NIAB TAG

Landmark

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Boosting natural enemy populations and stepping up monitoring

Photo: Patrick Stephenson

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Whatever happened to Sustainable Intensification?

It is only 12 years since the Royal Society's *Reaping the Benefits* report coined the term 'Sustainable Intensification' and just 10 years since Professor Sir John Beddington's Foresight Report on global food security identified Sustainable Intensification as the most effective way forward to feed a growing world population while preventing biodiversity loss, tackling climate change, protecting and enhancing the natural environment.

None of the factors which made up Beddington's 'Perfect Storm' warning on global food security have disappeared – the balance between food supply and demand remains as precarious as ever and it will only take a single year of harvest failures around the world to plunge the situation back into crisis.

And yet the UK Government's appetite for Sustainable Intensification appears, for some reason, to have dissipated in recent years to be replaced by this new, as yet undefined, 'Path to Sustainable Agriculture'.

The Agriculture Act, the first major reform of farm policy in more than 40 years, seeks to balance new payments for public goods with incentives to improve farm-level productivity.

In its 2009 *Reaping the Benefits* report, The Royal Society espoused a vision which interpreted 'agroecology' as the foundation of sustainable intensification, using modern genetic technologies to reduce input use without compromising yields or production efficiency.

Government ministers today must be very cautious in their support for what is termed 'agroecology'. Somehow this word has been effectively hijacked by campaigning NGOs to mean farming without artificial fertilisers, pesticides or advanced breeding technologies such as gene editing.

Rather a disturbing report crossed my desk earlier this year. Entitled *Farming for Change: mapping a route to 2030*, it came from the official sounding Food, Farming and Countryside Commission (est. April 2020), and essentially claimed that new research showed how transitioning to 'agroecology' could produce enough healthy food for a UK population while reducing GHG emissions and leaving more room for nature. The modelling 'data' presented in the report is, in my view, inadequate. It appears to be largely derived from IDDRI, a Paris-based think-tank with strong links to campaigning NGOs including Greenpeace. The report also includes forecasts of a 20% reduction in crop yields, for example, but optimistically assumes this will be offset by radical dietary change across the UK population.

Sounds too good to be true?

George Eustice talks positively about his vision of a fusion between traditional farming practices such as soil management and rotation alongside greater access to modern technologies, including precision breeding techniques. That's good! Sounds like the 2009 version of agroecology.

But many of the organisations now championing a transition to their version of 'agroecology' are actively campaigning against such techniques. Many of those same organisations – Soil Association, Sustainable Food Trust, Wildlife Trusts, RSPB, Green Alliance, Buglife – dominate the Government's ELMS test and trial programme which apparently is set to determine the future direction of agricultural support.

To avoid potentially irreversible damage to our national food security, we must put scientific rigour and evidence at the heart of the UK's future agricultural policy, not doctrine and ideology.

Let us not forget that the world needs to increase food production and availability by up to 70% by 2050 to keep pace with the food needs of a rapidly expanding global population, in the face of climate change and increasing pressure on the world's finite natural resources.

A global, 10-year study led by conservation scientists at the University of Cambridge, published a year or so ago in *Nature*, challenged the popular notion that more extensive farming systems are always and inevitably the most sustainable. In fact, their research suggests that high-yield, intensive farming may be the only way to feed the world sustainably.

With its temperate climate, highly equipped and professional farming sector, and world-leading R&D expertise, Britain is uniquely placed not only to optimise its food production capability in response to the global food security challenge, but also to become an international hub for agri-science excellence and innovation: exporting technological solutions, attracting inward investment and fostering international research collaboration.

Early action by Defra to consult on regulatory change to take precision breeding techniques out of the scope of GMO rules, so re-aligning our approach with other non-EU countries such as Australia, Japan, Brazil, Argentina and the USA, is a positive and welcome first step.

Government figures point to a drop in UK agricultural productivity of more than 2% between 2017 and 2018, signalling the scale and urgency of the challenge, and the importance of getting the policy balance right. Future UK policy must focus on optimising the balance between food production, resource use, and environmental impact by encouraging farmers to adopt higher-yielding, more resource efficient production methods so freeing up unfarmed land, habitats and environment for biodiversity, recreation and nature conservation.

There are mounting concerns that without a clear vision and definition of what is meant by the Government's 'Path to Sustainable Agriculture', the UK is at risk of sleepwalking into its own food crisis.

Outside the EU, the UK now has a unique opportunity to embed data science and sustainability metrics at the heart of a policy agenda focused on securing the optimum balance between food production, resource use and environmental impact.

Access to metrics capable of objectively and consistently monitoring a broad range of sustainability parameters will be essential to define the concept of 'sustainable intensification' in practice, to set targets, measure progress and develop coherent R&D programmes. It will also provide the basis to understand and disseminate advice on best practice throughout the industry.

The opportunity to do this already exists within the Agriculture Act, which includes new provisions on data sharing, on providing farmers with the equipment and technology to generate/collect data, and on the development of policies to support improved productivity and resilience in agriculture.

Rather than rewarding individual farmers for specific 'public goods' – which past experience of agri-environmental schemes suggests is inefficient and ineffective – it may make more sense to finance and strengthen the infrastructure itself, particularly in terms of metrics, applied research and knowledge transfer, which will drive the uptake and application of sustainable intensification in practice.

The urgency of the pressures facing our food supply is such that all farming systems and inputs – intensive and extensive – must be subjected to the same process of independent, science-based scrutiny, and measured according to consistent sustainability metrics. This must apply to 'agroecology', however you define it.

According to Professor Andrew Balmford, the University of Cambridge conservation scientist who led the 10-year global research project referred to above, meaningful comparisons between different farming systems – in the context of the food security challenge – require an assessment of resource use and external impacts per unit of food produced, rather than per area farmed.

Comparing environmental costs per unit of production should provide the norm, both in terms of policy development and research to evaluate future technologies. Evidence-based decision-making is the only way properly to understand and identify the path to sustainable agriculture.

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Boosting natural enemy populations and stepping up monitoring

The new Environmental Land Management Scheme (ELMS) is due to be fully rolled out by the end of 2024 with the proposed scheme including three 'tiers' of entry, enabling anyone from any farm or land type to participate at the right level. Faced with changes in land management policy, plus evolving legislation on restrictions in pesticide usage, farmers are also contending with the reality of increasingly warmer winters which hamper efforts to effectively manage key crop pests such as aphids and beetles. It would seem like the time is right for a re-think about how we view our land and farming practices as useful tools for natural pest control.

One of the most sustainable ways to minimise economic damage from pests is to boost populations of existing or naturally-occurring beneficial organisms, or 'natural enemies', by supplying them with appropriate habitat and alternative food sources. The term natural enemy includes large predators such as ground beetles, spiders and ladybird larvae, smaller parasitic species such as wasps and pest-attacking pathogens, and nematodes that are naturally occurring in our soils.

To an insect pest, a fertilised, weeded and watered monoculture is a dense, pure concentration of its favourite food. Many pests have adapted to these cropping systems over time. Natural enemies, however, do not fare as well because they are adapted to natural systems. Natural enemies need more than prey and hosts; they also need refuge sites to overwinter in, and alternative food such as pollen and nectar from nearby flowering weeds while searching for hosts. Tilling, spraying, harvesting and other typical farming activities can thus damage their habitat, and farms that

Photo: Martin Lines

Habitat creation

Insect trapping and monitoring setup at NIAB's Dorset site

A slug and pitfall trap in place at Strategic Farm East, Suffolk

Parasitoid wasp species

Ground beetle species

host plentiful populations of natural enemies share some typical characteristics. Fields are smaller and surrounded by natural vegetation. Pesticide use is kept to a minimum. Cropping systems and rotations are diverse and plant populations in or around fields include perennials and flowering plants. Soils are high in organic matter and biological activity and, during the off-season, covered with vegetation in the form of stubble or a cover crop.

The good news is that a high proportion of conventional farmers in the UK already embrace many of the practices that encourage natural enemies. But we can always do better. With this in mind, what can you do on your farm in the short, medium and long-term to conserve and develop rich populations of natural enemies and support their biological needs?

Make adjustments to cropping practices

Even small changes in farming routines can substantially increase natural enemy populations during critical periods of the growing season. Think about looking to reverse practices that disrupt natural biological control, such as insecticide applications, hedge removal and comprehensive herbicide use intended to eliminate weeds in and around fields. By leaving stubble instead of ploughing in, it provides humid, sheltered hiding places for predators like spiders and ground beetles. In tandem with this, by decreasing the visual contrast between foliage and bare soil, stubble can also make it harder for pests like aphids and flea beetles to see the crops they attack.

Diversify and manage vegetation in field margins

Carefully selected flowering plants or trees in field margins can be important sources of natural enemies, but they can also modify the crop microclimate and add organic matter. Predaceous ground beetles – like many other natural enemies – do not disperse far from their overwintering sites, so access to permanent habitat near or within the field gives them a jump-start on early pest populations. By sowing diverse flowering plants into strips across the field, natural enemies can use these corridors to disperse into field centres. Natural enemies are attracted to specific plants, so if you are trying to manage a specific pest, choose flowering plants that will attract the right natural enemy(s). The size and shape of the blossoms dictate which insects will be able to access the flowers' pollen and nectar. Timing is as important to natural enemies as blossom size and shape, so try to provide a mixtures of plants with relatively long, overlapping bloom times. This might include species from the daisy or sunflower family (*Compositae*) and from the carrot family (*Umbelliferae*).

Step up monitoring activities

There is often a high degree of variation in invertebrate abundance both within and between fields. But do you know which and how many pests, pollinators and natural enemies are generally present on your farm? Available to download by Agronomy members on the NIAB TAG Membership website (www.niabnetwork.com) our Pests and Beneficials Monitoring Guide provides advice on carrying out monitoring activities, whether for specific pests (e.g. aphids in winter cereals) or more generally to gain an understanding of the presence of natural enemies and pollinators. It contains practical guidance, with lots of photographs, on how to set up pitfall traps (used for ground active species) and sticky traps and water traps (used for flying species), as well as guidance on the species to look out for and when.

