	6.39	149	150	149
NW 735/60072	02/09/2020	Longlands East	8.6	6.36	137	139	138

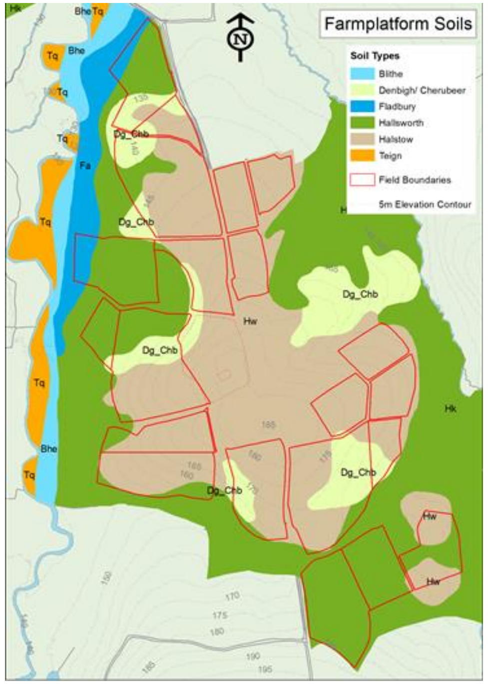
Challenges – Acknowledging inherent confounders

Weather

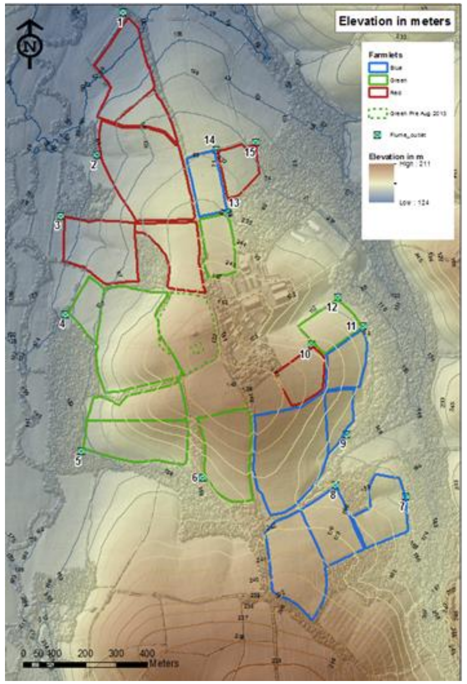




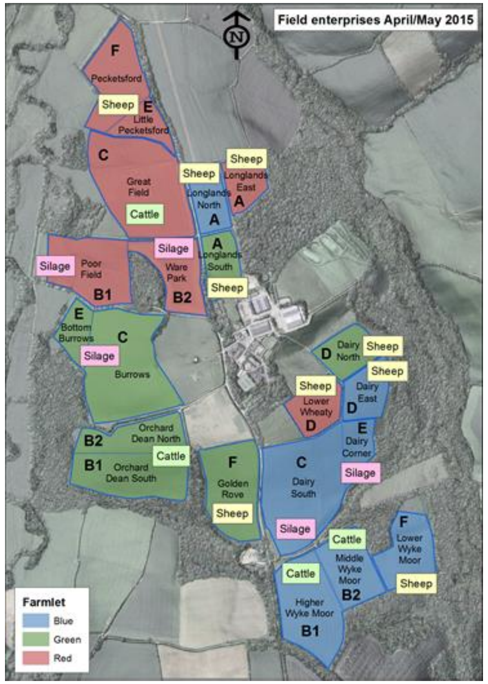
Also "We have introduced confounders & we have unintentional confounders"



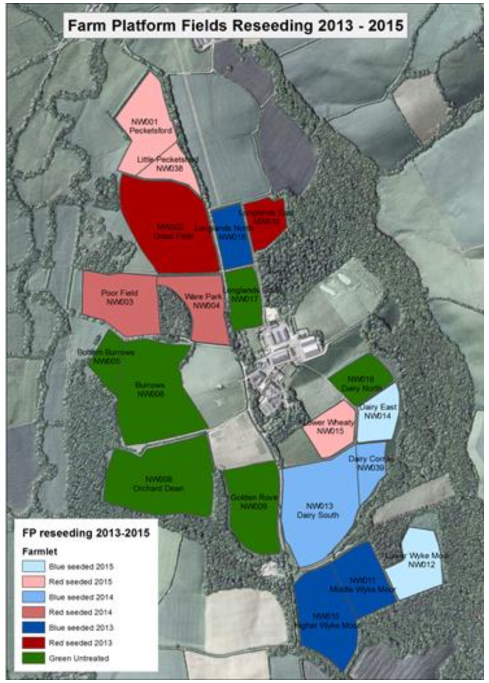
Soil class



Topography



Enterprise history



Re-seeding history

Challenges and Lessons Learned from 12 years of operation

- Statistical & physical design: replication; physical confounders (soil class, field size, etc.); measurements that confound others
- System decisions: when/how many/how long/legacies; severity (plough/min till, etc.); should we dispense with systems?
- Scale: matching measurement to process scale; scales of analysis (farm, sub-catchment, field, within-field / months, seasons)
- Data collections: review & relevance; cost-benefit; sensor development & testing; coherence within membership networks etc.
- Data release: moving from basic to advanced QC; infilling; user feedback;
- Generic & bespoke analytical toolkits: process-based models/LCA/statistical/ML; hybrids; uncertainties & their propagation;
- Organisational structure: Scientists, Digital Scientists, Technicians; highly inter-/multi-disciplinary; long-term memory critical
- Output route map: tailored to multiple stakeholders; encourage co-development; ensure continued value / benefit

On-going objectives:

1. **<u>Infrastructure, Management and Measurement:</u>** Ensure its physical integrity, and that best practice is observed in its farm management. Maintain and manage the instrumentation and measurement of all data collections.

