Sustainable soil management and mapping

Dr Nick Girkin
Associate Professor in Environmental Science
Director, Centre for Sustainable Agricultural Systems
Nicholas.Girkin@nottingham.ac.uk

Challenges and solutions for sustainable agriculture

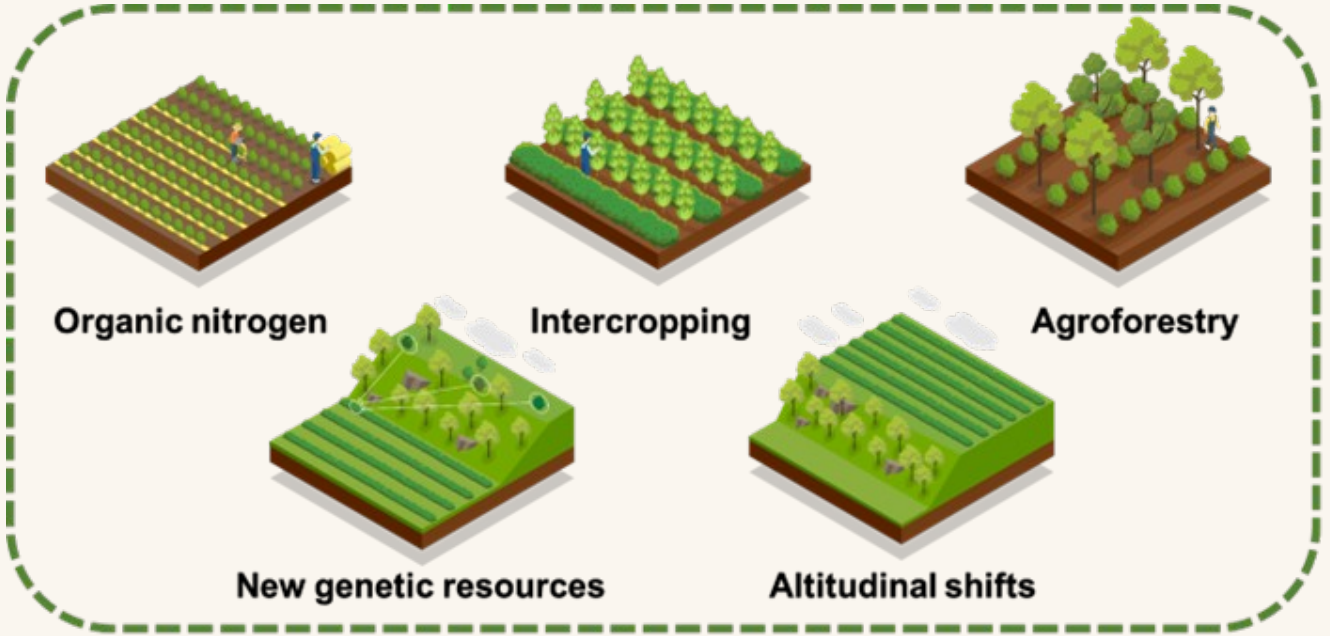
The challenge

- Understanding soils and soil condition (health) is vital to support agricultural production.
- Approximately one-third of the world's soils are moderately to highly degraded through erosion, nutrient depletion, compaction, salinisation, and loss of organic matter.
- Globally, land use has driven the loss of 116 Pg C over the last 12,000 years.
- Agriculture accounts for 20 - 34% of global greenhouse gas emissions, driving ~1.5°C warming to date
- Higher temperatures, altered rainfall patterns, and more frequent extreme weather events are already affecting crop yields worldwide.
- This is already impacting food production and effects will increase with time