Knowing where to begin can be tricky, so start by getting your eye in on a specific area or crop and look for larger generalist species that are present all year around. Ground-based predators such as beetles and spiders are an easy identification win. In the spring, species like lacewings, hoverflies and ladybirds should start to be more prevalent. More advanced monitoring would include looking for parasitoid wasps and predatory midges. However, this is difficult to do with the naked eye and requires time spent out of the field to correctly identify then. The Guide also includes a sample recording sheet and images of common species to look out for.

The AHDB Strategic Cereal Farm programme

As part of the Strategic Cereal Farm programme, AHDB is working with three research groups and three host farmers to determine the impact of perennial flower strips on the abundance and distribution of natural enemy and pest populations, both within the flower strips and within the arable crop. NIAB is managing Strategic Cereal Farm East, with an ADAS/SRUC collaboration for Strategic Cereal Farms West and Scotland. These farms are located in Suffolk, Warwickshire and Fife.

Seed mixes have been sown to establish flowering strips at each Strategic Cereal Farm, and a range of monitoring methods for pests and natural enemies are being tested, which farmers could feasibly carry out themselves with minimal support. The work also includes an assessment of whether flowering plants from the strips move into the cropped area during the season. Results from the trials and demonstrations will be available this coming autumn, but regular Knowledge Exchange activities are taking place until then. As well as testing practical methodologies, the work is creating a robust baseline dataset to demonstrate the inherent variability in abundance of natural enemies and pollinators. By investigating how location, both within fields and within farms, affects abundance, this helps to identify the likely drivers of variation across the farms. We will also look at how our observation data needs to be interpreted relative to that variation in order for it to be practically useful in a commercial farm setting.

For more information on any of the points raised in this article, if you would like to be involved in our on-farm projects, have further ideas, or challenges to raise, please get in touch with NIAB's Aoife O'Driscoll on aoife.odriscoll@niab.com or 07808 241598.

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Yield maps – putting decades of data collection to use

The spatial recording of agricultural productivity has been practiced directly and indirectly, for millennia. The Domesday Book, completed in 1086, recorded the number of plough teams in each English parish, fertile lands supporting up to four ploughs per square mile with less fertile lands requiring up to eight times fewer.

I once read that 80% of the land cultivated at the beginning of the 20th century was cultivated in 1086. If this is true it is fair to assume that the variation in productivity seen across farms today has been causing management headaches for growers for centuries and in some places likely a result of differences in historic management. No-one can argue that we have not got better at recording spatial variation in crop growth. Since the 1990s yield monitors on combines have become commonplace. Satellites have allowed periodic monitoring of crop growth through the season, and even more recently, drones and other sensors are being employed to map variation in crop and soil properties.

Many farms have been collecting spatial data such as yield maps for a number of years. It is much more recently, however, that these datasets have become temporally rich enough to start doing meaningful analysis with. Using a five-year rotation of oilseed rape, winter wheat, sugar beet, spring barley and winter barley at Morley Farms in Norfolk as an example; it took over a decade of yield mapping to acquire multiple years of data for each crop. Now, with 13 seasons of yield mapping each field has on average three years of wheat yield data, allowing for a cross-year analysis to better understand drivers of spatial and temporal variability and how this could be managed.

Trusting the data

Before anything useful can be done with yield map data we have to trust the data is a true representation of yield. Data points that are not representative of actual crop yield can occur through a number of mechanisms, most notably swaths not filling the header or running over previously combined areas. These inaccuracies make meaningful analysis difficult, and can lead to misconceptions that the whole dataset is inaccurate. Therefore, although some scepticism in interpretation is useful it should not prevent us from trusting values from points we are confident have been collected in normal combine operation.

Fortunately, there are techniques that allow us to find and remove data points that are not representative of actual performance. Behind each combine yield point is data, including the speed at which the combine was moving. So, quite easily, points that are outside normal operation speed can be removed. Anything outside the threshold of the field average yield, plus or minus three times the standard deviation, is considered unrealistic of actual performance and can also be removed. These steps will not remove all errors, particularly in fields with high levels of variability, so we have to be a bit more creative.

A technique I like, for its conceptual simplicity as well as it efficiency, is the Local Moran Statistic. Local Moran identifies local spatial outliers, i.e. it tests whether a yield point is significantly different from its neighbours. This algorithm then provides a value for each point, if the number is above zero (positive Moran) it indicates that the feature has neighbours with similar high or low yields. If the value is less than zero (negative Moran) this indicates the yield point is dissimilar to the values around it and therefore is an outlier. If the significant value (p-value) is also small enough (<0.05) the point can be removed.

Identifying patterns

One key theme in the literature is a list of methods for analysing patterns of yield variability over time. This allows fields to be divided into zones in which points within that zone can be expected to perform the same in a given season. These zones could provide spatial constraints to adjust inputs based on crop demands (variable rate) or through targeted soil sampling or using farmer knowledge to ascertain what is driving yield variability. A lot can be learned from this, by identifying factors responsible for increased yields in high yielding zones growers can then work to replicate this across farm.

A popular method in the literature is cluster analysis. Clustering attempts to find patterns in datasets, a simple example is the K means cluster. Figure 1 shows an example dataset in which we have yields for specific areas of a field in 2011 and 2013 plotted against each other. A clustering algorithm can cluster these into groups that perform similarly in both years, i.e. orange areas are low and red areas high-yielding in both years, whereas blue areas fluctuate between high and low in 2011 and 2013 respectively.

The most popular clustering algorithm used in yield map analysis is the Fuzzy K-Means clustering; AHDB Project Report No. 565 provides a good description with examples. To do this, yield maps are normalised to a 10-20 m^2 grid, providing a mean yield for that grid cell in each year.

Morley – using yield maps and targeted soil sampling to understand spatial variation in productivity

The use of yield maps to quantify variation and its drivers and how this might be better managed at Morley Farms started in 2018 with the Morley Soil and Agronomic Monitoring Study (SAMS), set-up by The Morley Agricultural Foundation. 30 sites of interest were identified through combining ten years of yield maps into gridded long-term performance. A mixture of high, low and fluctuating yield sites were selected as well as a number of headland sites across farm. Each receive annual soil and agronomic measures to better explain variation across farm as well as how properties are changing over time with modern agricultural best practice. Figure 2 shows the soil organic matter contents at each site measured in baseline testing in 2019.

Although variation in soil type does have an impact there appear to be more influential drivers, such as historic land use. During and after World War II the RAF compiled aerial maps of the country, many of which are now available to view online for free. The two fields, Home Pasture (HP) and Perownes (P), whose sites have much higher soil organic matter look to have been in grass pasture in 1946 compared to arable cropping in other fields. A second aerial survey compiled in 1988 showed both fields in arable cropping, suggesting they have been part of an arable rotation for at least 30 years. The higher organic matter is not surprising. The Rothamsted Ley Arable experiment has demonstrated that after converting long-term pasture to arable cropping, soil organic matter levels still have not returned to an equilibrium (compared to long-term arable) after 40 years. Whether current practices on-farm at Morley, which involve rotational ploughing for sugar beet and the use of farmyard manure, are enough to maintain these higher soil organic matter levels at a point above the equilibrium of

Figure 1. Example of a clustering algorithm clustering two years of yield data

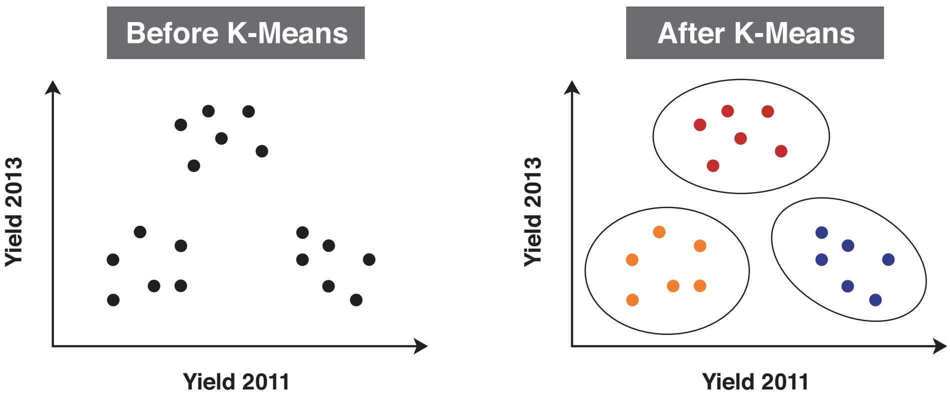
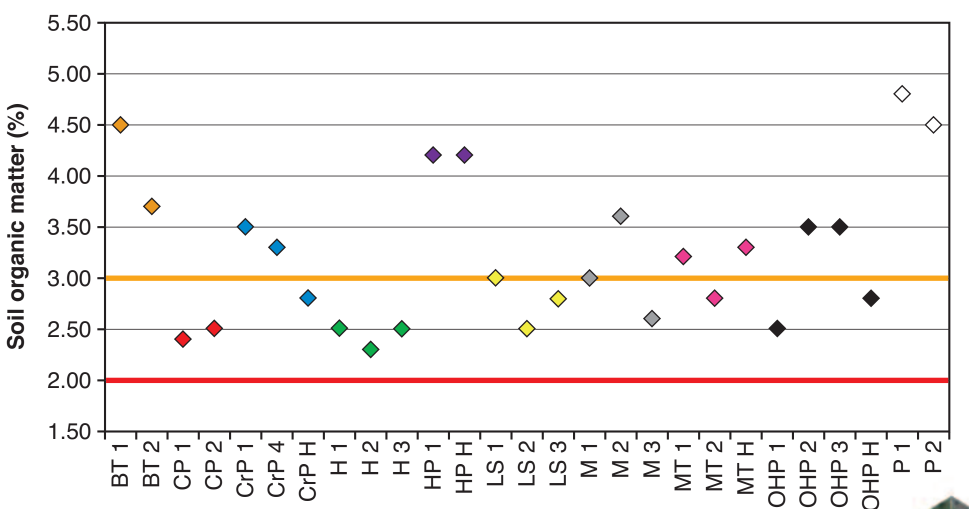


Figure 2. Morley soil organic matter (%) tested by loss on ignition, 2019. Colours indicate sites in the same field

Orange line indicates target threshold, below which soil function may be reduced, red line is very low threshold (Soil Biology and Soil Health Partnership 2018)



the rest of the farm will hopefully be captured in the Morley SAMS dataset.

