NIAB TAG

Landmark

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IN THIS ISSUE

A royal centenary celebration

HM The Queen visits NIAB

NIAB welcomed Her Majesty The Queen to NIAB Park Farm in Cambridge in July as part of our centenary celebrations. She had previously visited NIAB as our Patron in 1969 and 1994. The Queen viewed exhibits of variety evaluation in ornamentals and cereals, as part of the delivery of Plant Breeders' Rights legislation, research work on monocot grafting and cowpeas, a showcase of 'superwheat' plants in the glasshouse, and a colourful visual display of NIAB's history. She also spoke with some of NIAB's longest serving members of staff, each with between 40 and 50 years' service, before planting a tree which garnered a great deal of media coverage.


News

Can one still plant a tree? Hold my handbag...

At 93, Her Majesty remains eager to carry out her ceremonial duty with a smile on Cambridge visit

'She wasn't scheduled to plant the tree, it was just to supervise the planting... she obviously wanted to do it'

Tina Barsby, Chief Executive, NIAB

Crop science key to climate change response

Climate change is undoubtedly one of the greatest challenges facing our generation, with huge implications for the food, water, energy nexus which sustains life on earth.

Tackling the causes and effects of climate change is increasing the focus and importance of NIAB's research, at all stages of the crop improvement pipeline, writes Tina Barsby.

Recent months have seen an unprecedented policy focus on the issue of climate change and agriculture. In August, the International Panel on Climate Change (IPCC) released a major report on global land use and agriculture, followed in September by a report on climate change and adaptation in EU agriculture from the European Environment Agency (EEA), and a manifesto from the NFU to achieve net zero greenhouse gas (GHG) emissions across the whole of agriculture in England and Wales by 2040.

The common theme across these reports is that, compared to other industries, agriculture is unique in its relationship to climate change – at the same time a major cause, victim *and* source of solutions.

It is particularly disappointing, therefore, that media coverage of the IPCC report took aim at livestock production and meat-eating, prompting claims of an anti-farming agenda and diverting attention from the enormous opportunities for agriculture to contribute positively to the causes and effects of climate change.

In fact, the IPCC report specifically highlights the importance of increasing crop productivity and resource-use efficiency through technological solutions such as precision farming and new breeding techniques, and explicitly mentions the promise of genome-editing crops.

This recognition of progressive, science-based crop production is hugely significant, particularly for farming systems in temperate regions such as northern Europe which, the IPCC report confirms, are predicted to be less susceptible to the yield-limiting effects of changes in temperature, rainfall and increasing weather extremes.

Cultivated plant species offer the ultimate clean and green technology, capturing carbon dioxide from the air and transforming solar energy, water and mineral nutrients into valuable and renewable sources of food, fibre and fuels. At the same time, our improved scientific understanding of how plants function at the level of individual genes is opening up major new opportunities to improve crop productivity, sustainability and resilience in areas such as nitrogen use efficiency, pest and disease resistance, and drought and stress tolerance.

In singling out the role of crop science in tackling climate change, the IPCC report underlines the critical importance of NIAB's scientific mission. Indeed, responding to the challenge of climate change is central to much of the research taking place across the NIAB group.

At the start of the crop improvement pipeline, NIAB's trait characterisation and pre-breeding supports the development of more climate resilient wheat requiring fewer inputs, while our in-house GM wheat capability recently helped scientists at the University of Sheffield to create wheat plants modified to survive drought conditions.

The phenomenal success of NIAB EMR's strawberry breeding programme, most notably through the market-leading Malling™ Centenary variety, is helping to increase productivity and reduce wastage in the UK soft fruit sector, while the Water Efficient Technologies (WET) Centre at East Malling is pioneering the development and application of high performance irrigation and moisture sensing technologies in horticulture.

Optimising the water use efficiency of crop production is also the focus for unique developments at NIAB CUF, harnessing innovations in data science, remote sensing and satellite technology to help potato growers plan their irrigation scheduling.

Alongside the requirement to

improve crop performance at farm level, the IPCC report also highlights the urgent need to reduce food waste. This is the core research focus of the Eastern Agri-Tech Innovation Hub, established by NIAB in 2014 to help food businesses reduce their waste or develop new ways to channel waste into alternatives uses and products.

The central objective of NIAB TAG's nationwide programme of applied agronomy research and knowledge transfer is to support improvements in productivity and input use efficiency across a range of crops, rotations and farming systems. Innovations in plant genetics and crop production systems offer crucial opportunities to mitigate farming's contribution to a changing climate, while at the same time adapting to its effects and securing a sustainable food supply for future generations.

As the examples above demonstrate, NIAB's crop science programme is already responding positively to this agenda, and in the years ahead, climate change will increasingly be the core driver of NIAB's research strategy.

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Conventionalising cover crops

John Innes Centre

syngenta

BBSRC Doctoral Training Partnerships

Cover crops are not exactly a cutting-edge innovation. Already popular in Roman times, the practice of growing crops to improve land fertility, and not primarily meant for harvest, was developed independently across continents. Decades of chemical fertiliser use and the Green Revolution may have made it appear they were destined for the scrap heap of obsolete practices. More recently, a range of circumstances driven mainly by environmental concerns about soil loss through erosion and depletion of global carbon stocks have paved the way for a comeback of cover crops. In addition to their traditional role in curbing erosion and – for legume cover crops – favouring nitrogen deposition, a range of other properties – from pollination support to weed suppression, from nutrient capture to alleviation of soil compaction, have caught the attention of industry as well as farmers. Similarly, cover crops are now part of several national incentive schemes and are mentioned in governmental plans as important techniques to increase soil carbon stocks in agricultural land.

The slow road to adoption

However, numerous obstacles have hindered their widespread adoption, and it is not possible to blame their slow progress purely on reliance on prevailing practices, resistance to change and conversion costs. The beneficial role of cover crops in reducing virtually all kinds of soil erosion is established, but a careful analysis of the existing literature covering the other services purportedly provided by cover crops shows a remarkably complex landscape made of conflicting findings and substantial variability. Nitrogen leaching is generally sharply reduced by cover crops, but the opposite may be observed in other circumstances, such as cropping legumes. Pest suppression is observed in some cases, but green bridge phenomena are also common. Above-ground biodiversity seems to be enhanced compared to bare ground, but not necessarily compared to cash crop stubble. More crucially, the effect of cover crops on yields and margins has not been found to be consistently positive across years, treatments and geographic areas. It is therefore no wonder that cover crops are not yet universally established in the toolkit of conventional agriculture. But what are the reasons for this striking divergence in observed outcomes?

An ecological outlook on soil health

Firstly, the mechanisms underlying many of the measured parameters are confused by a range of local environmental variables. Secondly, cover crops are often lumped with, and tested alongside, a range of other techniques, such as reduced tillage or manure addition, going under the generic umbrella terms of organic or non-conventional agriculture. Thirdly and most importantly, the living or biotic component of soil, which catalyses and mediates all processes underpinning soil organic matter storage and depletion, nutrient availability, buffering and resilience to stressors, is very often overlooked in scientific trials.

It is precisely to address this point that the BBSRC and Syngenta funded a research project carried out at the John Innes Centre in Norwich under the supervision of Professor Tony Miller and benefiting from the collaboration with NIAB TAG and its extensive system of long-term field trials. The overall goal of the four-year study is to determine whether cover crops have the potential to shape below-ground communities and – in turn – whether these changes can alter nitrogen availability throughout the cash crop season following a cover crop.

To make sense of the overwhelming diversity in soil organisms, the study concentrates on important groups such as bacteria, to be detected and classified with molecular methods, and earthworms, springtails, soil mites and ground beetles, which are surveyed and sampled with traditional ecological and morphological techniques. Marker gene assays, traditional soil analytical protocols and the use of patented real time nitrate sensors complete the toolkit used to gain insights on the processes taking place beneath the surface at a community ecology scale.

Figure 1. Earthworms collected in 1,250 cm^2 quadrats on the STAR trial. The left column shows continuous wheat plots, the centre a herbal ley three months after establishment, and the right column a field margin. Note the size differences between plots

The study will involve targeted experiments in controlled environments as glasshouses or growth chambers to differentially test the effect of soil meso- and macrofauna on nitrogen cycling and degradation of crop residue, as opposed to sterile controls, allowing also the monitoring of soluble nitrate and ammonium at different depths in the soil profile. For the time being, the study targeted exclusively environmental soil and faunal samples collected mainly at NIAB TAG's New Farming Systems (NFS) rotations and cultivations trials in Morley, Norfolk, and Sustainable Trial in Arable Rotations (STAR) trial in Suffolk.

Cover crops, herbal leys and companion crops

The aim of the sampling sessions conducted at the STAR site is to test the effectiveness for soil recovery of a particular type of cover crops, herbal leys. Such leys are often integrated in rotations to regenerate soil structure and fertility. Two sets of plots, under continuous winter wheat, and an alternate wheat – fallow (2006-2017) followed by a second wheat (2018), now in conversion to herbal ley – are being monitored.

A further factor embedded in the trial design is the application of two different tillage regimes, mouldboard ploughing and shallow non-inversion, to evaluate the legacy of more intense disturbance of the soil profiles. Most studies carried out on herbal leys up to now have focused exclusively on physical and chemical parameters, neglecting the potentially longer recovery times for biological communities. Particular types of organisms, perhaps due to extended life cycles or obstacles to recruitment might need more time to get back to reference levels.