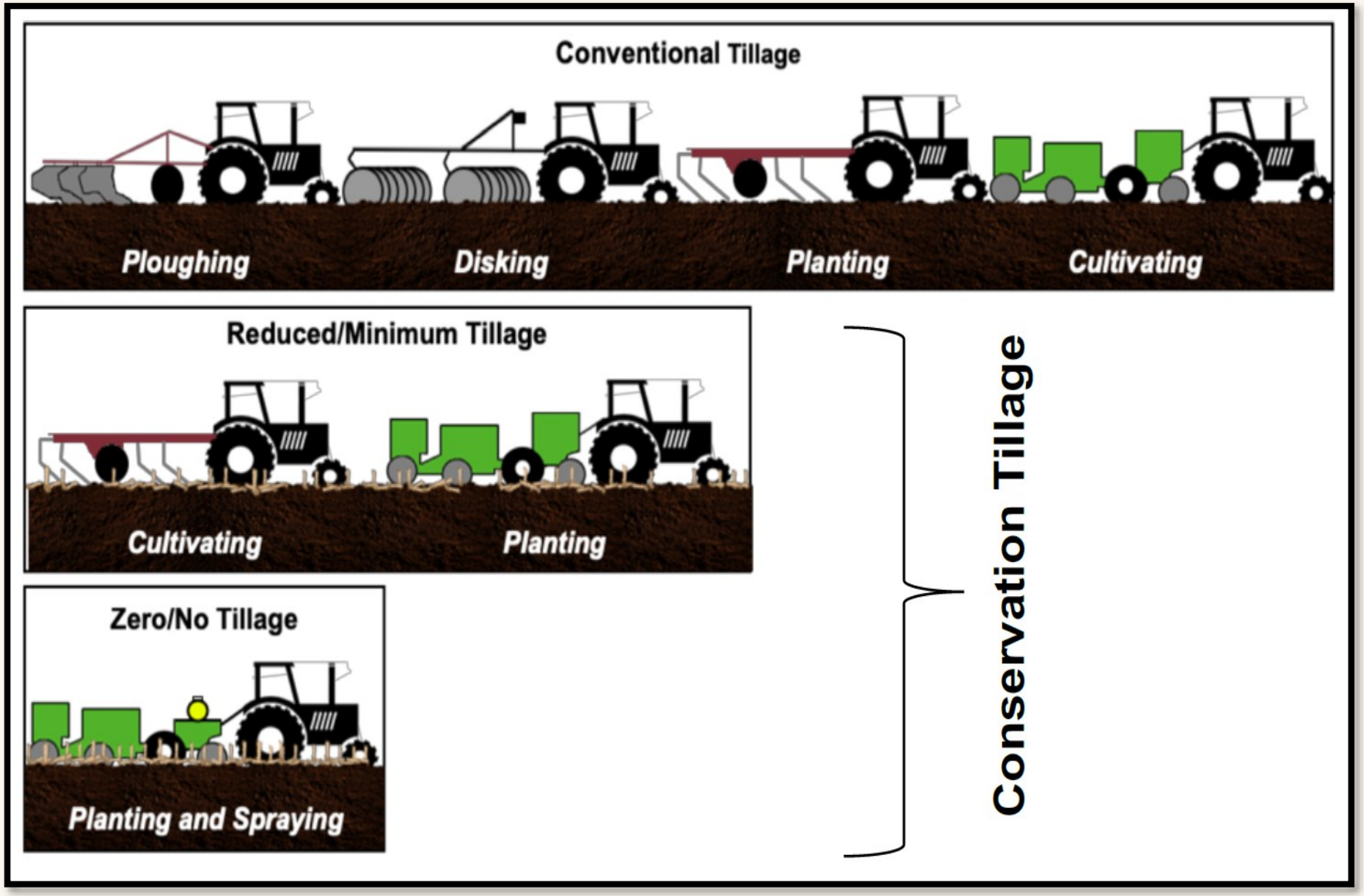


Sustainable soil management: regenerative agriculture

- Regenerative agriculture describes a suite of less intensive soil management practices that provide multiple benefits to soil health.
- Various definitions exist (outcome based versus process based)
- Key regenerative practices include:
  - **Conservation tillage**
  - Intercropping/agroforestry
  - Cover cropping (mixed species)
  - Rotational grazing
  - Organic management
  - Permaculture
  - Landscape conservation restoration



