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Climate change special

IN THIS ISSUE

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Adapting to climate change and coping with Covid-19

The focus of this special issue of *Landmark* is on climate change, providing an insight into some of the pioneering research NIAB is involved in to help the crop production sector adapt to and mitigate its effects.

Before introducing the climate change theme, however, it would be remiss of me not to say a few words about Covid-19, and NIAB's response to it.

Since the Coronavirus outbreak took hold in the UK in mid-March, the pandemic has turned everyone's lives upside down. Each day brings new challenges and restrictions on the way we live our lives, and the world looks set to be a very different place in the aftermath of the crisis.

I must take this opportunity to say a very public and heartfelt thank-you to all NIAB colleagues who have adapted so well to new ways of working, helping each other through these challenging times, and developing innovative approaches to ensure our research and knowledge transfer activities continue to support the needs of members and the wider industry.

Those NIAB staff who can work from home are doing so, but we are maintaining essential research and field trial activities, taking care to safeguard the welfare of employees and respecting government guidelines on hygiene and social distancing.

Across all parts of the organisation we are adapting and finding alternative ways of getting things done, and I have no doubt that many of these new working practices will continue to form an integral part of life after Coronavirus.

We have embraced digital communication and videoconferencing across the entire organisation. We have identified innovative new ways to provide online technical advice, with the creation of the NIAB Virtual Event Hub, featuring a mix of videos, webinars and podcasts, alongside downloadable guides, topic sheets and information posters.

This continuation of the support we provide to the agriculture industry is a remarkable achievement, reflecting not only the strength and support of NIAB's broad customer base, but also the fantastic commitment of staff to maintain levels of service and delivery despite such difficult circumstances.

Maintaining access to timely and relevant technical information, as well as the statutory services NIAB provides to ensure seed certification and official trials of new varieties continue undisrupted, are vital to help British farmers safeguard future harvests and sustain the nation's food supply.

The Coronavirus pandemic has provided a stark reminder that food is a basic human need, and that we ignore the importance of supporting a productive and profitable domestic farming industry at our peril. It is unthinkable, therefore, that the Covid-19 crisis will not stimulate a renewed policy focus on productive agriculture as the first link in our vital food supply system.

But it would be equally wrong, in charting our recovery from this catastrophe, to downgrade action on issues such as climate change or sustainable development.

The past two years have signalled the devastating effects of man-made climate change. Record summer temperatures and extreme rainfall in the UK; wildfires in California, the Amazon Basin and Australia; and flooding in Bangladesh and East Africa, have all made national headlines. Alongside high-profile protests by Greta Thunberg and Extinction Rebellion, these climate change-induced disasters have turned the spotlight on governments to tackle greenhouse gas (GHG) emissions across different sectors of industry.

This applies equally to farming in the UK. Reducing agricultural GHG emissions by at least 100% of 1990 levels by 2050 is written into law as part of the UK Climate Change Act. The Clean Growth Strategy, published in 2017, set an interim target of 57% reduction by 2032. The NFU has committed to 'Net-Zero' by 2040.

However, the 2018 progress report to Parliament by the Committee on Climate Change made sobering reading, reporting "virtually no change in agricultural emissions since 2008".

Farming occupies a unique position as both a significant contributor to climate change and a major source of solutions to mitigate and reduce its impact. The new Agriculture Bill sets out new financial powers to support the management of land, water or livestock in a way that mitigates or adapts to climate change.

However, slashing the environmental impact of farming is not easy. There are many thousands of individual farm holdings across the UK, each with a range of unique features and potentially requiring a different set of approaches to lower overall emissions.

Another challenge for agriculture is that carbon dioxide (CO_2) emissions constitute a relatively low percentage (10%) of total GHG emissions. While these emissions can be offset by CO_2 taken up by crops and soil throughout the growing season, by contrast methane and nitrous oxide, which are also very potent GHGs, are emitted in higher quantities by farming-related activities, and are much harder to reduce, offset, or counterbalance.

The complexity of these issues, and the urgency of the climate change threat, underline the importance of targeted research into net-zero or carbon neutral farming.

NIAB is ready to take up this challenge. As the ground-breaking research projects discussed in this issue of *Landmark* make clear, sustainable and efficient crop production can go hand in hand with action to reduce greenhouse gas emissions, to sequester carbon, and to adapt crop varieties and cropping systems to a changing climate.

Simon Kightley

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Pulse variety candidates for 2021 recommendation

Pulse varieties showing good diversity

There are seven pea candidates, two winter beans and seven new spring beans for consideration for PGRO's Recommended Lists next autumn. As always with pulse varieties, we would caution that trial numbers in the early years, before entering Recommended List trials are rather low and yields can take three or four years to stabilise. Furthermore, bulking up seed production can be a fairly slow process, before new varieties are fully commercialised.

Peas

Judging by the seed production figures last year, the main demand is for large blue peas (55%), followed by marrowfats (27%), with white grain peas, small blues and maples making up the rest. However, this market pattern could change progressively in the coming years, with a growing appreciation of the nutritional value of pea flour and pea protein in food products. Here, the flour colour of the white peas is preferred.

The new candidates comprise five large blues, one marrowfat and one white grain, or yellow pea as they are sometimes referred to.

The large blue pea set is headed by **Stroma** (LS Plant Breeding) with a relative yield of 107% of controls, with consistent performance over its two years in National List trials. Using a four-year fitted constant projection, we would estimate that this yield level would place it about 3% ahead of the new Recommended variety, Kactus, and 4% above the better-established variety, Bluetime. It is medium for straw length, with indications of good standing ability, early maturity but only moderate downy mildew resistance.

Kaiman (Senova), on 106% for yield has shown more seasonal variability and was top-yielder in high-yielding 2019 trials. It, too, is medium for straw length, with good standing ability. It is medium late for maturity and has good downy mildew resistance. **Kiravi** (Senova) is another percentage point down, on 105% of controls for yield. Another

Dr Aoife O'Driscoll

Aoife joined NIAB in April 2020. With a background in molecular plant pathology, she has broad ranging experience in crop protection research and agronomy of both arable and horticultural crops. Her PhD, conducted with Teagasc, investigated novel sources of genetic resistance to *Septoria tritici*. She has since held roles as a regulatory scientist working for Life Scientific and most recently as a field vegetable pathologist with ADAS. She achieved her BASIS certificate in Commercial Horticulture in 2018. Within the Farming Systems team at NIAB, her research interests are in varietal improvement of combinable crops, biological control of pests and pathogens, fungicide resistance management and integration of crop sensing data.

medium height variety, it is moderately stiff-strawed, late maturing and has good downy mildew resistance.

A numbered variety, memorably labelled **NOS309.052-004/3** (IAR-Agri; National List pending: proposed name Mikka) is on 103% for yield, is medium-tall, with moderately good standing ability, early maturity and has very good downy mildew resistance. **Greenway** (IAR-Agri) is also on 103% for yield. It has the longest straw of this group but I would still only rate it as medium-tall, like the previous variety. It has moderately good standing ability, early maturity and good downy mildew resistance.

The marrowfat candidate is **Akooma** (LS Plant Breeding). As always with marrowfats, its yields look fairly modest but, on 92% of controls, this represents an 8% yield improvement over the best of the recommended marrowfats, Sakura. Agronomically, we would characterise it, at this early stage, as medium-short, rather weak in the straw, late maturing but with moderately good downy mildew resistance within the marrowfat group.

The new white pea, **Raider** (IAR-Agri) has a relative yield of 102% of controls on the candidate table but, with two widely differing annual yields, this could go up or down quite dramatically with another year's data. The current four-year fitted data places it in the same yield category as Manager and Karpate but well short of the newly recommended variety, Kameleon. It has relatively short straw, good standing ability, medium-early maturity and moderately good downy mildew resistance.

Historically, white pea yield improvement has tended to be marginally better than for large blues but, without as many premium end-markets and no particularly strong market in the animal feed sector, their crop area has shrunk. There are still options in the dry packet and split pea markets, for which a bold grain size and an attractive, bright appearance are valued and we will have a better appreciation of these qualities for Raider in the coming year or so. As discussed earlier, steady growth in demand for white pea flour is now predicted.

Winter beans

Norton and **Vincent** (Senova; National List pending) are both very promising candidates. Our four-year analysis puts them just ahead of the top Recommended variety, Vespa. At this early stage they are best characterised as medium-tall, with good standing ability. Norton is early maturing, while Vincent is medium late. And this may be as much as we learn before next year's trials, with a high proportion of this year's trials having already fallen victim to the very wet conditions throughout the autumn and winter.

Spring beans

The seven spring bean candidates include five normal grain quality types and two in the low vicine/convicine category. We will know more about any with improved protein content after the coming harvest.

Top Recommended variety is Lynx, with its good downy mildew resistance. The best new candidate is **LG Viper** (Limagrain), on 103% of controls for yield, the same as Lynx. It is a short variety, with good standing ability and medium maturity, again similar to Lynx. At this stage the downy mildew resistance appears to be not quite as good but this will clarify in the coming season. **Stella** (Saaten Union) is 1% lower yielding on 102% of controls. It is medium for height, has good standing ability and medium early maturity but is susceptible to downy mildew.

LG Sphinx (Limagrain) is also on 102% for yield, medium for height and very good for standing ability. It has moderate downy mildew resistance. **Capri** (Saaten Union) has a yield figure of 101% of controls, medium plant height, good standing ability and medium-early maturity but is susceptible to downy mildew. Just behind Capri, **Daisy** (Saaten Union; National List pending) is short-medium for height, with good standing ability and medium-early maturity but, once again, susceptibility to downy mildew.