Using guidelines published in AHDB's 'Soil Biology and Health Partnership' project summary, 44% of sites across Morley Farms may see an improvement in soil function from an increase in organic matter. Figure 3A shows the fields Manns (M) and Perownes (P) in 1946 with the north corner of Manns and Perownes in pasture. Following cluster analysis using the Fuzzy K-Means algorithm a high yielding zone (cluster 1) can be seen at the bottom of a slope in the south side of Manns, SAMS site M1 sits inside this. However, this zone is featured heavily inside the old pasture field boundary of 1946. It recorded a mean yield 0.7 t/ha and 1.0 t/ha higher than the next best zone in the 2011 spring wheat (Figure 3C) and 2013 winter wheat crop respectively (Figure 4). These were both challenging seasons with spring and summer 2011 being one of the driest on record in east England. Potentially the higher organic matter levels improved water availability to the crop in this area compared to the areas around it. Supporting the guidelines set out in AHDB's 'Soil Biology and Soil Health Partnership' – some sites might see an increase in soil function if soil organic matter levels were raised to that of Perownes. Soil textural classification at P2 and M2 shows there is little difference in soil texture (Figure 3D), suggesting differences in soil organic matter levels are a result of historic management not underlying variability.

Through a Central England NERC Training Alliance (CENTA) PhD with Cranfield University, NIAB and the British Geological Survey (BGS) we hope to develop these methods over the next three years to help better understand spatial and temporal variability in productivity at Morley and how this can be better managed.

Figure 3. A SAMS sites and 1946 aerial field layout, B current field layout with area in grass in 1946 highlighted by red polygon, C 2011 yield map showing higher yields in old pasture field, D soil texture for P2 (circles) and M2 (triangles) at 10 cm (red), 30 cm (green) and 55 cm (blue) soil depths

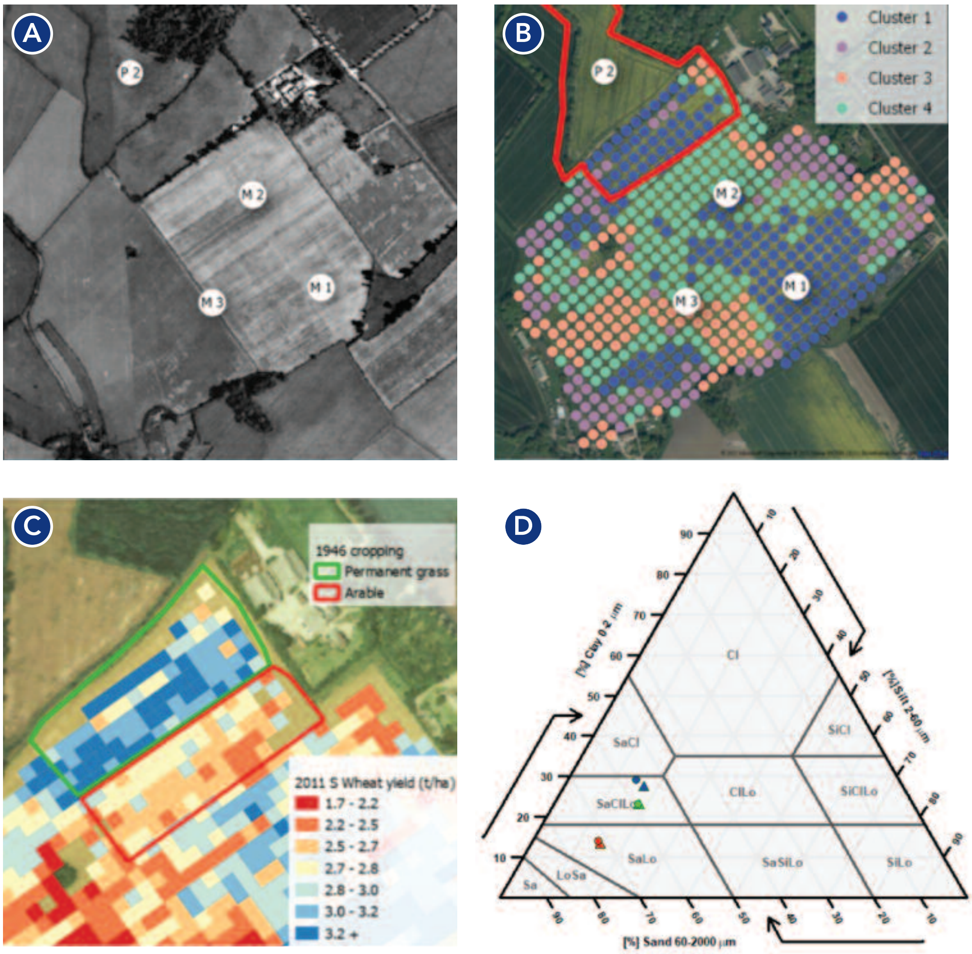
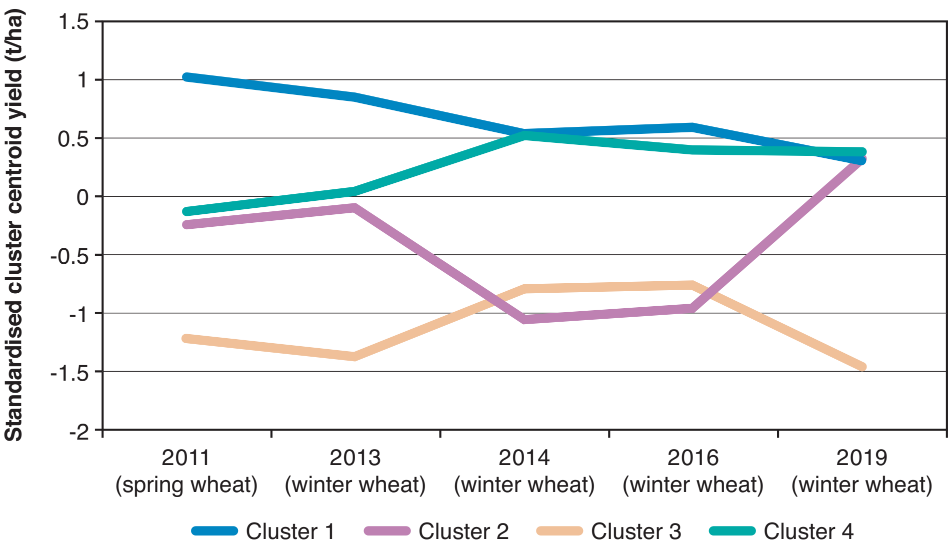


Figure 4. Normalised yield for Cluster centroid means identified at Manns from five years of yield data



AHDB Strategic Farm East – using yield maps to identify marginal land

The Environmental Land Management Scheme (ELMS), due to be rolled out in 2024, will see farmers paid for delivering public goods such as clean air and water, thriving plants and wildlife and protecting against environmental hazards among others. As well as supporting farm husbandry that supports the environment it is expected that areas of land currently used for food production will be taken out of production to deliver these services. Being able to identify areas of the farm that perform poorly for a given crop will allow for the more targeted use of Tier 1 (e.g. wild flower strips) ELMS schemes with the smallest impact on farm business in that year. Alternatively areas identified that perform poorly consistently across the rotation will be best suited for long term schemes such as woodland and habitat creation.

AHDB Strategic Cereal Farm East, managed by Brian Barker near Stowmarket in Suffolk, has 10 years of yield map data and field level fixed and variable costs. An AHDB project, led by NIAB, will use the methods described above across the farm to identify areas of land that could be classed as marginal and therefore potentially best suited for ELMS schemes. These areas are likely to have the smallest economic impact on farm business as well as providing accurate estimates of lack of revenue from converting areas to ELMS. The project is due to conclude in autumn 2021, hopefully providing a framework that can be implemented on other farms.

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Herbal leys in arable rotations

British arable farmers are increasingly facing problems of declining soil quality and adverse growing conditions. Frequent deep tillage without cover cropping or ley periods can cause slow deterioration of soil fertility, making it even more difficult to produce crops in increasingly hot and dry summers. At NIAB we believe that the reintegration of livestock grazing and ley cultivation into arable systems may be a promising means of replenishing soil organic matter, improving soil hydraulic functioning, and reducing reliance on mineral fertilisers. To investigate this, we have established five trials in southern England where we have reintegrated ley periods and grazing into arable farms, and assessed the effects of these treatments on soil fertility.

Traditional ley systems in Britain have mostly been some combination of clover and grass, most commonly white clover (*Trifolium repens*) and perennial ryegrass (*Lolium perenne*) with red clover (*Trifolium pratense*) becoming a popular inclusion for its high-quality forage. More diversity within the forage mixture may however further boost the fertility-building capacity of leys, and the inclusion of deep-rooting forages like sainfoin (*Onobrychis viciifolia*) and chicory (*Chicorium intybus*) may improve soil structure. Diversity in cropping systems is also known to bring multiple benefits, and we have included this dimension in our field trials by cultivating two different leys – one traditional grass/clover mixture, and one 'herbal' ley, a 17 species mix of grasses, legumes and herbaceous flowering plants produced by Cotswold Seeds.

