



# Centre for Sustainable Cropping

## Arable Transitions Toolkit



The James  
**Hutton**  
**Institute**

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# Step 1: Goal setting/priorities



## Soil health – Biodiversity – Yield

Goal

Soil physical structure & biological function for better yields, with less fertiliser and pollution

*physic*  
*s*

Mechanism

Water holding capacity, infiltration, aggregate stability, soil pore diversity, lower bulk density

*biology*

Microbiome diversity, decomposition, symbiotic associations (mycorrhizae, rhizobia), antagonists

Management options check list:

Organic matter amendments



Conservation tillage



Cover cropping  
Green manure



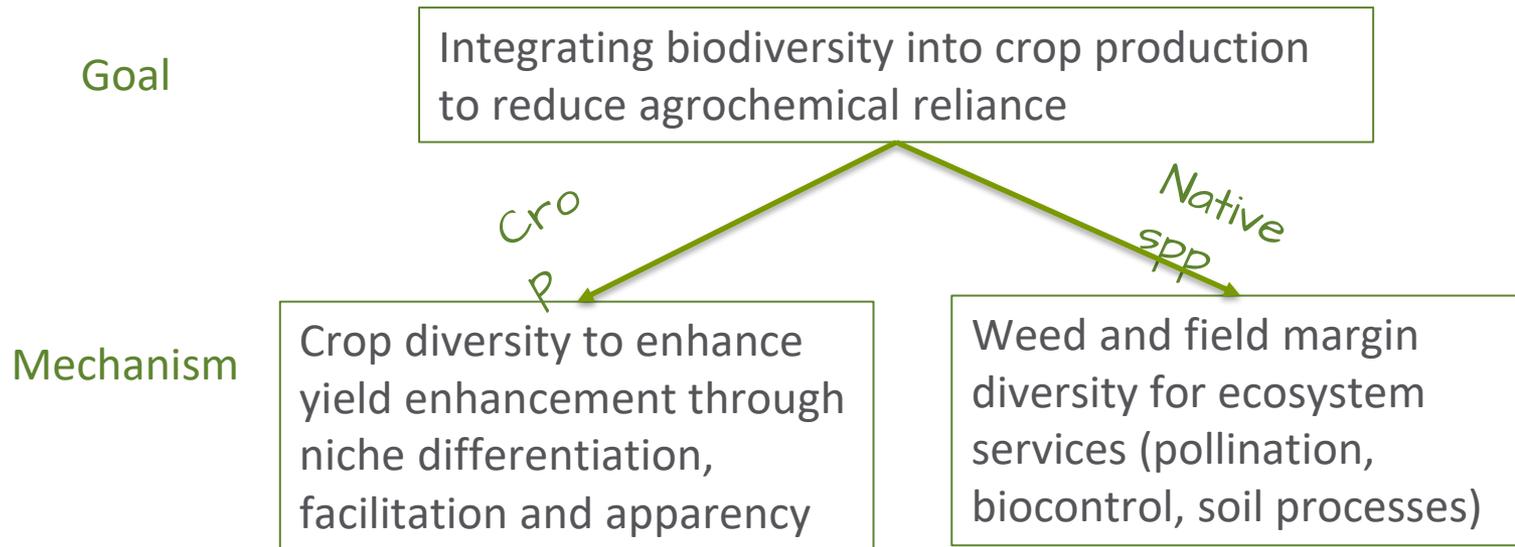
Legumes  
Under-sowing





# Step 1: Goal setting/priorities

Soil health – Biodiversity – Yield



Management options check list:

Legume undersowing



Co-cropping & inter-cropping



Diversified field margins



In-field broad-leaved weeds

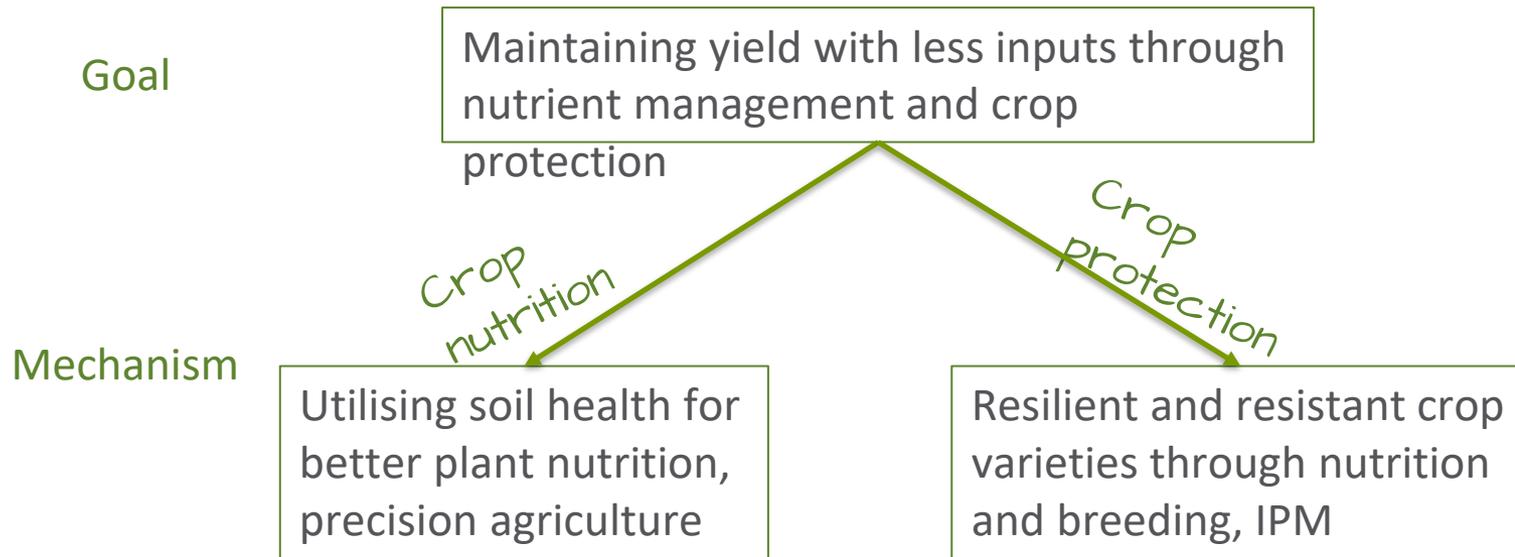




# Step 1: Goal setting/priorities



Soil health – Biodiversity – Yield



Management options check list:

Legumes for BNF



Soil N Supply measurement



Fert timing and placement



Biofortification and nutrition





# Searchable Resource Library

linked to management options selected by user



The James  
**Hutton**  
Institute

Minimum tillage



Technical Note

TN553

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Key points to success with minimum tillage are:

- Minimum tillage is not an easy option, it demands commitment, time and patience.
- Ask the experience of others in your area before starting on minimum tillage.
- Well more stable structured soils are best suited to minimum tillage.
- Operate one main system to reduce costs but be prepared to be flexible throughout – necessary to change the tillage system or even cropping at short notice.
- Working with neighbours or contracting in labour and machinery.
- If machinery is available and used properly, with minimum compaction, at harvest.
- Attention to soil conditions and grass weeds.
- Comparisons comparing minimum tillage with ploughing.

*Used in this note is based on evidence of a wide range of Further advice and ideas ce with minimum tillage . This technical note was t of a minimum tillage advisory activity and as*



## SIMPLY SUSTAINABLE BIODIVERSITY

Six Simple Steps to help improve biodiversity on your land



## Managing Soil for Crop Protection

**SUMMARY**  
Set-aside and fallow breaks can reduce pressures may change for numbers can build up in set

## SIMPLY SUSTAINABLE SOILS

Six Simple Steps for your soil to help improve the performance, health and long-term sustainability of your land



Business plans   Marketing   Markets and prices   Knowledge library   Tools   Events

Home > Knowledge library > How to use red clover

## How to use red clover

- > Growing red clover for silage and grazing
- > Case study
- > Useful links

Find out how to use red clover to benefit your system. See our tips on growing red clover with grasses.