Dropping down below 100% for yield are the two low vicine/convicine (LV/CV), improved nutrition group. **Bolivia** (LS Plant Breeding) is on 98% for yield and is short, with very good standing ability and medium maturity. It has moderate resistance to downy mildew. The four-year analysis suggests that Bolivia is equivalent to Tiffany in the LV/CV group and but 3% below Victus. **Allison** (LS Plant Breeding) has a yield figure of 96%, short plants with good standing ability and early maturity. Its weakness is its susceptibility to downy mildew.

Simon Kightley

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Oilseed variety candidates for 2021 recommendation

There is a good mix of new varieties coming forward for harvest 2021 with twelve varieties of oilseed rape to consider.

At the time of writing, six of the twelve varieties selected as candidates for AHDB's Recommended List have passed statutory National List tests, allowing their data to be published. The remainder are held up, mainly through lack of distinctness from other similar varieties. This makes providing a useful commentary somewhat difficult, especially when we also consider that the set of control varieties would all be regarded as being relatively low yielding now, in the order of 10% below recent additions such as Acacia and Ambassador. For information, the full set of candidates is included in the adjacent panel and I would recommend checking the AHDB website periodically to see if the candidate table has been updated.

Looking at the six varieties for which data have been released; all are hybrids and in test for the AHDB East/West Region with two of them for the North as well. We find ourselves in exciting times with three of them, from different breeders, topping the charts with 108% relative to the mean of controls for the East/West region, yield figures which should put them on a par with the best varieties already recommended. These varieties are: **Voltage** (DSV UK), **LG Antigua** (Limagrain UK) and **DK Expectation** (Bayer CropScience). All three varieties boast Turnip Yellows Virus resistance. They are all of similar height which is a little on the tall side but have excellent stiffness and resistance to lodging.

DK Expectation, with the data we have so far, appears to flower slightly earlier than the others, but this is not reflected in the maturity dates with LG Antigua being earlier and Voltage fairly late. Voltage has a slightly better resistance to light leaf spot but all are adequate in this area. DK Expectation and LG Antigua have an excellent resistance to stem canker, both scoring a commendable 8 out of 9 but this is an area where Voltage appears to struggle, scoring a 4 out of 9.

All in all, they are a tightly packed group at this stage, and we look forward to the harvest results this year to see if they all maintain their consistency.

Hermione (KWS) is an interesting variety – tall and late flowering but has shown very good yields in the north with a score of 103%. It has good disease resistance, especially stem canker although it does not have Turnip Yellows Virus resistance.

Two of the other varieties are both from RAGT. **Blackmillion** also has a promising gross output, just 1% down, at 107% of controls. It is a taller variety but has good resistance to lodging. It has a good resistance to stem canker and above average oil content. Finally, **Kazze** has a more modest gross output figure of 104% of controls in the current dataset. It is medium-early for flowering and medium-tall, with good ratings for both lodging and stem stiffness. It is medium early for maturity.

Colin Peters

Colin joined NIAB in early April 2020 as a break crop specialist. He has experience in commercial farming having spent time managing farms for Sentry Farming in East Anglia before moving to Rothamsted Research where he was involved in both commercial and trials crops.

AHDB candidates for Recommended List consideration in autumn 2021

UK candidates

Voltage (DSV)

Hermione (KWS UK Ltd)

East/West candidates

LG Antigua (Limagrain UK Ltd)

LG Aviron (Limagrain UK Ltd)

Respect (LS Plant Breeding)

DK Expectation (DEKALB)

Kazze (RAGT Seeds)

LE17/342 (Limagrain UK Ltd)

Blackmillion (RAGT Seeds)

LG Arcade (Limagrain UK Ltd)

Blackpearl (LS Plant Breeding)

DK Imprint CL (DEKALB)

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Cereal varieties for the future

Usually, when writing this article, we are looking forward to a month of open days with plenty of opportunities to view and discuss the new varieties coming through. This year, of course, is going to be slightly different. However, the progression of new varieties marches on regardless and in this article I will outline the new candidate varieties of cereals currently in trial. We are in the process of planning ways to ensure growers still have all the variety information you need to make the necessary decisions and hopefully also provide opportunities to view variety plots, even if it is remotely, as well as offering access to questions and answer sessions. I am, of course, always on hand to respond to queries by phone or email.

Winter wheat

Yet again we have a plethora of new wheat candidates to consider, but with a good choice of varieties already in the marketplace I suspect that this group will have their work cut out to make an impression.

We have one candidate with breadmaking potential: **LG Seeker** (Limagrain). The variety has good yield potential with treated yields 1% above those of KWS Siskin and untreated yields just below. It has stiff straw and excellent resistance to mildew, brown rust and eyespot, with good eyespot resistance being particularly noteworthy in the current variety set, where resistance is generally low. As a breadmaker this variety has plenty of testing ahead of it so the data coming out of harvest 2020 will be particularly influential on its progress.

Six varieties with biscuit-making potential have made the candidate list this year. **LG Prince** (Limagrain) tops the group with a treated yield currently 3% ahead of KWS Barrel. It has a good untreated yield and excellent resistance to both yellow and brown rust. **LG Illuminate** (Limagrain) has a treated yield 1% lower and an improved untreated yield. It too has excellent resistance to both rusts and combines this with good Septoria resistance.

With similar good levels of yield and disease resistance is **LG Astronomer** (Limagrain), and although this variety is more susceptible to mildew it has the benefits of a high specific weight. **Merit** (Elsoms) again has a similar treated yield levels and disease resistance with the exception again of mildew. Limited data also currently suggests possible susceptibility to eyespot. **LG Quasar** (Limagrain) has a treated yield similar to KWS Barrel, it is a taller variety and has good resistance to both yellow and brown rust but again, limited data shows susceptibility to eyespot. Finally, we have **RGT Galactus** (RAGT), again with a similar treated yield to KWS Barrel and excellent resistance to yellow and brown rust. All

the varieties in this group have resistance to orange wheat blossom midge (OWBM).

Moving on to the feed varieties we start with the soft varieties. **LG Tapestry** (Limagrain) has a treated yield 1% above the soft feed control variety Elation but remember that Elation is 4% lower yielding in Recommended List trials than LG Skyscraper. It has excellent resistance to both yellow and brown rust, but limited data suggests eyespot susceptibility. **KWS Plectrum** (KWS) has a similar treated yield but a low untreated yield. It has a moderate disease profile and again, limited data suggests susceptibility to eyespot.

RGT Quicksilver (RAGT) also has a similar treated yield. It is slightly later to mature than many other varieties and has good resistance to both rusts as well as Septoria, although eyespot is a possible concern here too, as is its low specific weight. **Swallow** (Senova) has a treated yield 1% below that of Elation, a moderate disease profile but again, limited data suggests susceptibility to eyespot. All these soft feed varieties have resistance to OWBM.

KWS Cranium (KWS) is the joint top of the hard feed group. It has a treated yield 2% higher yielding that KWS Siskin, but again, it is worth pointing out that this is still below the level of the top hard feed varieties currently available. It is later maturing than many varieties and while it has excellent resistance to yellow rust it is susceptible to mildew and relatively susceptible to brown rust. It does have resistance to OWBM. **Banquo** (Senova) has a similar treated yield with excellent resistance to yellow rust but poorer Septoria resistance and an indication of eyespot susceptibility. **Astound** (Elsoms) also has a similar treated yield, but this time it is accompanied by a very high untreated yield. It is a tall, stiff variety with excellent yellow rust resistance but does not have the benefit of resistance to OWBM.

RGT Wolverine (RAGT) has a treated yield just 1% below this group. It has good resistance to brown rust and respectable ratings for both yellow rust and Septoria. RGT Wolverine is also the first variety seen at this stage of testing with resistance to barley yellow dwarf virus (BYDV). Evidence from RAGT suggests that this variety consistently shows lower levels of virus when compared to susceptible varieties. This new trait is bound to generate huge interest in the farming community.

RGT Silversurfer (RAGT) has a treated yield similar to KWS Siskin combined with excellent yellow rust resistance and good resistance to Septoria. It also has the benefit of OWBM resistance. Finally, we have **SY Clipper** (Syngenta), a hard feed variety that has not yet completed National List testing, so no data is currently available.

Summarising the feed varieties, it looks unlikely that they will offer a step forward in yield terms, but they may well bring other useful characteristics to the farm.

Spring wheat

This year we have two spring wheat candidates, one with breadmaking potential and one feed variety. **WPB Arcade** (LS Plant Breeding) is the potential breadmaker and, based on limited data, has a treated yield 2% below that of KWS Cochise. It has excellent resistance to both mildew and brown rust but is susceptible to yellow rust. WPB Arcade also looks to have a good specific weight. The feed variety is **WPB Escape** (LS Plant Breeding) and limited data for this suggests a treated yield 1% above that of KWS Cochise. WPB Escape has good resistance to both mildew and yellow rust.

Winter barley

Ten winter barley varieties have made it through as candidates this year, nine feeds and one with malting potential. **Chester** (Elsoms Ackermann), the malting candidate, has unfortunately not yet completed National List testing and so no data is currently available.

The first seven feed candidates are two-row varieties. **Bordeaux** (Senova) has given very high treated yields, 6% above those of KWS Orwell and competitive with the six-row varieties. It has a good specific weight but is susceptible to *Rhynchosporium* and has seen quite high levels of lodging in the limited untreated trials available. **Bolton** (Elsoms Ackermann) is 2% lower yielding but still with a very good treated yield and has good net blotch resistance. On a similar yield is **Pixie** (Senova) which also offers good net blotch resistance and a high specific weight. **KWS Oasis** (KWS) is another 1% lower but also offers good net blotch resistance. The final three two-row varieties are still waiting to complete National List testing and so no data is available but they are **KWS Tardis** (KWS), **SU Laubella** (Saaten Union) and **Paloma** (Senova).

