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Biodiversity for Agriculture

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Executive Summary

The Bio4Ag toolbox is an online, open access, interactive resource hub providing resources to assist farmers and policy makers in understanding complex in-field agroecosystem networks and using this knowledge to design optimal cropping systems and facilitating the application of new strategies in the transition towards more sustainable, biodiversity-based production systems. The project draws together datasets on indicators of crop productivity, soil health and biodiversity from the Hutton's Centre for Sustainable Cropping (CSC) long-term experiment (Hawes et al. 2019, Hawes et al. 2025) and associated projects. Dashboards provide the opportunity to review data-driven evidence for the costs, benefits and risks associated with the adoption of regenerative farming approaches. An interactive network representing key elements of the in-field agroecological system allows users to explore likely impacts of selected management options on outcomes for biodiversity, soil health, greenhouse gas emissions, carbon footprint and financial return. After exploring options online, users can then apply combinations of strategies on their own farms and monitor the outcomes by following our user-friendly monitoring procedures. The Bio4Ag Toolbox thus facilitates an iterative process of bespoke, whole-system design and testing for those wishing to adopt and promote regenerative agricultural practices.

Background

1. Reversing biodiversity loss and enhancing food production are often seen as conflicting goals in farming, but integrating biodiversity into cropping systems is crucially important for maintaining and regulating agroecosystem services in low input systems.
2. By increasing system resilience and the efficiency of resource use, these services support sustainable production with less reliance on agrochemical inputs and therefore also contribute to reductions in climate change impacts.
3. However, integrating biodiversity into cropped systems requires an understanding of agroecological processes and comes with an element of uncertainty and, therefore, risk to growers.

Aims

To promote better understanding of underlying farmland ecology and how biodiversity can help improve efficiency and regulate system processes for lower input farming, using:

- Data dashboards inform users on impacts of regenerative approaches on key indicators of ecosystem health and how management options adopted at the Centre for Sustainable Cropping can effect change;
- The toolbox allows land managers, agronomists and policy makers to understand the potential for achieving multiple benefits and optimising trade offs through the adoption of specific combinations of crop management strategies;
- Resources are provided to support the adoption of beneficial practices including technical notes, guides and user-friendly methods for monitoring outcomes.

Legacy

The Bio4Ag Toolbox will provide project legacy as an open access, online resource and design support tool which will continue to be updated annually, in collaboration with Linking Environment And Farming (LEAF), Agricology, BOFIN, ClimatexChange, Royal Botanic Gardens Edinburgh (RBGE), Plant Health Centre (PHC), SRUC and BioSS.

- For farmers, agronomists and industry organisations, the site will be developed to include technical notes, videos and information on alternative management approaches as they are tried and tested at the Centre for Sustainable Cropping platform.
- For policy, future developments will align the suite of management interventions listed in the toolbox with those required by policy and supply chain actors.
- For science, development of a Bayesian Belief Network model will replace the conceptual model allowing representation of uncertainty and providing predictive capacity.

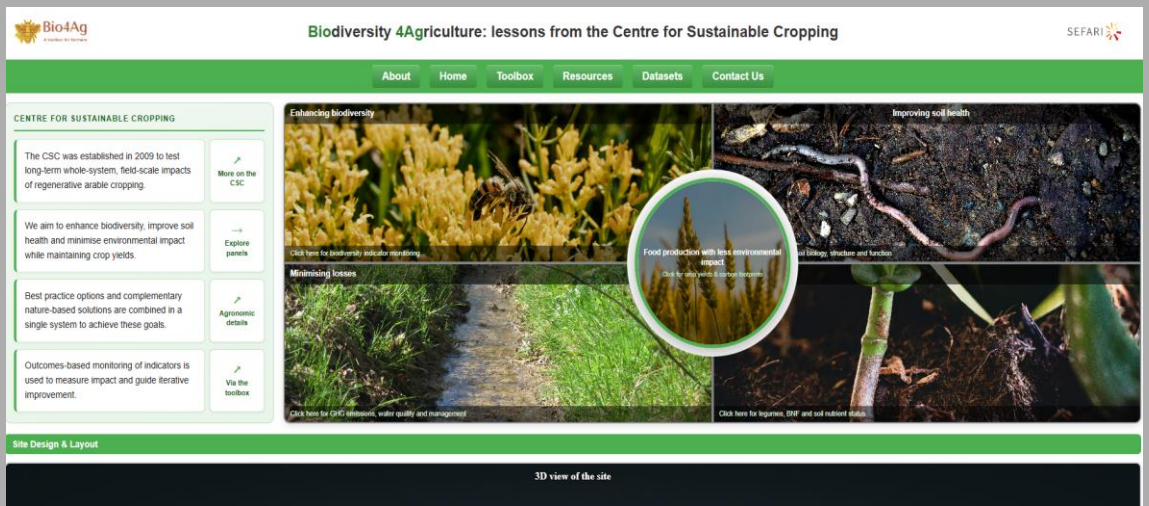
Agroecological design: utilizing biodiversity and soil health for more efficient crop production