Adopting undisturbed field margins as a reference and monitoring the site for up to three years, it is envisaged that a multivariate analysis of whole community structures will identify how long a herbal ley must be established to have a substantial impact on soil health. Preliminary results show for instance that the recovery of earthworm populations could be a non-linear process, slowed down by limitations in recruitment and affected by the differential impact of cultivations on larger-bodied individuals (Figure 1).

The two trials at Morley are focused on more traditional variations using a stricter definition of cover crops. The subset of plots selected from the NFS cultivations trial will allow comparison of the effect on a winter oilseed rape cash crop of the presence of a bean companion crop. No substantial differences in any of the relevant parameters were detected in the treatments shortly after establishment, but detectable changes may be expected later in the season, when the bean crop residue is degraded and releases nutrients to the cash crop.

This trial will test whether the combination of a legume crop with brassicas can increase biodiversity with the creation of additional niches for soil organisms. This mechanism could be more than compensated by the enhanced production of isothiocyanates by oilseed rape when grown in association with legumes. Irritating substances like isothiocyanates, which confer mustard its pungent smell, are known for their biofumigating properties, and brassica crops are often used for their purported effectiveness in containing some agricultural pests. However, the effect of these substances may impact the soil food web unselectively, and the preliminary results obtained from the sampling sessions performed on the NFS rotations trial at Morley seem to suggest this is the case.

It is often assumed that soil organic matter is strongly correlated to soil health and soil biodiversity. However, comparing the effect of two types of cover crop (a legume-based mix and radish) plus the bare fallow control at three nitrogen application levels, it was possible to observe a divergence of soil organic matter and below-ground diversity dynamics. The incorporation of cover crop residue in combination with medium and high doses of inorganic nitrogen fertiliser was effective at increasing soil organic matter during the following cash crop season, but the effects on yield and biodiversity were largely dependent on the type of cover crop. The springtail, mite and beetle populations under radish were effectively less diverse when compared with those recovered under the legume mix, with an increase in plant-feeding pests and a decrease in large predatory beetles. Harvested spring barley in the following season showed a consistent positive correlation with diversity, and a generalised approach in modelling yield clearly shows the contrasting effects of the legume mix and radish cover crops (Figure 2). While radish has been proven to be an effective cover crop for improving soil structure, due to its large biomass and long tap root, its effects on biodiversity, allelopathy and soil health in general, probably mediated by isothiocyanates, is worthy of further investigation.

Acknowledgements

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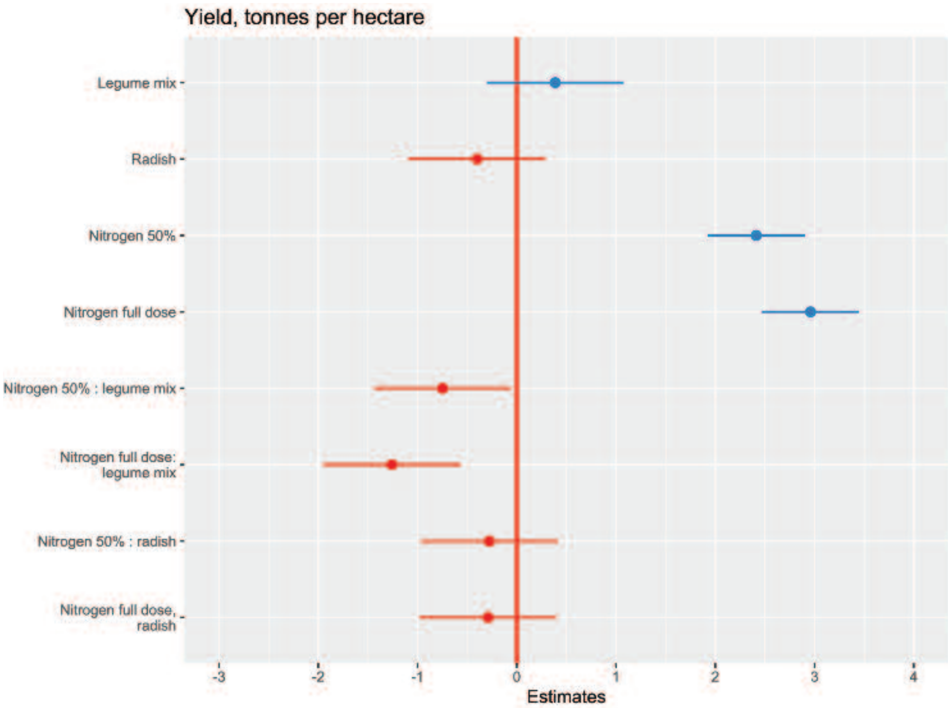
Figure 2. Parameters of a generalised linear model fitted on the spring barley yield data from the NFS rotations trial, season 2018. The values refer to the difference in yield associated with each single factor or interaction of cover crop and nitrogen application compared to the baseline yield of the zero nitrogen/bare fallow cover crop, 3.65 t/ha



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Seed: the start of something…

Seed has been at the core of NIAB's business since it was established in 1919. However, before we get started on NIAB's role in seed certification, we should probably establish some common vocabulary, notably seed is not grain. Seed crops have a very specific set of rules that must be followed to legally produce seed to be marketed. Crops grown to produce seed are more costly than crops grown to produce grain as measures are taken to ensure higher purity, although the returns tend to be higher. Growers rely on the variety purchased being the variety grown so varietal identity is crucial to the seed certification system. Seed certification is a quality assurance-type scheme used to deliver quality seed to the growers. The current system has been in place for many years, with improvements on risk-based strategy implemented along the way.

Where it began

Seed production began long before NIAB was established. A UK plant breeding and seed production industry existed by the end of the 19th century. The industry governed itself, some opting for a voluntary scheme organised by members of the trade. If an 'official' seed test was required, samples were sent abroad. In 1901, a committee of the Board of Agriculture and Fisheries was set up to review the seed trade with the majority of the committee recommending that the UK should establish its own national testing station. The recommendation was not taken up. Eight years later the Irish Board of Agriculture set up its own national seed testing station with the Scottish Board of Agriculture following suit in 1914.

NIAB's eventual founder, Sir Lawrence Weaver, was instrumental in the passing of the Testing of Seeds Order 1917 and a seed testing station was set up within the civil service. Samples of seed lots were submitted for purity, germination and weed seed contamination tests. The results of the tests were given to the buyers. The Order also gave representatives of the three national testing stations permission to enter premises where seed was being sold, take samples (without payment) and submit it to the same three tests. Seed not meeting prescribed standards could not legally be sold. The Order did not apply to cereal species as the testing was deemed too slow and would delay

drilling of the following year's crop.

The Cereal Seeds Advisory Committee (CSAC) first assembled in May 1917 with the aim "to organise a national co-operative to manage the trade in improved crop varieties". The Committee identified four wheat varieties – Wilhemina, Victor, Little Joss and Browick – to focus on. Crops were identified and the selection team, led by Sir Roland Biffen, head of the Plant Breeding Institute, visited the farms and decided if the crops were worth buying for seed – the first field inspections.

Farmers were paid a bonus for the harvested material to ensure the higher purity and quality standards were maintained. Traders acted on behalf of the Department to pay the growers, but did not benefit from this arrangement, so unsurprisingly the seed stocks were not sold to growers and the majority was sold as grain.

The following year minimum germination standards were introduced. The other big change in 1918 was the addition of cereal species to the Seed Testing Order. The establishment of a seed testing station in London was the start of Sir Lawrence Weaver's influence on UK agriculture, including the founding of the National Institute for Agricultural Botany in 1919, in part to help address food security issues arising from the First World War. The Official Seed Testing Station moved to the Institute's new building on Huntingdon Road in Cambridge in 1921, becoming part of NIAB and accounting for around 80% of the business.

The International Seed Testing Association (ISTA) was founded at an international seed testing conference held at NIAB in 1924. This independent organisation has been developing seed testing methods, supported by the non-profit co-operation of experienced seed scientists and analysts ever since. NIAB, as the Official Seed Testing Station of England and Wales, has contributed and continues to work towards the group vision of "uniformity in seed quality evaluation worldwide".

The link between NIAB and government remained strong. In 1942 when the UK was once again at war, the Ministry of Agriculture and Fisheries turned to NIAB to request the formation of a Seed Production Committee (SPC). This included farmers, representatives from the seed trade and scientists, all to be collectively responsible for producing quality seed in the UK, for the UK.

In 1944, NIAB launched the first Recommended List and, as a seed producer as well as tester, committed to certifying all seed it produced. Inspections were carried out in the field during the growing season and a representative from NIAB would be present during harvest and packing. This service was open to other seed producers who wanted to have their seed officially certified.

Aftermath of war

Following the end of WWII, the four-year Marshall Plan was put in place with the inception of the Organisation for European Economic Co-operation (OEEC) in 1948. This programme removed trade barriers to allow the rebuilding of Europe's economy. The OEEC continued to function throughout the 1950s.

The introduction of the Cereal Field Approval Scheme in 1955 meant that representatives of breeding companies and trade could carry out field inspections, provided they had been trained by NIAB. The area of inspected crops doubled in the first five years. The Comprehensive Certification Scheme was also introduced, aimed at providing top quality seed stocks known as 'foundation stocks' – early generation production. Crops entered for this scheme were inspected by NIAB staff only.

It was a pre-requisite to the Recommended List trials that varieties had been entered into the Schemes by the original breeder, therefore records of varieties and seeds were kept. A breeder's control of a variety and its production came ahead of the Plant Breeders' Rights (PBR) legislation, introduced in 1964.

In 1959, NIAB reviewed the production system and believing the supply of seed of a new variety was not good enough, restricted the sale of seed to only those who had participated in the Field

Approval Scheme in England and Wales, or an official scheme elsewhere.

