

BCPC Diseases Review 2019

Integrated disease management for soil-borne pathogens

Dr Amanda Bennett, AHDB

Overview

- Research often focused on understanding a single pathosystem
 - Biology, ecology and epidemiology of the pathogen
 - Host genetic tolerance and resistance
 - Environmental conditions
- Practical management on-farm
 - Detection in soil
 - Integrated methods for control
- Rotational soil management
 - Soil health and crop health



Developing targeted management methods for clubroot through pathotyping and field mapping



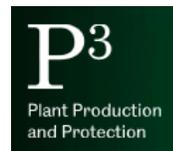
Prof. Fiona Burnett, SRUC

Dr Julie Smith, ADAS

(Aug 2015 – Feb 2019)



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soilessentials
precision farming solutions



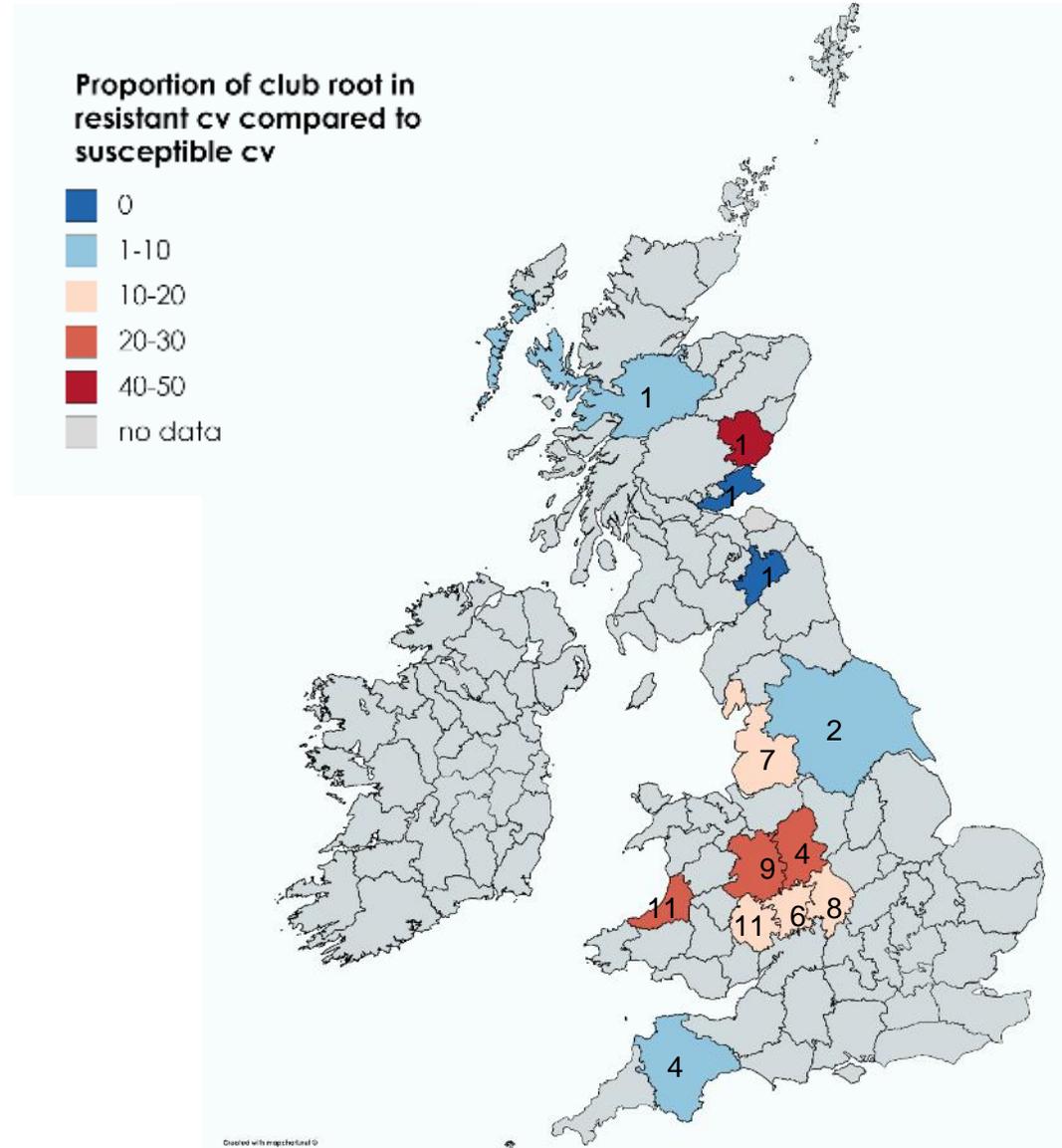
Clubroot caused by *Plasmodiophora brassicae*

- Wide host range: oilseed rape, vegetable brassicas, cover crops, weeds
- Yield reduction = 0.3 t/ha for every 10% clubroot severity
- Inoculum can survive in soil for 15 years, half life of 4.5yrs
- Exacerbated by close rotations
- Often goes undetected at field and national level
- Cultivar resistance based on single dominant gene and is being eroded
- Fungicide and bio-control options not available
- Limited management from agronomic strategies