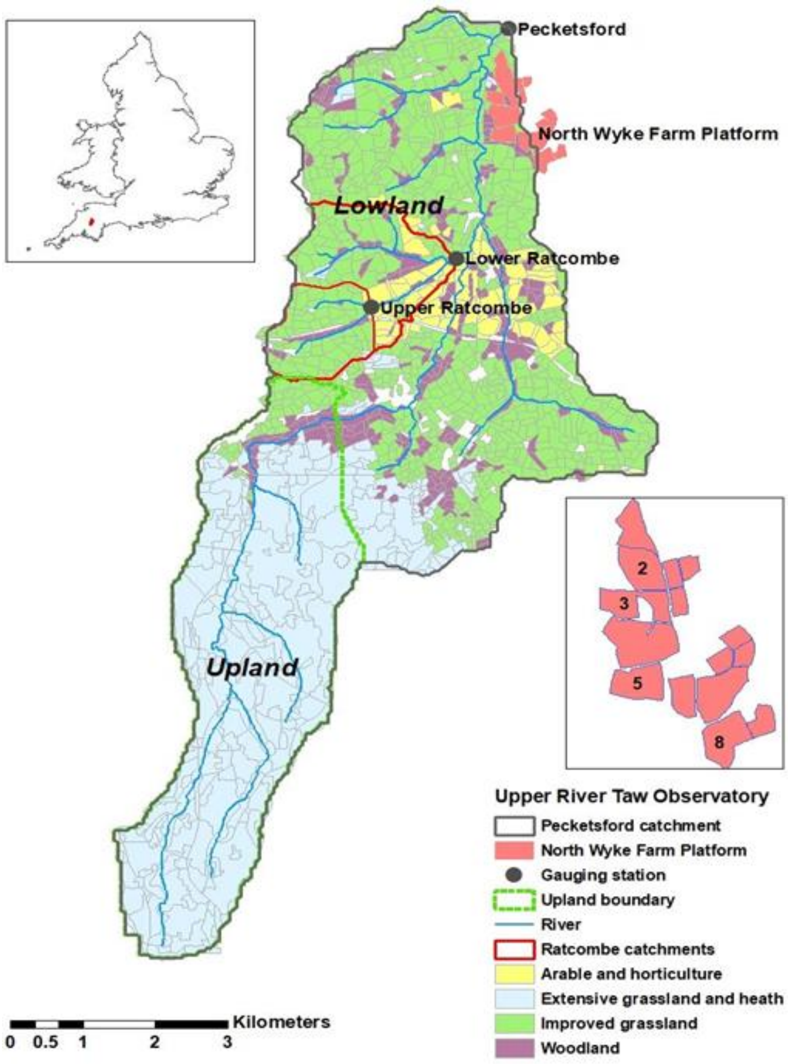
2. **<u>Design and Review:</u>** Ensure data collections are coherent with respect to inherent limitations in the platform's statistical and physical design. Ensure data relevancy, for hypothesis- and non-hypothesis-driven research, together with timely system changes based on prevailing policy and scientific knowledge.

3. **<u>Open Data Delivery:</u>** Ensure timely release of quality-controlled data, together with complementary data products (user guides, data summaries, data processing tools) to facilitate and promote usage. Ensure FAIR data principles.

4. **<u>Digital Platform:</u>** Ensure the continued digitalization of the platform via efficient data workflows using modern digital science tools, including those for sensing and communication, to directly support collaborative, down-stream, digitally focused research projects.

5. **<u>Stakeholder Engagement:</u>** Ensure the continued strategic relevance of the platform to all stakeholders through dissemination and knowledge exchange activities. Promote usage as a virtual platform and a physical facility. Promote co-development.

Forecasting: Ensemble models using Upper River Taw Observatory (URTO)



Science of the Total Environment 824 (2022) 153824

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Exploring the effects of land management change on productivity, carbon and nutrient balance: Application of an Ensemble Modelling Approach to the upper River Taw observatory, UK

Kirsty L. Hassall[a], Kevin Coleman[b,1], Prakash N. Dixit[b,1], Steve J. Granger[c], Yusheng Zhang[c], Ryan T. Sharp[b], Lianhai Wu[c], Andrew P. Whitmore[b], Goetz M. Richter[b], Adrian L. Collins[c,1], Alice E. Milne[b,*,1]

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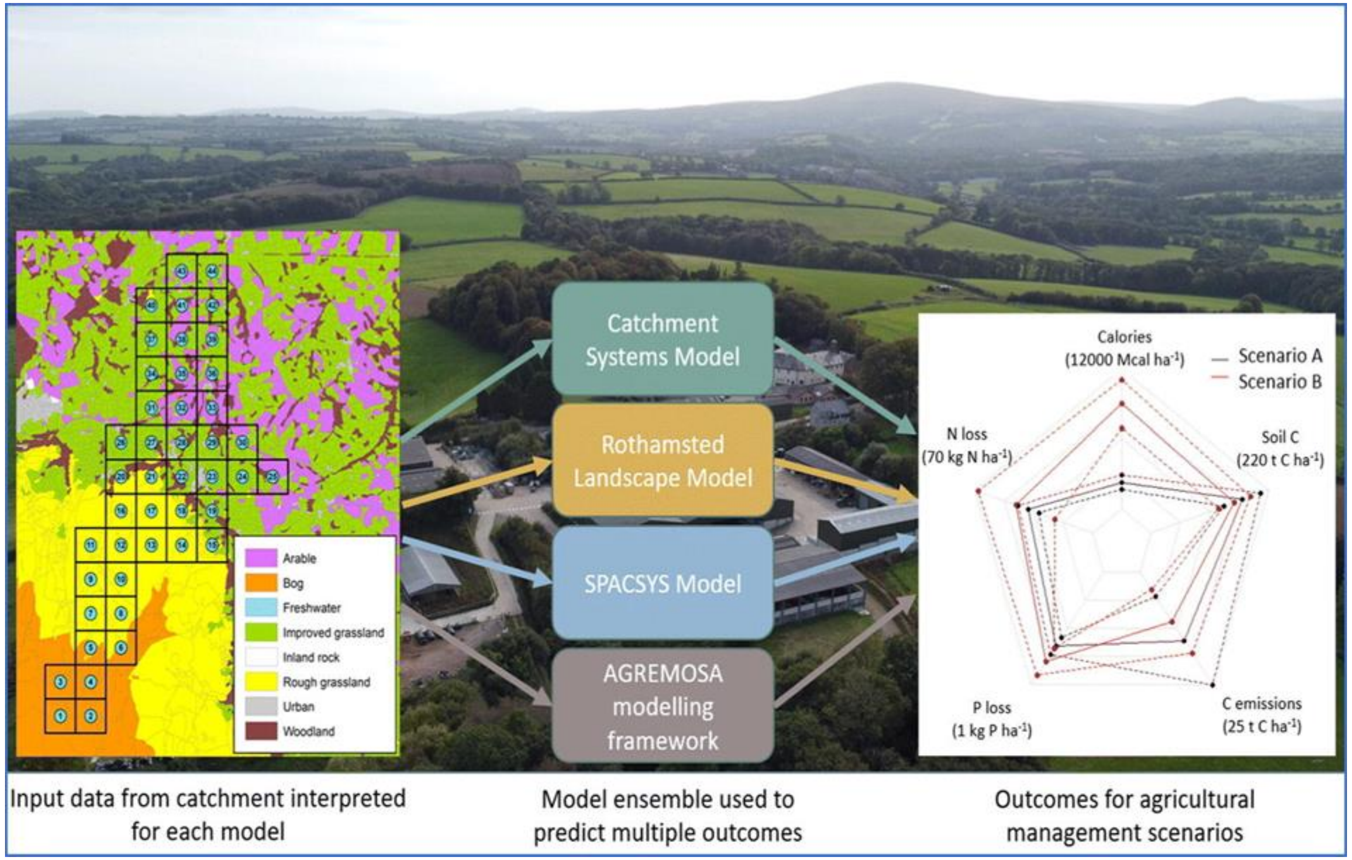


Sensor Testbed and Digital Twin co-development

Sensor testbed utilizing core (open) measurements:

A. **Low-cost vs. high-cost Eddy Covariance systems for GHGs** - CO_2 and CH_4 (x2 low-cost options)

B. **Low-cost water quality sensors** coupled with AI to predict high-cost water quality data (x2 projects)

C. **Low-cost soil sensors** coupled with AI to predict high-cost soils data (e.g., soil Carbon)

D. **Assess and couple different communication technologies** - Low Power, Wide Area (LPWA) networking using the LoRaWAN protocol or Narrow Band

E. **Assess entirely new sensors** with ground-reference only (e.g., for soil Phosphorus; soil sediment in water)

Sensor Testbed and Digital Twin co-development

<u>**GHG emissions and livestock-based sensors:**</u>

A. **Prediction of enteric methane (CH_4)** emissions from freely-grazing animals using a harmless tracer gas technique. Relies on a known source of synthetic inert tracer, sulphur hexafluoride (SF_6), inserted into the rumen as a bolus.