Formation of OECD

On a wider scale, the continuation of the OEEC was being questioned. These discussions led to the Convention on the Organisation for Economic Co-operation and Development which was signed in 1960. The UK was a founding member of the OECD in 1961, which had a more global outlook than the former OEEC. The Seed Schemes were introduced, harmonising procedures for seed production across member states to encourage the use of high quality (officially controlled) seed. Fenwick Kelly, who became a deputy director of NIAB, played a vital role in the development of these Schemes, the beginning of NIAB's close involvement. NIAB still acts as the co-ordinating centre. Maintaining the list of varieties eligible for seed certification under the OECD Seed Schemes is part of the co-ordinating centre's task list – the 603 page document covering 204 agricultural and vegetable species can be downloaded from the OECD website (although searching the online database is easier).

With an increasing seed trade within the UK and across the OECD members, the seed bag label was adapted to indicate the year of release from the breeder and the purity of the seed being purchased. This system remains today with specific requirements for labelling included in the Seed Marketing Regulations.

NIAB's Seed Multiplication Branch was moved to the National Seed Development Organisation (NDSO) in 1967, which were then responsible for the production and sale of nationally funded varieties. NIAB ceased to produce seed commercially, a move to confirm its independence.

Modern times

Today, NIAB is contracted by the Animal and Plant Health Agency (APHA) to oversee the day-to-day seed certification system in England and Wales. All crop inspectors active in England and Wales, official and trade, are licensed by APHA, but trained by NIAB.

Plots from samples of all seed lots entered for certification in England and Wales are grown and assessed for varietal identity and purity. The Agricultural Crop Characterisation Team at NIAB are skilled in identifying plants that do not conform to the description of the variety using characteristics that some may consider obscure. Have you ever looked at the hair on the inside of a glume on an ear of wheat? It can be very telling!

On the face of it, small differences in botany can appear to have very little effect on a crop. However, that tiny difference could be indicative of a major problem. If a wheat variety chosen for breadmaking qualities is contaminated with a feed wheat, the grain will be rejected. Seed certification aims to reduce the risk of that happening by providing a system that tightly controls the early generations of seed to ensure the correct purity levels are achieved for the end user. Of course, there are many things that can go wrong in a risk-based system, but if it does, the seed certification process allows the tracking of seed lots so the source can be identified and the effects mitigated.

The words of former NIAB Director Graham Milbourn in 1987 remain as relevant today: "the potential for improved crop varieties can only be achieved in practice when farmers, skilled in producing seed crops, can convert the breeders' genetic material into marketable seed-lots for crop production".

NIAB's role in promoting a transparent system where all stages of the process, from breeder to end user, benefit has influenced policy on a local, national, European and global stage. The current team continue to advise Defra and APHA on issues affecting the industry, particularly in these uncertain political times where stability of seed supply is so important to UK agriculture. NIAB's role as co-ordinating centre for OECD provides an insight to the seed systems in place across the 61 member countries. It also means that we are aware of new developments such as the increasing use of molecular techniques to complement traditional phenotyping methods for seed certification or developing standards to apply to varieties produced using new breeding techniques. Seed certification at NIAB has a long history, but is always moving forward, most recently with the move from Huntingdon Road to our new facilities at Park Farm, on the outskirts of Cambridge. Who knows what the future will hold!

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Barley net blotch: new symptoms, new problem?

Barley net blotch, caused by the fungus *Pyrenophora teres*, is easily found across UK barley crops and is unmistakable with its net-like appearance. Over the past few years the plant clinic at NIAB has received samples that look a little different.

There are two sub-species of the net blotch fungus: *Pyrenophora teres* f.sp. *teres*, that causes the net-form of net blotch and *Pyrenophora teres* f.sp. *maculata*, that causes the spot-form of net blotch. The two different sub-species are almost impossible to distinguish, even under the microscope, so molecular PCR-based diagnostics are required. NIAB has also seen some very distinctive large brown stripe symptoms which have proved to be *Pyrenophora teres* f.sp. *teres* when tested with a molecular diagnostic.

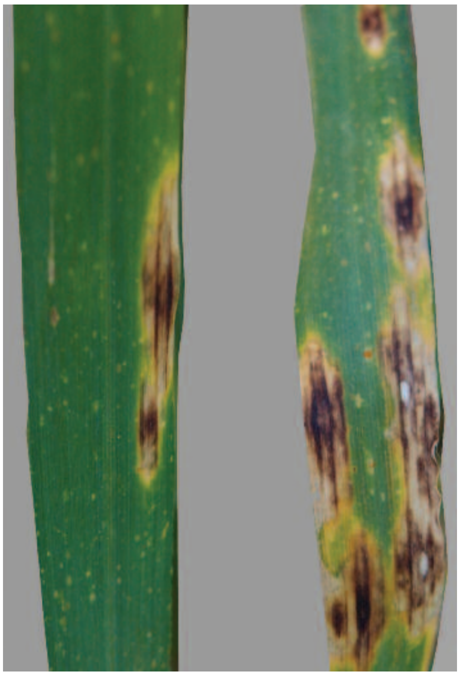
Why is this important?

Barley crops regularly suffer from spotting and blotching and accurate identification of the underlying cause can assist in disease control programmes. Net blotch is controlled by SDHI and azole fungicides, although resistance issues have been reported for both modes of action. Nevertheless, control is still possible unlike Ramularia, another disease of similar appearance. It can be difficult to tell the difference between these two diseases: subtle differences between the two include lesion shape (Ramularia lesions have straighter sides) and the appearance of the lesions on both sides of the leaf (Ramularia). It is also possible to confuse these lesions with Septoria nodorum blotch, caused by the fungus *Parastagonospora nodorum*, and in this case, diagnosis is only possible by using a microscope.

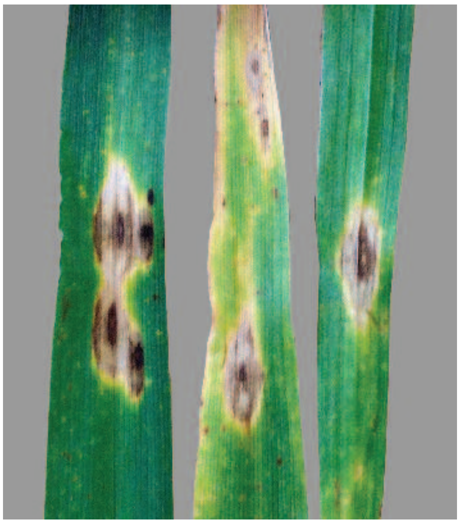
Is the prevalence of the spot form of net blotch increasing?

It had been assumed that the spot form of net blotch was rare and not an issue. Understanding whether this remains so is important in case control approaches need to be refined. NIAB LabTest's Plant Clinic service can identify spot and net forms, on plants or on seed with a molecular diagnostic, so suspect samples can be confirmed.

Striping symptoms of Pyrenophora teres f.sp. teres



Spot symptoms of Pyrenophora teres f.sp. maculata



Spot form of net blotch

Check seed samples for net blotch with NIAB LabTest

Seed disease test: leaf stripe and net blotch	£50.00
Upgrade to a NIAB LabTest standard test package for a comprehensive picture of seed quality. Includes: germination, thousand seed weight, moisture, loose smut, leaf stripe and net blotch	£157.00

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NIAB LabTest

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www.niab.com/labtest/

Summer 2019 will be remembered for our centenary celebrations alongside our traditional event programme – highlighting NIAB's impact and influence on crop production in the past, present and future. With record attendance at our members' and open events, we were lucky with the weather at all but the very wet national Cereals Event and our own Black-grass Open Day in Cambridge. There was lots to talk about, from new varieties and soils and rotation advice to plots showing the activity of new fungicides coming next year. And thank you to all those who joined us in late June when NIAB staff, members, industry partners and stakeholders came together to celebrate 100 years of plant science.


NIAB
100
YEARS OF PLANT SCIENCE
1980s


100
Claire
Yeoman

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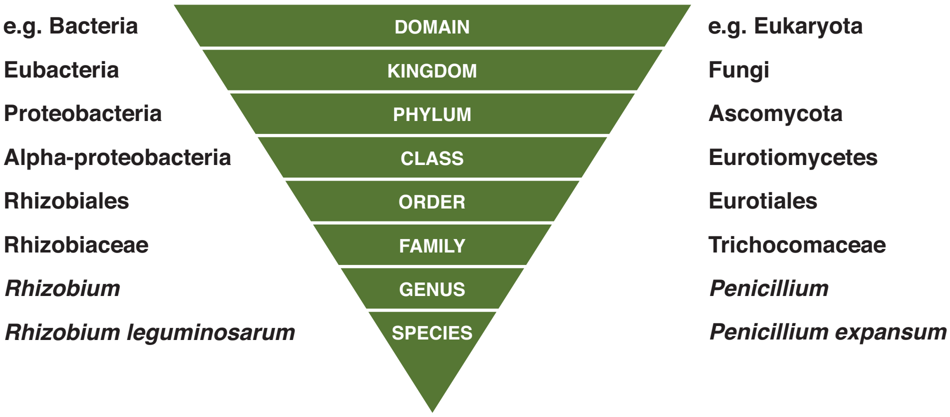
Big Soil Community – working together to describe microbial diversity in soil

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. While currently used indicators such as pH and worm counts are already providing valuable information on soil health, new measures are being evaluated and added, such as total nitrogen, microbial biomass carbon and potential mineralisation nitrogen. For the future, DNA-based measures of the soil community including pathogens, nematodes and other soil fauna are likely to become a key component of regular soil analysis.