The Bio4Ag Toolbox

Regenerative agriculture aims to improve soil health and biodiversity to enhance ecosystem services (nutrient cycling, pollination and predation) and increase the capacity of agroecological systems for internal regulation of processes to maintain productivity and build resilience with less reliance on agrochemical interventions and therefore lower environmental impact (Hawes et al. 2021). However, agroecological systems are highly complex and achieving these multiple benefits simultaneously can be challenging. The Bio4Ag Toolbox aims to provide the resources needed by farmers to better understand how management impacts the ecology of the cropped environment and how practices can be combined to optimize essential ecological functions and processes (Squire and Hawes 2024).

Structure & Content

1. About Page gives an overview of the toolbox, links to the project partner's web sites and short cuts to the dashboard pages. This page also provides a link to a video with instructions on how to get the most out of the toolbox and where to come for additional information and feedback.
2. Home Page contains links to further information on the Centre for Sustainable Cropping long-term experiment, its background and purpose as well as site layout, design and a virtual tour. Links are also provided to information on cropping, agronomy, the toolbox (where monitoring methods can be accessed), and each of the 5 data dashboards for indicators of biodiversity, soil health, pollutant losses, crop nutrition and yields.
3. Toolbox Page is the main focus of the website which allows users to explore the likely effects of management options and combinations of different management strategies on outputs from the arable system via the network of interacting elements within and immediately surrounding cropped fields. This is described fully in the sections on pages 6-7.
4. Resources Page provides additional resources for users wishing to delve deeper into particular aspects of agronomic practices and outcomes-based monitoring of impact. Links to technical notes on specific agronomic interventions (conservation tillage, cover cropping, organic amendments, nutrient supply etc.), resources for automated monitoring of soil and biodiversity, plant, bird and insect and earthworm ID guides and examples of citizen science projects where these methods have been applied are collated here for easy access to further information, grouped by topic.
5. Datasets Page gives a summary of the available data and archived samples that can be accessed by stakeholders wishing to carry out their own investigations or comparisons of indicator variables across sites. All data are open access, but a passcode must be requested from the project manager to allow coordination across projects and effective collaboration between users.



Bio4Ag
A toolbox for farmers

Data Dashboards

Data-driven evidence of the impact of management change on cropping systems is essential for farmers to make informed decisions when planning a transition to regenerative agriculture. The Bio4Ag Dashboards summarise results from the Hutton's research farm platform, allowing users to explore costs and benefits over time, thus facilitating uptake of appropriate best practice options with minimal risk to their own farm businesses. Each dashboard provides options for selecting indicators to view out of a suite of measured variables and links to technical notes describing trends from the CSC experiment and the standardized monitoring methods used..

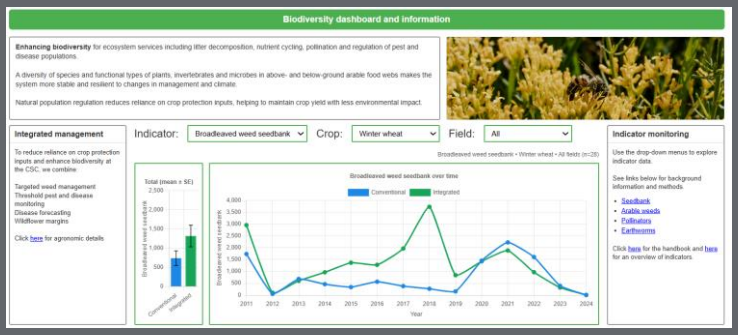
Enhancing Biodiversity for ecosystem services including litter decomposition, nutrient cycling, pollination and regulation of pest and disease populations: diversity of species and functional types of plants, invertebrates and microbes in above- and below-ground arable food webs makes the system more stable and resilient to changes in management and climate. Natural population regulation reduces reliance on crop protection inputs, helping to maintain crop yield with less environmental impact.