These leys were established in 2018 and the treatments were assigned splits of grazing with sheep or mowing for silage. This was done to investigate whether grazing sheep would further improve soil by stamping some of the forage into the ground and by contributing soil nutrients via their excreta. Some trials are grazed constantly throughout the growing period, whilst others are mob-grazed intensively twice a year. An adjacent arable control is maintained at each site to allow us to describe the effects of these leys with and without sheep grazing in comparison with the usual arable rotation on each farm.

We are documenting standard soil quality parameters such as soil mineral nitrogen, phosphorus, potassium, pH and organic matter percentage. More detailed assessments are also carried out on

Diverse herbal ley growing

Field trial at Duxford

undisturbed soil cores taken to a depth of 60 cm. Here, bulk density is assessed in 5 cm increments to determine if the deep-rooting plants containing in the herbal ley are improving soil structure by breaking up the hardpan. We are also interested in dry-matter yield and nitrogen fixation, and another goal of the project is to determine if the diversity of the herbal ley will give higher dry matter yields and fix more nitrogen than the traditional grass/clover mixture.

Some interesting results have already been seen on our trials. Dry matter and N yields tended to be higher in the herbal ley; this may have been caused by a higher land equivalency ratio and the deeper roots of some of the plants allowing the ley to remain productive in dry weather. When sheep were mob-grazed on the herbal ley on NIAB's Duxford trial their weights increased by 5-10%, but this was not repeated on the grass/clover ley. Small but significant increases in soil organic matter have also been seen in the herbal ley treatment in some sites, but only those with low levels prior to the trial beginning. We have been working with both livestock and arable farmers throughout the trials and feedback has been very positive – farmers have been particularly impressed by the high productivity in the dry summer of 2019 and the natural anthelmintic properties of the leys on the sheep.

The research is at an exciting point as a section of the leys has now been returned to arable. Winter wheat was planted at three of the five sites in November and the hope is that the yield data for this crop will give a real-world understanding of what farmers should expect from these leys. The wheat is being managed on much lower inputs than would be used conventionally because the soil data indicates soil nutrient levels have been improved by the leys and by grazing. Different cultivation regimes have also been trialled because the effect of the leys on subsequent crop production may be further enhanced by particular termination strategies. Some of the growers involved in the trials expressed concerns about nutrient lock-up following ley termination, and we have responded by including two cultivation regimes to investigate this – half of the wheat was planted following a herbicide spray and a conventional plough, whilst the other half was direct-drilled into the ley residues following a herbicide application. These treatments will cause different rates of nutrient release, and the performance of the wheat in both will show which termination strategy is optimal for subsequent wheat cultivation.

This project will continue for another two years, and at the end of this year another section of the leys will be returned to arable. This will determine if keeping the leys for more than two years will further improve wheat performance, and to insure against potentially unusual weather conditions in the first year making conclusions difficult to draw. The research in a sense is nothing new; before fertilisers became ubiquitous in British arable systems farmers used ley periods and grazing to maintain soil fertility. The belief is that this system is still valuable in 2021 because it delivers more soil benefits than just nitrogen or phosphate. The hope is that the results will show how this traditional farming system can be optimised for the modern world, and how farmers can maintain soil fertility and protect environmental integrity without over-reliance on mineral fertilisers.

Biomass difference between herbal ley (left) and grass clover ley (right) in dry summer of 2019 (Duxford)

Return to arable in Duxford (winter wheat in grass clover ley residues)

Return to arable in Duxford (winter wheat in herbal ley residues)

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Exploring reseeding options

After some recent dry springs and summers, a soil moisture deficit was identified in much of the UK's grassland area. The oncoming 2021 spring has seen some very wet, heavy weather so far coming into the west of the country, whilst some eastern areas have been relatively unscathed.

It is important not to base future forage decisions on one or two otherwise non-normal seasons, but it is worth considering whether systematic changes are on the cards.

Those who were challenged with getting enough forage for their livestock through the drought of 2018 and flooding of 2019, discussed the need for more adaptable, resilient forage systems that allow farms to better tolerate extreme seasons and it has since become a hot topic across the ruminant sector. This was also echoed in the responses to NIAB's 2019/20 survey.

Options for reintroducing forage types and species grown on farm to make best use of available resources is a pragmatic conversation to have, particularly involving both arable and livestock systems depending on each individual farm's requirements and circumstances.

With many farms moving away from relying solely on grass-only swards, research into mixed species swards and herbal leys has shown promising results. Deeper rooting plants are more drought tolerant, mining their own minerals, reducing plant nutrient applications, associated costs and environmental impact, whilst promoting growth rates that rival standard perennial ryegrass leys with the addition of further nutritional benefits.

Mixed swards, whilst relatively novel in today's systems, are not new. A wider range of forage species and multiple species swards were grown across the UK prior to World War II. These days there is an increased pressure to reduce ammonia emissions associated with localised environmental impacts and reducing greenhouse gases, nitrous oxide and carbon dioxide emissions into the atmosphere. Including legumes in the sward minimises these emissions by reducing the need for applied nitrogen and increasing food conversion efficiency, which also reduces methane production.

Clovers are not the only nitrogen fixing legumes available. Sainfoin, whether in a mixture or as a monoculture, is a deep rooting, mineral-rich perennial species that provides very palatable conserved forage. It also contains condensed tannins that play an anthelmintic role in the gut. It can provide one or two cuts of hay or silage as well as late season grazing, useful in a dry summer when high temperatures can lead to dormancy in grasses.

Lucerne is another perennial legume, grown extensively on the continent, providing high protein forage. It can be grown with sainfoin, as a monoculture (usually the case in the UK) or in a multi-species sward, providing quality protein, minerals and some resilience to dry seasons.

Legumes, in general, prefer a warm soil for the development of the nodule inhabiting rhizobial bacteria and are best sown by mid-August with plenty of light and warmth in order to develop in time for productive spring growth. They also require a soil pH of 6 or above, with sainfoin preferring pH 7. Care must be taken to ensure the right soil conditions for establishment with sufficient soil moisture within the top 2.5 cm and a fine, firm tilth to provide good seed to soil contact. An inoculum of the right strain of rhizobium may also be needed.

Other deep rooting plants include chicory and ribwort plantain (ribgrass) promote good lamb growth rates, bringing up minerals and withstanding drier conditions. Chicory also contains condensed tannins.

Grasses, such as cocksfoot and the new festuloliums (hybrid of ryegrass and fescue), provide dense root systems that convey some resilience in drier conditions.

Perennial ryegrass continues to be the most versatile and consistent agricultural species when well-managed, suiting most growing conditions, including wetter seasons and can be established into September. New varieties are added to the AHDB Recommended Grass and Clover List every year, with yields increasing by 10% and quality by 5% over the past ten years. This means that the

newer varieties produce higher yield and quality without increased nutrient input so are more cost effective to grow. High sugar varieties also increase protein utilisation in the rumen so work well with legumes in the mixture. Variety selection should be based on the timing of required growth. The Recommended List trials system measures seasonal growth as well as conservation and simulated grazing yields and quality. Selecting a mixture of species to provide flexibility is useful with more vigorous growth of tetraploids balanced with the persistence of diploid varieties. The inclusion of clovers to minimise nutrient input and increase protein levels should also be considered.

Digging holes to assess soil structure across both productive and poor areas of the field and comparing these with the soil structure under the neighbouring ungrazed hedgerow, will give you an idea of how well the soil biology is functioning. Compaction can be an issue, restricting root development which impacts on plant growth and resilience in both dry and wet conditions.

The presence of moss can also indicate nutrient deficiency, particularly phosphorus, and is present due to lack of competition from the required species, normally a result of either the nutrients not being present or the roots being unable to access them due to poor development or compaction restrictions.

A detailed soil analysis will identify any minerals that may be lacking and allow targeted applications. Sulphur and molybdenum are particularly important for legume development. Magnesium can be a limiting factor. Soil pH significantly affects the availability of trace elements such as manganese and zinc. Sodium is also important for palatability. Refer to the Nutrient Management Guide (RB209) or a FACTS qualified adviser for interpreting soil analyses into a nutrient management plan to give both existing swards and reseeds the best chance to reach their potential.

Compaction issues, from livestock and/or machinery travelling on the ground in wet conditions, can really restrict plants reaching their potential and may be improved with aeration rather than deeper, more damaging cultivations. Tightness in the topsoil can also be a symptom of low soil magnesium.

Alleviating soil structural issues and addressing pH and competition from weeds may be all that is necessary to increase sward productivity if the sward has over 50% of desirable species present. However, where these species are at, or below, 50% of the sward, investment in reseeding provides a good return within the first year of production if done well.

Slot seeding or broadcasting seed into existing swards is less expensive than a full reseed and reduces a field's time out of use. To ensure successful establishment larger seeded tetraploid varieties of ryegrasses, which have vigorous early growth, are usually used although they are less persistent than the diploid varieties so this may be a relatively short-term solution. This can be a good way to increase other species into the sward although it is critical to minimise competition from the existing species so swards must be tightly grazed or cut immediately prior to sowing.

Where a full reseed is the best option, minimum tillage will cause less disturbance to soil fauna and existing root structures and retain more organic matter, moisture and nutrients as well as reducing opportunities for pests, such as leatherjackets, to establish themselves. Ploughing can be worth doing if a clean seedbed is necessary, alleviating perennial weeds and surface compaction.

Farmer groups, such as the Soil Association's FAB farmers in the south-west and Innovative Farmers' groups, provide opportunities to see how different mixed swards are performing around the country through on-farm research. Also check out The British Grassland Society and the regional grass societies' useful and interesting farm walks. The GrassCheck GB website (https://grasscheckgb.co.uk/) provides useful information on grass growth around the country. Technical information on including mixed swards and legume crops can also be found on seed companies' websites. These are all worth tapping into for guidance on making the most of your swards, along with handy guides to soil assessment on the AHDB and NIAB websites.