B. **Livestock movement and activity** using GPS for behaviour, welfare, performance and GHG emissions. Dynamic linking to dung and urine deposition.

Sensor Testbed and Digital Twin co-development

<u>Remote Sensing:</u>

A. **Prediction of soil moisture** using SAR satellite data (x2 projects). Includes out-scaling using COSMOS UK network

B. **Prediction of Carbon dynamics** using satellite data and model-data fusion

C. **Image analysis with drones** for livestock size and growth (in prep.)

D. **Prediction of biomass (yield) and crop growth** linking ground-reference to forage harvester, hand-held, drone and satellite imagery

Sensor Testbed and Digital Twin co-development

Water use efficiency:

A. **Water Harvesting** - rainwater falling on livestock buildings flows into harvesting tanks, and release of the water is remotely controlled in order to optimise water use (say, through efficient use of water for field spraying).

B. **Mobile versus fixed-location water troughs.**

Other possibilities:

A. Use of **robotics**

B. **Housed** capabilities (e.g., image analysis, video for livestock welfare)

C. **Farm management** (e.g., fuel use)

Resources & Outputs

Core Funding - Biotechnology & Biological Sciences Research Council (**BBSRC**):

- 2010 setup: **approx. £10M +**
- 2012 onwards: **approx. £12M +**

Capital Funding – CIEL/BBSRC/NERC

- 2016 onwards: **approx. £3M +**

Staffing on Farm Platform:

13 (9.65 FTE)
Technicians in Data Science, Ecology, Livestock, Agronomy, Instrumentation, Drone Sensing, Lab & Field

Wider Scientific Team & FP committees:

10+ RRes Scientists, plus statisticians, modellers, informaticians etc.

Outputs since set up:

# of FP experiments: **130 (45% external)**

# of publications (using data): **55 (34% external lead)**

# of other publications: **71**

# of external projects/collaborations: 23*

# of research-focussed events: **55**

# of industry-focussed events: **37**

# of people trained: **127**

Data portal outputs (from 2016 start):

# of registered users: **314 (64% external to RRes)**

# of measurements: **74+ million**

# of downloads: **4025 (26% external to RRes)**

Further outputs:

# of BSc/MSc projects: **22**

# of visiting researchers: **29**

# of PDRAS: **29**

# of PhD students: **15**

# of media activities: **15**

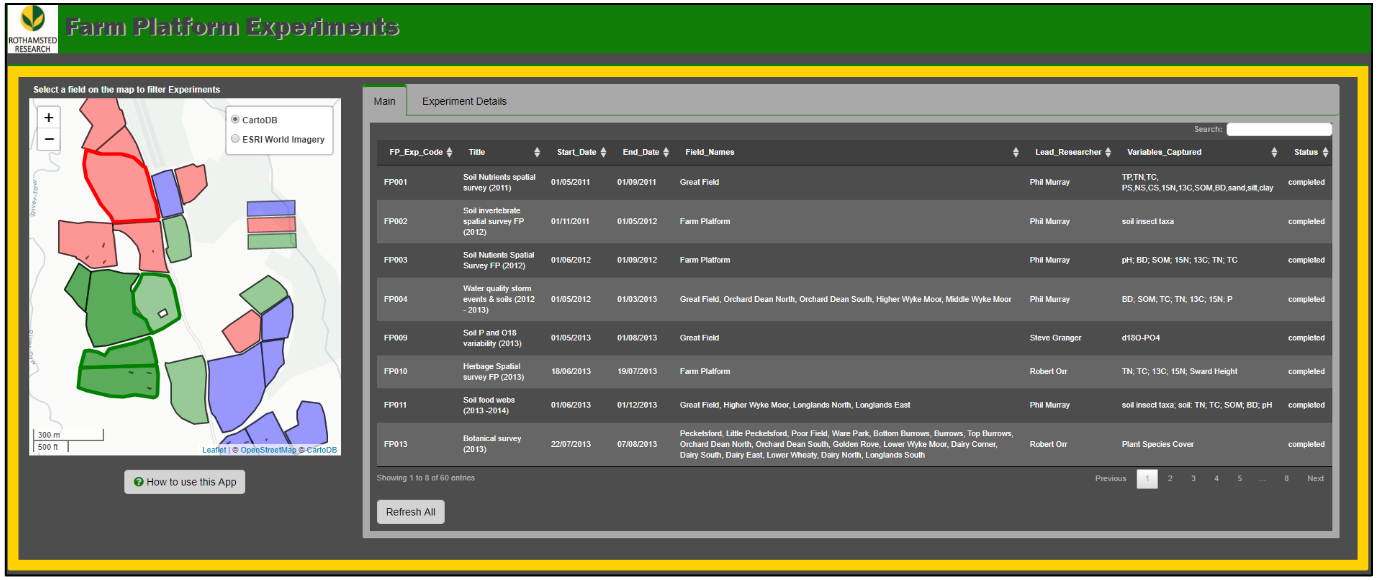
*** Awards typically range from £100k to £700k**

Small Ruminants Facility use (2020)

- First major trial in the Orr Small Ruminants (Sheep, Goats) Facility:
- For FP ewes (RFI trial)
- Other (FP & non-FP) trials due to take place or being proposed
- Proposed use in BBSRC responsive mode grant application
- Procedures & costings set up for its use
- Joint CIEL / BBSRC funded