Improving Soil Health for ecosystem services: organic matter inputs enhance decomposition, nutrient cycling, pathogen suppression, more efficient uptake of resources by crops, plus lower rates of soil erosion and runoff. Minimising soil disturbance by reduced tillage, including cover crops to keep living roots in the ground all year and adding organic matter all benefit soil structure . Healthy soils support regulation of pests and pathogens, nutrient cycling and retention and therefore reduce reliance on agrochemical inputs.

Sustainable Crop Nutrition to minimise fertiliser inputs legumes are incorporated for Biological Nitrogen Fixation (BNF) and Soil Nitrogen Supply (SNS) is used to calculate crop fertiliser requirement. Mineral nitrogen fertiliser use is the biggest contributor to greenhouse gas emissions from arable production, both as direct emissions and indirectly in the manufacturing process. Efficient use can be achieved by better soil health to optimise uptake, timing of application, legumes, and cover crops to minimise losses over winter.

Minimising Losses deploying Nature Based Solutions in diversified field margins, riparian buffers and uncropped areas is effective for managing erosion, runoff and flood risk, reducing risk at a wider spatial scale by capturing losses during heavy rainfall events.

Crop yields can be maintained by optimising production efficiency and utilising ecosystem services. However, management for low environmental impact can incur a yield penalty. Yield and financial margins therefore need to be included in environmental audits to inform incentive schemes and guide crop system design to minimise economic impact, particularly in the early stages of transition before long-term benefits of a healthy, resilient crop system can be achieved.



Agroecological design tool

The central component of the Bio4Ag Toolbox is the interactive agroecological network representing key components of a typical in-field system. The aim is to provide the user with a tool to explore the likely impact of different management interventions on soil physical properties, biodiversity, nutrient cycling processes, crop nutrition, weed biodiversity and arable foodwebs. Management options can be combined to optimize benefits for environmental impact, biodiversity and yield.

Management options

Management options are those that are included as part of the regenerative cropping system at the Centre for Sustainable Cropping, grouped by goal - soil health, nutrients and biodiversity.

Soil health is divided into organic matter inputs (either internally generated from cover crops, weeds or crop residue or externally derived sources such as green waste municipal compost) and cultivations (reduced tillage disturbance through direct drilling or occasional till).

Nutrient management is divided into three categories: nutrient budgeting (using soil testing to determine soil nutrient supply and basing mineral fertilizer rates on these calculations); precision spraying (ensuring the timing and location of fertilizer inputs matches crop requirement), and; incorporating legumes as cash-, cover-, companion- or inter-crops to boost soil nutrient supply using renewable biologically fixed nitrogen.

Biodiversity management is classified into (a) strategies to reduce non-target effects by Integrated Pest Management options including threshold monitoring and forecasting, biocontrol and biofortification to increase crop resilience to pests and disease, and (b) increasing habitat diversity and resource provision by planting species rich field margins, wildflower strips, headlands and buffers, targeted weed management to support low but viable populations of in-field weeds, and weedy stubbles or diverse cover crop species mixes overwinter.