The two six-row candidates are both hybrids. **SY Thunderbolt** (Syngenta) has treated yields 4% above those of Bazooka and also offers a high untreated yield. It is earlier to mature than the other candidates, has good resistance to mildew and a high specific weight. It has, however, seen quite high levels of lodging in untreated trials. **SY Armadillo** (Syngenta) is 2% lower yielding and offers good resistance to both *Rhynchosporium* and net blotch.

Although the treated yields, particularly of the two-row varieties, look to be a real step forward, we have seen before that the addition of a year of Recommended List trials data can often bring these varieties back to a more comparable yield level to current varieties. However, they are certainly still worth keeping a close watch on.

Spring barley

Six spring barley varieties have been taken forward as candidates. Four of these are under test for malting but only one has completed National List testing with **Skyway** (Agrii), **SY Emerson** (Syngenta) and **SY Fable** (Syngenta) still awaiting completion. **Cadiz** (Senova) has a yield 1% above that of Laureate, excellent mildew resistance although it is susceptible to *Rhynchosporium*.

LG Mermaid (Limagrain) is a feed variety with a treated yield 2% above that of Laureate. It has excellent mildew resistance and a good specific weight. The final feed variety **AC17/02** (Elsoms Ackermann) is still waiting to complete National List testing and so no data is available.

Oats

There are no oats varieties, spring or winter, due to come up for recommendation this November so the choice will remain unchanged.

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Trials delivery at Morley

THE MORLEY AGRICULTURAL FOUNDATION

East Anglia, the bread-basket of England, is a well-deserved moniker. Probably more than any other UK region, it has embraced larger scale food and farming production and the widespread take-up of technology and new farming methods. And it is renowned for its strong agri-tech research base; the corridor stretching from Cambridge to Norwich incorporates most of the UK's leading agricultural science organisations. So, it is an ideal location for NIAB's East Region Trials team, continuing over a century of on-farm research work that began with the Norfolk Agricultural Station, through to the Morley Research Station and more recently The Arable Group which became part of NIAB in 2009. Regional manager Hannah Parish and centre manager Rebecca Owles explain.

The team, based at The Morley Agricultural Foundation's (TMAF) headquarters at Morley Farms near Attleborough, is responsible for an extensive range of crop trials across a wide geographical area – from the north Norfolk coast, across Suffolk and down into Essex. With over 8,500 crop plots, including 2,000 at Morley Farms, the centre is also home to NIAB's Farming Systems research team who specialise in soils and longer-term rotational research.

The trials programme includes combinable crops, roots and forage species for statutory testing, levy funders, NIAB TAG membership and many commercial and charitable customers/partners. Overall, research themes include crop inputs, crop nutrition, pest impact and management, variety evaluation, wider agronomy interaction studies and novel systems. While the team works closely with colleagues at Cambridge for access to specialist equipment, transport and resources the centre has its own tractor (JD 5820) with RTK GPS, a bespoke disc drill for plot establishment, a new 12 m tractor mounted sprayer and a plot combine.

The average farm rotation uses a range of crops and cultivation approaches, so it is important that research considers the rotation as a whole and the interaction of the individual elements. As our landlord and host farmer, alongside a valued shared history, TMAF is a key funder of NIAB's wide range of long-term farming systems research projects, along with the other funders JC Mann Trust and the Felix Cobbold Trust. Research programmes include:

- New Farming Systems – a series of long-term studies seeking to develop bio-sustainable cropping systems for conventional arable cropping
- STAR – a fully replicated field-scale study examining the interaction between four cultivation methods and four rotations
- Morley Long Term Trials (LOTS) – a continuation of the original National Agronomy Centre and MENTOR work, covering many of the long-term strategic field trials, including the Saxmundham Experimental site (est. 1899) and long-term wheat, barley and sugar beet fungicide response trials
- In 2018, TMAF set up the Morley Soil and Agronomic Monitoring Study (Morley SAMS), delivered through NIAB. A network of 30 monitoring sites across the farm have been identified using ten years of yield maps. A comprehensive set of soil and crop specific agronomic measures aim to link soil health and its impacts on yield, profitability and resilience at Morley.

Within these projects NIAB's work at Morley, and sites across Suffolk and Norfolk, includes amendment use, cover crops, crop rotations, cultivations, long-term nutrient management, soil biology and structure, and trafficking. In addition to our main programme of sow, grow, assess and harvest trials, much of the work done in conjunction with the Farming Systems team requires more complex and often very labour-intensive assessments.

However, one labour saving device, for the farming systems work, that has pride of place at Morley is the Wintex 3000 soil corer mounted on a converted Suzuki Jimny. This takes thousands more

soil cores than we can manage manually – extracting and splitting cores at three predetermined depths in under 30 seconds. The two-seater Suzuki is fully road legal, removing the need to unload and load the rig onto a trailer. It is also fitted with all terrain tyres, providing a small footprint on a cultivated and winter drilled fields. In its first season it took over 1,000 0-90 cm scores, equating to 3,000 cores by hand.

Recent years have seen an increase in NIAB's winter oilseed rape work in Norfolk as we tried to relocate trials away from the cabbage stem flea beetle hotspots around Cambridge. However, it would appear the A11 corridor has become a flea beetle superhighway and, in combination with this season's early autumn drought and resulting crop failures, several of our host farmers are removing OSR from their rotation.

The rain came too late for the OSR but a bit too soon for the wheat drilling and a difficult autumn became an even more frustrating winter. The team worked hard and didn't miss a single opportunity, ensuring our autumn trials programme was established before Christmas. But then it was a depressingly similar story in the spring, too wet, too wet, too dry! The much-needed rain may have arrived just in time for the sugar beet and forage maize crops which were struggling in an unseasonably warm and dry April. With spring drilling behind us we are now into the hectic phase of treatment applications and assessments on our trials as they romp through the growth stages and our data gathering picks up pace.

Of course, none of this compares to the challenges we are all facing through the Covid-19 situation this year. Fortunately, the Morley team, as with all the NIAB trials teams, has found ways to ensure we can continue to deliver our trials programmes and support the most up to date, in-season agronomy in safe, socially distanced ways. Often this means jobs take longer to do and the logistics are more complicated, but we are as confident in the delivery of our trials information this year as any other.

One of the highlights of the year is our field demonstration at the Morley Innovation Day in June. Our staff are on hand to meet over 200 farming visitors who come to hear the latest information on varieties and agronomy and find out more about our ongoing research programmes. One of the best things about working in agricultural research is that every year is different and brings its own new challenges. Although the event's cancellation this year is disappointing, the trials teams are working hard to ensure the science continues. All the data will be available, and we will be involved in NIAB's virtual activities, bringing the technical content from these events and trials to you in the comfort of your own home, office or tractor cab!

Suzuki Jimny with soil corer

NIAB East Region trials team

Rebecca Owles – Centre Manager

Will Watling – Trials Agronomist

Chris Whyles – Trials Manager

Hannah Parish – East Regional Manager

Andrew Watson – East Regional Agronomist

NIAB Farming Systems team

Dr Nathan Morris – Farming Systems and Soils Specialist

David Clarke – Soils and Farming Systems Technician

Stephen Walker – Trials Officer

Dan Hewitt – Weed Research Assistant

Julie Phillips – Office Administrator

Stuart Roberts, Deputy President NFU

Delivering net-zero in agriculture: producing the world's most climate friendly food

In 2019, Britain became the first major world economy to legislate for net-zero greenhouse gas (GHG) emissions, aiming to end the contribution of UK economic production activities to climate change over the next 30 years. Other countries and trading blocs like the EU have followed suit. The NFU's net-zero vision, published before the UK government's announcement, shows how British agriculture can meet its ambition for a net-zero contribution to climate change across the whole of agricultural production by 2040, and play its part in the UK's plans.

British farmers provide the nation with safe, traceable and affordable food, produced to some of the highest standards of animal welfare, environmental protection and food safety in the world. With the right policy framework in place we can produce the world's most climate-friendly food and make our net-zero aspiration a reality by 2040. Agriculture is part of the solution – it is unique in being both an emissions source and a sink.

We can do this without downsizing our production or exporting it abroad. The UK cannot, should not, export food production, and its associated greenhouse gas emissions to other countries, and we do not need to deliberately reduce livestock numbers. UK red meat and dairy production is already 50% more efficient than the global average.

A three-pillar approach

Our science-based approach shows that to get to net-zero, to hit that sweet spot that balances our GHG costs with GHG benefits our industry can bring, we need a combination of policies and practices focused on three key pillars:

1. ***Improving farming's productive efficiency to reduce our emissions*** using a wide variety of techniques to deliver the same output or more from every farm, and working smarter to use fewer inputs.
2. Targeting measures to ***increase and manage carbon storage*** on UK farms to take carbon dioxide out of the atmosphere though bigger hedgerows, more trees and woodland, enhancing soil organic matter and conserving existing carbon stores in grassland and pasture.
3. ***Boosting renewable energy and the wider bio-economy*** involves displacing greenhouse gas emissions from fossil fuels and removing carbon dioxide from the atmosphere through bioenergy and bio-based materials such as hemp fibre and sheep's wool.