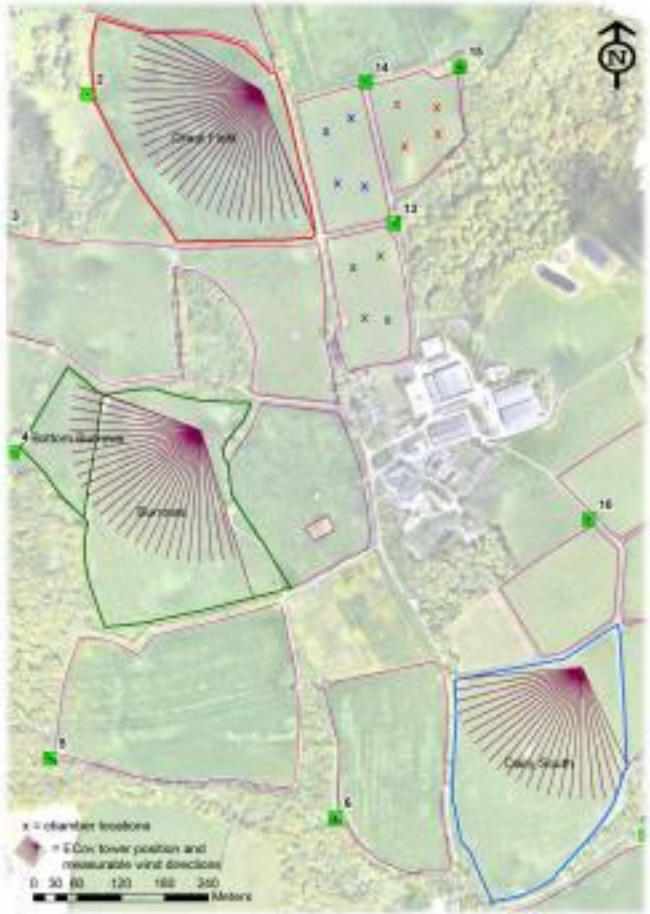
Data updates (2020)

1. Data Portal release of **Low Resolution field surveys** (core data for soils/ plants)
2. Release of **FP experiments database**
3. Data Portal release of **Eddy Covariance GHG** core data
4. Significant updates in **Data Portal architecture** (with Tessella)
5. On-going increase in # of data portal registrations & downloads
6. Progress on open advanced QC with infilling & anomaly detection etc.



FP_Exp_Code	Title	Start_Date	End_Date	Field_Names	Lead_Researcher	Variables_Captured	Status
FP001	Soil Nutrients spatial survey (2011)	01/05/2011	01/09/2011	Great Field	Phil Murray	TP,TN,TC, PS,NS,CS,15N,13C,SOM,BD,sand,silt,clay	completed
FP002	Soil invertebrate spatial survey FP (2012)	01/11/2011	01/05/2012	Farm Platform	Phil Murray	soil insect taxa	completed
FP003	Soil Nutients Spatial Survey FP (2012)	01/06/2012	01/09/2012	Farm Platform	Phil Murray	pH; BD; SOM; 15N; 13C; TN; TC	completed
FP004	Water quality storm events & soils (2012 - 2013)	01/05/2012	01/03/2013	Great Field, Orchard Dean North, Orchard Dean South, Higher Wyke Moor, Middle Wyke Moor	Phil Murray	BD; SOM; TC; TN; 13C; 15N; P	completed
FP009	Soil P and O18 variability (2013)	01/05/2013	01/08/2013	Great Field	Steve Granger	d18O-PO4	completed
FP010	Herbage Spatial survey FP (2013)	18/06/2013	19/07/2013	Farm Platform	Robert Orr	TN; TC; 13C; 15N; Sward Height	completed
FP011	Soil food webs (2013 -2014)	01/06/2013	01/12/2013	Great Field, Higher Wyke Moor, Longlands North, Longlands East	Phil Murray	soil insect taxa; soil: TN; TC; SOM; BD; pH	completed
FP013	Botanical survey (2013)	22/07/2013	07/08/2013	Pecketsford, Little Pecketsford, Poor Field, Ware Park, Bottom Burrows, Burrows, Top Burrows, Orchard Dean North, Orchard Dean South, Golden Rove, Lower Wyke Moor, Dairy Corner, Dairy South, Dairy East, Lower Wheaty, Dairy North, Longlands South	Robert Orr	Plant Species Cover	completed

For 2021 onwards: 'FarmOS' rollout to link all RRes experiments with FAIR data principles & more…



Eddy Covariance Sites

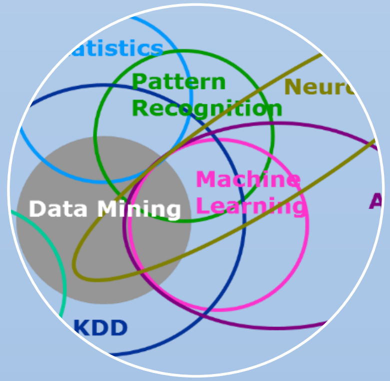
Broader interlinked objectives

1. **RRes Research Projects** – "Soils to Nutrition" (ISP) mechanistic understanding, sustainability metrics and scaling to the landscape (via the plot & farm scales) to **optimize land use**

2. As a **UK National Capability**: data & research facility, incl. training & outreach

Long-term monitoring in 'GREEN' only

3. As a **node** of a farm platform **network** (e.g. the Global Farm Platform, GLTEN) or a high-resolution data **hub** of a local farmer network **(spokes)**



4. **AI, technology-driven & industry-linked research**: sensor technologies, IoT, Cloud-based, Open Data, Open Code, Complexity, **Digital Twin** & Food Supply Chain

Where we are and where we are increasingly moving towards

Lawes and Gilbert

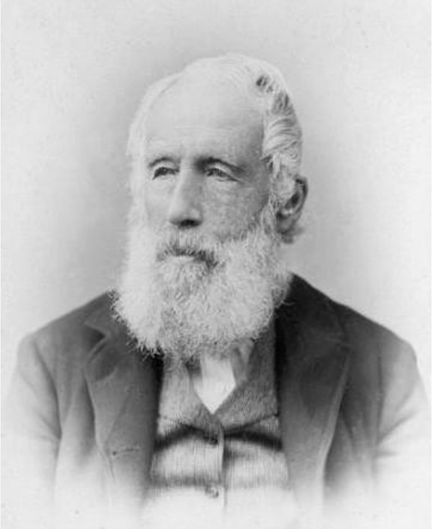
1837-1842: John Lawes starts some experiments on his Hertfordshire estate and patents method for treating bones with sulphuric acid – **superphosphate**. Constructs worlds first commercial fertiliser factory in Debtford, London.

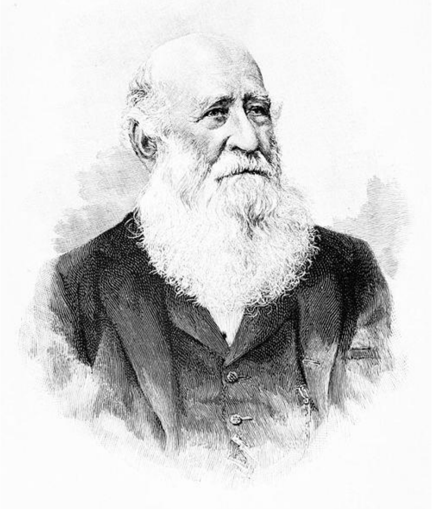
1843: John Lawes appoints chemist Henry Gilbert as a scientific collaborator and lays down first 'classic' experiments.

1889: Lawes places in trust laboratory, experimental fields and £100000, ensuring the continuation of agricultural research at the estate.

During the 20th century, government progressively increased its support for agricultural food production in response to pressures created by the two World Wars and a burgeoning urban population.