Ellie Sweetman is NIAB's Forage Crop Specialist and manages the AHDB Recommended Grass and Clover List trials programme as well as overseeing the wider forage trial work and providing technical advice to the NIAB TAG Membership programme.
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Developing our understanding of soil health

The AHDB and BBRO-funded Soil Biology and Soil Health Partnership has entered its last year of work and so increasingly you will begin to see the practical outputs of that work emerge more fully. Some aspects will emerge almost fully formed and ready to roll out on farm. Other projects that have taken place within the Partnership will provide the foundation for research and development for years to come. Alongside these developments, NIAB is involved in a wider range of research projects on measuring soil health, and the better diagnosis and management of soil-borne disease. So, we thought that it was timely to give you an update.

If you are yet to download your copy, then set aside a few minutes to have a look at the new soils publications produced by AHDB during 2020 – the ***Principles of soil management*** and the ***Arable soil management: Cultivation and crop establishment*** guides bring together the management foundations for arable systems. The Principles is an underpinning document which does what it says on the cover and explores the intricate web of relationships between biological (e.g. earthworms, microbes and plant roots), chemical (e.g. pH, nutrients and contaminants) and physical (e.g. soil structure and water balance) soil components. Whether soil is light, medium or heavy, the guide outlines the most important things to consider and provides management actions that can be applied in all sectors. The Establishment guide shines a light on the factors that influence the need to cultivate or restructure soils. Produced by machinery expert Andy Newbold and cultivation specialist Philip Wright, with contribution from NIAB CUF, the guide covers all forms of tillage, from soil restructuring, to ploughing, to no-till.

The overall aim of the Soil Biology and Soil Health Partnership is to improve on-farm understanding of soil health by sharing current academic and industry knowledge, as well as developing and validating indicators of soil biology and soil health in research trials and on-farm. The Partnership has developed a soil health scorecard approach to provide a routine health check using physical, chemical and biological indicators that can be readily measured and benchmarked for soil health. The approach combines in-field scoring of soil structure and earthworms with laboratory measures on soil samples collected in the same place at the same time. Within the Partnership we have been testing the theory in practice – from theory to field – to assess whether the descriptive models for soil biological function, which were developed in the initial phase of the project, hold true in the real world. As part of this, the scorecard has been evaluated to make sure it makes sense both in terms of benchmarks and its usability. More information on how to put the approach into practice on-farm is expected to be ready for sampling in autumn 2021.

Soil biology is widely recognised as a key component of soil health but measures to assess the below-ground communities are only just being developed and our understanding of the link between soil biology and agriculture remains limited. Soils are an important reservoir of biodiversity, and contain up to a third of all living organisms on the planet. Soil microorganisms are hugely

diverse and play a range of critical roles in most soil processes. The functions of some microorganisms have been well defined. However, a large proportion of bacteria and fungi found in soil are unculturable and have yet to be named; consequently their functions and role in soil health have yet to be identified.

Within the Partnership's programme of research there are two very integrated projects evaluating and developing the more innovative measures of soil-borne disease risk and overall soil biological health using molecular measures. This is cutting-edge innovative science – but grounded within the practical application of the research into measuring soil health and establishing links to management practices. A key target of the Partnership is to make sure the work is joined up from laboratory to the spade. The molecular science is a high-cost element of the work, but it will help us begin to understand how soil management affects soil biology and soil-borne diseases. The aim of the work is to demonstrate the value of molecular methods to quantify the effects of management on soil health across a range of existing (long-term) trial sites and to better understand the link between soil management approaches and minimisation of soil-borne disease risk. For the future, molecular-based analysis of the soil microbial community (and soil fauna too) is a new developing tool that will revolutionise the understanding of soil biological function and underpin an increased focus on the management of soil biology, alongside soil chemistry and physical structure. But this won't be soon!

Who's Bean hanging out together?

Plant pathogens can be a major factor limiting yields of peas and field beans, particularly foot and root rot diseases. These diseases are caused by a complex of (fungal/oomycete) pathogens including *Aphanomyces euteiches*, *Fusarium* spp. (*F. solani, F. culmorum, F. graminearum, F. oxysporum* f sp. *pisi*), *Phoma medicaginis* (*Ascochyta medicaginicola/Didymella pinodella*) and *Rhizoctonia solani*. However, current knowledge surrounding foot-rot diseases and the soil microbiota associated with UK pulse crops is still relatively limited, both in terms of the key microbial taxa present in agricultural soils and the abiotic/biotic factors that contribute to sculpt the ecological diversity within the rhizosphere. Improving knowledge of which microorganisms are present in the soil of productive and poor crops, and if differences in cropping history, variety, soil type or nutrient status contribute to shape the composition of soil microbiota could help to improve crop management practices and maintain productivity in UK pulses.

In an effort to address some of these knowledge gaps, the first student in the new TMAF Studentship Programme will explore the potential differences in the microbiome between soils with a long-history of intensive legumes and those with no history of legume cropping. Harvey Armstrong will work with supervisors Tom Wood (NIAB) and Nik Cunniffe (University of Cambridge) and TMAF's Stephen Rawsthorne. Particular focus will be placed on organisms associated with the promotion or prevention of pathogens species responsible for causing foot-rot diseases. Harvey will use metagenomics sequencing approaches to profile the soil microbiota from a number of different pea/bean crops to help understand which key taxa are associated with high-yielding crops and which are present on poor or unproductive land. Harvey will also investigate if differences in soil type, pH, nutrient status and plant variety affect the establishment and structure of the microbiota, and if this composition differs the first-time pulse crop grown is grown. This will hopefully enable him to identify potential bio-indicators associated with productive and at-risk crops. Whilst control strategies have been developed for a number of pea and field bean pathogens, chemical treatments are not effective for foot-rot pathogens and growers rely on limited sources of low-level genetic resistance, the use of healthy seed and rotation to avoid issue with disease. It is hoped that this work will pave the way to more targeted controls in the future; the PhD will complete in 2024.

SNIFF THIS!

Charles Whitfield at NIAB EMR is part of an Innovate UK-funded project with P.E.S. Technologies (lead), H.L. Hutchinsons, Small Robot Company, University of Greenwich, and University of Essex, that is developing a new type of low-cost sensor to detect volatile organic compounds (VOC) from soil – that is to say, their sensor can sniff the soil. This is not as mad as it sounds, organisms in the soil release VOCs as part of their metabolic processes and detecting these volatiles provides a rapid way of measuring the biological community in action. The project involves assessing a range of soil types and cropping systems around the UK, and linking the VOCs detected by the new sensor with conventional laboratory-based assessments of the biological components of the soil. Machine learning will be used to find the links between the measurements, resulting in an entirely new way of understanding what is happening in our fields. The new soil health sensor system will be usable as a quick, easy, and cost-effective manual tool in the field giving instant results. In addition, an autonomous robotic system is being developed to allow thorough and systematic sampling of soil without the need to muddy your boots. The project is due to complete at the end of 2022.

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Barn4 opens for business at Park Farm

NIAB's newest building, Barn4, opened its doors to new tenants and members on 1st March this year. Barn4 is a dedicated agritech incubator located at NIAB's Park Farm site on the outskirts of Cambridge. Funded by the Local Growth Fund, through the Cambridgeshire and Peterborough Combined Authority, it provides office, laboratory and workshop accommodation for agritech start-ups and SMEs.

The underlying drivers behind the establishment of Barn4 were:

- Cambridge has the perfect combination of a vibrant tech cluster located adjacent to some of the highest quality farmland and the most forward-thinking farmers in the country;
- agritech start-ups and SMEs will benefit from proximity to NIAB's cutting edge facilities and world-class scientific expertise; and
- NIAB will get the opportunity to collaborate with companies developing novel technology and techniques.

The vision for Barn4 is that it will provide a nurturing environment for the best agritech companies to grow and flourish. This in turn will help NIAB stay ahead of the technology curve and benefit alongside the companies it is supporting.

Facilities

The new hub is an addition to NIAB's redeveloped Park Farm field research station which includes Barn 1 and Barn 2 – the two new large research and office buildings (5,500 m^2), the 2,500 m^2 MacLeod Complex of research glasshouses with an additional 300 m^2 in construction, 3,000 m^2 protected outdoor growing space, event and demonstration field and nearby field trials.

Rather than being converted from other uses, Barn4 has been purpose-built as an agritech incubator. On the top floor there are five private offices, two meeting rooms and a large open plan co-working space. This layout provides the optimum balance of private and shared space for companies at different stages in their development. Currently limited to around 15 people working on the top floor this will increase to around 45 once the Covid-19 restrictions are lifted.

On the ground floor there are five labs and a large workshop/storage bay. Three of the labs are multipurpose and could be used for a variety of things. The fourth is an experimental kitchen lab to be kept at 'food-safe' standards for teams wanting to work in the space between the field and the fork. The final lab is a 'soil' lab, kitted out with equipment specifically designed for soil analysis and management.

Flexibility is the key throughout Barn4 and while we know who some of the first users will be, there is no crystal ball that tells us who will be here in the following years. With this in mind we have purposefully left space free to be configured in whichever way best suits future members.

Further information and enquiries

www.barn4.com

contact@barn4.com

@barn4_NIAB

Charles Gentry (Barn4 Manager) or Michael Gifford (NIAB Director of Commercialisation)

Linking to NIAB

In developing the plan for Barn4 it has been important to consider how it can best support its members alongside providing the greatest benefit to NIAB. The widely held view is that there will be a natural tendency for members and NIAB staff to interact both at a personal level, and on technical and scientific challenges, when they are working adjacent to each other. We anticipate that from time-to-time members will require direct support from NIAB in the form of validation trials, technical consultation, access to specialist facilities and support in navigating the industry.

We are already seeing a strong trend for SMEs to look to NIAB as the collaborative partner of choice for Innovate UK, Horizon 2020 and similar programmes. These help to strengthen the links between NIAB and the agritech sector as well as providing NIAB with a clear opportunity to develop its own commercially valuable intellectual property.

One deliberate design decision was to not have a social space within Barn4, with members and tenants encouraged to walk the 10 metres to join NIAB staff in the common area in the Barn 1 building for breaks and lunch. This will promote the more informal discussions from which ideas can be developed.