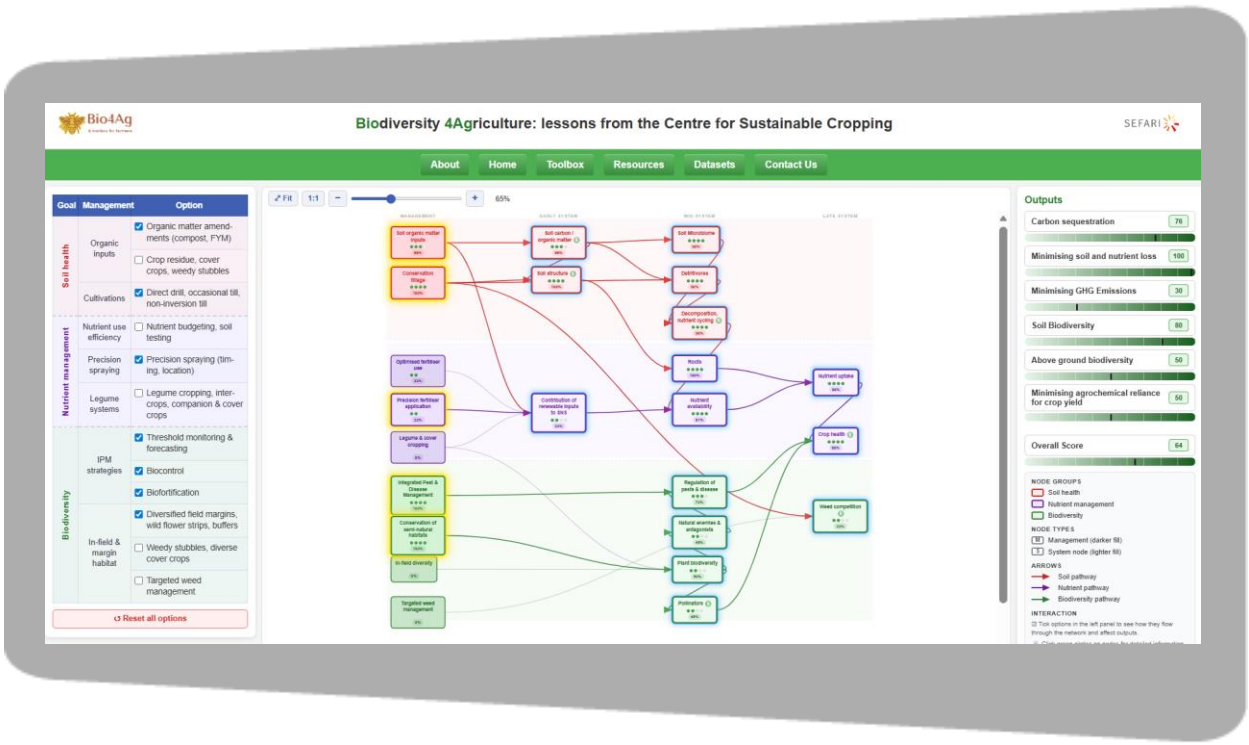
Further information and technical notes are linked to each of these management interventions on the Resources Page for the user to review, and can be selected by the user by clicking the check box on the list next to each option. Multiple options can be combined to improve on predicted outcomes depending on the users' farm business, the resources they have available and management targets, whether that is optimizing yield, managing for biodiversity, improving soil health, or a whole systems approach incorporating all three.

Agroecological network

When a management option is selected, the relevant nodes that are impacted by that management in the in-field agroecological network are highlighted along with the links between them. So, for example, if the user selects "organic matter amendments" the OM inputs node is highlighted along with the knock-on effects to soil organic matter, physical structure, microbial and detritivore activity, litter decomposition and nutrient cycling, soil nutrient supply, crop rooting and nutrient uptake. Positive effects of a management practice are indicated by an increase in score for each node. These scores are qualitative, based on literature review and trends from the Centre for Sustainable Cropping (Hawes et al. 2021). So, in the above example, soil organic matter amendments makes a large contribution to soil carbon content (set to 60% of the maximum). This can be improved upon by also including crop residue and cover crops in the check list of management options, increasing the score to 100%. These two options combined result in a score of 50% for soil structure which can be further improved by adding in conservation tillage to the list.

Outputs

Impacts of the combination of management options selected are summarized in terms of likely consequences for a range of desired outcomes from the farming system: soil carbon sequestration (depends on carbon inputs and tillage), minimising losses of nutrients (influenced by on soil structure and nutrient management), minimising greenhouse gas emissions (depends on soil management and mineral fertilizer inputs), soil biodiversity (impacted by tillage and organic matter inputs), and above ground biodiversity (varies with habitat conservation, weed management and IPM strategies). These scores are qualitative and based on observations from the Centre for Sustainable Cropping, expert opinion and literature review, but aim to guide the user in the selection of combinations of management strategies that are most likely to achieve multiple benefits from the land.