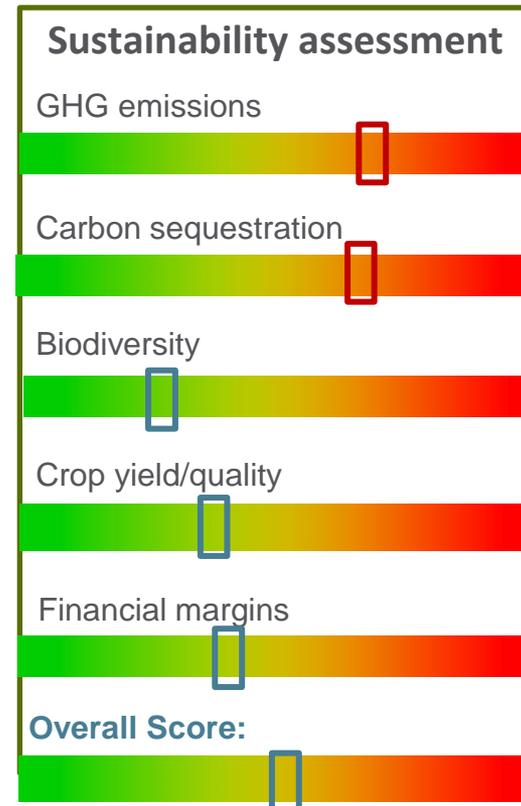


# Step 2: Predict sustainability impact

Checklist of options linked to DEXi model

**Integrated management options**

- Soil carbon amendments
- Cultivations – direct drill
- Co-cropping, intercropping
- Variety selection
- Precision ag options
- Fertiliser alternatives
- IPM strategies, threshold monitoring
- Biofortification
- Weed management
- Margins and buffers
- Habitat/resource provision



# Step 3: Baselining to monitor change

## Resource library for monitoring linked to selected management options



The James Hutton Institute



### Monitoring: soil carbon and structure



**Background**

Soil structure is determined largely by the level of disturbance and the organic matter content of the soil. Reduced disturbance by conservation tillage, plus organic matter inputs from dead plant matter, root exudates and external amendments (e.g. compost) provide better environment for both root growth and microbial activity.

Improved soil structure is critical in minimising losses through erosion, facilitating better drainage and water holding capacity.

**Methods**

A simple Visual Evaluation of Soil Structure VESS was developed by SRUC and is widely used by farmers and agronomists to assess agricultural soil structure on a point scale from friable to very compact.

The guide and colour chart can be downloaded from <https://www.sruc.ac.uk/media/139744/vess-color-chart.pdf>

Measuring soil organic matter is straightforward but requires access to a muffle furnace.

- Take 20 soil samples in a W-pattern across the field.
- Weigh each and dry in an oven at 70°C for 48 hrs or until constant weight. This will give the soil moisture content at the time of sampling.
- Using a pestle and mortar, crush a 10g sample into a fine powder.



### Monitoring: arable weed seedbanks



**Background**

Unlike the emerged weed flora in an annually cropped field, the soil seedbank provides a buffer against annual changes in weather or cropping practice. This buffering capacity is due to the persistence of seeds over long (decadal) periods in the soil and confers an evolutionary opportunity.

**Measurements**

Aim – to determine the taxonomic and functional diversity of plant biodiversity held in the soil indicator of previous cropping and management and the potential for future recovery.

Sampling – as with above-ground vegetation, sampling is spatially variable and therefore is taken either across the field (grid pattern), or along a W transect in-field areas, or stratified according to properties where field maps are available.

Weeds also deliver other ecosystem services, such as cover for beneficial insects.



### Monitoring: arable weed flora



**Background**

In-field arable weeds are an important resource for insects, supporting up to ten times more herbivores than the same mass of crop. Diversity in this weed layer is propagated through the food web to pollinators and natural enemies which then regulate crop pest numbers.

Weeds also deliver other ecosystem services, such as cover for beneficial insects.

**Measurements**

Weed distribution in fields is highly variable due to localised seed rain and limited dispersal away from the parent plant. The resulting heterogeneity requires systematic monitoring to ensure an accurate picture of overall diversity and abundance.

Quadrat counts of weed numbers for each species present are made over about 20 sample locations per field. Unless the whole field is to be mapped, sampling should follow a W-pattern to ensure a spread of points across the field.



### Monitoring: insect pollinators



**Background**

Many pollinator species are in decline, intensification and fragmentation of farmland has led to a loss of floral resources and reduced productivity. Population decline is a common problem for many species. The James Hutton Institute is leading a continuity of pollinator research.

**Measurements**

Insect pollinators include a wide range of taxonomic and functional groups.



### Monitoring: earthworms and other soil invertebrates



**Background**

Soil biodiversity is essential for litter decomposition, pest suppression, nutrient cycling and uptake by plants, but in cultivated soils, these functions are reduced compared to natural ecosystems. Soil disturbance by cultivation particularly impacts larger soil invertebrates but all taxa (earthworms) and all rates of agricultural use.