Prevalence of resistance breaking strains present in the UK

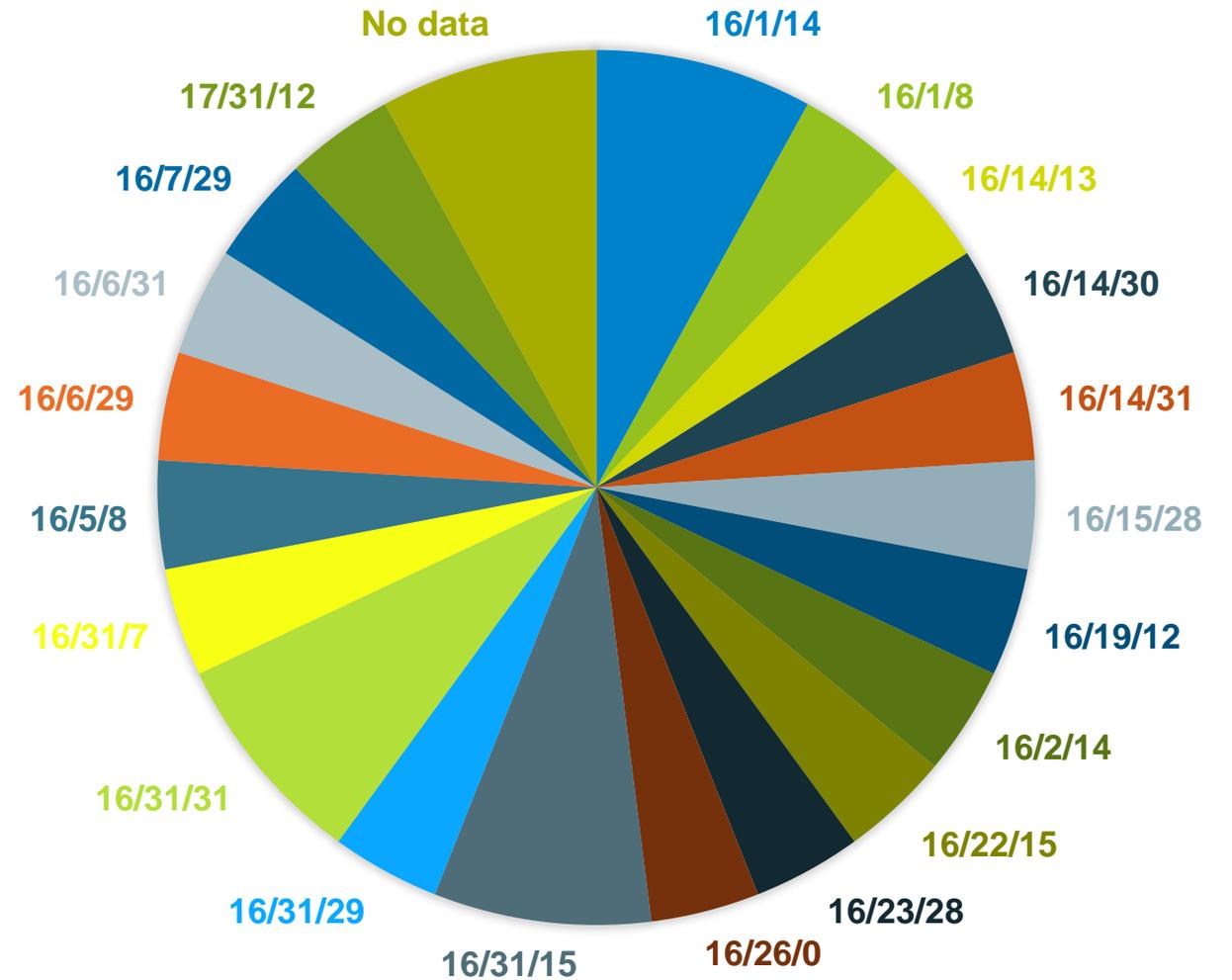
~75 commercial fields sampled

'Mendel' resistance breaking strains identified

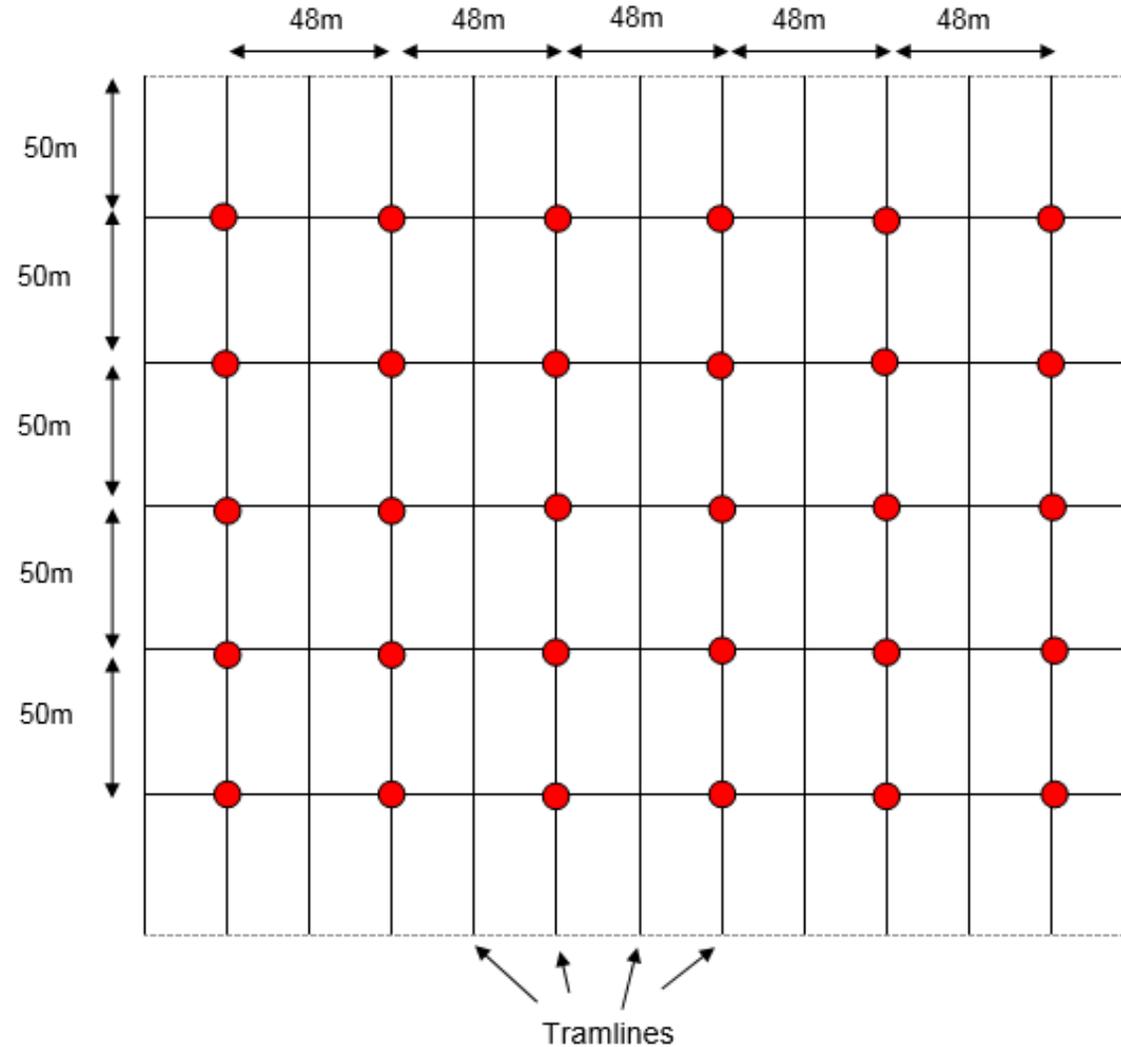


Diversity of pathotypes in the UK

European clubroot differential set