Member packages

Start-ups and SMEs come in all shapes and sizes and a flexible set of packages have been developed to suit members' needs. This includes Virtual Membership which offers a range of benefits to support companies that either do not require or cannot make use of any of the physical facilities available at Barn4, but are still looking to develop a close relationship with NIAB.

The next step up is Premium Membership giving the member access to hot desks and meeting rooms from time-to-time. There is a lot of interest in this level from companies based outside Cambridge looking for a central spot for their internal meetings, or to spend some time in the area and looking for a comfortable friendly base to work from. Premium Membership is seen as being an easy route into full Resident Membership.

Resident Membership gives the member company allocated desks on the top floor and, if they need it, space in the ground floor labs and workshops. Simply by being in the building they will end up closer to NIAB and the package includes a full range of support.

All members will have a dedicated point of contact within the Barn4 team who will help them to navigate the organisation and make sure that they are able to talk to the right people at the right time. The full range of benefits and information on pricing is available at barn4.com/membership.

As with the physical space, flexibility is important within the membership packages. Members can change their requirements at a month's notice and increase or decrease the space they use. This flexibility is essential if NIAB is to be able to support the earliest stage companies on their journey.

Germination Programme

Alongside the official opening of Barn4 we have also launched the Germination Programme. This allows groups or individuals interested in starting agritech businesses to access support. The programme is aimed at teams or individuals who are still at the concept stage in developing a venture. Support will be in the form of advice on the technical elements and business model together with a free period of Barn4 membership.

The application process has deliberately been made as simple as possible with a single document to submit. It is also a rolling process and there is no deadline for submission. We understand that in the early stages of developing a concept there is lots of uncertainty but the Germination Programme is looking for candidates with enthusiasm, drive and an idea that could scale.

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So, how did your potatoes grow?

It is frustratingly still possible to reach the end of a growing season and be unsure why a potato crop has not performed as well as expected. At the same time, potato yields can be highly variable, differing at field, farm and national levels. Whilst some of the variation in crop productivity is related to differences in the weather or differences in end-market specifications, much of it is unaccounted for, and likely contributes to the plateau in, national yields around 45 t/ha. One step towards reducing the unexplained nature of yield variation is to more closely monitor crop growth during the season. Yet this is challenging with potatoes and other root crops, since the saleable biomass develops beneath the soil. However, we are exploring how variation in above-ground growth during the season can help explain variation in yield, and also be used to predict yield before harvest by applying the NIAB CUF Potato Yield Model.

Focus on canopy

As the most visible structure of the crop, the potato canopy can offer valuable insight into potato growth and variation. It is the site of both light interception and photosynthesis, fuelling further growth. There is a strong relationship between light intercepted and total biomass produced by a crop, which was first quantified by John Monteith in the 1970s. The Scottish scientist showed that, when well fertilised and with adequate supply of water, dry matter accumulated by a crop strongly correlated with radiation intercepted by the foliage in barley, apples, potatoes and sugar beet. Then later, good evidence for a linear relationship between total plant biomass and potato tuber yields was found across a range of potato cultivars, planted at a range of spacings and dates. This formalised the basic relationship which has long been known to underpin crop yields – that intercepting more light, enables more photosynthesis, greater crop growth and higher yields.

Multiple methods can be used to either measure or estimate light intercepted by crop canopies and the three most widely used are direct measurements with solarimeters or ceptometers, leaf area index (LAI) and percentage ground cover (GC). Each has the potential to record changes in the ability of the crop to intercept light throughout the growing season.

Sarah Roberts, NIAB CUF Research Associate

Sarah has recently completed her PhD which focused on quantifying potato canopy growth. Funded by CUPGRA the research captured the effect of common changes in potato agronomy – such as plant spacing and planting date – upon whole canopy growth. She monitored field experiments across three years with destructive mid-season harvests to calculate leaf area index (LAI), which included many hours in a barn stripping leaves to collect that data. The conclusion that LAI was a poor predictor of the duration of near-complete canopy cover and yield, means that future experiments of this kind will not need to include the laborious measurements of LAI carried out here.

Solarimeters and ceptometers

These metre-long light sensors can be installed beneath the canopy, at soil height, and detect the proportion of total light (all wavelengths; solarimeters) or photosynthetically active radiation (wavelengths 400-700 nm; ceptometers) which passes through the canopy. Yet this is an expensive way to measure light intercepted by a whole crop as each device is costly and samples only a small area, so the use of solarimeters and ceptometers is typically limited to small scale experiments.

Leaf area index

Leaf area index is the total one-sided area of leaf material per unit of ground area. Initially in potatoes, increasing LAI directly increases light interception, then as leaves start to overlap (around LAI of 2) each new leaf contributes less to overall light interception. The proportion of total light intercepted increases after complete ground cover (approximately LAI of 3), maximising light intercepted around LAI of 4.

Leaf area index can be measured directly with destructive harvests (time consuming and labour intensive) or indirectly using image analysis software to calculate LAI based on light distribution within the canopy and the typical distribution of leaves within the canopy. However, the indirect methods were originally developed for estimating LAI in forest canopies and have not been optimised for potatoes, resulting in potentially misleading values.

Ground cover

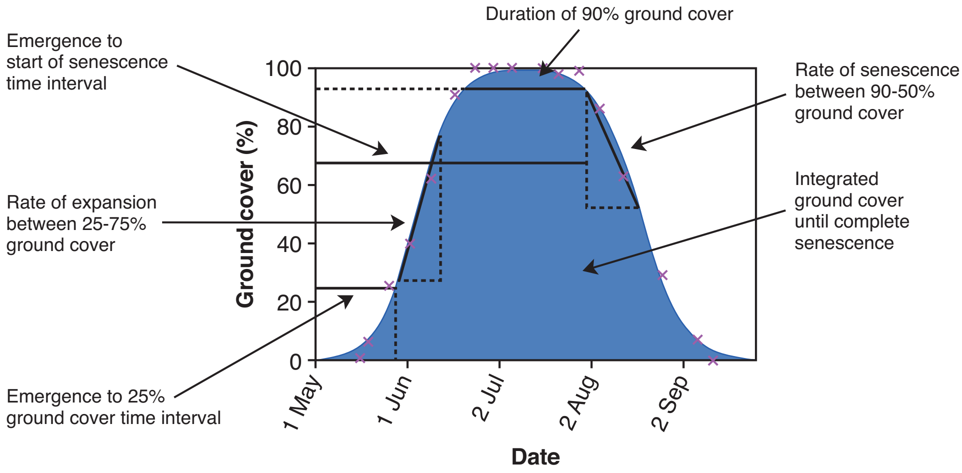
Canopy 'size' can also be represented by the proportion of bare soil covered by green (and photosynthetically-active) leaves in a given area. A range of different methods can be used to measure GC, ranging from the low-tech (hand-held grids) and small scale (smartphone apps) to farm-level drone and satellite-based image capture. Whilst photographic methods can dramatically increase the sample area, care needs to be taken with image processing.

Ground cover is the focus of the rest of this article since it has the greatest potential for widespread data capture – both in research and on-farm – due to the low data-input requirements and scalability of analysing data collected not only on the ground, but from low-Earth orbit.

The output

Once the GC measurements have been taken, a curve is fitted and then used to describe growth, both across the whole season and for specific periods of growth (Figure 1). This allows field observations of differences in canopy cover to be quantitatively compared – determining both how large the differences are and whether they are significant. For example, early canopy expansion (between emergence and 25% GC) is faster at higher stem densities, but stem density tends to have little effect upon integrated ground cover (a summary

Figure 1. Example fitted ground cover curve, labelled with calculated canopy descriptors. Raw data points in pale purple



variate, reflecting maximum GC reached and duration of canopy cover).

Differences in varietal canopy production can be seen and are linked to differences in yield (Figure 2). Canopy data can also be used to identify stresses upon the crop, for example soil compaction can have a severe stunting effect upon canopy growth, dramatically slowing canopy expansion (Figure 3) since the reduced rooting of the plants means that water and nutrient uptake rates cannot support rapid canopy growth. Waterlogged soil can also have a severe impact on both canopy growth and final yield and an extreme example is shown in Figure 4.

Caveats

There are, however, other factors which can influence the relationship between intercepted light and final tuber yield. These include:

- Varietal determinacy – the propensity of a variety to continue producing leaves after flowering. There is greater initial investment in the canopy in indeterminate varieties, enabling longer canopy duration and potentially greater yields if the season is long enough.
- Nitrogen availability – most potato varieties respond to additional N by producing a higher canopy biomass. This can extend canopy life, but the season must be long enough to get a good 'return on investment'.
- Season length – duration in between planting and harvest. Harvesting a crop before canopy senescence

Figure 2. Example ground cover curves. Mean GC values taken from 2018 plant density experiment. Mean total fresh weight tuber yields: Estima: 54.3 t/ha and Maris Piper: 64.1 t/ha

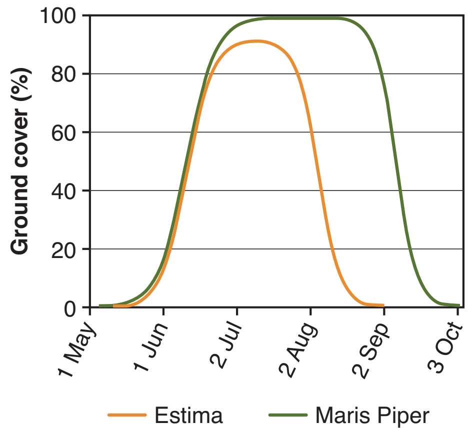
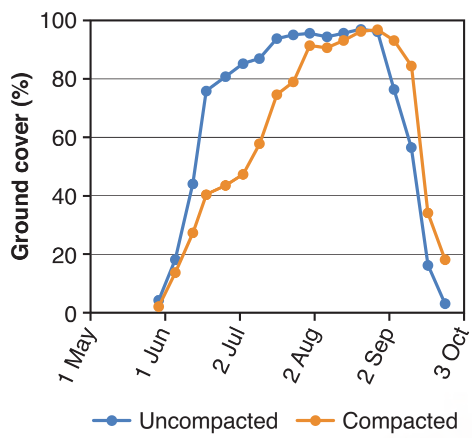


Figure 3. Example of the effect of severe soil compaction on Maris Piper canopy growth. Mean total fresh weight tuber yields: compacted: 43.9 t/ha and uncompacted; 49.6 t/ha. Curve not fitted due to stunting of canopy expansion under compacted conditions



prevents reallocation of resources within from the leaves to the tubers, so a greater proportion of the plant biomass remains in the canopy.