Earthworms are especially important in arable fields. They connect above and below ground processes and stimulate microbial activity in the soil. They maintain soil structure, increase nutrient cycling and improve organic matter and water infiltration.

Other arthropod groups, (springtails and mites), are also essential for soil functioning, breaking down dead plant matter and providing resources for other organisms.

**Measurements**

Traditional methods for sampling earthworms are based on in-field extractions using mustard solution (or other repellent chemicals), followed by a time-consuming species identification in the lab. This is a major limitation in large-scale surveys needed to understand patterns in earthworm communities and how they are affected by agricultural management.

A simpler method is to hand sort a standardized volume of soil and 10 adult worms just to functional group level. This provides less detailed information for a given field, but takes less time allowing more sites to be surveyed. Data correlate well with standard extraction methods.

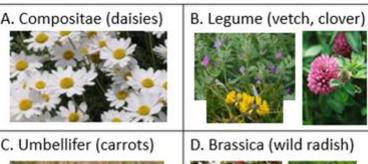
Smaller soil dwelling invertebrates such as springtails, mites, nematodes and the soil-dwelling larvae of surface-dwelling insects can be sampled using Berlese-Tullgren funnels to give a more complete representation of the soil and ground-surface food-web.

Trends in the data gathered will depend on the properties of local micro-habitat conditions, so measurements of soil moisture, texture, organic matter) and vegetation (ground cover, species composition) should be included alongside these indicator groups.

**Findings**

- More earthworms in conservation tillage systems and with organic matter amendments are high.
- Earthworm numbers are correlated with litter decomposition rates through interactions with soil micro-organisms.
- Soil invertebrates are sensitive to changes in soil conditions.

### Field Margin Plant Functional Types



### Economics and whole-system sustainability

**Background**

Agricultural practices that benefit the environment in terms of soil quality and biodiversity, are often in conflict with management to maximise yield output. However, degradation of the farmland environment in which food is produced is unsustainable in the long-term.

To assess how well a cropping system meets these multiple goals, indicators of both economic and environmental sustainability need to be combined.

**Methods**

Environmental indicators include the biodiversity and soil health assessments outlined here which, together with data on agronomic practices and inputs (collected from farm records), impact overall system sustainability.

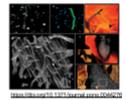
Economic indicators for the impact of a change in management at the field-scale include all input costs (agrochemicals, amendments, seed), plus fuel use, tractor time, yield, product quality and sale prices.

Using these data, a qualitative, multi-criteria sustainability assessment can then be carried out via the CSC Toolkit: all indicators are aggregated into a hierarchical framework where overall sustainability at the top is broken down into economic and environmental components, each of which are further subdivided into progressively smaller elements, down to individual measured indicators at the bottom.

This user-friendly tool highlights where the positive and



### Monitoring: soil microbial function



**Background**

Earthworm activity, organic matter inputs and low input agriculture enhance the microbial soil-plant system, giving resilience to stresses.

Microorganisms are critical fungi which form communities with availability of nutrients. Activity is maintained such as litter decomposition.

Microbial diversity also enhances pathogen competition, antagonists, as the past properties of

**Methods**

Assessment of the soil microbiome and quantification of specific microbial responses to field management requires specialist knowledge and laboratory techniques.

Simple indicators of the soil functions that are driven by the microbial community are therefore required.

Most indicators focus on litter decomposition processes, e.g. the community science projects:

- "Time for tea" - the Global Litter Decomposition Study, which uses the loss in weight of teabags buried for the duration of the growing season to calculate rates of litter decomposition. ([www.teacomposition.org](http://www.teacomposition.org))
- "Soil my Undies Challenge" a fantastic KE exercise where farmers were encouraged to bury cotton underpants to test the level of biological activity in their soils. Breakdown of the cotton was greater in fields with 'healthy soil' management.

A more formalised protocol for measuring organic-matter decomposition represented by the breakdown of cellulose in standardised strips of woven cotton fabric can be used to give a quantifiable comparison across sites and fields.

**Findings**

- Faster rates of litter decomposition can be detected in fields with relatively high levels of organic matter (>3% carbon) and low disturbance (conservation tillage).
- Organic matter and less disturbance enhances the soil microbial community and therefore the rate of associated decomposition processes.

**Measurements**

No single sampling method can capture a complete and accurate picture of the invertebrate community in a particular habitat. However, selecting a suite of sampling strategies with a knowledge of their inherent bias in mind, can give sufficiently reliable measures for estimating biodiversity impact.