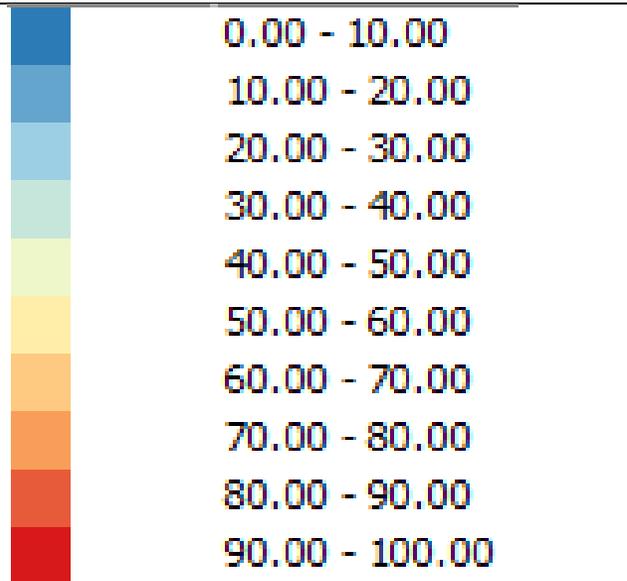


Impact of inoculum density on yield - when would patch treatment be economic?

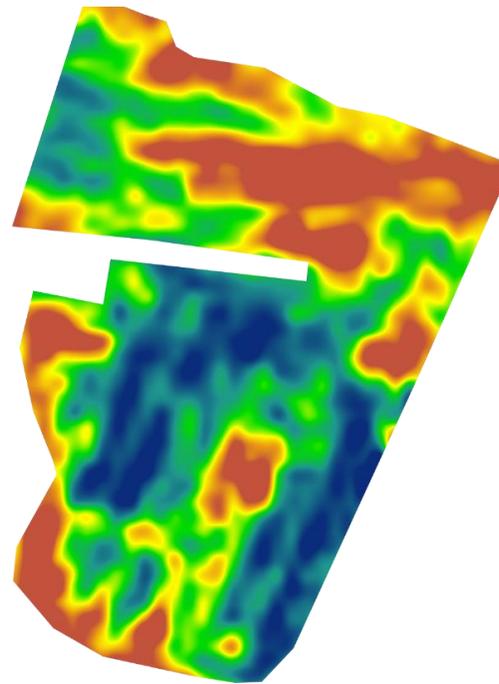




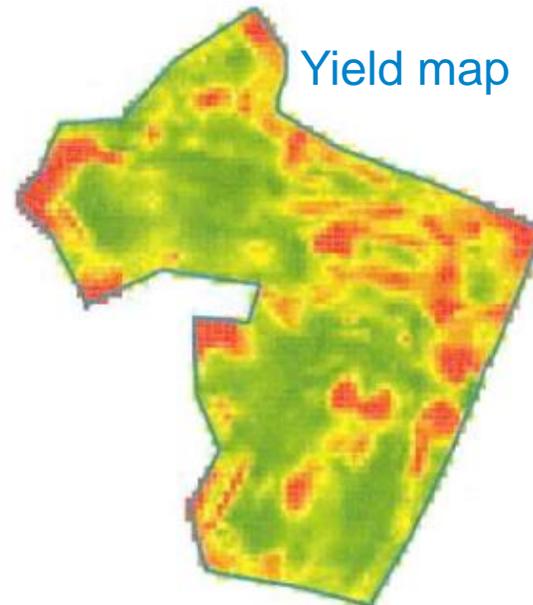
Congrieve, April 2018 – club root severity index (0-100)