All of these factors influence crop harvest index (HI) – the ratio of total biomass to harvestable biomass. It is important to note that bigger canopies are not always best. Figure 5 shows that for both Estima and Maris Piper HI is lower at the higher rate of nitrogen applied at the early harvests, but that as the season continues the difference in HI between high and low nitrogen in Estima decreases before the gap in Maris Piper. This suggests that different varieties reallocate resources from haulm to tubers at different points in the growth season and that this occurs earlier in determinate (Estima) than indeterminate (Maris Piper) varieties.

A number of other factors (Figure 6), can also influence the relationship between intercepted radiation and yield, making it difficult to directly compare canopy growth and yield between different crops, but that once these have been accounted for canopy cover can be used to understand variation in tuber yields.

Ultimate goal

By increasing the amount of data which can be collected from individual crops we hope to be able to identify the factors under grower control which, together, can result in the large amount of variation in yields between farms. Some of these differences will be accounted for by soil type, rotations, manure and nitrogen fertiliser use – factors expected to effect yield – but other variation is also expected to result from between-farm differences in practice, which have been shown to be a significant source of yield variation in the Yield Enhancement Networks (YENs) of other crops, such as wheat. In 2020, we worked with ADAS to pilot the Potato YEN, funded by WRAP and AHDB, giving growers a chance to benchmark their crops against similar crops and identify opportunities improve on-farm practice. Hopefully in the future the Potato YEN will allow more crop management data to be collected enabling us to identify further sources of variation in potato growth.

Figure 4. The plot in foreground was heavily waterlogged throughout the season and produced a stunted canopy and correspondingly low yield. A Mid-season photograph of waterlogged (foreground) and non-waterlogged (background) plots. B Canopy development throughout the season of waterlogged (green) and non-waterlogged (blue) plots. Fresh weight tuber yields were 25.1 and 57.3 t/ha in waterlogged and non-waterlogged plots respectively

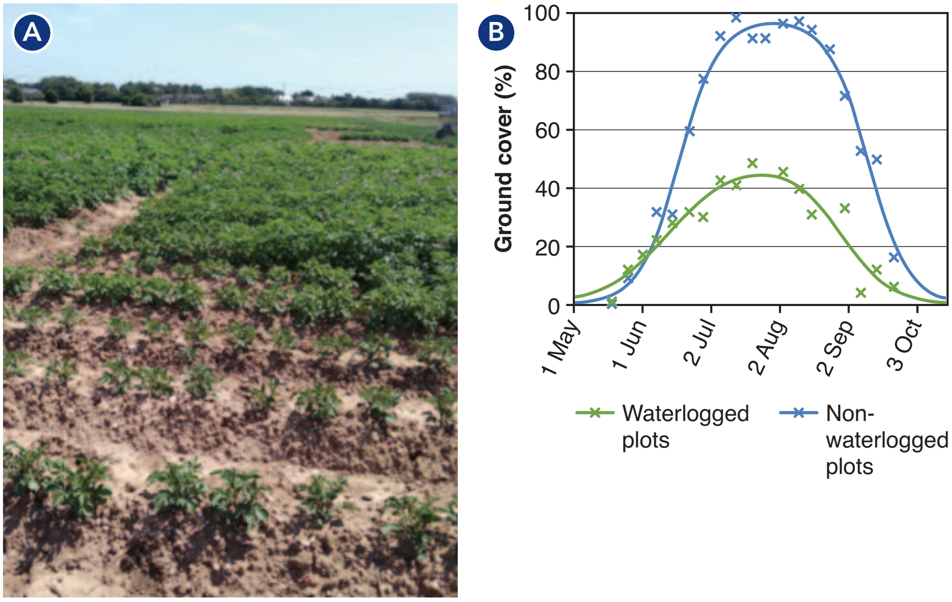


Figure 5. Change in dry matter harvest index (HI) at harvests throughout the season, for both cultivars, at differing nitrogen rates. Error bars represent S.E. (27 D.F. for all harvests in both experiments, except H2, Expt 1 and FH, Expt 3, both 26 D.F.)

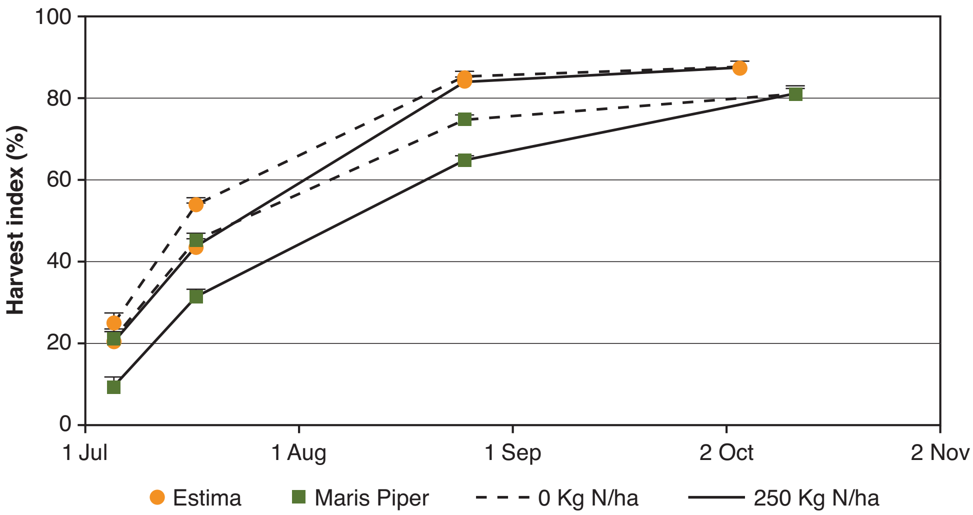
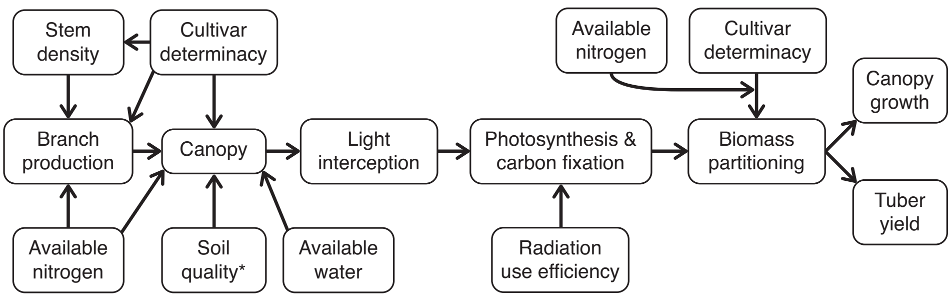


Figure 6. Illustration of the link between canopy and potato yield, with canopy size modifiers and yield modifiers

* Including degree of compaction, organic material, soil type and microbiology



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Herbicides and integrated weed management – so we need an overall strategy?

I was caught by surprise over Christmas by a simple question; while discussing ongoing trials programme with a new colleague from another organisation she asked what was NIAB's position on herbicide use and integrated weed management? This was surprising because, although NIAB's programme of work on weeds over the past few years has been determinedly around IWM rather than focusing on herbicides as the only tool to manage arable weeds, I have never actually been asked about the strategy.

All modern herbicides, but especially those effective on grassweeds in our major grass crops, are an amazing piece of human technology. Progressive improvements in the technology of manufacture and development, alongside the evolution of regulation, mean that we have a tool for protecting the crops we are growing that have become empirically safer over time, in terms of their inherent chemistry. At the same time control over their use in practice have helped to mitigate against the risk they pose to the environment. It seems self-evident that maximising the efficiency of herbicides (note I highlight efficiency rather than outright efficacy) in practice, which is a lot of the work we do carry out on herbicides, is a key element of and minimising potential harms caused by their use.

Where inappropriate herbicides are used either because of the weed species of the context this is inefficient. Where we identify scenarios where typically, more herbicide is used in practice that can be justified, this represents inefficient herbicide use. Where multiple herbicides used in a mixture result in reduction in suppression provided by the crop this result is inefficient use of herbicides. These are specific examples of experimental work that NIAB has carried out on herbicides in the last few years. This work on efficiency in herbicide use needs to run alongside work on cultural and non-chemical approaches and be closely integrated with those other approaches.

In integrated weed management, much more so than in integrated pest and disease management, we do seem to struggle to put together and maintain a simple paradigm for implementation of IWM in practice. All too often use of the phrase IWM seems to imply that non-chemical approaches should entirely replace herbicide use. We seem to want to setup a dichotomy between the 'technology' of herbicides and the 'natural' basis for cultural control. This has to be a false dichotomy; yes, herbicides represent technology but so many old and new non-chemical approaches are also technology-based. Think of insurgent companies like the Small Robot Company, approaches like Garford's precision guided mechanical weeder, new precision physical weeders using heat, electricity or foam and the evolving area of harvest weed seed control – these are examples of non-chemical approaches which are rooted in technology and engineering. If we are going to set up a contrast between good and bad approaches, then forget 'technology versus nature' or 'conventional versus organic', let us focus on knowledge.