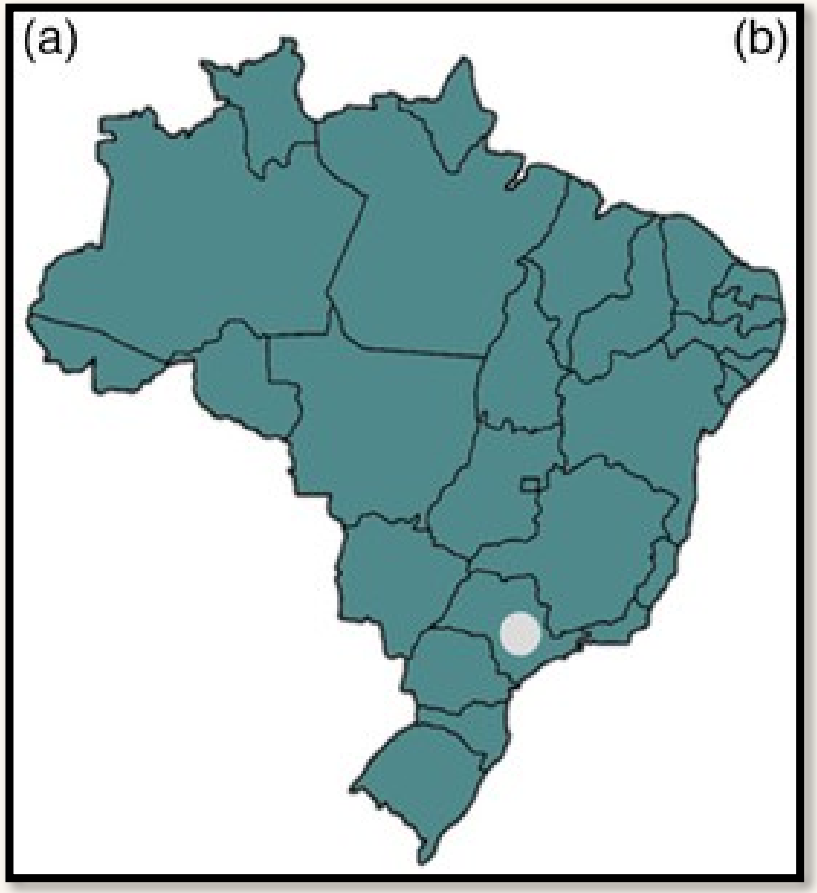
Tillage methods



Cooper et al. 2021

Conventional and conservation tillage

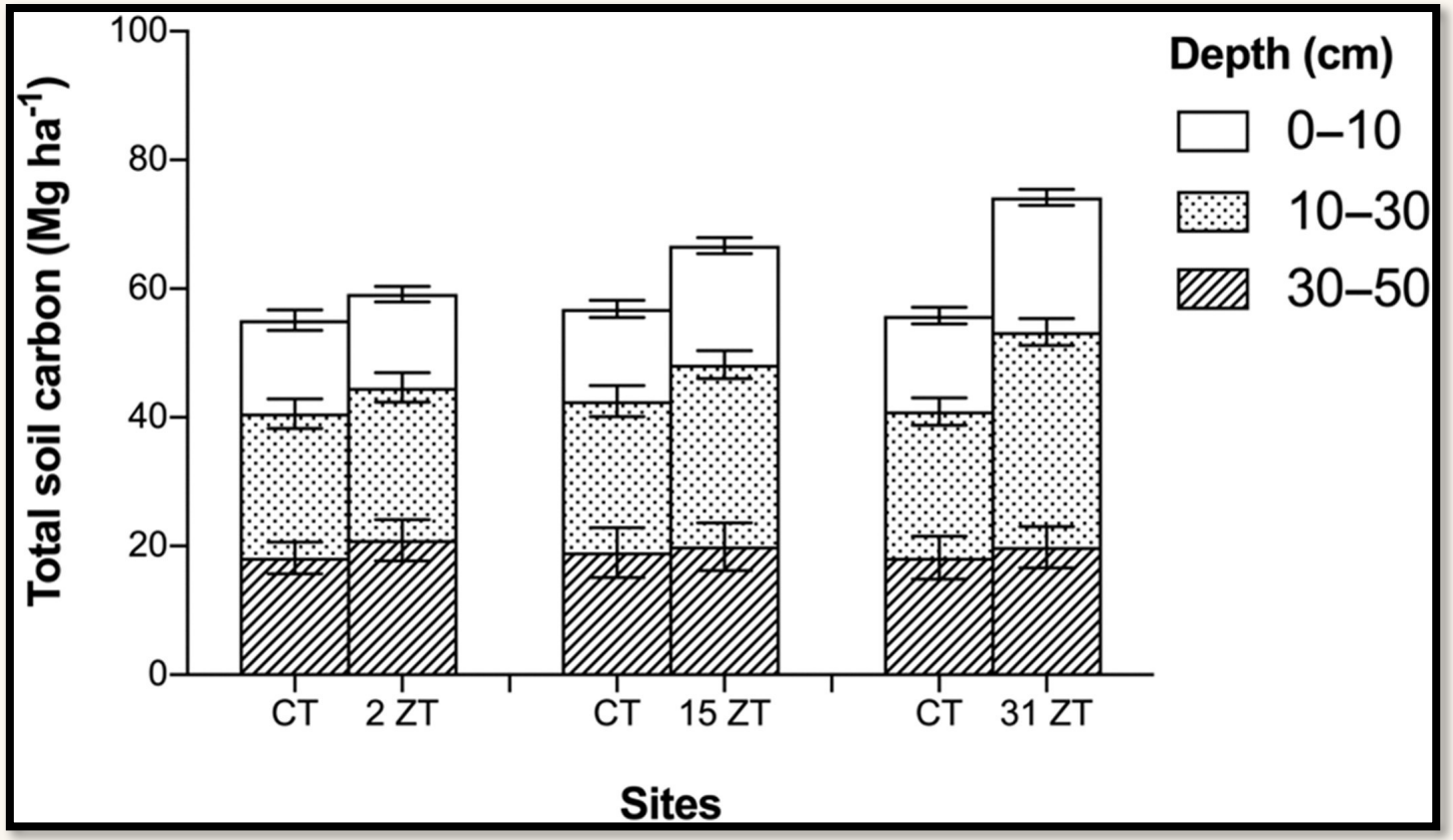
- How does long-term management impact soil carbon, soil health, and other processes?
- Tested impacts using paired plots comparing conventional and long-term zero/no-till systems at São Paulo University, Botucatu Campus
- Sites farmed with rotation of triticale, maize, and soybean
- Includes sites with >30 years without tillage



Cooper et al. 2021

Conventional and conservation tillage

- No differences in crop yields after 15-20 years (~6–8 t h^{-1})
- Total carbon stocks increase with time under zero tillage
- Carbon is increasingly redistributed throughout the soil profile