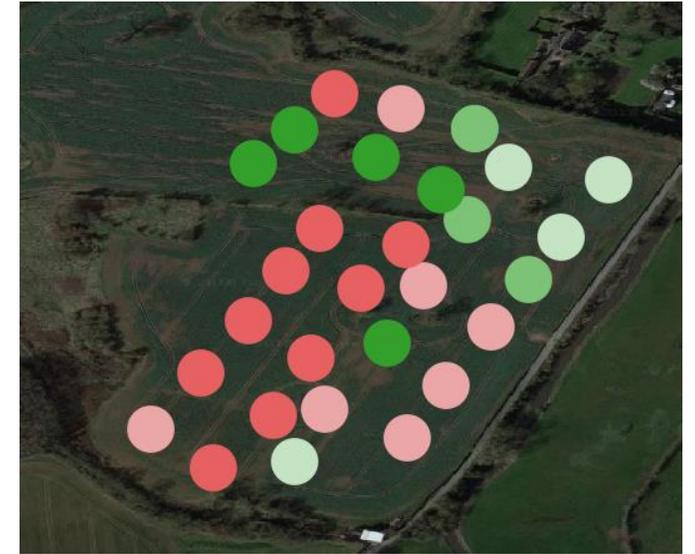
Congrieve, Clubroot severity index key (0 – 100)



Congrieve, April 2018, NDVI map



Yield map



Margin over liming cost

Colour	£ per hectare (£/ha)
	-150 – -100
	-100 – -50
	-50 – 0
	0 – 50
	50 – 100
	100 – 150

Integrated management for clubroot (OSR)

- Rotation planning – cover crop mixes often contain susceptible species
- Use field mapping to target control
- Keep accurate crop records of clubroot occurrence, location and intensity
- Frequency and detail of testing is key in susceptible rotations
- Buy certified seed; do not home-save resistant varieties
- Manage volunteers and susceptible weeds
- Long term planning should be based on the long-term profitability and sustainability of a field

Clubroot management in crops

Pathogen

Plasmodiophora brassicae

Hosts

Clubroot affects all cultivated and wild cruciferous plants. In addition to oilseed rape, all vegetable brassica species are affected. Other susceptible broad-acre arable crops include turnip, swede, Brussels sprouts, cauliflower, calabrese and mustard. Numerous weed species, such as charlock and shepherd's-purse, are also common hosts.

Symptoms

The first symptoms usually occur within six weeks of planting, provided soil temperatures are greater than 15°C. In oilseed rape, symptoms commonly start in late autumn. Roots become swollen and distorted, and develop small, irregular, white-coloured, solid galls. These are present on taproots and/or lateral roots. As the season progresses, galls may enlarge and discolour, before starting to rot.

Above-ground symptoms do not usually develop until later in the season. Typical symptoms include stunting and yellowing. Under dry conditions, plants may wilt, especially when galling is severe. Distinct patches of poor growth are often visible. Plant loss occurs in the most severely affected areas and, occasionally, the whole field may fail.

Life cycle

Clubroot is a soilborne pathogen that produces resting spores. These spores have thick walls and help the pathogen survive for up to 15 years in the soil. Chemicals, released by the roots of host plants, cause nearby resting spores to germinate and release motile spores (zoospores). These move through soil water and infect the host's root hairs, where a secondary spore stage occurs. These spores invade the outer layer of the root (the cortex) and form structures called secondary plasmodia. These structures cause the root cortical cells to enlarge and increase the rate of cell division. Ultimately, this results in the formation of the characteristic clubroot galls. These galls decay during the season and release large numbers of resting spores back into the soil.

Importance

Clubroot is a global problem and has increased in recent years. For example, many new UK cases were reported in 2016, often on farms with no history of the disease. The trend for shorter rotations, along with milder and wetter winters, have probably



Figure 1. Clubroot symptoms in oilseed rape



Figure 2. Inspection of soil from a suspected clubroot site

www.ahdb.org.uk/clubroot

Rotational soil management

Healthy soils, healthy roots

Soil Biology and Soil Health Partnership



Soil Biology and Soil Health Partnership

- Five years to deliver linked knowledge exchange and research on soil biology and soil health
- Building on work already carried out

Aims to:

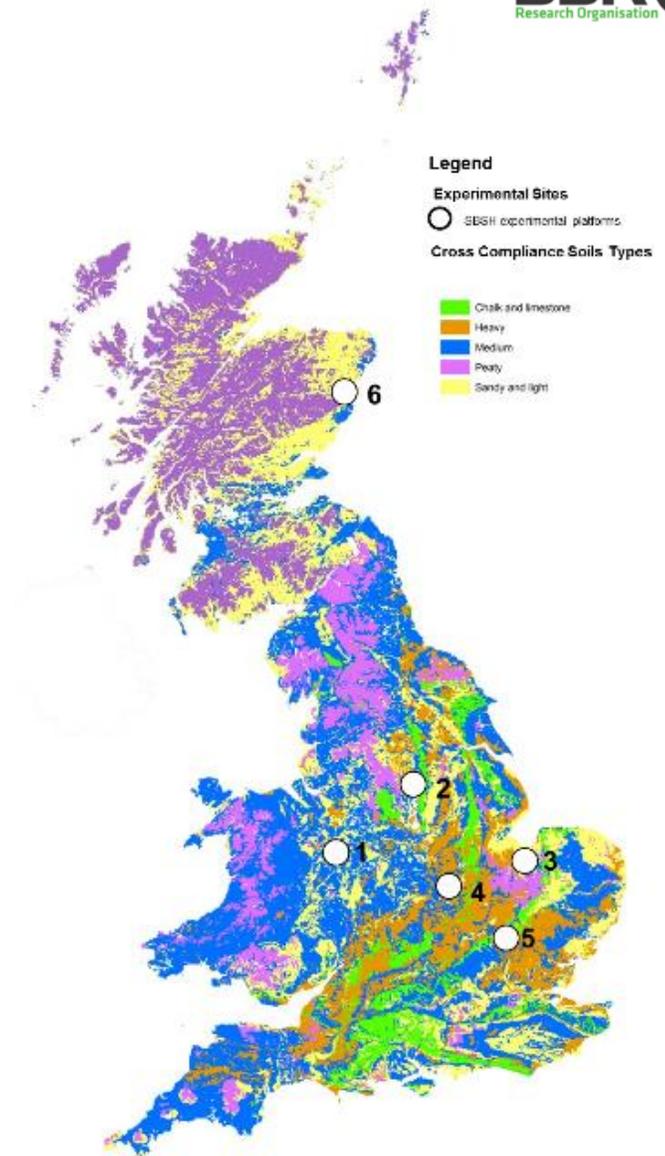
- Improve on-farm understanding of soil health by sharing current academic and industry knowledge in usable formats
- Develop and validate indicators of soil biology and soil health in research trials and on-farm