2018 marked the 175^{th} anniversary of RRES





ROTHAMSTED RESEARCH

BBSRC bioscience for the future | UK Research and Innovation

Huge reduction in meat-eating 'essential' to avoid climate breakdown

Major study also finds huge changes to farming are needed to avoid destroying Earth's ability to feed its population

- **We label fridges to show their environmental impact - why not food?**

▲ Steak and a healthy vegetarian meal with pulses. Composite: Getty Images

A future with reduced meat consumption?

What are the positives and negatives of removing livestock from the landscape?

What are the positives and negatives of growing human edible crops on marginal land?

It's a complicated story: Ruminants are very good at turning something we can't digest (grass) into something we can: high quality protein.

The NWFP has the infrastructure to help answer some of these challenging questions.

ROTHAMSTED RESEARCH

BBSRC bioscience for the future | UK Research and Innovation

Type-1 Collection	Spatial or Operational unit	Temporal Frequency	Start	New
Grazing & arable farm management activities (e.g., fertilizer apps, ploughing)	Farm-scale	Variable	2011	No
Housed livestock management activities	Farm-scale	Variable	2011	No
Livestock performance (liveweight gain, condition scores)	Individual animal	2- to 4-weekly	2010	No
Livestock performance (sales & carcase data)	Individual animal	End of life	2010	No
Livestock (cattle) performance (fat scanning)	Individual animal	2-scans per lifetime	2023	Yes
Livestock (cattle) genomics & phenotypes	Individual animal	1-sample per lifetime	2018	Yes
Grazing crop quantity (silage cuts); RS ground reference	Field-scale	2-cuts per grazing season	2011	No
'GrassCheckGB' extension; Un-grazed grass growth; RS ground reference	Off-platform ('Top Burrows' Met site)	Weekly	2018	No
RS ground reference for ecosystem provisioning & plant communities	Field-scale	2-weekly	2023	Yes
Grazing crop quality (forage)	Field-scale	2-weekly	2015	No
Grazing crop quality (silage)	Farm-scale via Clamp / Bale	2-weekly	2015	No
Arable crop quantity & quality (wheat, oats, beans)	Field-scale	Annual Harvest	2020	No
Fine-scale field surveys (soils & herbage nutrients, soil insects, vegetation)	Within-field level	Annual but intermittent	2012	No
Coarse-scale field surveys (soil & herbage nutrients)	Field-level (bulked samples)	Quarterly	2018	No
Above-ground biodiversity surveys (vegetation); RS ground reference	Transects across all 3 farms & into field margins / adjacent habitats	Bi-annual	2023	Yes
Above- & below-ground biodiversity surveys (soil insects)	Sub-terranean traps	Campaign-style	2023	Yes
Automated Chambers GHG (N_2O, CH_4 & CO_2 from soil & plant).	Campaign deployment for 3 fields at any given time	Sub 10-minute	2013	No
Sampling for soil retention curves for improved model parameterisation	Transects covering all platform soil classes	One-off campaign	2024	Yes

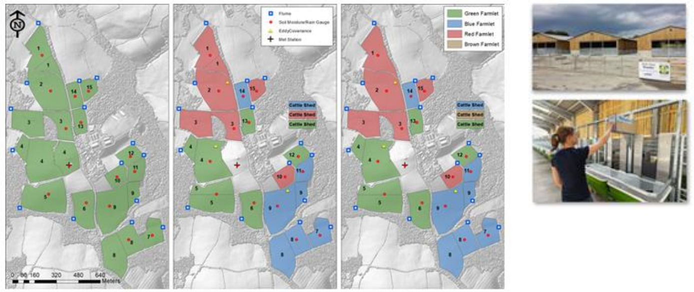
Type-2 Collection	Spatial or Operational unit	Temporal Frequency	Start	New
Livestock (cattle) welfare (behaviour & health)	Individual animal	Weekly	2019	Yes
Bio-acoustic monitoring for biodiversity (birds, insects, bats)	Farm-scale	Continuous	2023	Yes
Citizen science app for wildlife sightings	Farm-scale	Intermittent	2022	No
Eddy Covariance GHG (CH_4 & CO_2 from soil, plant & livestock).	Sited in 3 of 20 platform fields (CH_4 measured in 2 fields only)	30-minute	2017	No
Eddy Covariance GHG (CH_4 & N_2O from soil, plant & livestock)	Addition of third CH_4 & single N_2O sensors	30-minute	2025	Yes
Housed Greenfeed GHG (CH_4 & CO_2 from cattle)	Farm-scale (individual animal)	Variable	2017	No
Housed Greenfeed GHG (CH_4 & CO_2 from sheep)	Farm-scale (individual animal)	Variable	2022	No
Coordinated RS from Drone & Satellite with links to Forage Harvester	Within-field scale	Variable	2024	Yes
Water flow, physics and chemistry	Catchment-scale	15-minute	2012	No
Water flow, physics and chemistry (enhanced for Total C, N & P)	Catchment-scale	15-minute	2022	No
Soil Moisture and Temperature (existing)	Field-scale (1 in 15 of 20 fields)	15-minute	2011	No
Soil Moisture and Temperature (enhanced)	Field-scale (3 in 20 of 20 fields)	15-minute	2025	Yes
Rainfall	Field-scale (1 in 15 of 20 fields)	15-minute	2011	No
MET data	Off platform (Top Burrows)	15-minute	2011	No

Fig.3 Data delivery. Type-1 data have an inherent human element. Type-2 data are either IoT-based or have the potential to be so.

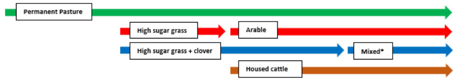
Digital workflows supporting a Resilience Digital Twin: Green - in place / Amber - refining or in current progress / Red – planned

Design, management & system timelines for real farms

3 or 4 farm systems with detailed management records



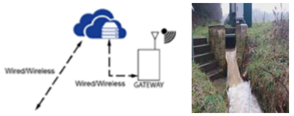
Est. 2010

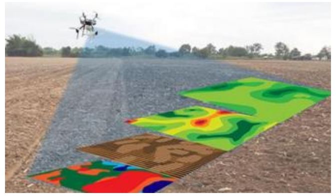


Digital workflows for data collection, processing & release

- Recording
- Field surveys
- Lab analyses
- Remote Sensing Ground Referencing
- Sensor downtime & maintenance
- Digital recording
- Basic Quality Control
- SQL database
- Website & complementary data products
- Open data release via FP data portal
- Advanced Quality Control (infilling & anomalies)
- Data Warehouse
- APIs
- Dynamic Quality Control
- Community open code platform
- Open release of simulated data
- Experiments Data (FP as a facility)

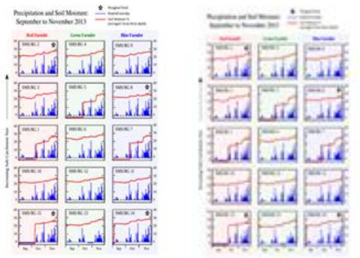
Digital workflows for IoT sensing & remote sensing technologies