In autumn 2018, NIAB linked up with the Big Soil Community (co-ordinated by Fera) where DNA sequencing and data science were used to address this complexity and reveal the breadth of the bacterial and fungal communities within the soil samples submitted. Farmers and growers from across the UK were invited to sign up to the community and purchase a sample via Fera. In 2018 samples cost £250 each. Samples were taken by participants from mid-October to mid-November using a standard sampling protocol to minimise the risk of contamination. Samples were then returned to Fera via post for sample preparation, DNA extraction and analysis. This is not a quick process as there are many rigorous steps involved, described later in this article. Final summary reports were available in late spring 2019.

Figure 1. Organisms are described according to a number of hierarchical taxonomic ranks; these are shown together with an example for a known bacterial and fungal species



The analytical process

DNA was extracted from 10 g sub-samples and purified to remove humic acids and other soil materials that can inhibit analysis of the DNA. A technique called DNA metabarcoding was used to measure the underlying microbial biodiversity found in each soil sample. This first involves a method known as PCR to amplify DNA that is specific to the different taxonomic groups of organisms – their 'barcode'. The barcodes of bacteria and fungi in each soil sample were then identified using high-throughput DNA sequencing technology.

By analysing DNA sequences of taxonomic marker genes that are unique to bacteria or fungi, the diversity of organisms present within each domain can be determined. Organisms with taxonomically distinct DNA sequences are grouped into operational taxonomic units (OTUs). These can then be assigned taxonomic rank where the sequences match those of known organisms held in specialised bacterial and fungal databases curated by third parties.

The SILVA database was used as a reference for bacterial metabarcode sequences, and the UNITE database for fungi together with the taxonomic classifications used by the National Centre for Biotechnology Information (NCBI). The relative abundance of each organism in the sample can then be estimated. Many soil microorganisms have yet to be fully classified, so it is not always possible to assign all the taxonomic ranks from a unique OTU. Some OTUs remain unknown even at family level (Figure 1).

The DNA sequencing approach enables us to quickly assess the presence and relative amounts of many hundreds, or even thousands, of types of organism, irrespective of whether they form a relatively large or small part of the community – but it does not tell us the absolute amounts of each type of bacterium or fungus present. The DNA sequences were then aggregated and analysed to prepare an overall summary for the Big Soil Community, as well as an individual sample report for each sample.

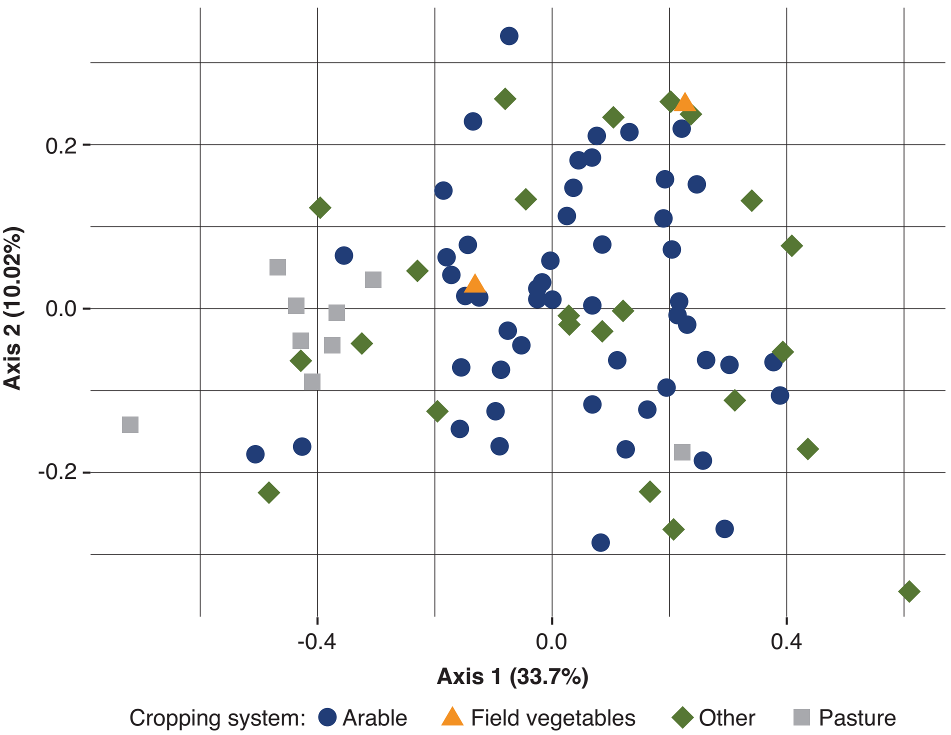
Results

In the first year, the Big Soil Community received and analysed 228 samples. Most of the samples were from soils of medium texture (loams and clay loams) under conventional arable production with moderate tillage intensity. But the full range of samples included heavy clays, blowing sands and peat soils; together with a range of farming systems, from upland moorland, permanent pasture, conservation agriculture to organic vegetable production.

There are many different definitions of biological diversity, with different units and different calculations. The simplest definition is simply the number of different types of organism in the sample (this is often referred to as "richness"). However, this ignores the possibility that two communities with the same number of organisms could have very different abundance profiles. For example, in one community the four types of organism could be present in equal amounts; in another, a one organism could dominate, with the others present in very low abundance. Most measures of diversity take such distributions into account, and the data is often presented using a measure called Shannon Diversity. A low Shannon Diversity (less than 1) would mean that the community is practically concentrated in one type, and the other types are very rare (even if there are many of them). A large Shannon Diversity means that there are both a large number of species and also that all species are equally abundant within the community.

In the samples collected for the Big Soil Community, a total of 22,808 bacterial and 3,539 fungal OTUs were identified. Soil biological communities show high diversity. The Shannon Diversity for the bacterial community was typically in the range 6-7.5 and is much higher than that for the fungal community which was typically 3-4.5. The fungal community is more dominated by a few common species, whereas the bacterial community is more diverse. Many of these different bacterial and fungal OTUs were matched successfully to the reference libraries at genus level.

Figure 2. Principal coordinates analysis of fungal diversity for cropping systems, displayed on the two main axes. Each plotted point represents a single sample; the further apart samples are the more different are their fungal communities. The graph suggests that pasture and arable systems cluster differently. This clustering suggests that there are some differences between the two systems, but this would need a larger dataset to confirm any true differences, and to identify which organisms underlying these differences might be genuinely be associated with one system or another



Fungi: By far the most abundant fungus identified was assigned to the genus *Mortierella*, a widespread saprotroph living on decaying plant material and other organic matter and accounting for 38.79% of the total reads. Other important decomposer fungi identified at the genus level included *Cladosporium* (4.04%), *Ceratobasidium* (0.41%), *Ascobolus* (0.34%), *Penicillium* (0.19%) and *Aspergillus* (0.01%). Many other functionally important fungi were also present in the soils at lower abundance. Three genera with potential biocontrol activity were identified along with numerous fungal genera that can act as plant pathogens, including *Fusarium* (2.91%), *Ophiosphaerella* (0.66%), *Alternaria* (0.06%), *Colletotrichum* (0.03%), *Neonectria* (0.03%), *Helminthosporium* (<0.01%), *Leptosphaeria* (<0.01%), *Monilinia* (<0.01%), *Paecilomyces* (<0.01%), *Ramularia* (<0.01%), *Rosellinia* (<0.01%), *Urocystis* (<0.01%) and *Uromyces* (<0.01%)

Bacteria: At the genus level, 946 bacterial taxa could be differentiated, but only 331 could be matched with known genera. The three most abundant bacteria identified at the genus level across all samples have yet to be classified; their ecology and functions are therefore unknown. Of the bacteria that could be classified at genus level, the most abundant was *Flavobacterium* (2.39% of total reads), a free-living plant growth-promoting bacterium that can fix atmospheric nitrogen when there is abundant energy present e.g. root exudates. Other important bacteria identified at the genus level included decomposers, nitrogen fixers, sulphur oxidisers and a range of genera known to have plant growth promoting species, as well as some plant pathogens including *Burkholderia* (0.06%), *Acidovorax* (0.02%), *Rhodococcus* (0.02%), *Pantoea* (0.01%), and *Xanthomonas* (<0.01%)

The diversity values were assessed using the site information (farming system, tillage, fungicide use etc.) to begin to assess any consistent differences. With some care, the abundances of taxa within and between groups were also compared. There seems to be some differences between the soil microbial community

Table 1. The most abundant bacterial and fungal phyla in 48 soil samples across all treatments in the long-term STAR trial experiment (> 10 years; Stobart and Morris 2011) determined by (a) 16S rRNA metabarcoding (1,160437 sequence reads) and (b) ITS rRNA metabarcoding (764,783 sequence reads) respectively

(a) Bacterial phyla	Relative abundance %	
Proteobacteria	20.5	Enormous range of metabolic diversity, including opportunistic pathogens, plant growth promoters, symbiotic and free-living N fixers, nitrifiers and de-nitrifiers, sulphur oxidisers; diversity within this phylum may be changed by agricultural management
Bacteroidetes	18.5	Wide range of metabolic diversity, some free living N fixers and plant growth promoters; often found to increase in relative abundance under agricultural management
Acidobacteria	17.7	Wide range of metabolic diversity; only recently described; common in soils, but relative abundance often declines under agricultural management
Verrucomicrobia	10.3	Recently described, common in soils; relative abundance may decline under agricultural management
Thaumarchaeota	9.3	Ammonium oxidisers, relative abundance may increase under agricultural management
Planctomycetes	9.2	Dominantly aquatic bacteria
Chloroflexi	6.5	Phylum includes free-living photosynthetic bacteria; relative abundance may decline under agricultural management
Actinobacteria	3.5	Decomposers with wide enzymatic capacity, form mycelial colonies similar to fungi, source of many antibiotics, some plant symbiotes, relative abundance may decline under agricultural management
Gemmatimonades	3.2	Recently described, relative abundance may decline under agricultural management

(b) Bacterial phyla	Relative abundance %	
Ascomycota	43.6	Active decomposers commonly hyphal but also a wide range of parasites and symbionts (including some ectomycorrhizal fungi); often with a high degree of specialisation within the phylum. Include some fungi with biocontrol activity such as *Trichoderma* and *Beauveria* spp. and a range of plant pathogens (e.g. *Fusarium*, *Verticillium*, *Gaeumannomyces*)
Mortierellomycota	36.0	Recently proposed phylum containing decomposers in the order Mortierellales. Saprotrophs on decaying leaves, roots and other organic material
Basidiomycota	20.4	Mushroom, rust and smut fungi; includes a range of symbionts including ectomycorrhizae of trees and some pathogens such as *Rhizoctonia*

associated with permanent pasture and arable systems. However, these data do not allow us to draw conclusions about true correlation and less still, about causes and effects.