All soils are different



Soil health assessment sites: Arable and ley/arable rotations

1. Harper Adams
 2. Gleadthorpe
 3. Terrington
 4. Loddington - Tillage
 5. Boxworth - Drainage
 6. Craibstone
 - a. Crop rotation x fertiliser; 90+yrs
 - b. Crop rotation x pH; 60+yrs.
- } 10-20 years of repeated organic material additions



Developing and validating indicators of soil biology and soil health

- Visual assessment of soil structure (VESS)
- Penetrometer resistance
- Bulk density

- pH
- Routine nutrient analyses (P, K, Mg)
- Soil organic matter / loss on ignition
- Total N
- Potentially mineralisable nitrogen

- Earthworms
- Mesofauna
- Nematodes
- Microbial biomass carbon
- Respiration: Solvita® test



- DNA measures of pathogens and soil health

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- DNA measures of pathogens and soil health

Attribute*	Field A; Farm 1	Field B; Farm 2	Field C; Farm 3
SOM (%)	3.4	2	2.2
pH	6.7	6.9	7.0
Ext. P (mg/l)	40.6	59.6	37.2
Ext. K (mg/l)	158	106	148
Ext. Mg (mg/l)	82	89	144
VESS score	2	2	2
Earthworms (Number/pit)	13	8	1