Pitfall trapping is a quick and easy method that samples ground-surface active predators including hunting spiders, ground beetles and rove beetles.

Sampling should be carried out in both spring and autumn to capture species with different breeding seasons and life history strategies.

This method does not measure abundance of the species present but is a combined measure of activity and population density; trapping is biased towards species that move rapidly with frequent changes in direction. Trap modifications can increase accuracy of population measures, but the basic trap gives a functional and ecologically relevant estimate of change in management or land use and a relative estimate of diversity between sites.



**Results**

- Ground beetles, rove beetles and spiders are good indicators of broad habitat quality and farmland management, but
- activity patterns and vegetation structure needs to be considered for an assessing subtle differences across systems.
- Further work is required to quantify the extent to which different species disperse into fields and their functional role in pest and weed seed predation.





# Step 4: Implementation and impact assessment

- Implement on farm
- Monitor using same indicator protocols
- CSC dashboard: analysis of impact on indicators over time – costs, benefits and risks

## Processes

- Minimising inputs
- Optimising resource use efficiency
- Reducing losses

## Outputs

- Biodiversity gains
- Soil quality
- Yield



# Minimising inputs: crop protection

## Engineered solutions



**Biofortification for crop resilience:** Preliminary data indicate less *Septoria* infection in winter wheat compared with standard fungicide treatment.

Contact: Andrew Christie



**Disease forecasting:** Blight sprays down by 1 to 4 a year using the Hutton Criteria and “One Class” model to predict risk.

Contact: Alison Lees

# Minimising inputs: crop protection

## Biodiversity-based solutions



**Diverse field margins:** provide habitat for insect predators and floral resources adult forms of Dipteran and parasitoid natural enemies.

Contact: Cathy Hawes

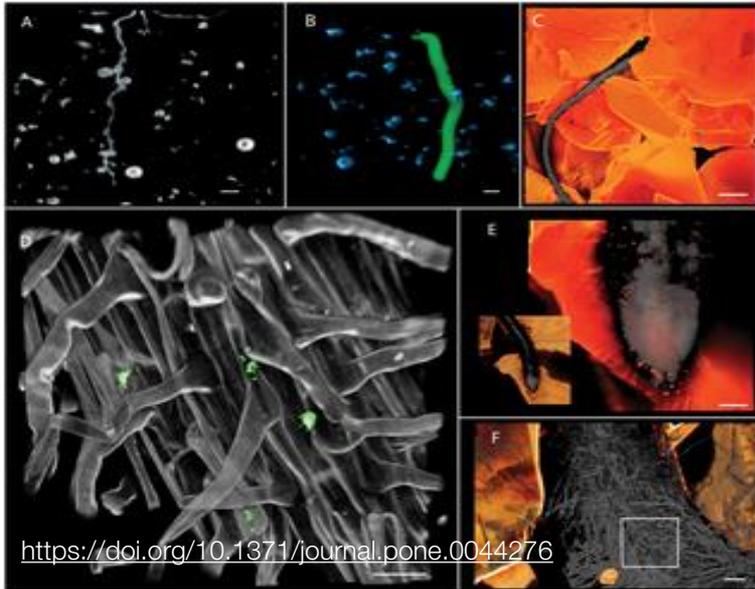


**Weed biodiversity:** supports diverse foodwebs, regulating pest populations through competition with non-pest herbivores and predation by natural enemies.