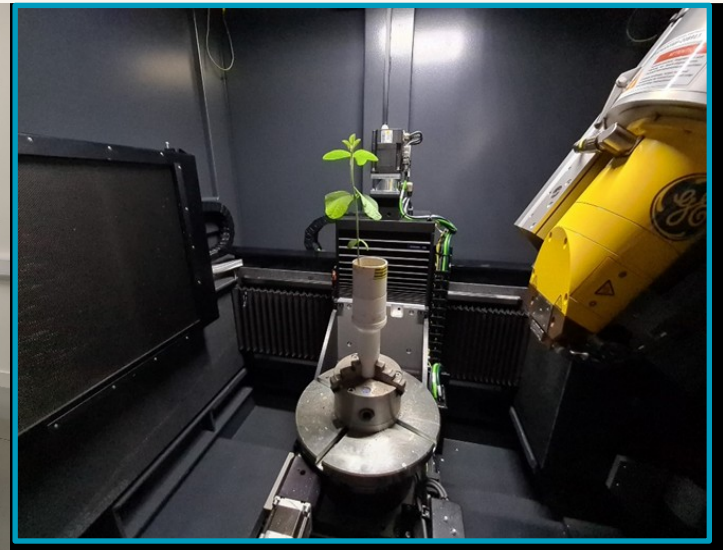


Cooper et al. 2021

X-ray Computed Tomography

Hounsfield Facility
3D X-ray imaging

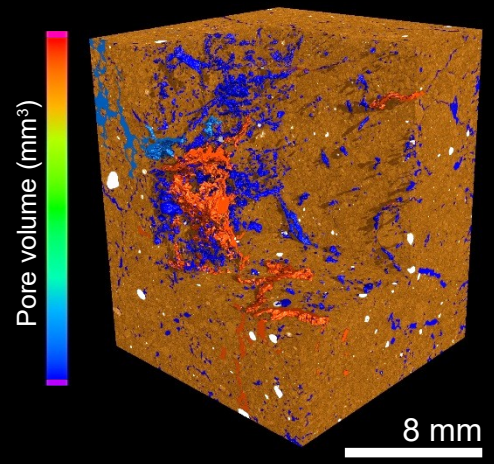


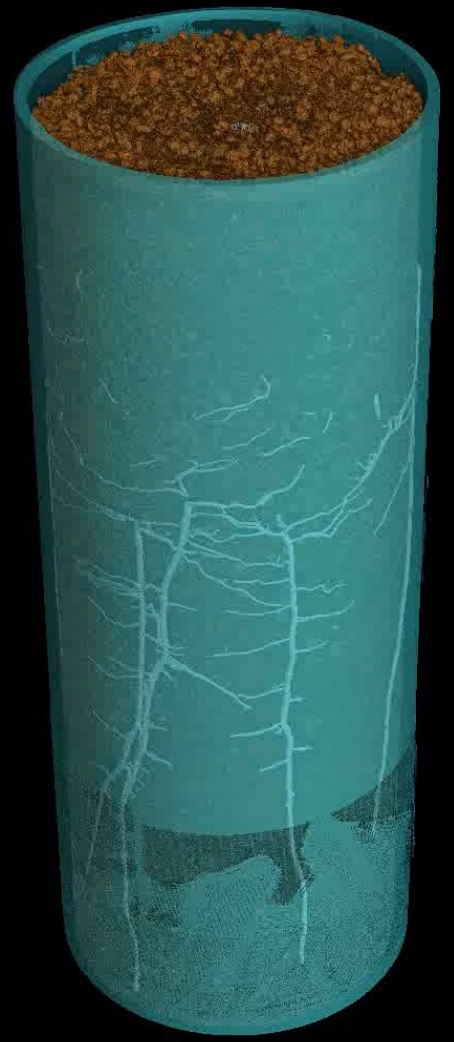


A non-invasive technique for visualizing & quantifying the interior of a solid object in 3D.

www.nottingham.ac.uk/microct/

Soil Structure

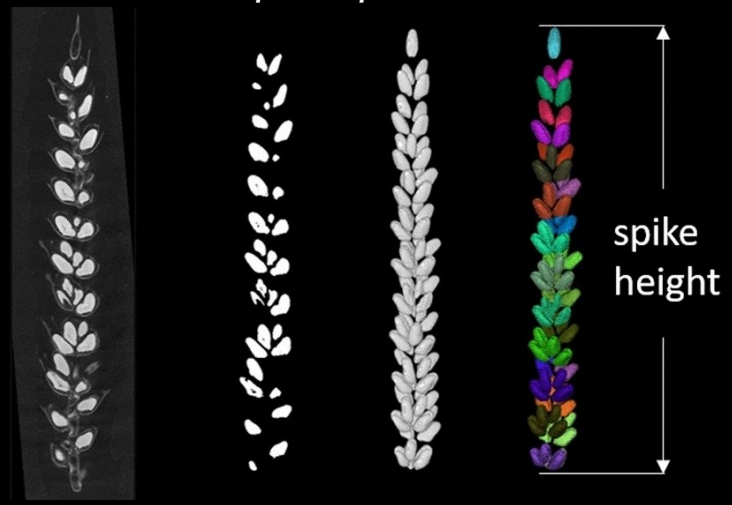




Grapevine (80 cm core)