 Investigate

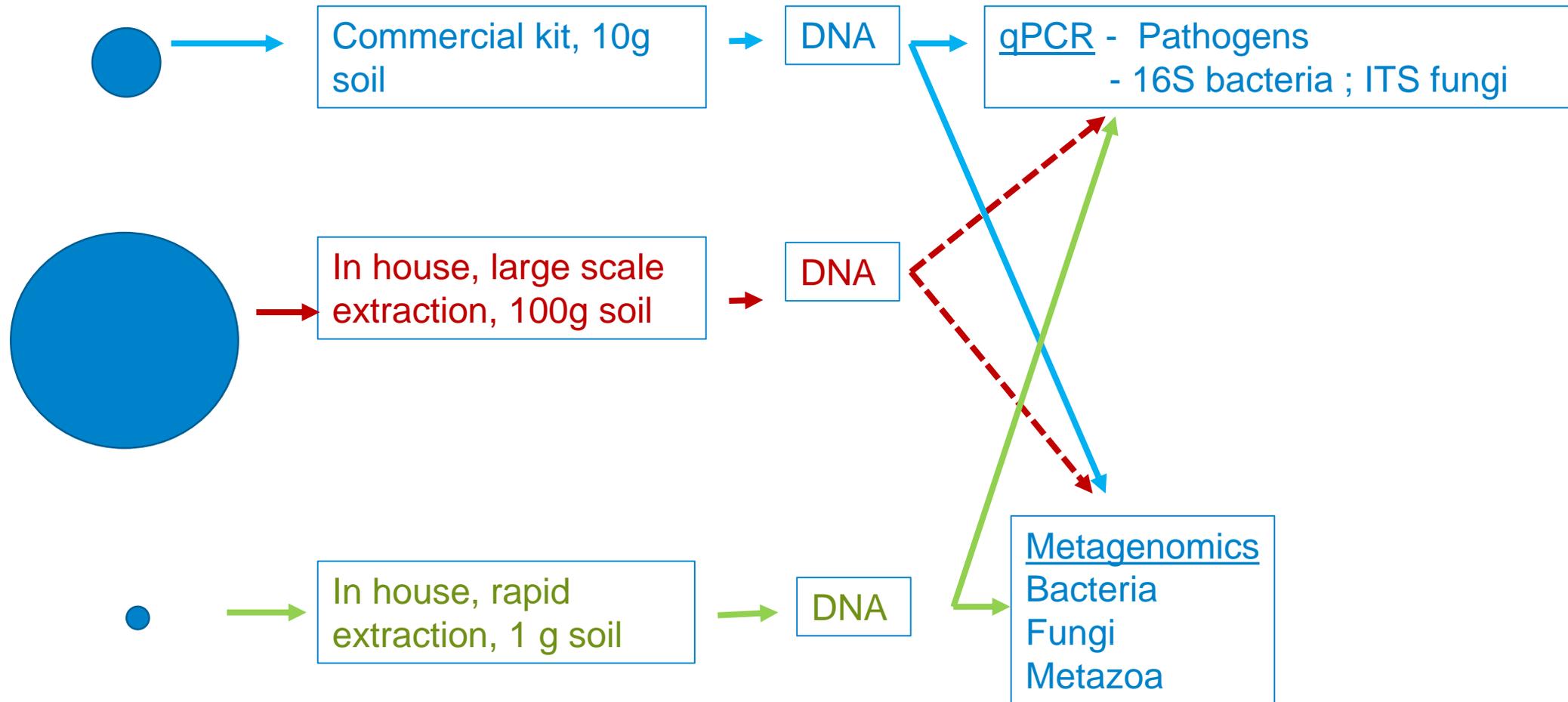
 Monitor

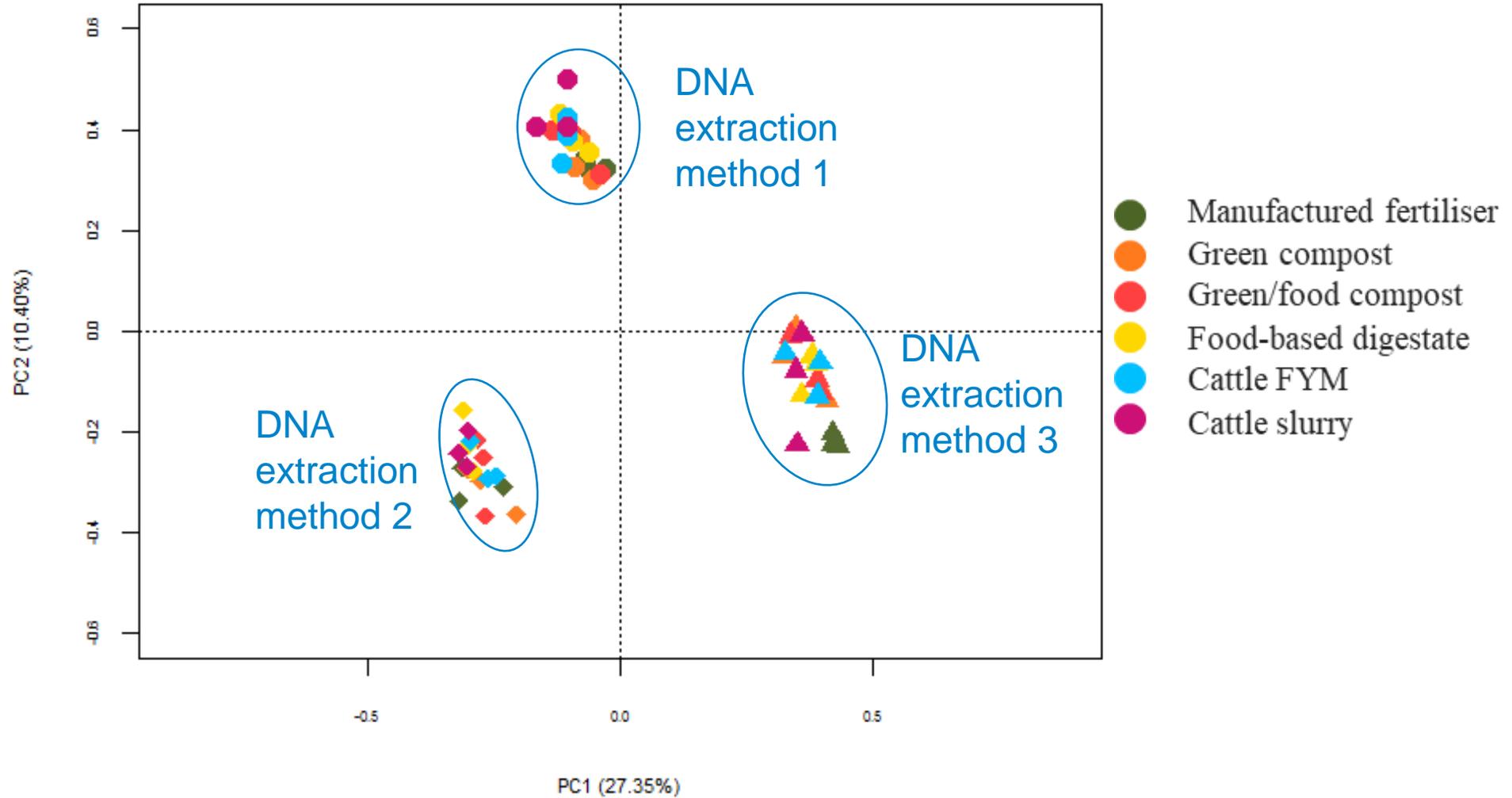
 No action needed

Assessing soil health using DNA

- Can we replace many of the biological assays with analysis of a single DNA sample?
- Sample size and cost evaluated in a comparative experiment
- Interpretation by analysing the same samples as the ‘traditional’ assays







Research case studies

- The role of molecular indicators for measuring soil health
- Testing the soil health scorecard (on-farm monitoring 2018-2019)
- Testing the effect of organic material additions on soil health
- Testing the effect of pH on soil health

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Soil Biology and Soil Health Partnership Research Case Study

Testing the soil health scorecard (On-farm soil monitoring 2018-2019)

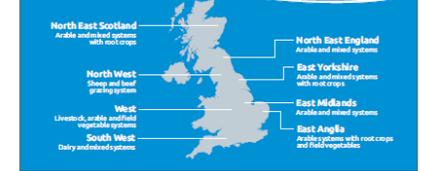


Figure 1. Locations of the farmer-research-innovation groups working with the Soil Biology and Soil Health Partnership.

Background
Growing food and fibre crops requires soils to be maintained in a suitable state that provides optimal soil structure, water retention and nutrient availability. The physical, chemical and biological properties of soil interact to deliver these functions. Measuring soil health therefore requires an integrated approach that combines the assessment of the chemical, physical and biological properties of soil. There is a good understanding of the soil chemical and physical constraints to crop and grassland productivity, however, the role of soil biology is less clear.

A key aim of the Soil Biology and Soil Health Partnership is to improve our understanding of soil biology and to explore ways that farmers can measure and manage soil health. The Partnership has developed a soil health scorecard, which aims to provide information on key indicators of the chemical, physical and biological condition of soil, to help guide soil and crop management decisions.