Across the samples collected from NIAB trial centres, an average of 1,908 bacterial and 323 fungal species (OTUs) were found. The average Shannon Diversity for the bacterial communities was 6.9 and for the fungal community was 4.1. The microbial diversity at these sites is fairly typical of the arable soils under moderately intensive cultivation. Microbial community data collected from the long-term STAR trial experiment, where treatments have been established for over 10 years (Table 1), did not show significantly different bacterial or fungal communities between the typical UK crop rotations (continuous wheat, wheat and winter break crops, wheat and spring break crops, alternate fallow); data not shown.

What next?

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!

The farmer community science in the Big Soil Community has generated a unique dataset that will accelerate research into how soil microbial communities influence our farming systems. More information is still likely to come from this dataset itself because of on-going analysis. However, many of the participating farmers may have been disappointed with what they learned from the analysis about their own soils and whether its microbial community is in good health. In fact, what we learned is how much there is still to learn, with two thirds of the bacteria found still not able to be identified. Much more science is needed before molecular-based analysis of the soil microbial community is of practical value to farmers. However, these approaches are likely to generate new soil health indicators over the next few decades.

But do not wait for those indicators before you begin to look more closely at your own soil health. It is already possible to link together soil health indicators measured in the field, such as earthworms and visual evaluation of soil structure (VESS) and the data from soil samples sent for laboratory analysis. Looking at a range of soil indicators together adds value to any single measure and will help enhance our understanding of the impacts of current soil management. In the future it may also be possible for farmers to pool these wider sets of soil health data to create a farm citizen science resource allowing benchmarking for farm data and to support selection of soil-improving practices. Then when the molecular indicator become available they will slot straight in.

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Black-grass is not the only weed to be concerned about

Black-grass dominates any discussion when the topic turns to weed control, which reflects the widespread problem that it is. However, it does marginalise other weeds that either do, or have the potential to, cause severe issues if left to establish themselves in fields. NIAB TAG has already begun work to identify, and address, these species that are coming to our attention, to ensure that appropriate and effective actions can be taken when necessary.

WHAT TO LOOK FOR

Italian rye-grass (*Lolium multiflorum*)

Italian rye-grass will certainly already be a major issue for many growers, although the geographical spread is smaller than black-grass with key populations confined to Kent, Essex and South Yorkshire. This is a species that cannot be tolerated, even at low populations, as it has an incredible capacity to compete with the crop, robbing yield.

Cultural control methods, such as spring cropping, can be effective as Italian rye-grass has a similar germination profile to black-grass, with the majority emerging in the autumn. However, a recent trial in Kent has shown that spring cropping can be less effective at controlling this weed than black-grass for example. Chemical control of this weed can be difficult due to resistance to the majority of contact herbicides. However,

Italian rye-grass

an incorrect perception that a significant proportion of ryegrass in an autumn sown crop actually emerges in the spring, has led to application timings that are ineffective for reasons other than resistance.

Rat's tail fescue (*Vulpia myorus*)

Populations of this emerging threat are causing issues for growers with a history of grass leys, as contamination has generally been traced back to this source. A rather peculiar weed, it often appears mysteriously, and then disappears as quickly, which makes the management of it very difficult. Herbicide options should be effective, provided applications are made to small plants. As a shallow rooting plant, it is highly suited to no-till systems, and should be viewed as a weed of the future as the path of UK agriculture heads in this direction.

Rye brome (*Bromus secalinus*)

Historically, the brome family has been important as an arable weed, with prevalence generally related to the reduction of tillage within a farming system. Whilst sterile brome (also commonly known as barren brome) remains the most widespread, it is rye brome that needs to be closely monitored as, once established, it is a weed that is extremely difficult to control within an ordinary arable rotation.

Rat's tail fescue

Broad-leaved weeds

There are concerns that several broad-leaved weed species are becoming more difficult to control. Leading the pack is bur chervil, from the *Umbelliferae* family. As a weed that often escapes a typical pre-emergence programme due to lack of activity, it is able to continue growth through the winter months, resulting in ineffective control from spring herbicides. Common field poppy is another species that can be difficult to control if resistance is confirmed; it requires a concerted effort to put in place a management strategy prior to growing a crop. This is equally important across all weed species.

Why are they becoming more problematic?

Biology and (the lack of) chemistry are the two groups where the answer to this question lies. Where farming systems are moving towards reducing the level of tillage then this gives a biological advantage to some weeds, whilst disadvantaging others. Weeds that are either shallow rooting, perennial or whose seeds are less able to cope with burial, are likely to thrive in the no-till systems.

Rye brome

Bur chervil

The use of herbicides has changed, even from five years ago. Commonly used herbicides, like isoproturon and trifluralin, which gave effective control of a number of broad-leaved weeds, are no longer an option. A lack of efficacy of some products against black-grass has seen their application moved from spring to autumn or dropped altogether. Whilst this may have helped to keep the black-grass in check, it has removed options against other species. Black-grass has become the ultimate smoke screen to hide the ingress of other species.

What is NIAB doing?

One key message around black-grass management has been to balance chemical and non-chemical control (not relying solely on any one management tool). This is something we need to adopt for emerging weeds as well. Field trials on emerging weed species are difficult to carry out, as finding patches of both a suitable size and uniform density is difficult. Instead, the route pursued with some of these species has been to run trials with artificial populations, which has given us a fantastic opportunity to carry out work that is ordinarily difficult to do in normal arable rotations. This initial work has focused on looking at the basics of Italian rye-grass control, and to get a grasp on the products and combinations that are most effective against Rat's-tail fescue. In the past season, we have graduated to trials on field populations in Italian rye-grass and rye brome, with additional work on bur chervil and poppy in the pipeline for autumn 2019. Alongside work on herbicide strategies we are attempting to carry out basic profiling of the impact of cultural control approaches.

KEY FINDINGS SO FAR

Rat's tail fescue

One of the most important outcomes, from two years of trials, is how dependent control of Rat's tail fescue is on the size of plants being tackled. The available products offer an excellent opportunity for control when applied at the correct timings. Getting on top of this species in the autumn is vital, so sequencing a flufenacet-based product at the pre-emergence timing with Broadway Star (a.i. pyroxsulam, cloquintocet-mexyl + florasulam) at post-emergence is a robust option. Compared to other grass-weeds, Rat's tail fescue does not have the capacity to compete with the crop; an indicative figure is that for every 100 heads a yield reduction of between 1 and 2% will be seen (Figure 1). Predicted as a weed of direct drilling, it is a priority to understand this species within different cultivation systems to understand how cultural control can be optimised to reducing weed pressure.

Figure 1. The effect of Vulpia populations on crop ear density

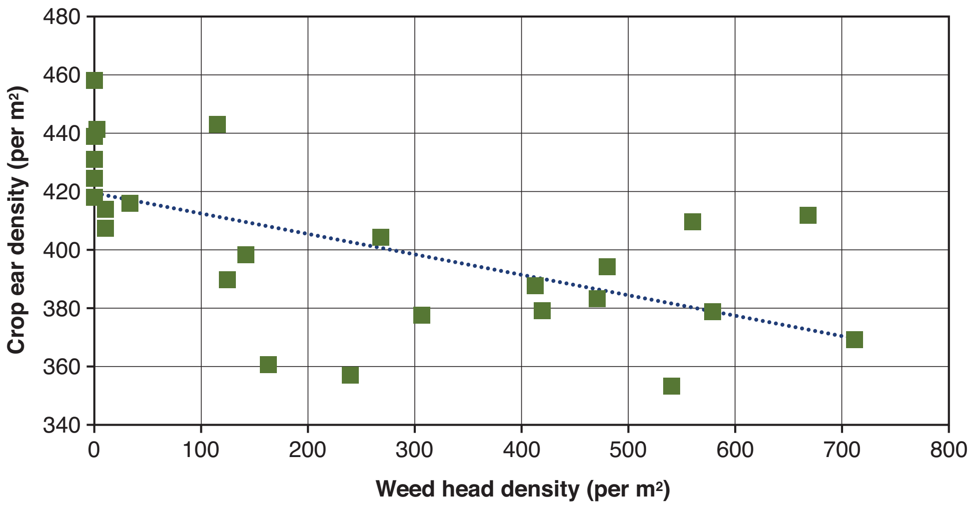
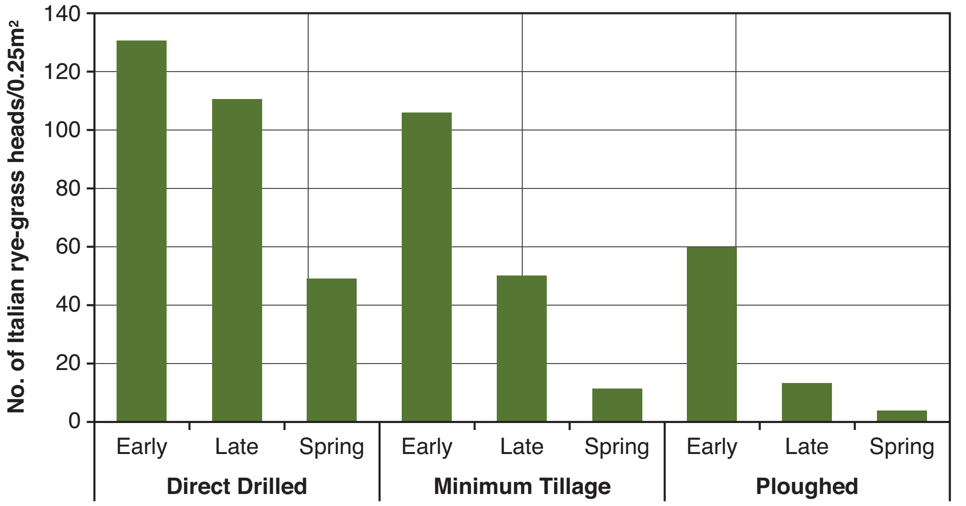