Current status and next steps

This project has funded the design and development of the Bio4Ag toolbox and website with voluntary contributions to its co-development from collaborating partners within the Hutton, SRUC, Plant Health Centre, ClimateXChange, Royal Botanic Gardens and LEAF, subsequently extended to include the British On-Farm Innovation Network (BOFIN), Agricology and AHDB. The toolbox was presented at the Agricology/AHDB Resilient Farm Roadshow (The Resilient Farm Roadshow | AHDB) in Nov 2025, and the Ecosystem and Land use Stakeholders and Policy Engagement Groups Meetings in Dec 2025 and Jan 2026.

The project has supported two rounds of demonstration, testing and feedback with stakeholders and we are currently in the final stages of incorporating the feedback and suggestions from the second iteration held in March 2026. Although the project is now beyond the official end date, the tool is relevant to and supported by a range of current RESAS and externally funded projects including RESAS D4-3 Scotland's Biodiversity: People, Data and Monitoring, RESAS Underpinning National Capacity: KUC-FO3-2 the Centre for Sustainable Cropping, The EU Agroecology Partnership, European Commission funded 'Research and Innovation Action' projects: www.econutri-project.eu (101081858), and www.legumESproject.eu (101135512). These projects will support the final stages of incorporating feedback received to date and a launch planned to coincide with the BOFIN North Inspiration day in May 2026, followed by a roll-out via Agricology, BOFIN and LEAF networks. Longer-term, the toolbox will continue to be developed in parallel with the Centre for Sustainable Cropping long-term experiment which operates on an iterative annual cycle of review, development and testing. New material will be added annually as data become available and alternative interventions are tested and incorporated into the regenerative cropping system at the farm.

Here we provide the resources needed to implement an iterative and adaptive process of system design to help facilitate uptake of biodiversity-based approaches for arable production systems.

1. & 4. Field guides and user-friendly methods for soil & biodiversity monitoring

2. & 3. Technical notes and resources collated for agronomic interventions

5. Data-driven evidence for effect of management system on indicators

6. Interactive network to explore likely outcomes of integrating new management strategies

Project legacy

As an online, open access resource library and decision aid, the Bio4Ag Toolbox provides a means by which results and lessons learned from the Centre for Sustainable Cropping long-term experiment and associated regen ag projects can reach a wider audience than is possible by in-person site visits and institute KE events alone. The site will be maintained as a long-term resource for industry, policy and science stakeholders and developed alongside the experimental platform as a digital "shadow", incorporating new information and data as it becomes available.

Industry

For farmers, agronomists and industry organisations, the site will be developed to include technical notes, videos and information on alternative management approaches as they are tried and tested at the Centre for Sustainable Cropping platform. The use of drones, robots, smart phone imaging and automated methods for monitoring and data collection are being investigated, and once tried and tested, could represent a valuable resource for innovative farmers wishing to increase the extent of data collection on their own farms. A facility within the site to allow users to record and upload data from their own farms, generate summary statistics of trends over time from a baseline and compare (anonymously) against national averages is also a future ambition for the project going forward. Industry funding will be sought to build in this functionality as part of a second phase.

Policy

With the rise in interest in outcomes-based monitoring of changes resulting from management practices introduced as part of new agri-environmental policy and incentive schemes, there is a need to join up action with outcome. Bio4Ag provides farmers and policy makers with the framework needed to achieve this and better appreciate some of the underlying processes involved and the potential for tradeoffs between them. Future developments will align the suite of management interventions listed in the toolbox with those required by policy and supply chain actors.

Science

The Bio4Ag project provides a basic starting point for a number of applications in the scientific community including the development of Living Labs and digital twins as part of the Agroecology Partnership with >100 partners over 31 Member States. Funded staff time within the partnership over the next 8 years also supports continued development of a Bayesian Belief Network (BBN) model of the agroecological in-field system which will eventually replace the existing hard-wired, qualitative model. The BBN is more sophisticated in that it captures uncertainty in the response of indicators to management change, developing the simple, descriptive and conceptual model to one with predictive capacity.

View over the Centre for Sustainable Cropping platform fields

3D digital elevation of the platform fields

Acknowledgements

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