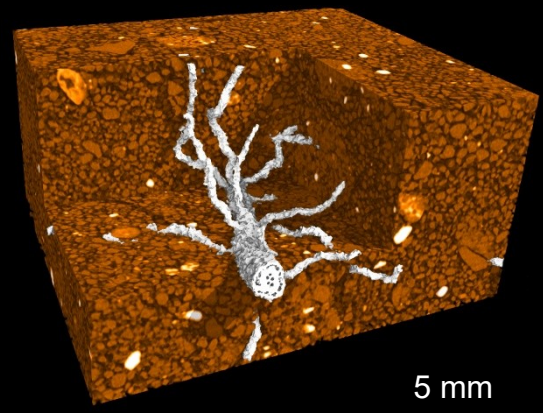
Schmitz et al. 2021. Vitis

Wheat spike quantification



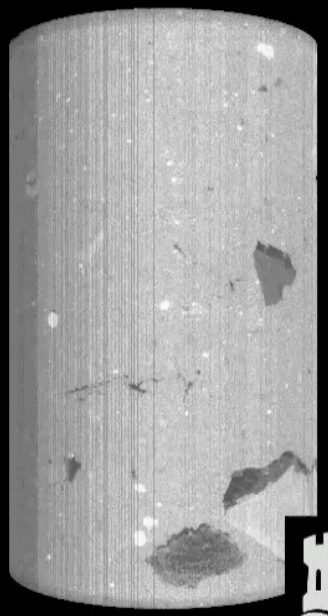
Zhou et al. 2021. Plant Methods

Rhizosphere



Zero tillage and soil structure

Zero tillage



Conventional tillage

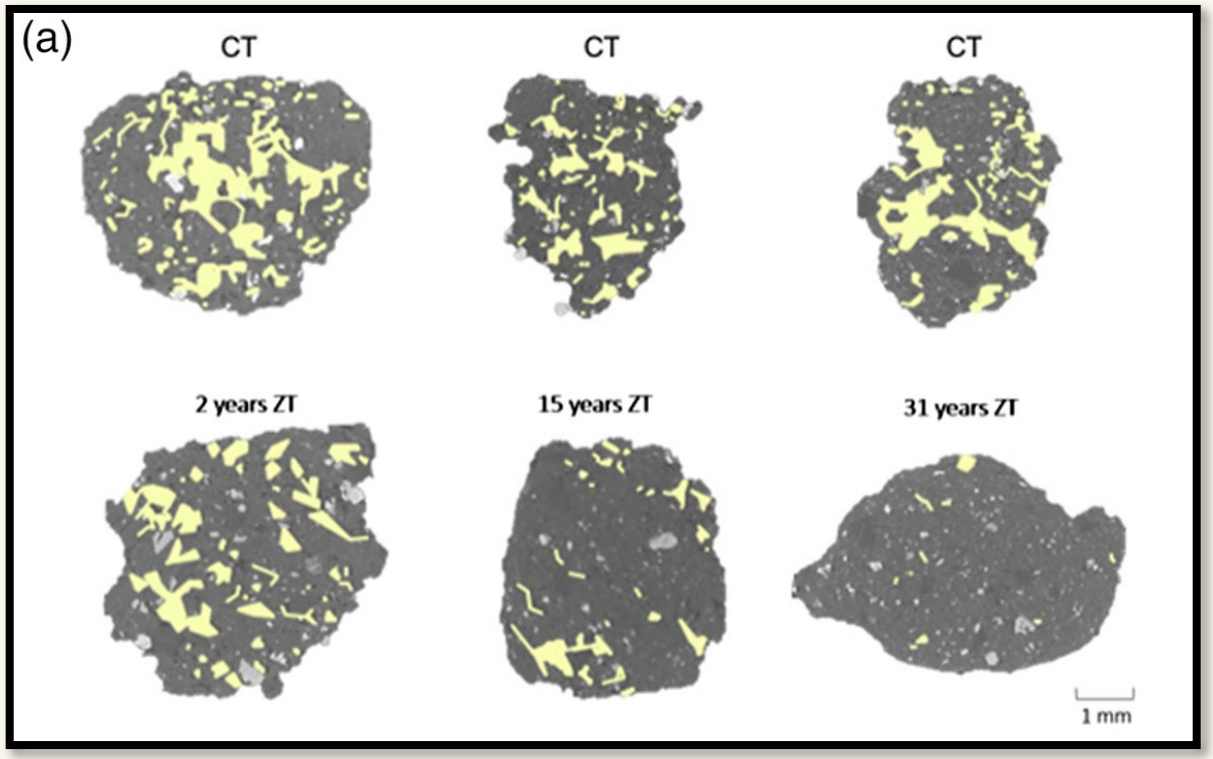


The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Conventional and conservation tillage

- Conventional tillage impacts carbon at the scale of soil aggregates
- Pore space within aggregates decreases with time under management, making organic matter less microbially available.
- Yield impacts from zero-tillage are more contentious



Cooper et al. 2021

Sustainable soil management: regenerative agriculture

Beyond impacts on soils, clear metrics are needed for impacts on a range of ecosystem services:

1. Crop yields
2. Crop quality
3. Farm profitability
4. Biodiversity
5. Incidence of pest and disease
6. Resilience
7. Farmer livelihoods