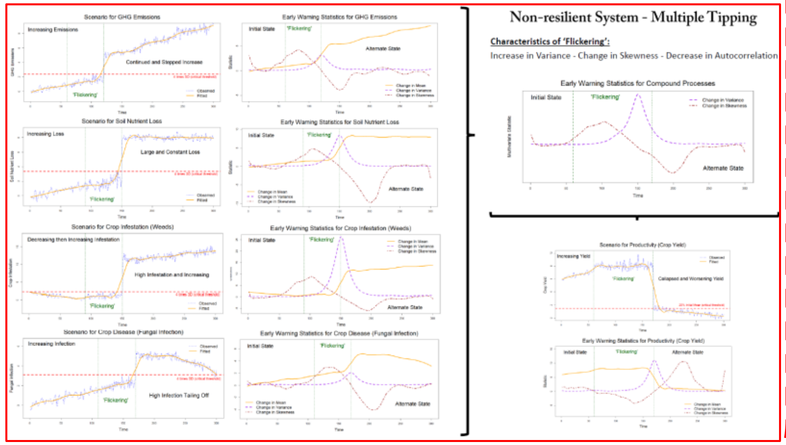
Sensing by drone

Sensing by satellite



IoT water, soil moisture & MET

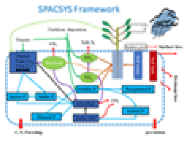
Data Science Toolbox



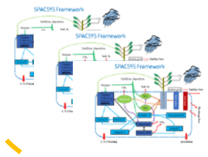
Critical slowing down, flickering, hysteresis & domino effects

Model development with ensembles & hybrids

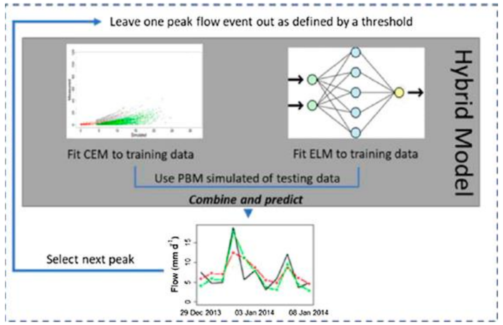
Process-based Model (PBM)



Ensemble PBMs

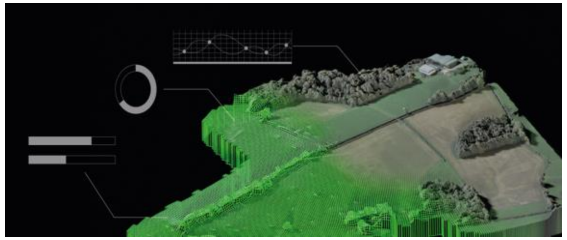


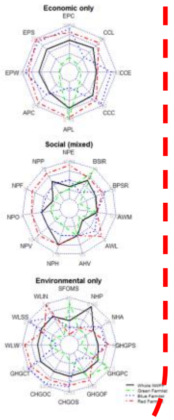
PBM-Stats-ML Hybrids



E.g., for Extremes

Digital Twin of each farm



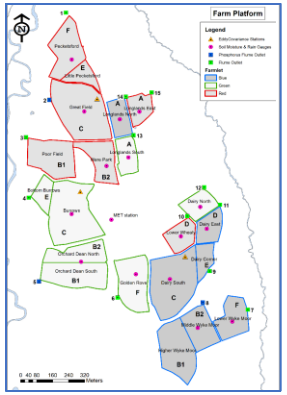


- Dynamic data fusion (including across scales)
- Dynamic validation of model simulations
- Dynamic data assimilation for model simulations
- On-line platform with interactive visualisation

Mock-up of Web-based Digital NWFP using Modern Data Science Tools (2018)

ROTHAMSTED RESEARCH

1. Portal - NWFP v2.0 (the real data)



'Real time' data platform capturing open data through use of IoT

Extend NWFP collections for:
- ❑ Water Use Efficiency
- ❑ Soil fauna & biodiversity
- ❑ Pests & disease
- ❑ Etc.

Strengthen links to:
- ❑ Upper Taw (nested catchments)
- ❑ Local farmer networks (spokes)
- ❑ Other data hubs (GFP)

Strengthen links to:
- ❑ External Monitoring
- ❑ External Research
- ❑ Industry
- ❑ Data Science & IoT groups

3. Digital Twin: Simulations conditioned on real data (from NWFP v2.0)

Uncertainties

WP2: Observation & Sensing

WP2.1 IoT in-situ sensor networks across each farm

Wired/Wireless — Wired/Wireless — GATEWAY

in situ sensor network

Arable — Perm Pasture — HSG + clover

WP2.2 Link to existing data via NWFP Portal

WP2.3 Collate with remote sensing data

Sentinel 1 & 2 — Space-time series

WP1: Digital Science & Infrastructure

WP1.1 Field data collation

WP1.2 Harmonize in-situ, existing & RS data

DATA Uncertainties — MODEL Uncertainties

WP3: Digital Twin Components

WP.3.1 Geostatistical simulations for all fields of 3 farms

Arable — Permanent Pasture — HSG + clover

WP.3.2 Spatially-informed hybrid field scale simulations

In field variability — Hybridised SPACSYS — Spatial-time outputs

WP.3.3 Hybrid simulations for each farm's land use type (DALEC-C)

Inference for Arable, Perm pasture & HSG + clover

Model +RS — GIS layers

Solid arrow: Data + data uncertainties

Dashed arrow: Model outputs + model uncertainties

WP4: Linking, Dissemination & Co-Producing

Project Management

WP1.3 Digital architecture (Observed Data, Digital Twin Simulations, Test Scenarios)

Component system:
- ❑ Can bolt on other portals
- ❑ E.g. Interactive AI
- ❑ E.g. Advanced Visualisation

- ❑ Open code
- ❑ Simulations from field to farm to landscape with Remote Sensing components
- ❑ Simulate metrics, nutrient cycling, LCA, Productivity, Emissions, etc.
- ❑ Project to Climate Change, Land Use Change

Digital Twins Options:
- ❑ Network of networks
- ❑ Research sites (UK & GFP sites)
- ❑ Regional & Local farmer networks
- ❑ Supply chain thru to the supermarket

2. Portal for generic data science tools

- ❑ Open code
- ❑ Data fusion & harmonization
- ❑ Up & down scaling
- ❑ Infilling
- ❑ Optimisations
- ❑ High performance Computing
- ❑ Visualisation
- ❑ Quality Control & Assurance

- ❑ NWFP github site
- ❑ See https://www.ceh.ac.uk/ukscape

4. Portal for "Resilience due to shock events and extremes"

- ❑ Hybrids with open code
- ❑ High-dimensional anomalies
- ❑ Non-stationarities in space & time
- ❑ GWmodel (for 'locally unusual')
- ❑ Extreme value theory