Working together

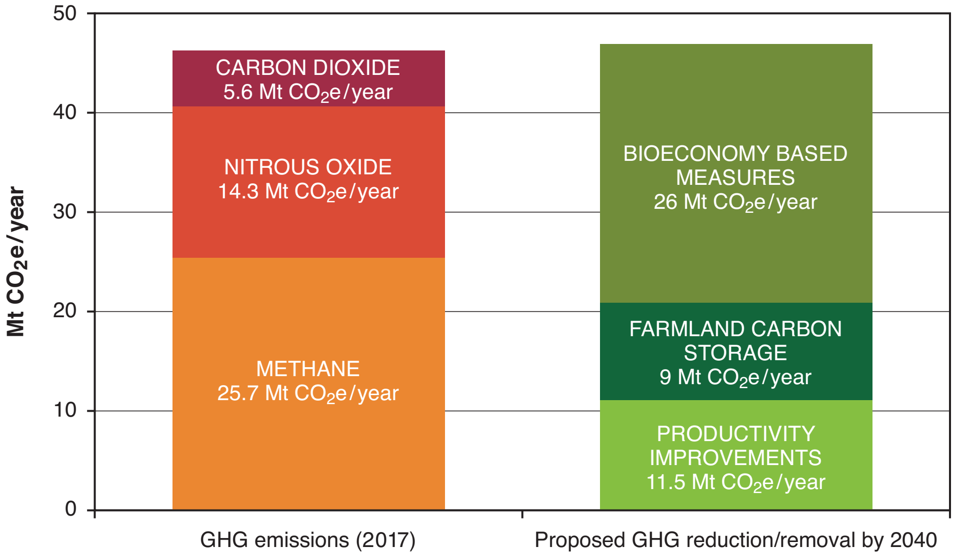
We know that we cannot do this on our own. We want others to match our ambition, which means working in partnership with government and other stakeholders. This will require policy measures not just from Defra, but also BEIS, HM Treasury and other government departments. Support from the supply chain, NGOs and British consumers will be equally important because this is a long-term commitment from everyone – there are no short-term fixes.

Science also needs to step up to the plate, answering the questions which farmers have now but also to research the practices and technologies that we're going to need to in 10-15 years' time. And it needs the entire industry to grab hold of this challenge with both hands. Organisations like NIAB have long been members of the Greenhouse Gas Action Plan so perhaps now is the time to give this initiative a new lease of life.

What does this mean for individual farm business?

This is a national aspiration, not an expectation that every farm will be able to reach net-zero. Every farmer will start

Figure 1. Current (2017) agricultural emissions balanced against potential GHG reduction through productivity measures and GHG removals by various methods



this journey from a different place, and the NFU does not want to see any farmer left behind. There really is something here for everyone but this is not business as usual for any of us.

What is clear from the science is that there no silver bullets, each farm will need a mix of measures which best suit its circumstance. In my own business, the biggest source of emissions will likely be the cattle and associated manure and so my personal journey towards net-zero will start by benchmarking the performance of the farm. Luckily I've got the experience of other NFU members on our net-zero steering group to help me when I'll be giving carbon calculators a shot.

Then I want to take a much closer look at what I am doing. Under Pillar 1, it will include looking for opportunities to improve the health status of my cattle and the quality of the forage I feed them, and trying to make better use of the red clovers I use for nitrogen fixation on the farm. Recent research found that cattle diseases can increase greenhouse gas emissions up to 113% per unit of beef carcass. This is clearly not good for the farm's GHG footprint nor for my bottom line.

One area I am particularly interested in is the grassland on the farm. This is already a good store of carbon but I want to better understand what more I can do to fine tune these levels and also about the carbon sequestration that is attributable to the grassland and woodland. I am also keen under Pillar 2 to look at our arable soils that probably need some attention. We are lucky to have a mix of historic and newly planted hedges and now I wonder if I could let some of them go a little, to double their normal volume to store more carbon quite quickly. I have an electric car for my NFU work but I do not have any renewables on the farm. There will be many others like me, some able to do more than others under the different pillars but improving productivity under Pillar 1 is a no-brainer for all of us.

The time is right

The pace of decarbonisation across the entire UK and global economy must speed up and urgent action to tackle climate change is required. Agriculture is on the frontline of climate impacts and many of us have first-hand experience of weathering extremes of drought and flood in recent years. This is an opportunity we cannot afford to let pass us by, and by working with the government and other stakeholders we can lead the recovery of our country and planet. The word 'recovery' has additional resonance as we battle Covid-19.

As Britain sets out to host the next big round of climate talks in 2021, I truly believe that British agriculture is ready to help lead and provide the climate solutions that are urgently needed. And our new domestic agricultural policy must lay the foundations, through trade access and regulatory alignment, of a profitable and forward-thinking agricultural sector that has the flexibility to respond to these new market trends.

Karolina Golicz, Cranfield University

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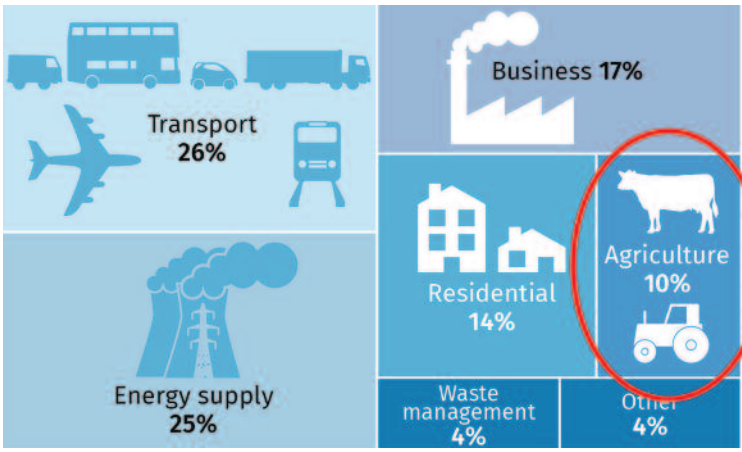
Towards net-zero arable farms

Measuring emissions to target improved practice?

Agriculture, more so than any other industry, is uniquely placed to be a part of the solution to climate change as it acts as both a source and a sink for greenhouse gases (GHGs). The UK's agricultural sector is in the position to become a global leader in low-carbon farming technologies – provided the concept of net-zero is embraced early on. Activities on arable farms consist of a mix of activities with low and high emissions of GHGs. Hence the aim is for an overall balance of net-zero when assessed at the farm gate. If a farm could assess its own emissions then the business could focus on actions which have the most overall impact, whether boosting productivity to produce more food with lower inputs and reducing emissions; increasing farmland carbon storage in soil, hedges, and trees; or, displacing fossil fuels by boosting land-based renewables. It may even be possible for a farm to become a carbon sink (a constant negative

Figure 1. Greenhouse gas emissions in the UK, 2016



45.6 million tonnes of CO_2 equivalent

Source: Department for Business, Energy and Industrial Strategy balance) – and hence sell its capacity to store carbon to other businesses. Two of the most user-friendly GHG emission calculators are the Cool Farm Tool (https://coolfarmtool.org), and the Farm Carbon Cutting Toolkit (https://www.farmcarbontoolkit.org.uk). Other articles in *Landmark* describe the use of such tools in practice. However, no calculator is accepted as 'standard' at present. There were attempts to develop an EU-wide programme involving an open-source software, but its success was limited. (See Box below).

The cautionary tale of the EU's farm level carbon calculator

Context: In 2010, the European Commission began a rollout of Carbon Calculator – a user-friendly open-source carbon calculator, used for assessing the lifecycle GHG emissions from different types of farming systems across the EU. The tool also offered farm-specific GHG emissions mitigation measures.

Problem: The Carbon Calculator was very data-heavy (requiring >80 individual data entries). Most interviewed farmers stated they were unlikely to use the tool without financial incentives. Challenges continued and were mainly linked to not seeing any benefit of using the calculator (especially in Slovenia, the Netherlands, Denmark and Sweden). However, not seeing the benefit of using the Carbon Calculator had less to do with farmers' unwillingness to partake in on-farm mitigation of greenhouse gas emissions and more to do with the fact that many were already undertaking a variety of mitigation measures and did not see the usefulness of undertaking the additional measures proposed by the tool (given the amount of effort needed to get the results).

What is already underway on-farm?

Many schemes, which include measures to improve on-farm efficiency or reduce environmental impacts, e.g. through Countryside Stewardship schemes or Catchment Sensitive Farming, also double up as GHG mitigation measures. For example, increasing soil carbon stocks through incorporation of cover crops, agroforestry, integrating grass and herbal leys in rotation, switching to low input forage crops (e.g. triticale), and reducing soil compaction have been long proposed as a way to maintain good soil health, are also effective methods of reducing and offsetting GHGs produced.

In general, on-farm reducing emissions and improving efficiency go hand in hand. Well-thought out deployment of many GHG mitigation measures results in limited disruption to management practices already in place. Countless farmers across England, Wales and Scotland are already developing their own ways to mitigate their farms' impact on the climate – these measures, alongside links to helpful case studies, are in Table 1.

What measures can reduce GHG emissions for arable farms: are they hard or easy to implement?

As part of work, to underpin the development of new payment mechanisms to farmers under the Agriculture Bill, Defra have commissioned a short project to consider the feasibility of GHG mitigation measures on-farm. The project is being carried out by SRUC (Scotland's Rural College), the Centre for Ecology and Hydrology and NIAB. Firstly, the project team at SRUC collated all the proposed GHG emission reduction measures from farming and reviewed the technical evidence about their expected effectiveness. The second phase involved consultation with farmers in different sectors arable, field vegetables, dairy, lowland beef and sheep, upland etc. In the workshops farmers shared their current actions to reduce GHG on-farm and discussed GHG-reducing practices that are being considered for their sector as part of the Defra-funded project. Attendees ranked these from 'easy' to 'hard' and commented on what each one might mean in practice and the implications, if any, to the business. The results from the arable farmers are as follows, starting with those that they felt were easier to implement:

- Improved nitrogen use efficiency using targeted release fertilisers within a farm-specific N management plan
- Reduced intensity of cultivation
- Increasing tree cover on farm
- Reduced area of cropping systems on peat and reversion to wetland
- Soil/land suitability mapping to define management and cropping choices
- Reduced use of diesel or increased renewable energy
- No bare soil – continuous green-cover cropping systems
- Improving soil health
- Targeted steps to increase soil organic matter.