Natural Environment Research Council

The Pantanal – a sustainable soils case study

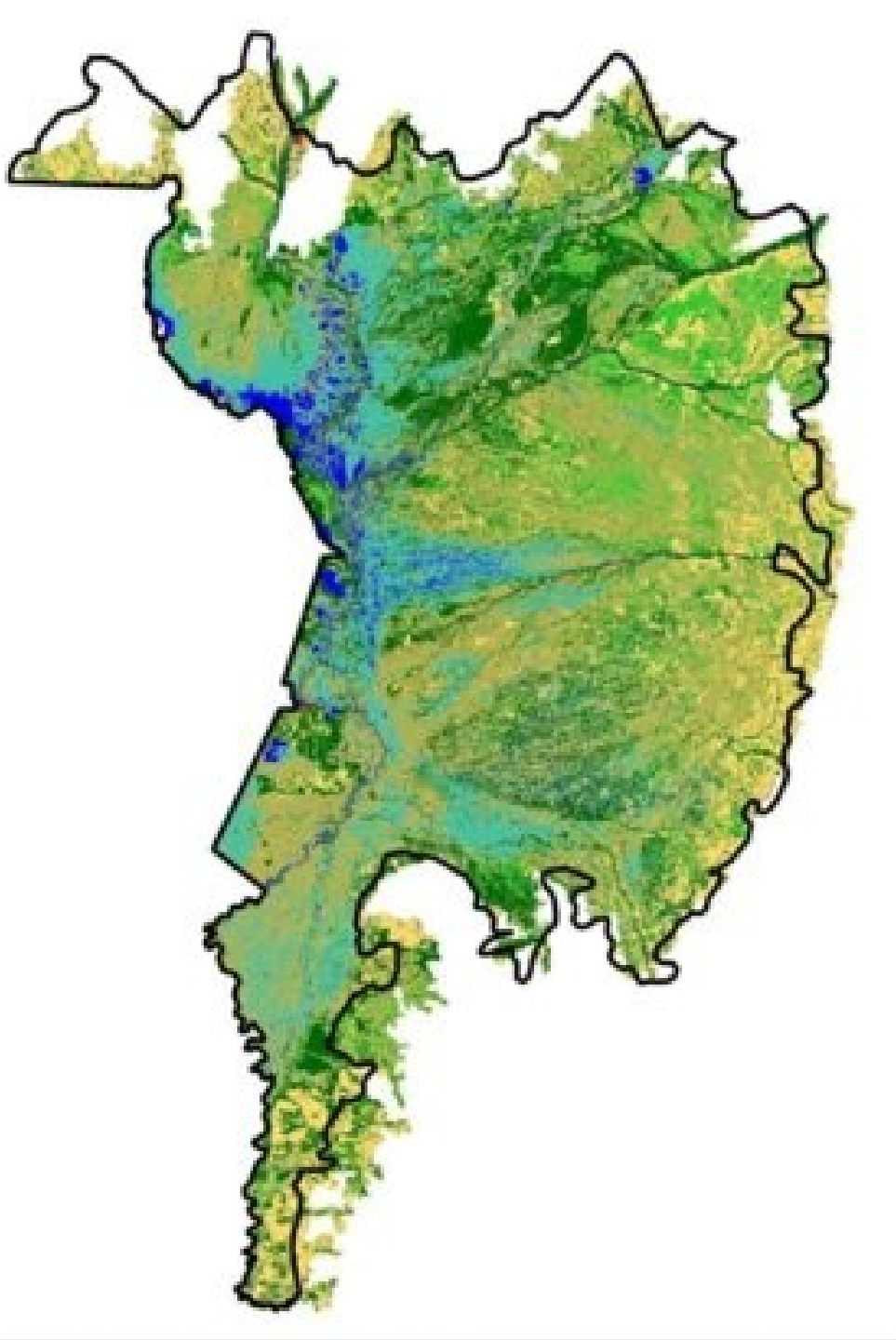
Sustainable soils in the Pantanal

- The Pantanal is the world's largest tropical wetland, covering roughly 150,000–170,000 km² across Brazil, Bolivia, and Paraguay, and functioning as a vast seasonal floodplain.

- Ecology is driven by an annual flood pulse, with ~80% inundated during the wet season, shaping species distributions, nutrient cycling, and human land use.

- It acts as a critical hydrological regulator for the Upper Paraguay River Basin, moderating floods, improving water quality, and influencing downstream ecosystems as far as the Paraná–La Plata system.

UFMT UFMS Embrapa Royal Geographical Society with IBG



Land cover in the Pantanal

- The Pantanal features a range of land uses and managements in a highly fragmented mosaic

- Ecological and environmental processes differ across ecotypes, and soils, and thus are likely to exhibit varying sensitivities to stress (e.g. warming etc) and emergent properties including resilience