Contact: Cathy Hawes

# Minimising inputs: crop protection

## Biodiversity-based solutions



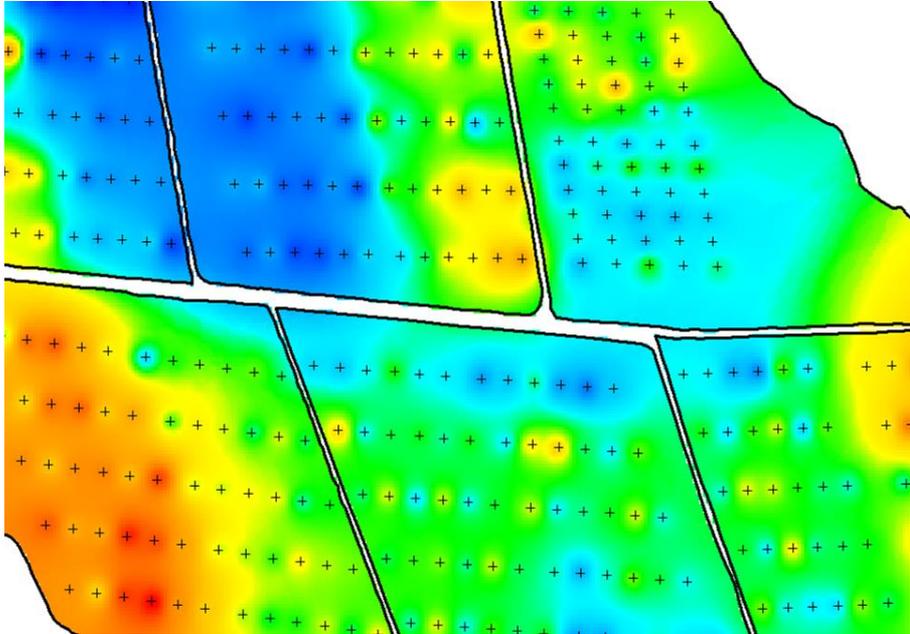
**Soil biodiversity:** organic matter & reduced disturbance generate diverse microbial communities with pest suppressive properties (antagonistic with soil borne pathogens).

**Crop diversity:** canopy heterogeneity in mixed varieties/species of crop reduces apparency to pests and disease, minimising population spread through fields.

Contact: Maddy Giles, Jennie Brierley

Contact: Ali Karley, Adrian Newton

# Minimising inputs: fertiliser



Soil Nitrogen Supply used to calculate N input requirements; timing of application targeted for max growth periods. Results in ca. 40% reduction in mineral N input.

Contact: Andrew Christie



Biological Nitrogen Fixation by Faba bean and under-sown clover can reach  $> 200 \text{ kg ha}^{-1} \text{ yr}^{-1}$  leaving up to  $50 \text{ kg ha}^{-1} \text{ yr}^{-1}$  residual N in soil post-harvest.

Contact: Pete Iannetta, Euan James

# Optimising efficiency

Reduced soil disturbance and diverse carbon inputs (weeds, cover crops, crop residue and compost):



Improved soil structure for better crop rooting and nutrient/water uptake efficiency: pore diversity, aggregate stability and water holding capacity are increased, bulk density is lower.

Contact: Tracy Valentine



Increased microbial biomass, mycorrhizal fungi and macro-invertebrate abundance resulting in faster rates of decomposition and nutrient availability.

Contact: Tim George, Cathy Hawes



# Minimising losses: in-field

Nitrogen losses from arable systems:  $\sim 280 \text{ kg N ha}^{-1} \text{ yr}^{-1}$ , 50% from erosion, runoff and GHG emissions

- Organic matter inputs + reduced tillage - improve soil structure, reducing **erosion**
- Tied-ridging - increased water infiltration, reducing **run-off**
- Cover crops - retain nutrients over-winter, reducing **leaching**
- Plant diversity - better resource use efficiency, reducing **GHG emissions** and **leaching**





# Minimising losses: field boundaries



Multi-functional margins take up leached nutrients and minimise GHG emissions.

Contact: Tim George, Tim Daniel, Cathy Hawes



Engineered riparian buffers to slow movement of water from fields into natural watercourses, using coppiced willow/alder to take up excess nutrients; NBS-AIMS (D2)

Contact: Marc Stutter, Mark Wilkinson, Ken Loades



“Magic margins” developed by farm team win RSPB Nature of Scotland Innovation Award.