Many of these practices are already in place on some farms (Table 1).

Figure 2. Barriers to adoption of on-farm GHG mitigation measures as identified by NIAB members

Table 1. What have other farmers done? Examples of farming systems and management decisions contributing to net-zero farming. Increasing efficiency is often the best strategy to minimise GHG emissions on farms with arable cropping

Who	GHG emissions mitigation measures	Link to case study
Adam Twine, dairy and arable	• Wind turbines and solar panels • Barns equipped with PV solar panels used to run dairy parlour • Farm Carbon Cutting Toolkit (FCCT)	https://www.nfuonline.com/news/latest-news/achieving-net-zero-meeting-the-climate-change-challenge/
I Cooper and Partners, mixed farm with beef, sheep, arable and woodland dairy and arable	• Increasing proportion of permanent pasture • Tree planting	https://www.farmingforabetterclimate.org
Euan Caldwell, arable	• Tied ridges in potato crops • Reducing soil compaction by optimising ploughing timing and using low pressure tyres • Accurate GPS system (precise spraying and drilling)	https://www.farmingforabetterclimate.org
Peter Robertson and Elaine Booth, arable	• Optimised rates/timings of fertiliser application • Precision fertiliser applicator • SOM maintenance • Use of local machinery ring • Use of nutrient planning • Using river haughs for permanent pasture • Set-asides for bog and moss • Tree planting • Reduced tillage	https://www.farmingforabetterclimate.org
Willie Hamilton, mixed arable and stock	• Time switches for light • LPG grain dryer • Frequent vehicle and tractor maintenance • Irrigation to reduce N_2O emissions • Running lorries with loads in both directions to optimise fuel • Farm-wide N budget • Locally sourced slurry to improve N efficiency • Grass mixes containing clover, used for silage • Ground source heat pump • Tree planting • Stubble cultivator • Minimum tillage	https://www.farmingforabetterclimate.org
Robert Ramsay, arable	• Minimum tillage • Yield mapping • Controlled traffic farming to reduce soil compaction	https://www.farmingforabetterclimate.org
Jorin & Aidan Grimsdale, arable	• Minimum tillage • GPS controlled equipment • Utilisation of drones to assess crop status • Soil health assessment • Soil organic matter content monitoring	https://www.farmingforabetterclimate.org
Home Farm, arable	• Permanent pasture • Tree planting	Low Carbon Farming – A handbook for farmers in the 21st century
Bairnkine Farm, arable	• Planting of hedges and trees • Solar panels • Permanent grass leys • N balancing	Low Carbon Farming – A handbook for farmers in the 21st century
Abbey Home Farm, livestock and arable	• Planting of hedges and trees • High quality feed • N management • Permanent pasture • Minimum tillage	Low Carbon Farming – A handbook for farmers in the 21st century

One of the top suggestions of what would help farmers was a funded, independent source of information – preferably web-based. Next came the suggestion of access to trained advisors and subsidised training and perhaps a facilitation fund for farm groups to support on-farm GHG mitigation. Demonstrations and case studies were felt to be potentially very helpful to share best practice, and perhaps funded farm demonstration sites to visit and learn from could inspire changes in management and farm practice. The introduction of a farm-wide carbon levy/rebate system was recognised to probably be unpopular.

Nevertheless, the group felt that financial 'teeth' might be needed to move more of the industry further towards hitting any GHG reduction goals for agriculture. Similar to other sectors, perhaps farms that produce too many GHGs could incur financial penalties whilst farms performing well could be rebated/rewarded.

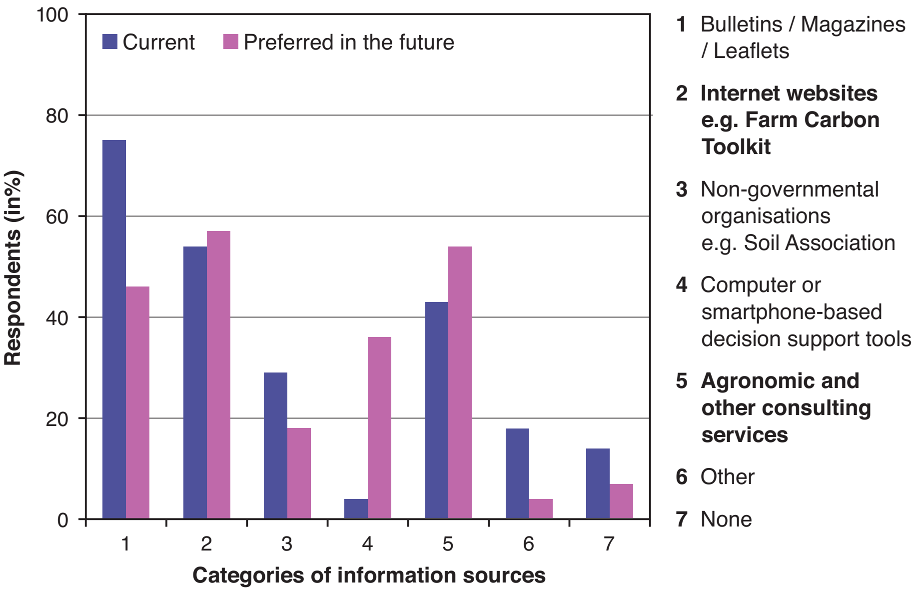
In these workshops, the farmers mostly admitted that GHG was not something that currently factors high in their day-to-day farming priorities. They recognised that, like other sectors, they will have to play their part. Farmer Stephen Ashford from mid-Norfolk, acknowledged the usefulness of the discussions and the value of looking at the sources of GHG emissions and how his farming can lessen its contribution to the problem. "In my domestic life, we have already been taking steps to be 'greener'. But I have not really paid much attention to how my farming could be changed in order to produce fewer GHG," he admitted. "This has been a useful session to get me thinking."

What do our members think?

We know NIAB TAG members recognise the importance of preparing for climate change and future-proofing their businesses by implementing mitigation measures against GHG emissions. A recent survey had thirty respondents and 61% have some knowledge and 39% have medium knowledge of how to mitigate on-farm GHG emissions, with two thirds already implementing mitigation measures on their farms. Those who did, favoured cover crops (four replies), zero till (four), tree planting (three), use of manures instead of manufactured fertilisers (two), investment in renewables, improving N efficiency, reduced cultivation, incorporation of straw, electric vehicles, direct drilling, strip tillage, herbal ley and improving fuel use efficiency.

Ten respondents did not implement any mitigation measures and three were unsure what they could do. Barriers to adoption of mitigation measures included lack of knowledge and information, concerns about how any scheme would work in practice as well as technical issues and the unplanned interactions between different policies e.g. loss of glyphosate undermining adoption of conservation agriculture systems. Since farming is at the beginning of a journey towards decarbonisation (Figure 2), it is essential that the information flow between practitioners, researchers and policy-makers is enhanced. Members gave the NIAB team some practical suggestions of the most important routes to share information in the future (Figure 3).

Figure 3. Information sources used by NIAB TAG members to learn about mitigation measures for GHG emissions. Currently, bulletins, magazines and leaflets are the most common source of information. In the future, there is an increased preference for information delivery on-line and through agronomic consultancy services and also for the delivery of robust on-line decision support tools



Additional notes

Special thanks to all survey respondents! Your time and help were invaluable.

I would also like to answer the question asked by one of the surveyed members: ***How many atoms of carbon have we as a species created?***

Answer: None, of course. But we have made significant difference to the types of molecules that the C atoms are found in and where they are within the Earth's system.

Annual carbon emissions to the atmosphere due to human activities are estimated at about 36 billion tonnes. Every mole of carbon weighs 12.0107 g and each mole of any substance contains Avogadro's number of atoms/molecules (6.02214 x e23) Simple answer – too many zeros on the number for me to count!

Then… 18.5% of human body is made up of C, there are 7.8 billion people in the world so that's an additional one hundred forty-four billion three hundred million C atoms moving around, and if we add all the livestock reared for human consumption with the same C proportion… These answers just give a taste of the changes we make as a species.

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The path to a 500 t/ha yielding soft fruit crop – energy

Dr Richard Harrison is Director of Cambridge Crop Research at NIAB, moving from NIAB EMR in 2019. In 2017, he was awarded a Nuffield Farming Scholarship on '*Where next for soft fruit in the UK? Addressing the yield gap and providing a path to 500 t/ha*'. In a series of articles for *Landmark* Richard covers his conclusions and recommendations, which apply far beyond the soft fruit industry.

In my first article 'The path to a 500 t/ha yielding soft fruit crop – genetics' (*Landmark* issue 41 – March 2020), I focused on the role that genetics plays in environmentally sustainable yield gains in strawberry and other crops. In this second part, I look at some of the requirements for new production systems and the implications for future net-zero horticultural crop production. As a consequence of this part of my study I reached my second conclusion:

Conclusion 2

Energy consumption in agriculture is rising and new production systems must 'design to avoid' and be developed with an awareness of wider energy policies.

Energy use in protected cropping

Within horticulture, most of the emissions from protected production electricity and gas use are counted as industrial and not agricultural emissions.