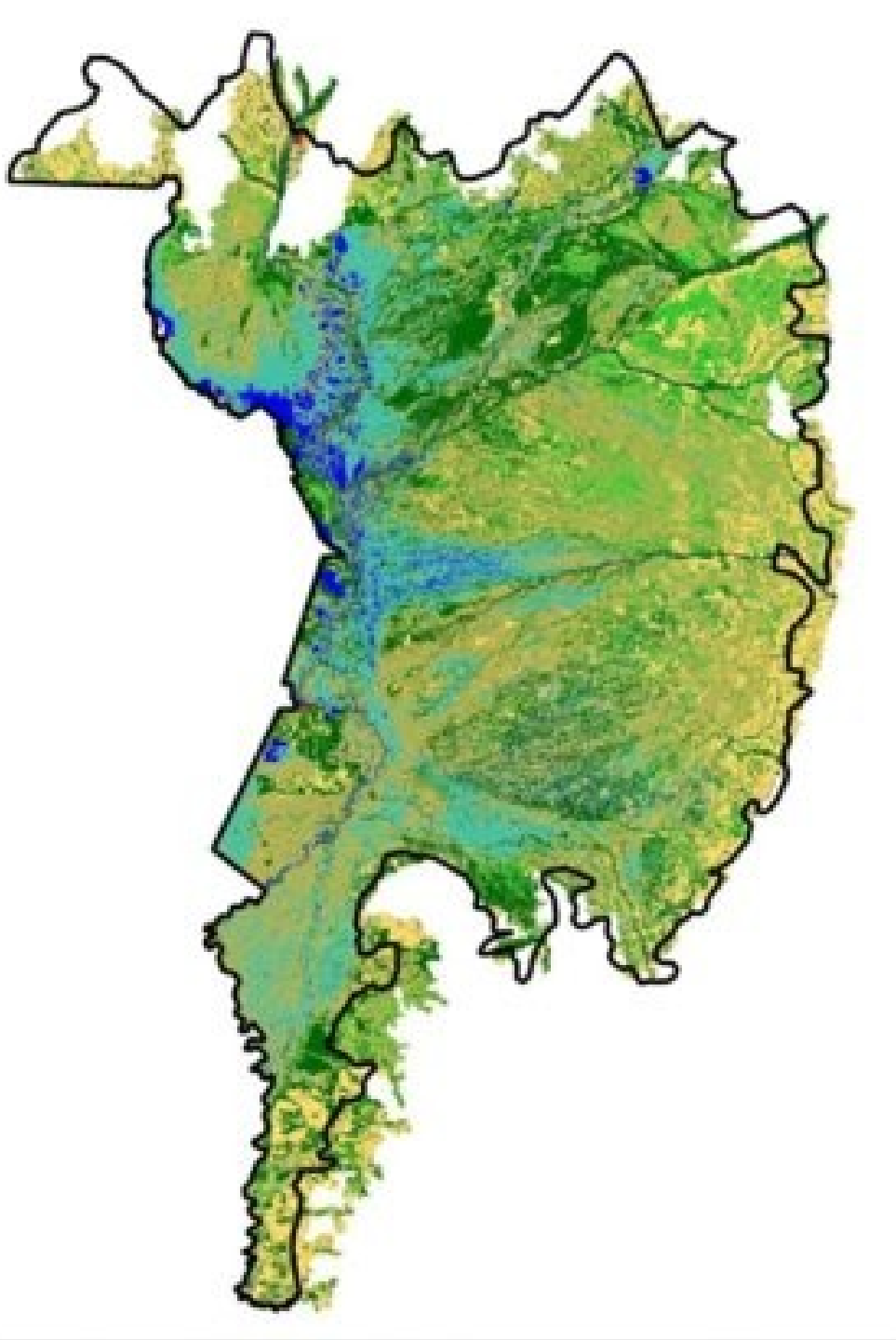


Quantifying soil properties at scale

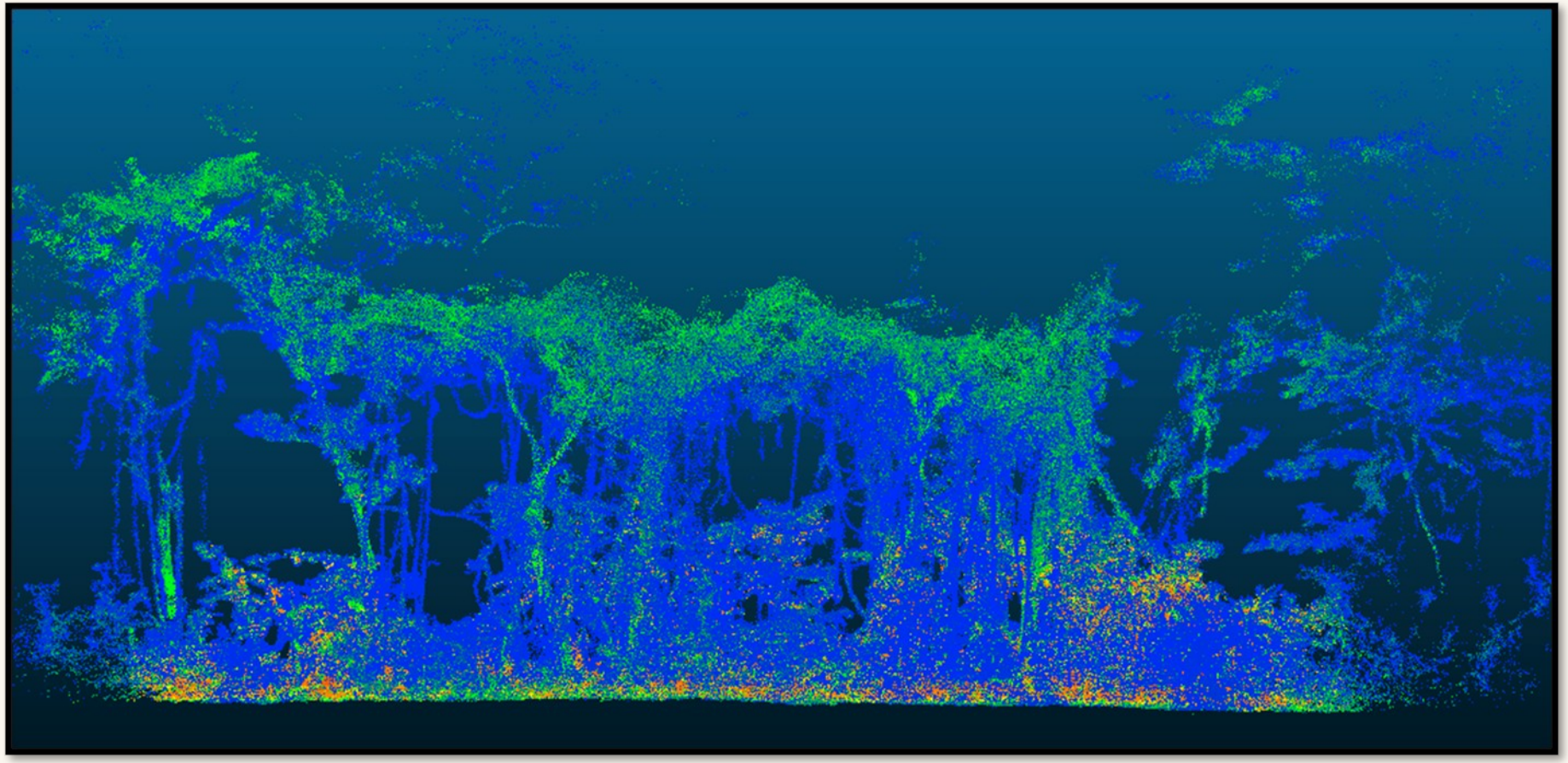
- Beginning in 2024, we established network of monitoring plots spanning the Pantanal and all major land cover (following the MapBiomass classification) and soil textures.

- Analysis of soil carbon and other properties using near-visual-infrared spectrometry to build a regional-scale soils database for carbon

- This allows us to develop a database for soil properties across the entire Pantanal, quantifying carbon and other properties for >1,000 samples.