- ❑ "Tipping Points"
- ❑ "Perfect storms"
- ❑ "Black Swan" events

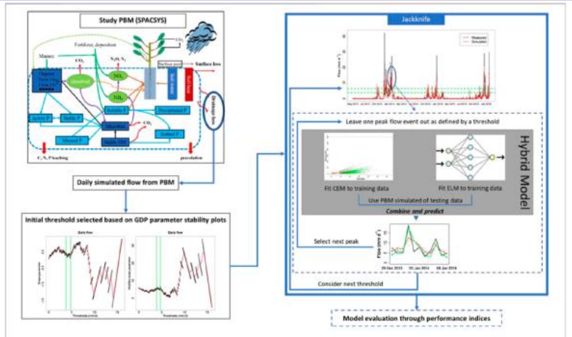
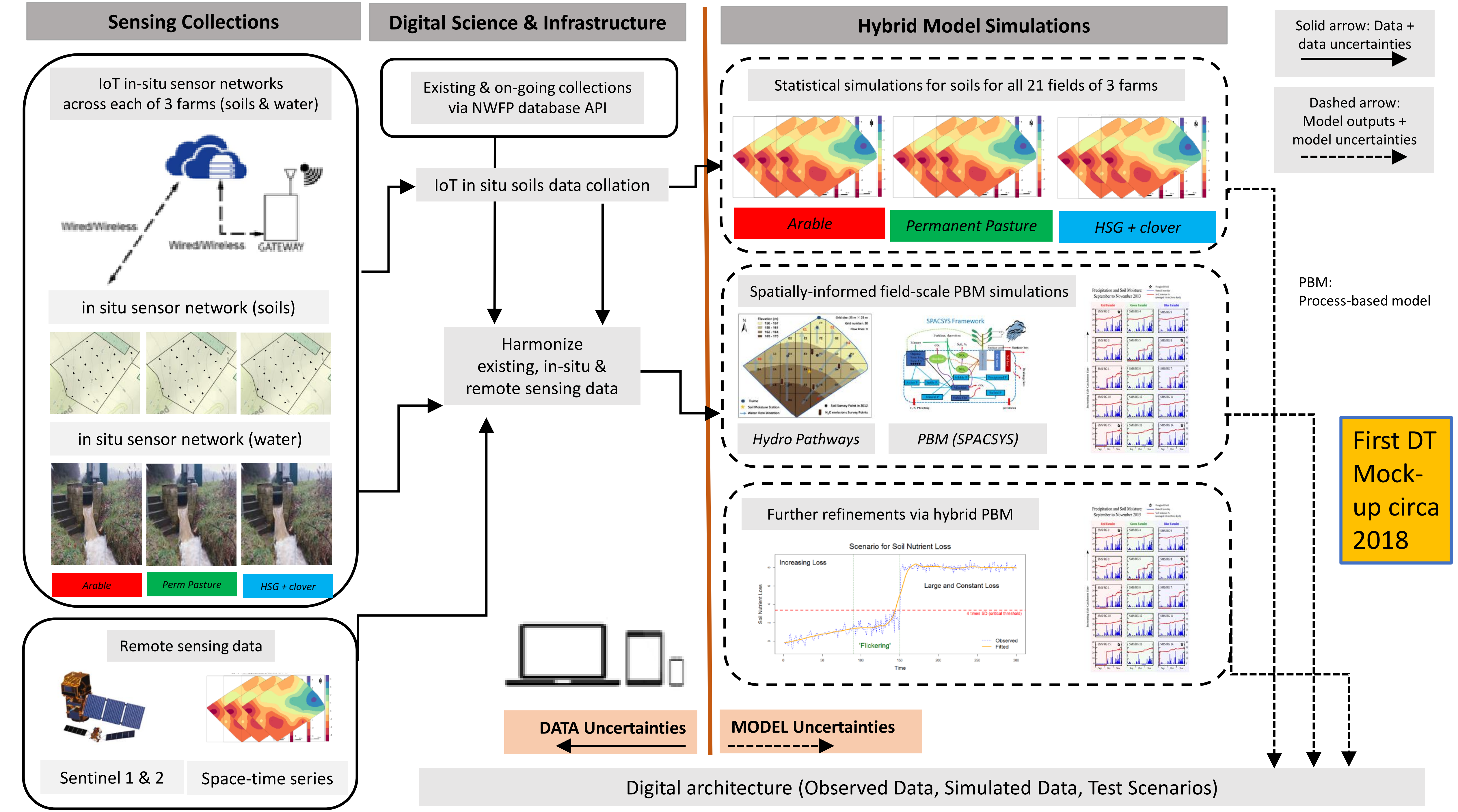


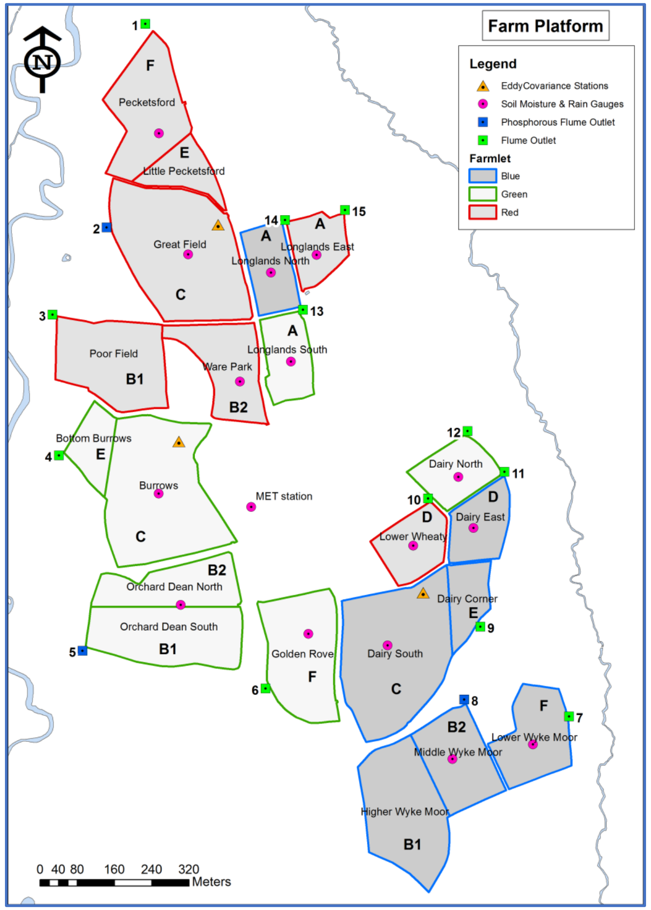
FIGURE 1 | Schematic of the proposed methodology.