The worst weed management and control adopts a tool whether herbicides, cultivations or even some novel approach in complete ignorance of the tool itself or the underlying biological processes and mechanisms. The optimum weed management comes a knowledge of the weed and the underlying mechanisms of the tools being used. IWM based just on adopting tools and approaches in ignorance of how they are working irrespective of whether those tools are herbicides or the most novel approaches like 'harvest weed seed capture' or electro-weeding is just not sustainable.

So NIAB does have a strategy – it is determined, pragmatic and, in a nutshell, optimisation and integration of chemical, cultural and herbicide options. To me the strategy is the easy bit; the hard bit is turning that strategy into approaches that farmers and advisors can adopt to make it a reality. I have proposed four areas to consider in practice that can help turn that strategy into a reality.

1. Appropriate herbicide use

Using appropriate herbicides, doses and timings; by optimising herbicides where they are applied, we can maximise efficiency and minimise waste. NIAB carries out a lot of trials looking at herbicides in the context of cultural management of weeds and that will continue to be our approach.

Often the appropriate level herbicide use can be based on careful observation of the weeds in the field – NIAB spends time talking about identification of weeds as well as scoring and monitoring. However, the reality of an increasing number of problematic weeds (in the main, grassweeds where herbicide resistance is a developing issue) is that efficiency in herbicide use requires pre-emergence application. For these weeds a risk-based approach is needed driven by agronomists and farmers own experience and knowledge. The appropriate herbicide programme needs to be based on an understanding of the weed problem (the weed abundance, level in previous crops etc) and the context (drilling date, crop end use etc).

Sometimes people refer to pre-emergence application as 'prophylactic', which seems rooted in a misunderstanding of the reality of weed management. The real-world situation is that

using a pre-emergence herbicide is done based on risk-reward calculation as an integral part of IWM. In part, because of the way herbicide resistance has reduced the control provided by whole families of herbicides, the effective herbicides are soil-acting 'residual' herbicides. To achieve the best control these needs to be applied pre-emergence of the weed and crop. Delayed application results in reduced efficacy from the herbicides used and so to achieve the same level of weed control more herbicide(s) is needed.

2. Avoid 'over-reaching' with herbicides

It is often said, particularly for our most problematic grassweeds, that getting the last few percent weed control is really valuable. That is unarguable given the long-term implications in these species of seeds that are allowed to shed BUT that does not mean that herbicides are the most appropriate tool to achieve this last few percent. To me this stretching to achieve a last few percent control with herbicides is over-reaching. Farmers and advisors know what is realistic, either by adding more herbicides to a pre-emergence or by returning to a field with well-established weed and crop in the spring and applying additional applications. I point to the disproportionately high cost of the last few percent control where using herbicides as the only tool to achieve those last few percent. To my mind, use the appropriate risk-based herbicide programme. In this area, more than anywhere else, we need new thinking; what tools and approaches can we bring to bear to close the gap between the level of weed control we can realistically achieve with herbicides and the control we need to achieve for the long term.

3. Using cultural 'management based' approaches

I separate cultural (management-based) approaches from direct non-chemical weed control. Cultural control of weeds is, in truth, both our most powerful tool to manage problematic weeds over the long-term and at the approach that needs the greatest understanding of the weeds themselves. Developing a cultural control approach is based on understanding the biology of the weed in order to manage crops and crop sequences in a way that is discordant to that biology. Cultural approaches are, by their very nature, implemented over the long-term and often have implications for wider whole-farm economics and financial structure. This means that this area is where there is most potential (and need) for long-term decision support tools, like NIAB's black-grass management tool which models black-grass population biology alongside the economics of crop production.

One area where we need to develop better tools and understanding is in the trade-offs in the management of different weed species. At the moment we have a focus on weeds like black-grass and Italian Ryegrass but the reality is that cultural changes which support more effective management of these species are likely to create 'opportunities' for other weed species and we need to capture this knowledge better.

This is the area where as an industry we seem to be hiding behind the rhetoric that "it's a system change" especially where the cultural change includes adopting a conservation agriculture approach. While it is true that such adoption does involve a system change, so that some aspects of weed biology/control become more important and some become less important, this is not a reason for not understanding all the changes and interaction involved. At NIAB we are working on the implication of reduced soil movement on germination of grassweeds, the impact of crop residue on herbicide efficacy and looking again at the losses of freshly shed weed seeds from a no-till system.

4. Developing and evaluating non-chemical weed control

I have separated direct non-chemical weed control from longer-term cultural approaches because the distinction is an important one that is too often ignored. It is in this area that we have some of the most interesting novel approaches as well as new technology that has become well established; harvest weed seed control and precision-guided mechanical weeding are good examples of 'novel' approaches becoming established commercially. Because an approach is non-chemical it does not mean that the same requirement to understand levels of efficacy in different scenarios and for different weeds is absent.

I would make the point that we should not be too proud to start using alongside time worn (old fashioned) approaches. It may well be the case that as new technology and approaches evolve and develop the need for conventional approaches will drop away, but even if old fashioned approaches are never entirely displaced we will still have taken a step forward. If we setup a false dichotomy between novel and old fashioned (clean/dirty) and pursue 'novel' weed management approaches with absolutism in practice we will hold back progress. One such example might be the move to autonomous robotic weeding it may well be that as this technology develops the optimum starting point is to use it alongside conventional herbicide programmes in the first place.

Ben Chivers and Alister Farr, Chivers Farms Ltd, Cambridgeshire

Beating black-grass

Chivers Farms covers 900 ha across five sites in Cambridgeshire, including 400 ha at Hardwick, just to the west of Cambridge and the home of NIAB's National Black-grass Centre. The article on pages 21 and 22 explains much of the research currently ongoing at the site, but here *Landmark* talks to the growers who manage the Hardwick site outside of the NIAB trials, to find out what the area is like and how NIAB's research has assisted their own management of the troublesome weed.

The farm

Run by cousins Ben and Caroline Chivers the estate has an arable team of three staff – Tim Clifton, Glen Norman and farm manager Alister Farr. The farm itself is a fully combinable arable farm growing wheat, barley, pulses and oilseed crops that used to be on a fixed rotation, but the approach has had to change over the past few years. The rotation is now far more reactive and flexible, based around what in seen in the field at the time. "The question is largely can we get a winter wheat in there, or shall we do a spring crop?" explains Alister. "It isn't set in stone that in two years time, we'll do x. We're also looking at how and where we fit in options like cover crops and bringing them into the mix."

Flexibility is obviously the key, not only in managing the high black-grass population, but also in trying to find a suitable break crop replacement. Chivers has not grown any winter oilseed rape in two of the last three years, and while they remain hopeful of growing some this year, it is a bit up in the air at the moment.

And, of course, the weather has played its part too! Some of the spring cropping has been deliberate, but some fields have been forced down that road by poor autumn weather. However, Ben suggests that, in terms of weed management, that has not been a bad thing. "Part of taking things as they come may be why our black-grass pressure has reduced so much. We've had to be more flexible."

Managing the black-grass problem

Farming on the soils around Cambridgeshire increasingly means dealing with significant black-grass problems, but Chivers Farms is an example of how the issue can be turned around and kept on top of. "Of course, it's very useful having the NIAB trials on soil that's the same as our farm!" Ben adds.

Every year, NIAB holds a series of open days and events on the site, mainly in late May and early June, where interested farmers and agronomists can visit, talk to staff and tour the plots, seeing for themselves the trials and getting information on tackling black-grass. The Chivers team say that they have gathered valuable information and management ideas from the events, such as growing hybrid barley. Ben adds, "We're picking up knowledge from many sources and cross-check with what we're learning from NIAB. We're constantly fine-tuning, and having the NIAB knowledge base has been a really good reference point to reinforce where you can't skip over things."

Using the toolkit

Getting close up with NIAB trials is only one way they are combating the black-grass problem. They are also gradually reducing the cultivation depth, hoping to make land working operations easier and cheaper.

"We're now confident in addressing other crop management issues as we feel we know how to manage black-grass – the toolkit is there and we have the knowledge to know when to use those tools. However, black-grass will always be waiting for you take your eye off the ball. If you think you've cured it, you haven't, it's always there. So, it remains our priority," finishes Ben.

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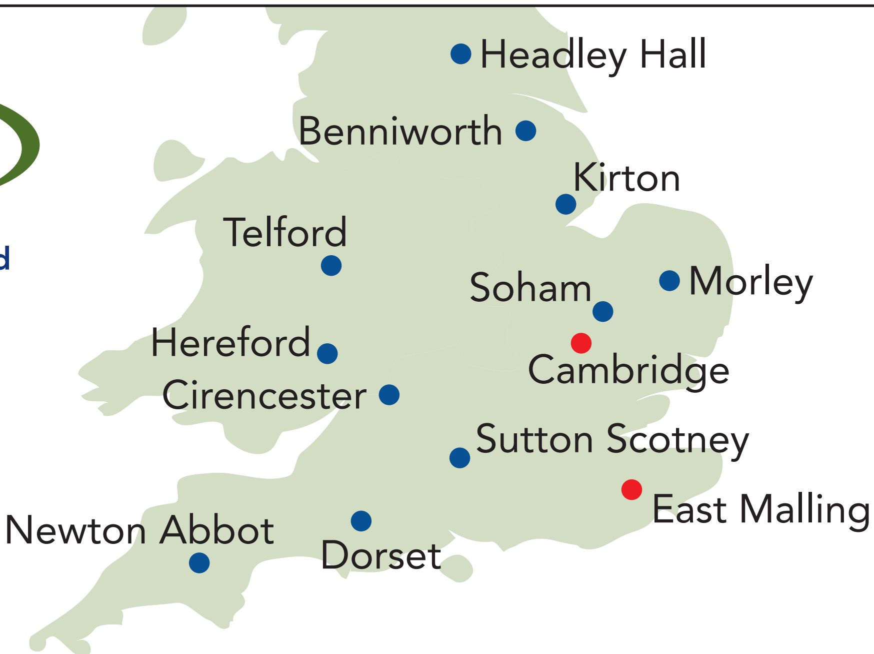

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