Figure 2. Establishment technique x drilling date for Italian rye-grass control



Italian rye-grass

NIAB's most recent data on this species has derived from the artificial population trials, and from a new site in Kent. It is clear that a sequenced approach of flufenacet-based products, followed by early spring application of ALS chemistry (specifically Atlantis OD (iodosulfuron-methyl-sodium + mesosulfuron-methyl) or Broadway Star) is capable of giving robust results. The sensitivity of this weed to post-emergence products is closely linked to the physical size of the plant, so application will be most effective in late autumn or early spring.

Using effective cultural control measures against Italian rye-grass is vital to keeping populations at bay, whilst reducing the risk of herbicide resistance. Using a matrix design of cultivation type and drilling date, NIAB has observed that the advice of delaying autumn drilling until as late as possible is sound for this weed but using spring crops, whilst it can be effective, carries more risk than for black-grass (Figure 2). The use of the plough, to hard reset the system if the weed is well established, should be encouraged, but not a strategy that should be persisted with. Unlike black-grass, this weed does not shed seed prior to harvest, so there is much greater scope to apply harvest weed seed management techniques such as seed destructors or chaff lining – the effectiveness of these techniques in the UK is still to be fully evaluated.

Rye brome

This is one species where NIAB has been successful in finding an excellent trial site that has yielded some extremely useful data. Rye brome is a very difficult to control weed, with a different profile of sensitivity to herbicides to other species within the brome family. Broadway Star is the single most effective product, but attention to detail around conditions for application is vital. Applications will be ineffective if made when the weed is not actively growing, or if the target is too large. This year's data demonstrates this beautifully. Expectations typically lead to an application in March to ensure conditions are optimum.

However, in the 2018/19 season this optimum timing was much earlier, in the middle of February. Due to the mild winter conditions, the weed never really shut down, so by March the weed was too well established to be accurately controlled. Interestingly, a tank-mix of 800 g/l of pendimethalin and Broadway Star was able to improve the robustness of an application in March significantly above a strategy of splitting the residual and contact material. The future of our work on rye brome will attempt to look at how timing of post-harvest cultivation can affect in-crop control, and to characterise some of the biology of the species as an arable weed

e.g. germination timing, response to drilling date.

Broad-leaved species

The majority of the work by NIAB has focused on the common poppy species, where the message on effectiveness must not be disconnected from a message of resistance risk management. Herbicide programmes must incorporate more than one mode of action to support those products that are at risk of resistance forming against them e.g. sulfonylureas.

Future work will evolve to study the interaction between these broad-leaved species and different farming systems, especially cultivation, while continuing to evaluate product selection. Cultural control against broad-leaved weeds has been insufficiently studied – the assumption being that no matter what the agronomic approach these weeds are present. However, as with grass-weeds, it is certain that some agronomic systems put more pressure of the herbicide element. This season, trials at NIAB's site at Hinxton, near Cambridge, explore the impact of cultural control on broad-leaved weeds (particularly poppy) and the interaction between agronomy and herbicide effectiveness.

For more information, read NIAB trial reports WW17-9127, WW17-9159, WW18-9162, WW19-9180, WW19-9179.

Anna Harper, Myerscough College

Effect of tillage on spider predation

University Centre Myerscough

Predatory spiders

The sheet-weaving spider, *Tenuiphantes tenuis* (Linyphiidae), is a common arachnid found in British agricultural habitats. *T. tenuis* is a pioneer species and recolonises disturbed habitats rapidly. This spider is carnivorous, does not harm the crop and spins a web to ensnare prey. This equates to increased crop pests caught in the web than actually consumed by the spider, a form of biological control. This, in the future, may reduce the need for chemical control, with environmental concerns and acquired resistance.

My PhD research in agroecology aimed to understand how sheet-weaving spiders may be a useful biological control tool to control crop pests that cause considerable impact to yields. A long-term trial, run by NIAB in partnership with Childerley Farm near Cambridge, investigating the impact of soil tillage intensity on the yields of cereal crops, was used to assess the impact of different tillage intensity on the behaviour of *T. tenuis* in relation to crop pests, such as cereal aphids and *Sitodiposis mosellana* (Orange wheat blossom midge). The different tillage systems were conventional non-inversion tillage of sub-soiling (CON) and two forms of direct drilling: direct drill (DD) and direct drill managed (DDM) – a shallower form of cultivation (Figure 1). Measurements collected from the field site centred on webs spun by *T. tenuis*.

Does tillage intensity affect the abundance of predatory spiders?

Clear differences of *T. tenuis* behaviour were identified between the different soil cultivations at times of primary and secondary cultivation. The DD allowed small webs to be woven into the stubble left above ground and increased abundance of *T. tenuis* (Figure 2) whilst large webs were spun between greater soil aggregates of CON due to the sub-soil technique. Low activity was observed in DDM, where the shallow cultivation led to a decrease in landscape complexity, *T. tenuis* requiring an abundance of accessible vegetation to attach thread for web building.

In later growth stages the density and height of the crop within each soil cultivation intensity was key. Increased landscape complexity permitted greater web abundance by providing a plethora of anchor materials. From stem elongation (GS 30) to anthesis (GS 61), *T. tenuis* biological control potential was exhibited in CON and DD areas where greater web area and thread length spun increased the capture of crop pests (Figures 3 to 5).

Biological control was further identified by webs spun of a greater area and height in an area of Barley Yellow Dwarf Virus-infected spring barley. This was confined to the CON area only but this was thought to be due to low aphid dispersal and moisture stress from the unusually high temperatures of the summer of 2018, more than a function of tillage intensity.

It is key that yields are also considered. In 2018, the highest crop yields in winter

Figure 1. Spring barley field in NIAB trial as seen from Google Earth, divided into the different areas of tilled intensity

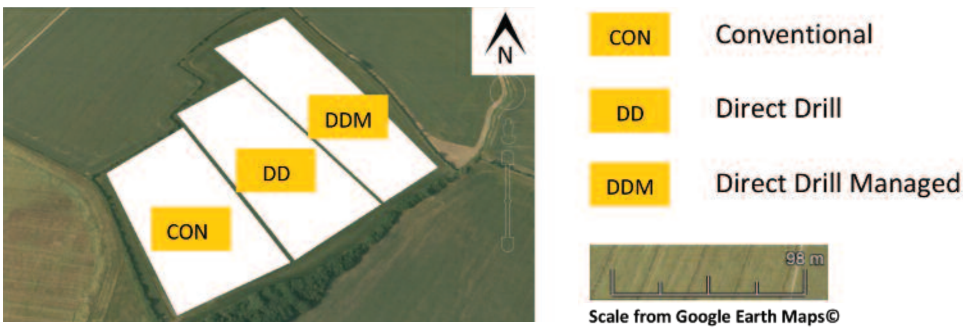


Figure 2. Total stubble positively correlated with number of *T. tenuis* of spring barley, harvest and primary cultivation, 2017/2018 season. (P-Value – 0.002)

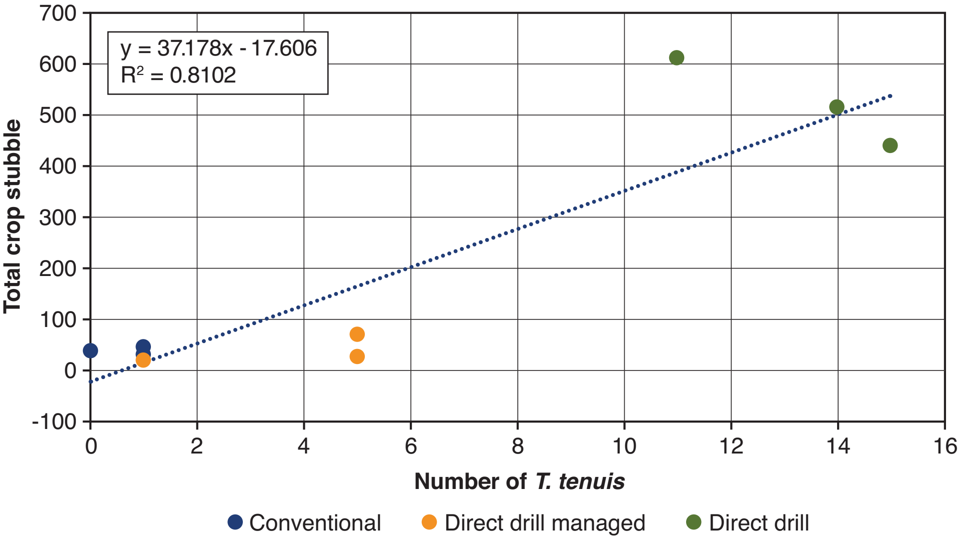


Figure 3. Number of sheet-weaving webs positively correlated with number of *S. mosellana* in web. Winter wheat, GS 31-GS 33, 2017/2018 season