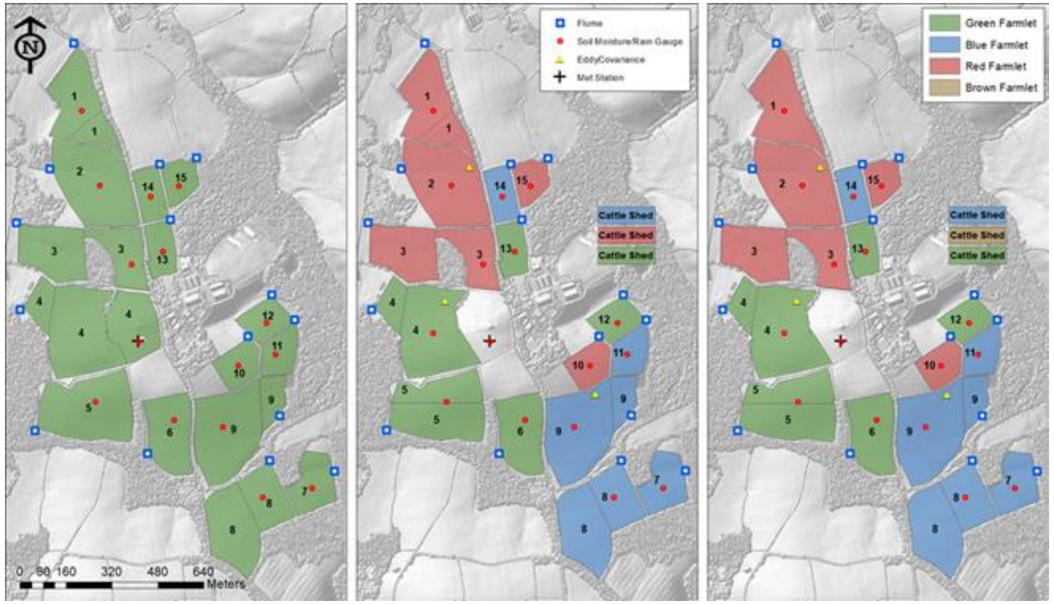
- ❑ Drive & fuel new RESEARCH HYPOTHESES



Sensing Collections
Digital Science & Infrastructure
Hybrid Model Simulations
Solid arrow: Data + data uncertainties
Dashed arrow: Model outputs + model uncertainties
IoT in-situ sensor networks across each of 3 farms (soils & water)
Wired/Wireless
Wired/Wireless
GATEWAY
in situ sensor network (soils)
in situ sensor network (water)
Arable
Perm Pasture
HSG + clover
Remote sensing data
Sentinel 1 & 2
Space-time series
Existing & on-going collections via NWFP database API
IoT in situ soils data collation
Harmonize existing, in-situ & remote sensing data
DATA Uncertainties
Statistical simulations for soils for all 21 fields of 3 farms
Arable
Permanent Pasture
HSG + clover
Spatially-informed field-scale PBM simulations
SPACSYS Framework
Hydro Pathways
PBM (SPACSYS)
Further refinements via hybrid PBM
Scenario for Soil Nutrient Loss
Increasing Loss
Large and Constant Loss
'Flickering'
Soil Nutrient Loss
Time
Observed
Fitted
MODEL Uncertainties
PBM: Process-based model
First DT Mock-up circa 2018
Digital architecture (Observed Data, Simulated Data, Test Scenarios)

North Wyke Farm Platform (est. 2010)





- Delivering 4-farm systems-scale data that is **representative** of all component processes
- Facilitating **scalable** research for **sustainable & resilient** land management strategies
- **Open collections – 74+ million measurements & counting…**

Objectives realised via 3 workstreams:

ROTHAMSTED RESEARCH

A. <u>Systems Science through Measurement (45%):</u>

- ❑ Continue to build **unique & open long-term datasets**
- ❑ Manage data from **130+ FP experiments**
- ❑ Manage **FP's physical archive**

B. <u>Systems Science through Digitalisation (35%):</u>

- ❑ **Static & dynamic** digital processing tools
- ❑ **APIs** & upgrade of FP database / portal
- ❑ Facilitate co-development of **digital projects**

C. <u>Scalability to different Geographies (20%):</u>

- ❑ Digital pathways for **out-scaling to the landscape**
- ❑ Uplift for the **food supply chain**
- ❑ Implement **3rd System Change Period**

Each with own working group

Digital Science synergies with RLTE & RIS NBRIs

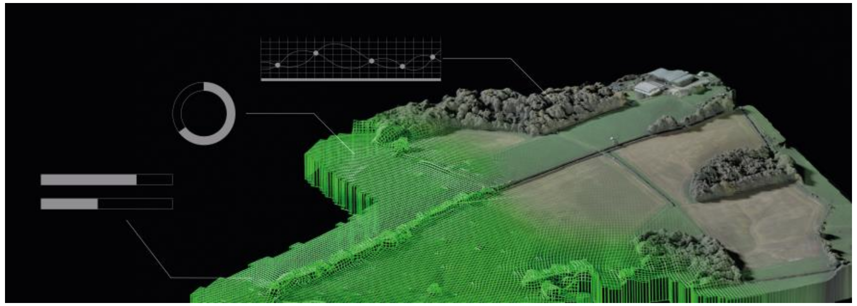
Detailed (living) Data Management Plan

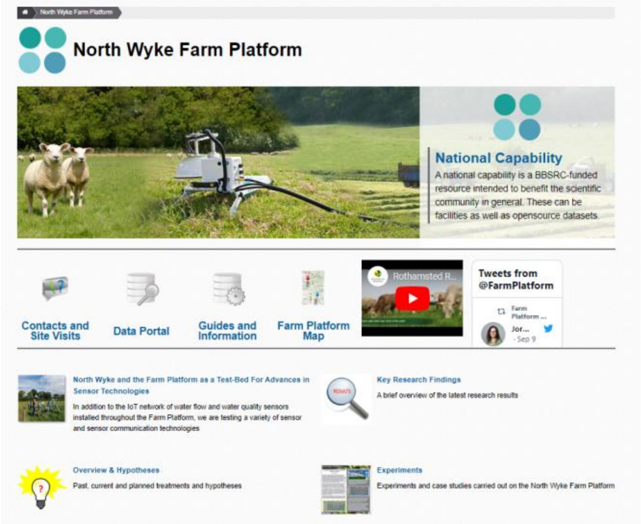
Biotechnology and Biological Sciences Research Council

Plans & on-going engagement:

ROTHAMSTED RESEARCH

1. **<u>'Digital' promotion & initiatives in place & on-going:</u>**
   - ❑ Workshops, conferences – academic / industry
2. **<u>Promotion of co-development on FP website:</u>**
   - ❑ https://www.rothamsted.ac.uk/north-wyke-farm-platform
3. **<u>Formation of new stakeholder group for co-development in progress:</u>**
   - ❑ Research partners, GFP partners, CIEL, farmers, sensor engineering, + more
4. **<u>Key publications in advanced prep:</u>**
   - ❑ 'Lessons Learned', 'Data' & 'Digital Twin Concept'





Expected Outcomes:

- **Digital Platform** increasingly recognised for world-class Farm-Scale research
- Clear pathways for **‘look-see’ / ‘PoC’ projects** to aid full project proposal success
- Implementation of **3rd system change period** – co-developed with leveraged funding
- **Next generation trained** in multidisciplinary agroecosystem science