Table 1 reveals the basic pattern that while cutting-edge production dramatically increases productivity it also increases energy usage; in 2012, Dutch tomato production was predominantly underpinned by utilisation of natural gas. The conversion efficiency of that energy into food is low in intensive food systems, although significantly more space efficient than extensive systems. If it was assumed that all tomatoes produced for the UK used the same amount of energy as the 2012 Dutch systems, emissions from tomatoes would range between 0.6-1.9% of the total agricultural emissions and around 11% of the total energy usage of UK agriculture.

However, it is also extremely important to note that where combined heat and power systems are used – rather than just gas boilers – heat and CO_2 are by-products of electricity generation for the national grid and therefore the emissions should not necessarily be apportioned directly to tomatoes. This does not lessen the absolute problem, but at least explains why the emissions are apportioned beyond agriculture. In the Netherlands the sector is changing rapidly and working hard to cut emissions.

Table 1. Comparisons of emissions between tomato growing systems in the Netherlands and Portugal (low input) – 2012

Active ingredient	Netherlands	Portugal
Area (ha)	1,676	1,440
Yield (t/ha)	640	150
Total annual tonnage	1,072,640	216,000
GWh/annum	7,035	40
GWh/t	0.0066	0.0002
Conversion efficiency (%)	3	115
Emissions if all electrified (tonnes of CO_2e)	1,266,218	7,128
Emissions if all gas (tonnes of CO_2e)	3,861,965	21,740
Annual cars on the road (2018 UK electricity mix)	275,265	1,550
Annual cars on the road (gas)	839,558	4,726

Assumptions:
- 1 kg tomatoes = 180 kCal
- Average CO_2e emissions UK power 2018 = 180t/GWh
- Gas CO_2e emissions = 540t/GWh
- Annual CO_2e emissions from a family car = 4 t/annum

Strawberry production

Current systems for strawberry growing are energy hungry. In 2012, field strawberry production, with a typical yield of around 20 t/ha (based on Defra statistics), used about 3.1 MWh/t (1,000 MWh = 1 GWh), or 300 GWh of energy on a total annual tonnage of 94 kt. In contrast, Dutch tomato production used around 7,000 GWh to produce over 1,000,000 kt of crop, using around 6.5 MWh/t. A FEC Energy report in 2017 estimated around 280 GWh of energy was used for the surveyed 225 ha of UK strawberries produced under glass– averaging 20 MWh/t, much higher than Dutch tomato production.

To produce the UK's present-day levels of self-sufficiency, around 138,000 t, and assuming 60 t/ha yield, would require 2,300 ha of glass consuming a whopping 2,872 GWh of energy per annum. However, if yields could be increased to 500 t/ha (unlocking the genetic potential covered in *Landmark* Issue 41) then this would fall to 346 GWh across an area of 277 ha. This most optimistic scenario would use 2.5 MWh/tonne, lower than both 2012 production levels and 2012 tomato levels (Table 2).

These calculations illustrate that, depending upon how intensification is carried out, the consequences could vary by several orders of magnitude (Table 3). For example, a highly unlikely, and uneconomic, scenario of shifting all current strawberry production to high intensity 'Dutch-style' glasshouse production could lead to the equivalent emissions of an extra 2.4 million modern cars for one year.

Under the most optimistic scenarios, realising large yield increases in a largely electrified glasshouse production system, the UK could maintain its current level of self-sufficiency (around 70%) and only increase its current glass footprint by 52 ha and hardly increase emissions from current levels. This would liberate around 4,367 ha of land. In terms of direct CO_2e (carbon dioxide equivalent) this could even be lower than present levels if our energy mix continues to shift towards renewables.

If we assume that in terms of our energy needs, we require around 350 GWh/annum of energy to produce our current level of strawberries, how much land would be needed to generate this energy through renewable sources? Based on current solar technology and UK average solar insolation 297 ha of solar panels, delivering around 13 W/m^2, would be required to support the national strawberry farming operation if yields could be boosted to 500 t/ha (Table 4). However, based on current yields of 60 t/ha. under glass, this would increase to 2,467 ha. Turning to biomass, due to the much lower power density, the area for production increases to between 9,100 ha and 76,300 ha, for the 500 t/ha and 60 t/ha scenarios.

It highlights how different choices around growing systems and energy sources can lead to dramatically different outcomes. The most optimistic scenario leads to a land area 13% of the 2012 level being used for berry and energy production, while our least optimistic expands the areas by around fourteen times that of 2012 levels.

Table 2. Intensification of strawberries under varying assumptions. Note the lower bound for intensive production is lower than current estimated energy use

Scenario (yield gains)	Area (ha)	GWh/t
UK strawberries 2012*	4,272	0.003
Dutch tomatoes (2012)	1,676	0.007
Intensive strawberry – 500 t/ha**	277	0.002-0.009

* Data taken from (Swain & Hardy, 2017), Defra Horticultural statistics (ONS & Defra, 2018), UK Energy Statistics, 2018 & Q4 2018, the agree consortium (Consortium, 2012) and Williams *et al* (Williams, Pell, Webb, Moorhouse, & Audsley, 2008)

** estimate based on maintaining current (2017-18) domestic supply levels

Table 3. Yield intensification using current varieties and growing systems dramatically increases energy usage

Scenario (yield gains)	Area (ha)	GWh/t
UK strawberries (2012)	4,272	0.004
Dutch tomatoes (2012)	1,676	0.007
Intensive strawberry current systems	2,300	0.021
Intensive strawberry (2012 Dutch tomato energy levels)	2,300	0.073

Data taken from (Swain & Hardy, 2017), Defra Horticultural statistics (ONS & Defra, 2018), UK Energy Statistics, 2018 & Q4 2018, the agree consortium (Consortium, 2012) and Williams *et al* (Williams, Pell, Webb, Moorhouse, & Audsley, 2008)

Table 4. Area of land (ha) needed to produce energy for indoor strawberry production

Yield scenario	Power type	Energy area (ha)	Total area (ha)	% of 2012 total	Energy area vs crop area (fold difference)
500 t/ha	Biomass	7,200	7,477	175	26.0
	Solar	297	574	13	1.1
60 t/ha	Biomass	59,771	62,071	1,453	26.0
	Solar	2,467	4,767	112	1.1

A key role for future system design

Although very 'rough and ready', this analysis highlights that system design is paramount to intensive production of year-round horticultural goods close to the point of consumption. Could new growing systems with high yielding varieties be designed to utilise solely renewable resources and improve their efficiency? Could there be a situation where the crop is adapted to grow in that new environment? Intuition would say 'yes', as our current growing systems for strawberries have never looked to the challenges of use of renewables in their design brief.

To achieve this, we need to link models of crop architecture, growing system design, energy system design and accurately parameterised improved lifecycle assessment methods to model out the optimum scenarios for the entire system. Equally important is whether this is worthwhile and economic to do so. Modern glasshouses and renewable energy solutions may be the most efficient and scalable way of reducing absolute levels of fossil fuel use in the short-medium term. There are virtually no decent solutions for long-distance transport that are low carbon, whereas a local solution in which all processes are renewable and/or electrified is likely within our immediate grasp. The local solution may require more energy and therefore be relatively less efficient than extensive production in warmer climates. But it may be lower in absolute emissions and have other aligned benefits such as import substitution and national economic growth opportunities.

Recommendation 2

Multidisciplinary approaches to system design are needed alongside greater awareness, training and tools to design 'net-zero' growing and production systems. These systems (to the extent that they exist) are currently high risk and high cost for all but the bravest or wealthiest. As well as the need to de-risk future development, current practice must be evaluated to avoid increasing emissions through scaling of current unsustainable production practices.

In the next of this series I will examine the whole lifecycle of production and discuss how the production system itself needs to be modelled through digital twinning and expanded 'real-time' life cycle assessment if we are to realise our net-zero ambitions.

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Improving disease resistance in *Phaseolus vulgaris* with wild bean hybrids

INTERNATIONAL YEAR OF
PLANT HEALTH
2020

NIAB project team – Sarah Dyer (lead), Jane Thomas, Tom Wood, Krystyna Gostkiewicx, Simon McAdam
CIAT project team – Marcela Santaella, Peter Wenzl, Steve Beebe, Juan David Reyes, Diego Conejo

Wild bean hybrids (*Developing a hybrid bean collection to advance climate ready bean breeding*) is an international project funded through the Grand Challenge Research Fund, working with CIAT (International Centre for Tropical Agriculture) in Colombia. The five-year work programme aims to explore valuable traits in a collection of wild hybrid beans which have been stored at the CIAT genebank.

The hybrids are between various species of Phaseolus, including *P. vulgaris, P. coccineus, P. costaricensis, P. dumosus, P. parvifolius* and *P. acutifolius*, and come from throughout Central and South America. Phaseolus beans are a major protein source in many resource poor regions of the world but are prone to both biotic (pests and diseases) and abiotic (heat and drought) stress. Part of the project will focus on disease resistance to see whether the wild parents of the hybrids have introduced valuable resistance traits which can be exploited worldwide. As with many pathogens, changes in weather patterns are leading to either increased or different disease pressures. Attempting to future-proof crops against these is a vital part of maintaining food supply in areas of the world where agrochemicals are limited or unaffordable.