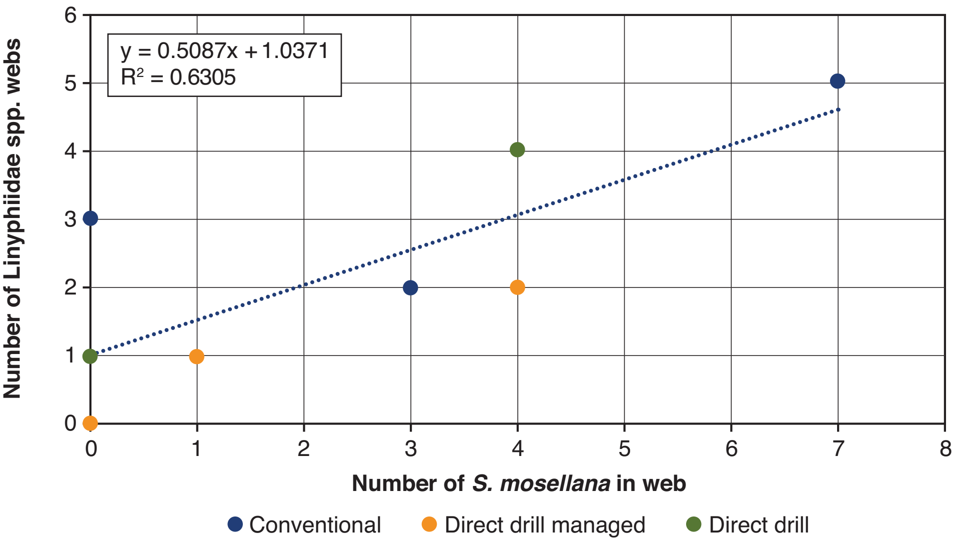


Figure 4. *S. mosellana* caught in sheet-web in conventional cultivated crop. Spring barley, GS 31-GS 33, 2016/2017 season

Figure 5. *T. tenuis* with wrapped cereal aphid in sheet-web direct drill. Spring barley, GS 31-GS 33, 2016/2017 season

wheat and spring barley were associated with CON tillage which is of benefit to food production and *T. tenuis* web-spinning with greater plant density. However, these yield results, taken from a single season of a long-term project, should be treated with some caution.

Field margins and floral diversity

A greater density of *T. tenuis* were found in the hedges than the field, providing a base for migration into the field as well as continuity pf generations. Removal of the hedges would be of a disadvantage. It may be that another slow growing companion plant could be grown in the field margins to push *T. tenuis* into the main field, noting that a small increase in vegetation complexity is of great appeal to web building. This is known as intercropping and can involve the use of non-invasive wild flowers such as *Lotus corniculatus* (Birds foot trefoil) and *Trifolium pratense* (Wild red clover).

Rapid dispersal of *T. tenuis* out of the hedge requires the hedge and crop to be in close proximity. It may be beneficial to create green-bridges to aide movement of *T. tenuis* into the main field by means of an undisturbed corridor where the grass species are allowed to succeed and provide landscape heterogeneity.

Key findings

CON appears to be the most beneficial method of cultivation, with high yields and *T. tenuis* able to spin webs and capture prey. However, there are further environmental effects to DD cultivation and at times greater prey was captured with low energy output due to small webs woven at a greater height in the previous crop stubble. The NIAB trial has been established for six years, it can take time for breakdown of organic matter to improve soil health through microbial build-up. These factors can potentially allow greater nutrient availability to a growing crop. If yields increase in DD, the effect of zero-till allowing dynamic *T. tenuis* activity in primary cultivation can translate to greater prey capture in further growth stages.

Acknowledgements

This long-term NIAB experiment is of continuing great scientific value in guiding recommendations for agriculture sustainability.
I acknowledge the support of Martin Jenkins (Childerley Farm) and Dr Nathan Morris (NIAB) for allowing me access to this field experiment for collecting data.

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Profiting from new breeding techniques

The science, benefits, drawbacks and regulatory issues surrounding new plant breeding techniques featured at a technical seminar organised jointly by BCPC and the Farmers Club, with industry and farmer attendance, in July 2019. The main discussion points from the speakers are outlined in this article.

A simple historic analysis of on-farm UK wheat yields shows that we have reached a plateau at around 8.0 t/ha for the last 10-15 years. In contrast to this, varieties that are coming onto the AHDB UK Recommended List continue to show an average of 0.5% yield increase year on year. It is clear that this yield potential being delivered by the Recommended List is not being transferred onto farms. Even if this was being transferred onto farms, the rate of yield increase is not sufficient to cope with the rapidly rising global population, which is rising at about 1% per year.

If we are to feed the growing global population, yields of new varieties need to increase more rapidly and the genetic potential needs to be transferred onto farm. This clearly indicates the necessity for new crop innovation.

Breeding techniques

The development of new breeding techniques is linked to the exponential reduction in the cost of DNA sequencing in the last 15 years, making genome sequencing cheap, quick and easy. The entire wheat genome has been sequenced for ten cultivars and we know the location of every wheat gene although we only understand the function of a handful of them.

Marker-assisted selection is now a widely used technique, where a DNA marker near or at a chosen gene location can speed up breeding. It allows breeders to identify plants with the desired trait even before they mature.

Mutation breeding has been employed for many decades, involving seeds being irradiated to promote random mutations in their DNA. Many thousands of mutations can occur during this process, only very few of which are likely to confer a positive trait. If a mutation happens to produce a desirable trait, the plant is selected for further breeding.

Transgenic breeding involves the direct transfer of genes identified in one species to an unrelated species, giving it an entirely new trait.

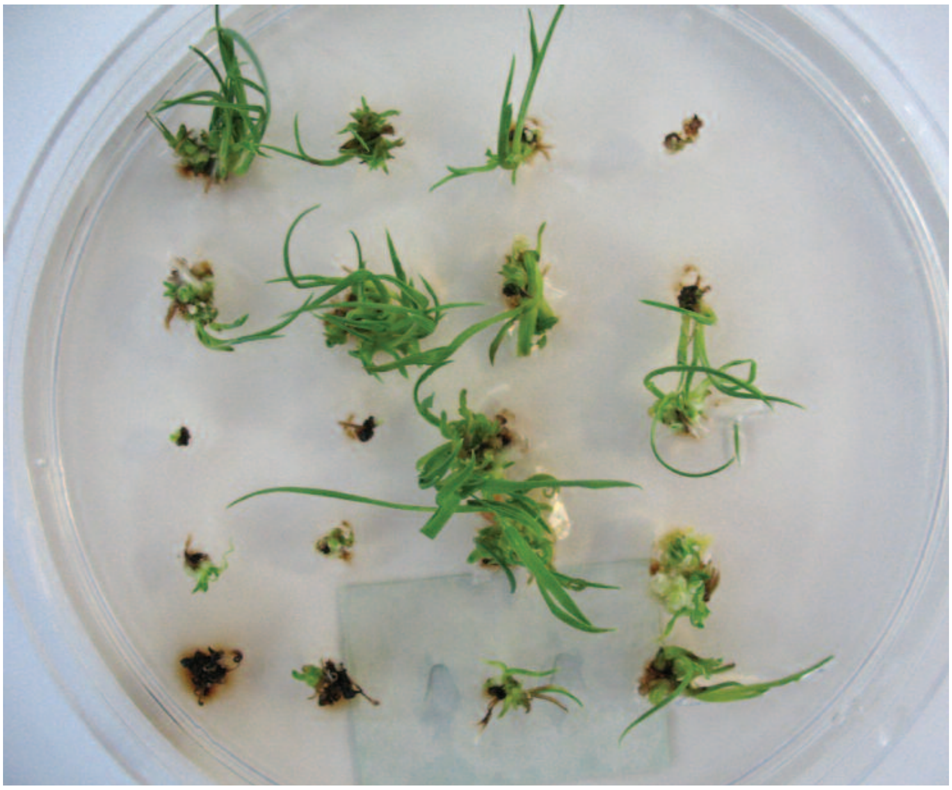
Gene editing involves specific, highly targeted edits to the existing plant DNA to confer a new trait. Genome editing can be used to either remove/alter DNA (mutation breeding) or add new DNA (genetic modification). Genome editing uses technologies such as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), ZFN (zinc finger nucleases) and TALENS (Transcription Activator-Like Effector Nucleases). Mutations generated via gene editing are indistinguishable from naturally occurring mutations.

The terms cisgenesis and intragenesis (where plants are transformed with genetic material derived from the species itself or from closely related species) were developed to distinguish them from transgenesis (GM) where genes from different species may be introduced. It is thought that the general public find the concept of cisgenesis and intragenesis (if not the terminology) more acceptable than conventional GM technology.