Measuring soil health on farm
The Partnership is working with eight farmer-research-innovation groups around the UK to evaluate the soil health scorecard approach, and test it on farm. Further groups with a focus on protected cropping and permanent fibre crops will test the scorecard approach during the summer and early October.

Farmers across the groups are involved in a range of practices that support soil health, including: regular soil testing; linking yield maps and soil nutrient patterns; extended rotations; innovative grazing management systems; application of a range of organic matter sources (PVM, digestate, compost); use of cover crops and companion cropping; livestock introduced to enable systems; adoption of no till and controlled traffic systems.

Testing the soil health scorecard
The farmer groups have tested the proposed new sampling approach for soil health: observations of soil structure and earthworm numbers are made at ground-level sites within a field, samples for laboratory analysis are collected at the same time. To allow us to benchmark data between the groups, the data must be collected in the same way and under similar soil moisture/temperature conditions. Currently, within the Partnership, we are making the soil health assessments:

- After harvest, and
- After the topsoil has settled up in the autumn, and
- At least one month after any cultivation/moderate soil disturbance.

In the dry autumn of 2018, 67 samples were collected by 29 farmers between late October and early December.

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Soil Biology and Soil Health Partnership Research Case Study

Testing the effects of organic material additions on soil health



Figure 1. Manure spreader (Source: AHDB)

Established in 1991 on a sandy loam soil PVMs* (Soil Services) treatments include annual applications of cattle farmyard manure PVM, cattle slurry, green compost, green/food compost and food-based digestate, compared with a control treatment receiving manufactured fertiliser only, thus providing a variety of 'food sources' for the soil biological community. Measurements of topsoil (chemical, physical and biological properties) were undertaken in October 2017.

Table 1. Organic matter treatments*

Treatment	Applications to autumn 2017	Organic matter loading (t/ha)
Control	None	0
Cattle PVM	23 years	136
Cattle slurry	23 years	53
Green compost	13 years	62
Green/food compost	7 years	27
Food-based digestate	8 years	7

*tailored with manufactured fertiliser nitrogen to ensure it supply does not limit crop growth

Soil health scorecard†
The scorecard approach brings together information about soil chemical, physical and biological properties. The integrated report uses 'traffic light' coding to identify the properties where further investigation is needed to deliver the management steps required to maintain and/or enhance soil health. This is now being tested at a series of long-term experimental sites exploring the key drivers of soil health: food sources, physical and chemical environment.

Long-term experimentation at Harper Adams University
This long-term experimental investigates the impact of repeated organic material additions (at recommended rates) on soil and crop quality in a conventionally arable rotation (wheat and potatoes), previously established as part of the WIPAC 20-Agri experimental programme (investigating the use of digestate and compost in agriculture [www.wipac.org.uk/20-agri]).

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Soil Biology and Soil Health Partnership Research Case Study

Testing the long-term effect of pH on soil health



Figure 1. Aerial image of the Waddesley long-term experiment at Chobson. Crop rotation: Three-year grass/clover ley (Green Year 1-3), winter wheat, potatoes, spring barley, beans, spring/soyabean (Wheat) with green/clover.

Background
Food and fibre crops need suitable soils that are maintained to provide optimal soil structure, water retention and nutrient availability. The physical, chemical and biological properties of soil interact to deliver these functions. Measuring soil health, therefore, requires an integrated approach, combining the assessment of these three factors. The chemical and physical constraints of soil on crop and grassland productivity are well understood, but the role of soil biology is less clear. A key aim of the Soil Biology and Soil Health Partnership is to improve our understanding of soil biology and to explore ways that farmers can measure and manage soil health. The Partnership has developed a soil health scorecard, which aims to provide information on key indicators of soil chemical, physical and biological condition, to help guide soil and crop management decisions. This is now being tested at long-term experimental sites (LTM), where the key drivers of soil biology – food sources, physical and chemical environment – are being explored.

Long-term experiments at SRUC Chobson
Soil pH is a key component of soil health because it affects soil chemical (e.g. availability of nutrients), biological (e.g. microbial activity and physical properties (e.g. aggregation of clay minerals). The long-term pH trial in Woodlands Field at SRUC Chobson near Aberdeen was set up in 1981.

Here, the effects of pH levels ranging between 4.5 and 7.5 (on 0.5 increments) on soil properties and crop performance are being tested. The trial involves an eight-crop rotation comprising 3-year grass/clover ley, winter wheat, potatoes, spring barley, beans and spring/soyabean with green/clover. Each crop in the rotation is present every year, enabling a comparison of the responses of all crop types within the same season (Figure 1). Measurements of topsoil chemical, physical and biological properties were taken in October 2018, from four crops (second-year ley, following winter wheat, potatoes and spring/soyabean) at four pH levels (4.5, 5.5, 6.5 and 7.5).

Soil health scorecard†
The scorecard brings together information about soil chemical, physical and biological properties. The integrated report uses traffic light coding to identify those properties requiring further investigation to determine the management steps needed to minimise potential risks to crop productivity. Here, we report initial testing of the scorecard for those soil properties that already have an established evaluation framework (e.g. soil nutrients, visual evaluation of soil structure score (VSS)). Research continues to develop interpretation frameworks for three soil properties, including biological indicators (e.g. microbial biomass/respiration, nematodes).

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Soil Biology and Soil Health Partnership Research Case Study

The role of molecular-based indicators for measuring soil health

Background
Food and fibre crop production requires soils to be maintained in a suitable state that provides optimal soil structure, water retention and nutrient availability. The physical, chemical and biological properties of soil interact to deliver these functions. Measuring soil health therefore requires an integrated approach that combines the assessment of the chemical, physical and biological properties of soil. There is a good understanding of the soil chemical and physical constraints to crop and grassland productivity, however, the role of soil biology is less clear.