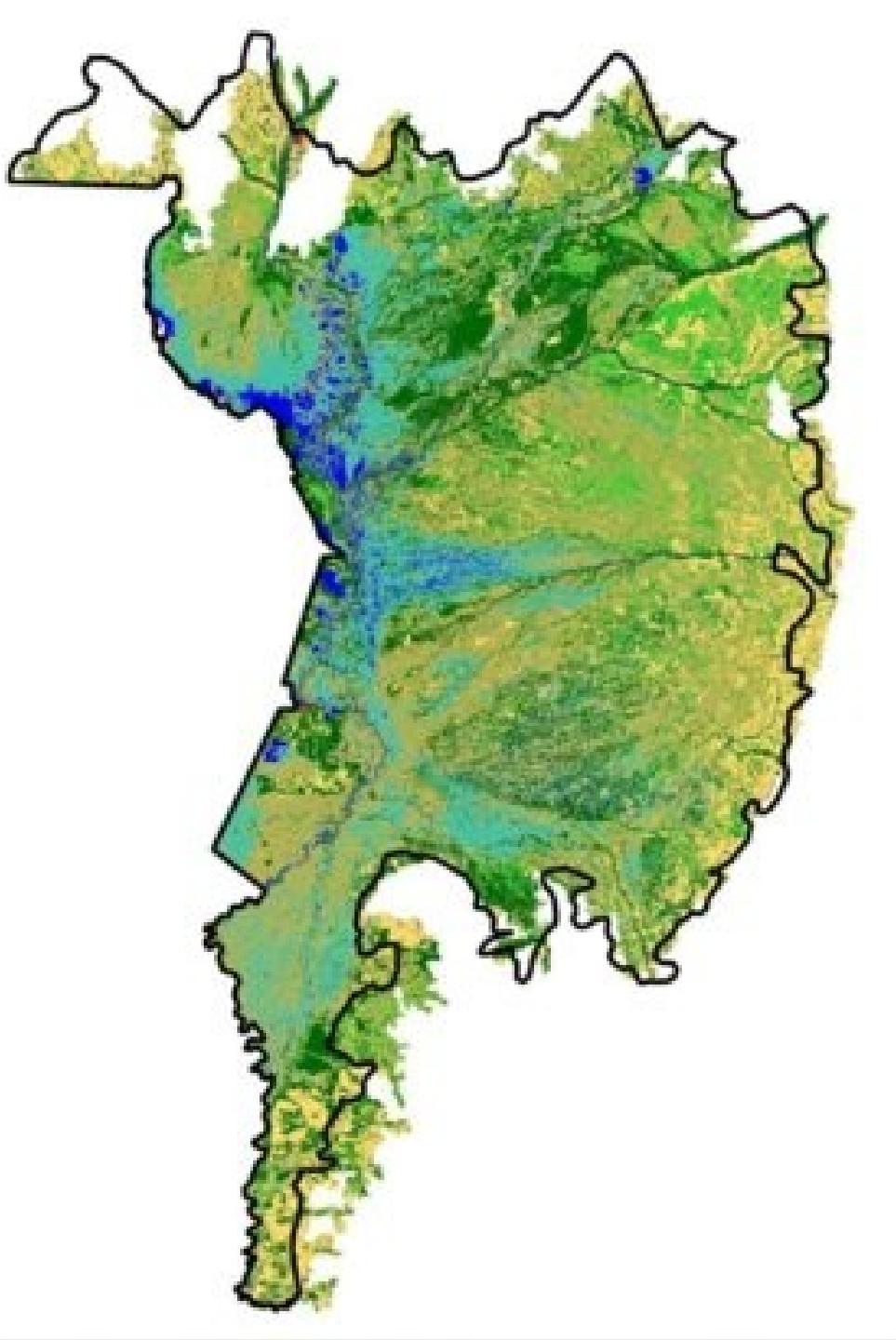


Terrestrial laser scanning for biomass



Sustainable resource management in the Pantanal

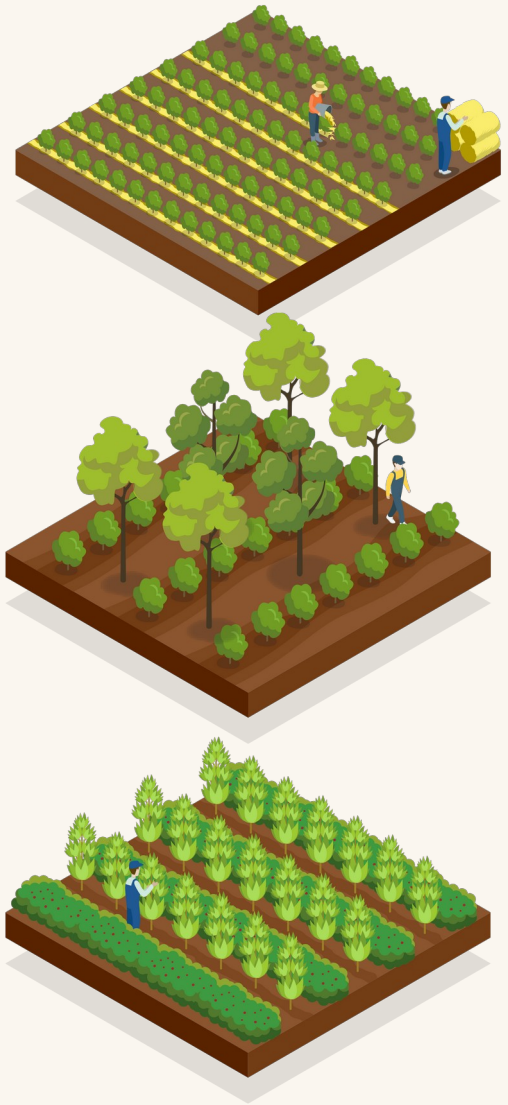
- Improved mapping of carbon hotspots (soil and biomass) is vital for adaptive management plans across the region, and as a baseline to understand impacts of any future interventions
- It can help prioritise funding for conservation and restoration efforts in high-carbon hotspots, and support continued sustainable agriculture in other areas
- REDD+, voluntary carbon credit markets, and other opportunities can provide funding to support targeted conservation effort
- Climate change will further impact soils and soil processes, affecting agricultural production (grazing and cropping systems)



Take-home messages

Sustainable soil management

- Sustainable soil management underpins both agricultural systems, but also many approaches for climate change mitigation (e.g. conservation of carbon hotspots)
- Global climate change will impact soils, crops and livestock systems. Changes in management (especially for soils and crops) are needed in most farming systems to build resilience
- Regenerative agriculture offers one set of potential solutions, but most need to be tested under local conditions to quantify benefits/trade-offs
- These changes can provide benefits to yield and climate resilience, leaving space for provision of other ecosystem services (e.g. conservation of carbon or biodiversity hotspots)



University of Nottingham
Food Systems Institute

Thank you

Nicholas.Girkin@nottingham.ac.uk

Food Systems Institute at the University of Nottingham

@foodsystemsinst

Sowing ideas, cultivating solutions

Sustainability Community Nutrition