Speed breeding is a powerful method to accelerate new crop research and breeding. It increases the speed of glasshouse plant production and coupled with crossing, can progress six generations/year for spring wheat, barley and chickpea and four generations/year for OSR. There are also the benefits of lower energy consumption and reduced infrastructure support.

Diversity breeding is useful for crops such as wheat that show relatively low diversity. This involves conventional crossing with closely related wheat species such as wild and cultivated emmer wheat (*T. dicoccoides* and

T. dicoccum) and durum wheat (*T. turgidum*) as well as wider crosses with distant relatives such as goat grass (*A. tauschii*). NIAB has been particularly active in this area, producing 're-synthesised wheats' by crossing durum wheat with wild grass species such as *A. tauchsii*. These re-synthesised wheats can then be crossed with current commercial wheat varieties, introducing new genetic diversity.



The benefits

Modern wheat (*Triticum aestivum*) has a complex genome of 17 billion base pairs comprising the genomes from its three ancestors *Aegilops speltoides*, *Triticum urartu* and *Aegilops tauschii*. In spite of this size, modern wheat shows relatively low diversity for breeding new varieties. These new types of breeding methods have been developed to introduce more diversity into the wheat genome.

Feeding the world

With the background of climate change and the need to increase food production in a way that protects the environment as much as possible, this represents a major challenge for plant breeders and agricultural researchers. The reality is that all forms of agriculture have an impact on the environment. Environmental sustainability means minimising the negative environmental impact of agriculture but environmental sustainability cannot be delivered without economic sustainability, as agricultural production systems must deliver reasonable economic returns (incomes) to the farmer.

The economic and environmental impacts of traditional GM crops include a reduction in pesticide use with a consequential reduction in their environmental impact, major increases in global farm income, increased production of food, feed and fibre and reductions in CO_2 emissions. These benefits have not been seen in the UK and in the EU (apart from a minor acreage of maize in Spain and Portugal) due to their stance on GM crop cultivation.

New breeding techniques provide scope for delivering a range of crop improvements: agronomic, quality (consumer-oriented) and environmental oriented traits. Breeding new crop varieties would be less expensive and quicker. They would allow increased scope for a wider range of traits and competition in seed markets for the large seed companies – but importantly, significant opportunity for smaller businesses and the public sector to enter the market. They would also provide scope for more UK crop-relevant innovations and R&D sector development.

The major issue for commercialisation of new crops, derived from new breeding techniques, is their regulation. If all crop innovations derived from new breeding techniques are regulated like GMOs (as currently in the EU) this will result in a higher cost of market entry, discouraging new entrants and fewer innovations; i.e. the situation with traditional crop biotechnology. If current EU regulations continue to categorise new breeding techniques as 'GM' this will put the EU at a disadvantage compared to some of our competitors such as the USA, Canada, Brazil and Argentina who have a more flexible approach to these new technologies. The detection and tracing of crops and crop products derived from some of these new breeding techniques can be more difficult than with GMOs (virtually impossible), leading to the greater potential for increased disruption to agricultural commodity/raw material trade and more legal (trade) disputes.

The farmer's viewpoint

UK and EU farmers (and citizens) have largely missed out on potential economic and environmental benefits. The UK economy has lost out because of the loss of skills in the plant science base and crop innovation focusing on UK crop-specific issues. An acceptance of new breeding techniques would offer scope for re-booting plant science-based crop innovations in the UK, from a wider base, i.e. more involvement of smaller companies and public sector.

UK and EU farmers have to compete with commodities and products derived from genetically modified crops from around the world. New technologies could help to re-balance trade and competition with other countries who have already accepted GM technologies. It is generally accepted within the farming industry that farmers need science to allow them to produce more and impact less, by reducing inputs, improving productivity, reducing environmental impact and encouraging biodiversity (all to be seen to be for the public good). New breeding techniques are crucial for the future of UK agriculture and we need politicians and society to understand the key role of arable farming in food production and the future of the UK economy.

Considerations for better regulation – a view from the industry

Regulation of GM and some new breeding techniques in the UK/EU is currently unpredictable and non-transparent. There is a focus on science itself rather than a scientific risk assessment, and on identifying unintended effects which leads to unlimited data requests to applicants. There have been multiple guidance documents (>30) with limited/no flexibility to change in accordance with scientific development. The approval system based on political positions of EU Member States has led to unpredictable and lengthy timelines and a consequential reduction in innovation.

The EU currently considers gene editing as genetic modification and this illustrates the unpredictable and non-transparent decision-making process. One major feature of genetic modification is that inserted DNA leads to the expression of one or more proteins and for which detection methods are available to quantify the inserted DNA and the expressed protein. Gene editing (GE) does not lead to any detectable change, making the data generation to differentiate a gene-edited crop or crop product difficult if not impossible. In a recent report, the European Network of GMO Laboratories concluded that under the current circumstances, market control will fail to detect unknown genome-edited plant products. There is an industry recommendation to the UK government to implement a predictable and transparent decision-making process for genetically engineered crops. Without this, the UK farming industry will struggle to compete globally with those countries who have embraced these new breeding technologies.

Contributors to this seminar included:

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Graham Brookes, agricultural economist at PG Economics

Tom Bradshaw, Essex farmer and the NFU's national combinable crops board chairman

Alison Bentley, head of genetics and breeding at NIAB

Karen Holt, senior regulatory affairs manager with Syngenta

Cristobal Uauy, project leader in crop genetics at the John Innes Centre

Board profile – Professor Ian Puddephat

Continuing our series of interviews with NIAB Board and Trust directors, Landmark talks to NIAB Board member Ian Puddephat about his background and his involvement with NIAB. Ian is Senior Director of AgroSciences at PepsiCo. A crop physiologist, his interests are in the application of genomic breeding to crops for the elevation of nutritional quality in grains and adaptation of new cultivars of grains and potato to high temperature environments. Ian is an honorary professor of life science at the University of Warwick and a visiting professor at Cranfield University.

Can you tell us a bit more about your background?

I've been at PepsiCo for the past eight years, responsible for developing a centre of expertise in agronomy. In that time, we've put together a 30-strong crop science team, focused on the pull-through of innovative practices and new technologies onto farm, with an emphasis on less waste and fewer inputs. This includes building collaborative R&D programmes with a range of technology and academic partners to support delivery and foster innovation.

My background is a mix of academia and industry in plant biology, crop breeding and agronomy. With a BSc in Applied Biology and PhD in horticulture I began as a lecturer and post-doc researcher at Coventry Polytechnic, developing selection systems in tropical woody legumes for salt and drought tolerance, and developing systems to aid reforestation in West Africa. I then spent some time at HRI Wellesbourne developing plant breeding technologies in vegetable crops before moving to Syngenta as a research leader in cell biology and GM technology, focused on health related traits in crops, including 'golden' rice and tomatoes. I then became Global Head of R&D for their vegetable seeds business before moving to PepsiCo.

How and why did you become involved with NIAB?

I've been on the NIAB Board for two years but have always been aware of NIAB's work, only developing a deeper connection on joining PepsiCo in 2011. We wanted to invest in agronomic innovation – to find solutions. So we needed a link to foundational crop research and NIAB was an obvious

Checking the stevia cultivars in Brazil

strategic research partner choice, particularly NIAB CUF's work on potatoes. NIAB's 'plant science into practice' ethos was a smart fit; we realised that the benefits of a new variety can be brought to life faster when also developed hand in hand with agronomic know-how and field management practices – which is where NIAB came in. As the partnership evolved Tina asked me to join the Board; I aim to bring a unique perspective from front end discovery through to commercial and on-farm research application.

What do you see as the big challenges facing UK agriculture, with a special emphasis on plant science?

Putting our obvious current political turmoil to one side the UK has similar issues and challenges in agriculture and plant science to the rest of the world – sustaining and improving productivity whilst reducing environmental impact. It is a paradigm anchored in food security. We've moved on from the traditional food and feed end markets to a multi-layered food, fodder, feed, fuel and fibre platform – but still need to balance these new opportunities with the dominant need for secure and enhance high quality food production. Agriculture is seen as a source of industrial raw materials, but it can be much more. There is a need to produce the right product for the right purpose and minimise the need for processing where this consumes energy, water and other resources.

As a NIAB Board member you are involved in the wider strategic positioning of the organisation. What are your ambitions and vision for NIAB?

NIAB is in a very strong position to deliver against the challenges facing agriculture and food production. It needs to capitalise on its uniqueness, its intimate connection to farming, and build out. We have to be resilient, flexible and productive as climate change continues to bring about so many permutations. NIAB's skill in translating plant science into practice is a key selling point, alongside its intimate relationship with members. But we need to create an 'engine' that feeds that ability to be impactful and ensure these scientific breakthroughs appear in the field. This means being at the front of 'next generation agronomy', driving the next wave of agronomic practice by using our field trialling ability to pull the science through into application.

Getting to know you

What was the last book you read?

'Never out of season' by Rob Dunn. It's about the impact of having the food we want when we want it and the advantages and disadvantages of our current food production system.

Which is your favourite sports team?

I'm a former hockey player so watching my daughter playing in her school hockey team takes up weekend time.

Where's your favourite holiday destination?

As a family we tend to go somewhere different every year, mainly beach holidays somewhere hot and sunny. But I have fond memories of childhood holidays in the Lake District.

Tell us something about you that would surprise people?

My first job was as a NatWest bank teller before I realised I needed more of a challenge and went to university.

If you hadn't worked in the science sector, what else would you have done?

I would have worked in forestry! But the industry went into decline in the 1980s and there were very few job opportunities.

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