Contact: Euan Caldwell



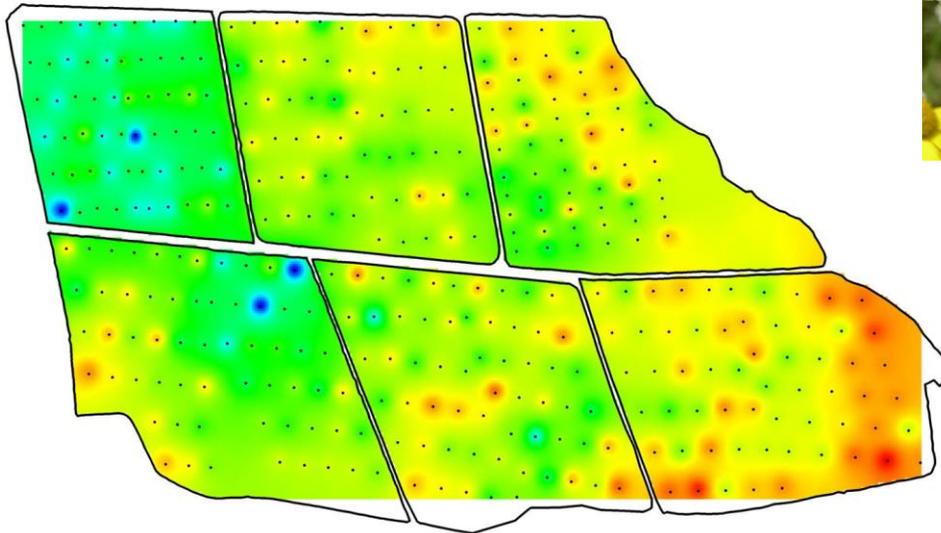
# Outputs: yield



- Yields comparable to national averages (Squire et al. submitted)
- 1<sup>st</sup> rotation – 1 t/ha yield penalty in winter wheat; no significant effect on other crops (Hawes et al. 2018, 2019)
- 2<sup>nd</sup> rotation – analysis to follow 2023
- Modelling work with Jagadeesh and Mohamed
- Differences in varietal responses to management
  - Deeper rooting cereal varieties perform better in integrated system (no-till) in extreme years (Newton et al. 2021)
  - Variation in BNF by faba bean varieties (Maluk et al. 2022)
  - Nutritional variation between potato cultivars, but no treatment effects (Frietag et al. 2016)

# Outputs: biodiversity

- More (beneficial) dicot weeds in soil seedbank
  - No overall effect of cropping system on grass weed seedbank, but more following wheat and bean crops
- Knock-on benefits to pollinators and other beneficial invertebrates



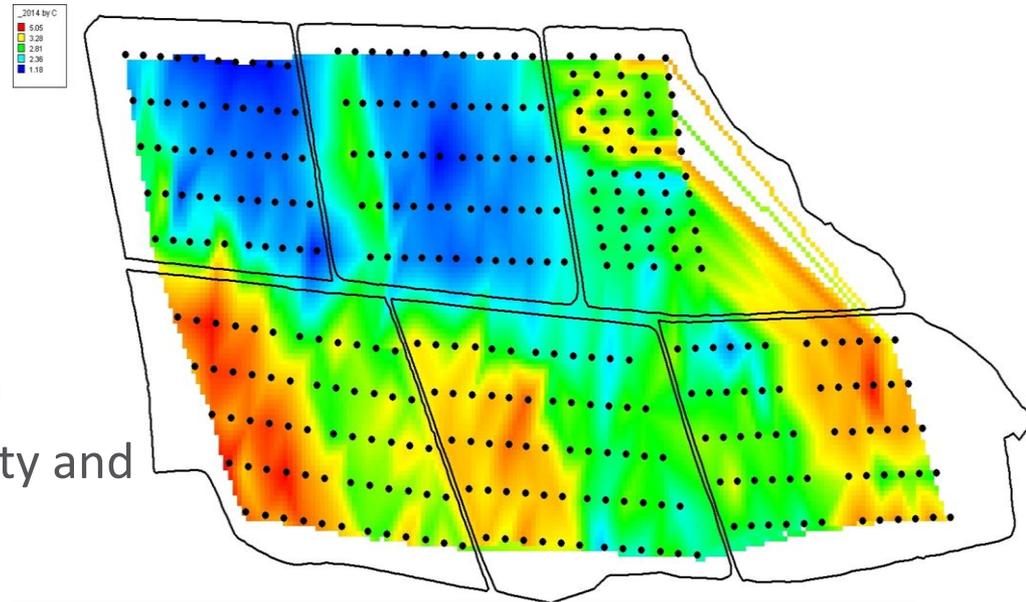
Species richness in weed seedbank



Drone/phone imaging for automated diversity assessment

# Outputs: soil

- More soil organic matter
- Positive correlation with litter decomposition rates
- Enhanced biological activity  
earthworms, mycorrhizae, pest suppression
- Aggregate stability, pore size diversity and bulk density improves





# Step 5: whole-systems assessment



- Data entry form for farmers/consultants
- Feed into automated summary stats/ farm report
- Sustainability assessment via DEXi-CSC
- 97 input variables; 332 aggregate variables
- Compares overall sustainability and components across cropping systems





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for more information

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