Phaseolus beans are a relatively small crop in the UK, with the best known being green or runner beans (*Phaseolus coccineus*) sold fresh or for freezing and canning. There is a small area of dry harvested beans (*Phaseolus vulgaris*) for speciality or niche markets (e.g. haricot beans). Some of the diseases we are working with, such as *Sclerotinia sclerotiorum* (white mold) occur on green beans and dry beans, and the same disease infects pea, faba bean and oilseed rape. While largely controlled by fungicide in Europe, disease resistance is much sought after in *Phaseolus vulgaris* beans for South America and Africa. Losses can be devastating, and production fields are contaminated with sclerotia for many years. Progress has been made through the selection of varieties which escape the disease, through their morphological characters, but even here, infection can still occur and increase. Tissue resistance, where the pathogen grows more slowly, or not at all, is important, and combined with escape, provides an integrated approach which will control the disease. Unfortunately, tissue resistance is quite rare, and at best only partial in nature, so discovery of improvements from the hybrid collection would be very valuable. We will be screening close to 5,000 individual plants with three isolates of sclerotinia using a detached leaf test. The most promising lines will be tested again using a stem inoculation technique and taken forward in crossing programmes to a common parent.

Anthracnose, caused by the fungus *Colletotrichum lindemuthianum*, is a devastating phaseolus bean pathogen, worldwide, but particularly where conditions are humid and wet. It is also seed-borne, so saving seed from infected crops is a major factor in initiating disease. The pathogen is highly variable, and there are many races which interact with resistance leading to breakdown and loss of effectiveness in the field. Using a full panel of pathotypes on the large number of individuals generated in the project is not feasible, so we have selected a combination of both frequent and widely virulent isolates from South America and eastern Africa, ensuring that any novel resistance identified will be relevant to major bean growing countries.

Finally, plants will be screened for resistance against *Rhizoctonia solani*. Rhizoctonia causes two different disease syndromes in bean, a root rot, infecting seedlings and causing plant death, and web blight, a foliar infection leading to major losses in seed yield. Both are important in tropical agriculture, but there is evidence from existing screens that resistance to one form does not always confer resistance to the other. Discovering lines which combine resistance to both would be a valuable trait for bean breeders, and even improvement in resistance to one or the other would aid the development of varieties for specific situations where one form predominates.

There are many other important diseases of Phaseolus bean which, unfortunately, the project cannot include, but focusing on three major pathogens, and crossing the best material to a common parent, could provide a major new resource for bean breeding programmes. Despite its importance as a major food crop for over 300 million people, *Phaseolus vulgaris* has a relatively narrow genetic base. Wild relatives are an important source of introducing diversity for important traits, but as with many crops, interspecific crossing can be difficult, and subsequently can take many generations to produce improved, adapted varieties. The occurrence of wild hybrids which have occurred naturally enables a short circuiting of the difficult first steps.

In the 2020 International Year of Plant Health, discovering novel sources of resistance to diseases in this protein crop would contribute greatly to the global objectives of ending hunger, reducing poverty and boosting economic development. The wild bean hybrid project will also examine other traits associated with drought stress, tackling another major constraint on bean production, as well as investigate the 'crossability' of the hybrid material to enable rapid introduction into breeding programmes at the end of the programme.

Acknowledgements

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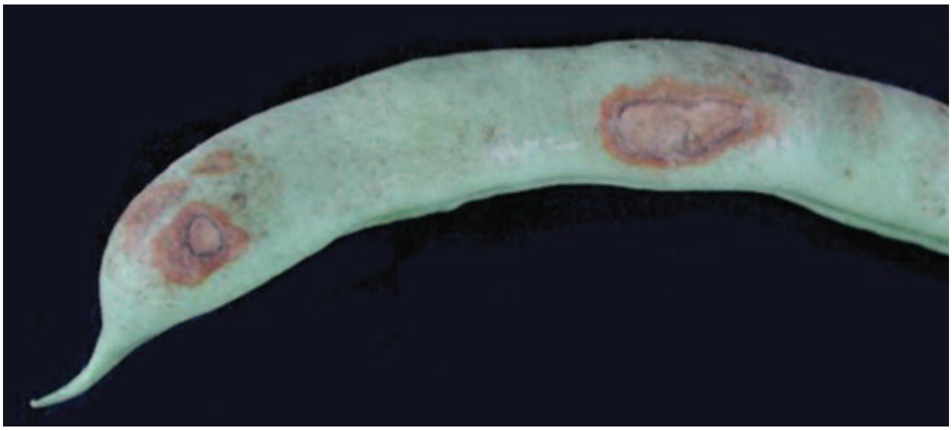
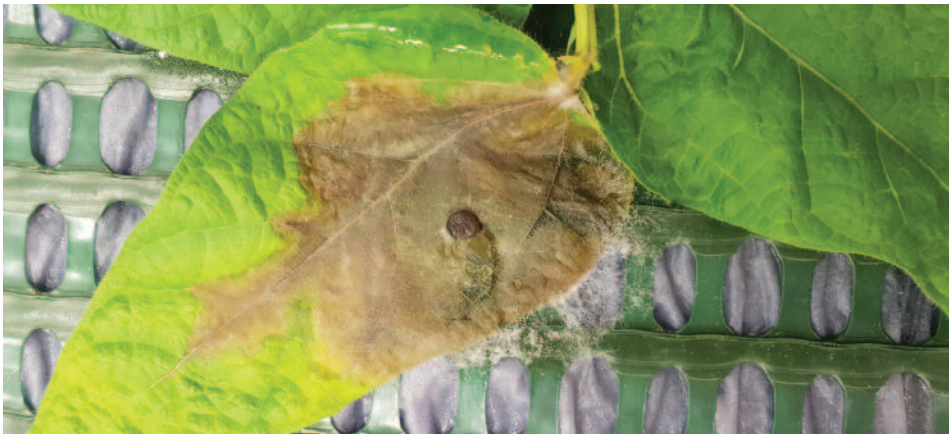
Pathogen tests are being carried out under Plant Health Licence, Authorisation Number 50970/194475-6

Target diseases

Colletotrichum – common and severe in wet conditions



Web blight – severe in tropical areas



Sclerotinia white mold – common in all bean growing areas

Becky Wilson, Farm Carbon Toolkit

Measuring the carbon performance of your farm

The old adage of 'you can't manage what you can't measure' is certainly true of carbon accounting. But when it comes to agriculture, measuring carbon is not as simple as it may first seem. Carbon accounting systems were designed to measure industrial processes; when measuring the emissions associated with a product manufactured in a factory, we are able quite simply to understand how the inputs lead to the outputs and it tends to all be neatly contained with a building. This is not the case when we use these metrics to measure farming systems.

On-farm we are trying to measure biological systems, which are impacted by climate, soil type, topography and vegetation, as well as what we, as farmers, are doing in terms of our management, which can make the whole thing a little tricky! However, undaunted by this complexity, carbon metrics are an essential tool that farmers can use to identify climate solutions, and to baseline the farm's emissions and drive technological change.

Identifying the carbon footprint of a farm business is the first vital step in being able to quantify the contribution that the farm is making to climate change. A carbon footprint calculation in its simplest form identifies the quantity and source of carbon dioxide, methane and nitrous oxide emitted from the farm (the emissions) and subtracts from the emissions the carbon that is being sequestered on-farm (sequestration) to provide a carbon balance. This balance is the starting point which should then highlight areas where improvements or changes can be made to reduce emissions and improve sequestration potential.

Reducing carbon emissions in a farming business makes sense on many levels. High carbon emissions tend to be linked to high use of resources, and/or wastage, so reducing emissions also tends to reduce costs. This makes the farm more efficient and should improve profitability. As well as the business opportunities that come from reducing emissions, farmers and landowners are in the unique position to be able to sequester carbon both in trees, hedgerows and margins and within the soil.

Before being able to reduce emissions, you need to know where the emissions are coming from. Are the largest emissions coming from livestock, soils, fuels, or fertilisers? It is vital to get a picture of the business which is made possible by carbon footprinting.

Choosing a tool to use

There are various carbon footprinting tools that have been designed for use by individual farmers (or groups of farmers) who are interested in understanding the carbon balance of farms. Tools include the Cool Farm Tool, AgreCalc, and the Farm Carbon Calculator. The golden rule is, once the decision has been made on which tool to use, stick with it, as there are differences within the methods used in each calculator, so comparing results between them is meaningless.

Although the simple principle of completing a carbon footprint assessment is the same there remains variation between what scope and boundaries the tools used to calculate the results. This is good to understand before starting the process of calculating a carbon footprint.

Boundaries are an important factor to consider (or understand with the tool being used) as it makes a difference on the data that you need to collect and also the results. Put simply boundaries refers to where you are drawing the line around what is included in your calculation and what is not. For example, do you want to calculate the emission associated with one farm enterprise or the whole farm, or just what is happening with the farm gate or further afield? Making sure this is clear before starting makes the whole process easier.

It is important to understand the scope of the calculations – which relates to the level of processes which are included in the calculation, for example – is the tool including emissions associated with electricity production? This is important when producing renewable energy on-farm or using a renewable tariff. It also deals with how the emissions associated with fertiliser production are assigned.

A key part of deciding which tool to use centres around what how the footprint is going to be used:

- ***Marketing*** – if using the results for marketing purposes, it is a good idea to choose one that has a clear method attached to it, which sets out what is included and excluded from the calculations – that way you can be completely transparent about your carbon credentials.
- ***A management tool*** – if planning on using the results and the data as a management tool, perhaps to highlight areas to improve in the future, then use a tool that evaluates the impact of changing your management. These tools tend to need more data added in at the start so that the impact can truly be seen.

Sequestration – in or out?

A key question when footprinting is whether carbon sequestration is included in the calculation. Carbon captured within trees, hedgerows and field margins, as well as the carbon held in soil, is an important part of the footprint and should not be overlooked. If the tool does not include sequestration, then the footprint will be looking at the negative without the positive!