A key aim of the Soil Biology and Soil Health Partnership is to improve our understanding of soil biology and to explore ways that farmers can measure and manage soil health. The Partnership is investigating the value of DNA markers for estimating the effect of soil- and crop-management practices on the microbiological diversity of soils as well as to study the population dynamics of beneficial versus plant pathogenic fungi and bacteria.

distinct individuals can be compared across the different treatments and bioinformatics software can be used to measure biological diversity in each sample.

Table 1. Organic matter treatments at the long-term trial at Harper Adams University

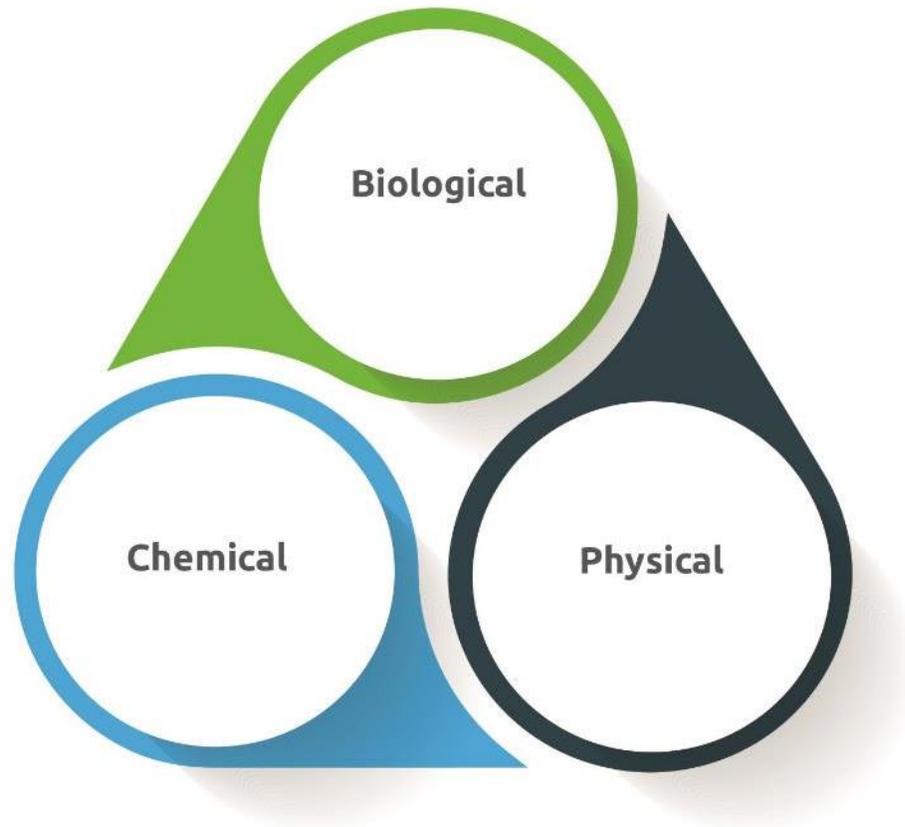
Treatment	Applications up to autumn 2017
Cattle PVM	23 years
Cattle slurry	23 years
Green compost	13 years
Green/food compost	7 years
Food-based digestate	8 years

Estimating the effect of long-term organic material additions on soil microbial diversity
To investigate the impact of repeatedly adding different organic materials to soil in a predominantly arable rotation (cereals and potatoes), samples were collected from a long-term trial at Harper Adams University in October 2017. Details of routine measurements of topsoil chemical, physical and biological properties were undertaken (see Research Case Study: Testing the effect of organic material additions on soil health).

For comparison, soil samples were also taken for total DNA analysis. The DNA was extracted and purified using three different methods and then analysed using high-throughput sequencing technology. This compares DNA sequences of marker genes that are unique to all bacteria (16S rRNA) or fungi (ITS rRNA) in a process known as metabarcoding. Using this molecular technique, most soil organisms can be identified at higher taxonomic levels (e.g. phylum, class or order), although there can be accurately assigned at the levels of family, genus or species. However, these, the numbers of taxonomically

Results to date
Between 100,000-200,000 DNA sequences were obtained for both bacterial and fungal groups from each soil sample from the Harper Adams trial, irrespective of the different methods used to extract the DNA, similar types of bacteria and fungi were recognised within the soil communities (Figure 1). The extraction method did, however, influence estimates of the relative abundances of these types of bacteria and fungi (Figures 1 and 2). Standardisation of methods will therefore be important when comparing samples collected from different locations and at different times. When results from plots with and without organic amendments were compared, no significant effects of any of the amendments on bacterial or fungal types or abundances were found (Figure 2).

Integrated management for soil health and soil-borne pathogens



- Field mapping – ‘know your soils’
 - Investigate poor areas
 - Dig a hole
 - Soil testing and diagnostics
 - Pull up a plant to look at roots
- Cultural practices
 - Extend and diversify rotations
 - Cultivations
 - Organic amendments
- Varietal resistance/tolerance
 - Seed rate

Future

- Soil management to suppress disease
- Precision mapping of soil-borne pathogens (monitoring)
 - Soil sampling
 - Diagnostics
 - Targeted management approaches
- Thresholds for disease development and impact on yield or quality
 - Environmental conditions
- Varietal tolerance or resistance
 - Breeding: examining below-ground traits
- Seed treatments

A vibrant landscape of a green field at sunset. The sun is low on the horizon, casting a warm glow over the scene. The sky is filled with soft, colorful clouds in shades of orange, yellow, and blue. A path of tall green grass leads from the foreground towards the horizon. In the distance, there are rolling hills and a few buildings. The overall mood is peaceful and inspiring.

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