Getting started

Once the decision has been made on which tool to use, the first step is to gather all of the input data. This includes information on fuel use, livestock numbers, fertiliser inputs, use of materials, waste produced etc. The list can look daunting at first, but if farm record keeping is reasonable then this process should be achievable in a couple of hours. It will be quicker next time!

It is then just a case of entering the data into the calculator, no more than an hour's work, after which you should have a breakdown of carbon emissions by sector, both in amounts (kg or tonnes of CO_2) and percentages of the total footprint by category. Armed with this data you are then ready to think about how to reduce emissions and increase sequestration.

When completing a carbon footprinting although value can be seen from completing it as a one-off exercise, the really interesting part comes when the process is repeated at regular intervals, usually annually. Then you can start to see the direction the farm is moving in and whether the actions you are taking are working.

Emissions sources

Although each farm will vary in its carbon footprint, the pie chart (Figure 1) shows the average breakdown of emissions across a typical arable farm.

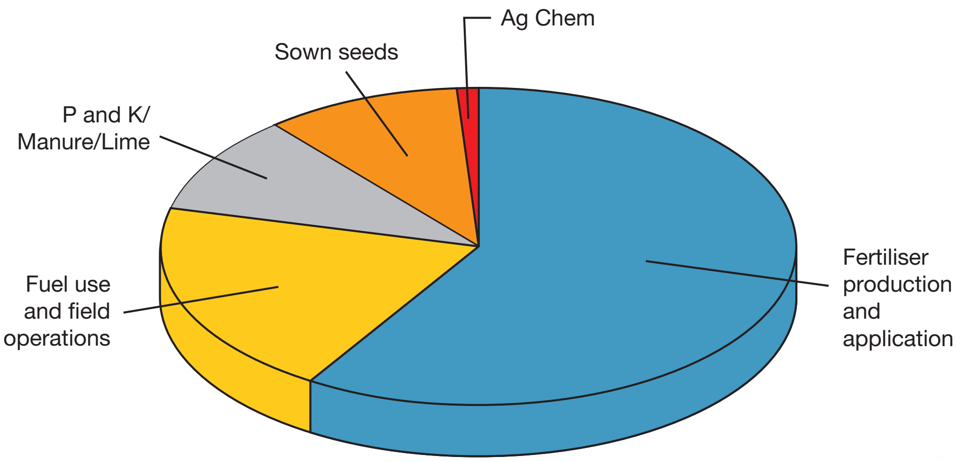
Next steps

This is the interesting part! The results will be reflected as a carbon dioxide equivalent but should also show how that breaks down into the three greenhouse gases. Key areas to focus on are the management of soils, fertilisers, manures, livestock, cropping, energy and fuel. There are numerous opportunities to reduce emissions and costs as well, leading to improved resilience and profitability, as well as opportunities to improve carbon sequestration and soil health, the ultimate resilient business model!

Absorbing more carbon than the farm emits is a goal that all farmers could work towards and understanding the farm's current carbon position by footprinting is the first key step.

The spotlight is being well and truly shone at agriculture's carbon credentials at the moment, and this offers an opportunity for us to take the first step and understand what is happening on our individual farm, and what we can do to improve profits, reduce emissions and build soil health and sequestration. Carbon offers a fresh lens through which to evaluate our business and build resilience for the future.

Figure 1. Emissions from a typical arable farm



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Gauging UK agronomists' opinions on earlier flowering time in winter wheat

Background

Flowering time (FT) marks the transition from vegetative to reproductive growth and its timing relative to local environmental conditions is the major determinant of grain yield in wheat. If water becomes limiting from drought conditions during the grain fill period, then this can lead to leaf senescence and a diminished grain yield.

Climate predictions state that warmer summers are expected to increase in frequency in the UK, accompanied by a reduction in summer precipitation, leading to an increased risk of droughts and thus potential significant yield losses. Varieties with early FT can help to avoid this risk during warmer summers, by flowering earlier in the season, still gaining enough thermal hours due to the warmer temperatures, and reaching maturation earlier, before the effects of drought severely impact the grain.

Winter wheat varieties in the UK are typically later flowering than varieties in other regions of northern European and there are currently no varieties with stated early FT on the AHDB Recommended List (RL; using 'Ripening' as a proxy for FT). In the past decade, there has clearly been both a shift to predominantly later flowering varieties on the RL as well as a reduction in variation in flowering time amongst varieties (Figure 1). Varieties with earlier FT are commonly used in southern Europe but these are not adapted to the UK's longer growing season conditions. Taking this all into consideration, we aimed to identify whether there is a demand for varieties with earlier FT that are adapted to the current and dynamically changing seasonal conditions experienced by wheat producers in the UK.

UK agronomist survey

To carry out our research, agronomists working with farmers across UK wheat production regions were consulted, roughly proportionate to the volume of wheat production in these regions (Table 1). Fourteen agronomists were interviewed including the NIAB TAG regional agronomy team (five), the TAG Consulting team (four) and from Velcourt (five), a farm management and advisory business. We also sought the input of a commercial wheat breeder.

The following questions were asked:

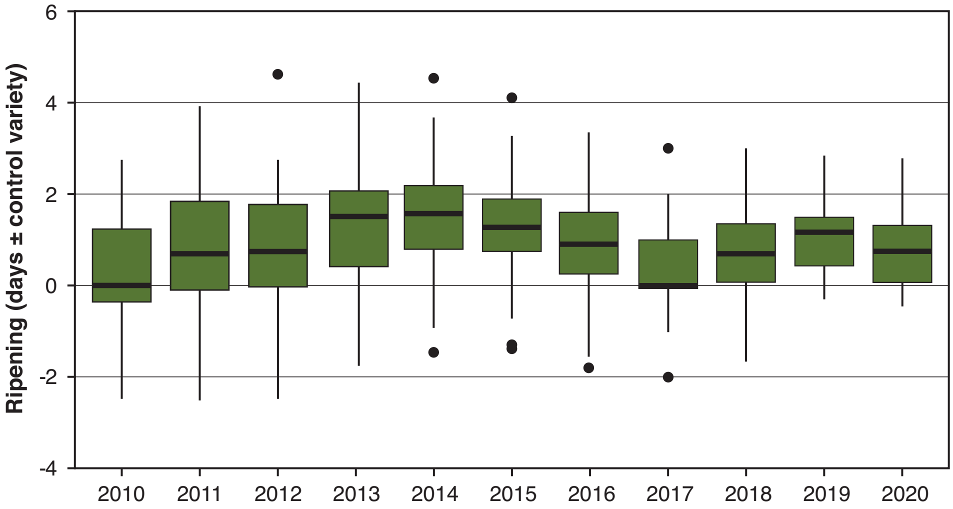
1. Do you think that winter wheat varieties with an early FT are desirable?
2. What do you think are the advantages and disadvantages associated with varieties with an earlier FT?
3. Is low water availability a problem experienced by farmers in your region, and have your customers suffered yield losses due to drought?

Key findings

Earlier flowering time in UK winter wheat is desirable given more fluctuating seasonal conditions

Responses were extremely positive towards a greater selection of winter wheat varieties with earlier FTs, with demand differing depending on the region due to climate and, within regions and localities, on the soil. There were recollections of early flowering varieties (e.g. Soissons, Grafton, Cordiale) that are no longer on the RL with some still grown by some farmers. This is reflected in the certified seed produced – in 2019, 14% of seed produced were varieties that at some stage have been classified as early ripening on the RL despite the absence of early ripening varieties on the current RL (although it is possible that these varieties are being grown for other favourable agronomic traits besides early FT).

Figure 1. Winter wheat varieties available on the AHDB Recommended List show a reduction in the number of earlier flowering/ripening varieties as well as a reduction in the range of flowering times available



The link between flowering and maturation date needs to be better understood

A common query during the interviews was about the relationship of flowering time to maturity date. Some interviewees pointed out that FT was not a growth stage of major consideration for farmers and agronomists, and rather that they were more interested in maturity date. Growth stages are typically correlated, therefore later flowering varieties are presumed to have a longer grain fill period in which to increase carbohydrate in the grain, and so have higher yield than earlier maturing varieties. For the purpose of these interviews, the assumption was made that an earlier FT meant an earlier maturity date, and advantages and disadvantages were discussed considering this. However, there is clearly a need for better data recording and reporting on the link between FT (used in research) and ripening/maturity (used on-farm).

Earlier flowering time can mitigate drought stress

Drought stress is already seen to be a problem in some regions and on drought-prone soil types. Almost all the agronomists surveyed reported that they had worked with farmers that had seen evidence of drought stress, or yield loss due to low water availability. They saw it as a concern going forward and could see the advantages of wheat with earlier FT used to mitigate risk of drought stress. However, there was also some scepticism that meteorological predictions about the coming season could be accurate enough on which to base variety decisions for the entire wheat crop. Rather, earlier flowering varieties could be used in a portfolio of other varieties with different FTs, in order to spread risk across the farm and have some assurance of productivity amongst certain parts of the wheat crop. Additionally, some interviewees saw the potential for earlier FT varieties to open areas for wheat cultivation that are not currently cultivated due to unsuitable soils, for instance, on more drought-prone soils in the south of East Anglia.

Improving the logistics of crop management

The most commonly acknowledged benefits of early FT varieties were those related to farm management. Farming is becoming more compact, applying pressure at certain key stages such as drilling, treatment timings, and harvest. For instance, for areas south of Yorkshire, the drilling window is contracting so as to drill as much of the crop as late as possible to reduce disease risk and control black-grass growth. This contraction means that the crop is more tightly synchronised at later developmental stages.

Table 1. Geographical areas of interviewed agronomists. Agronomists may be responsible for more than one region

UK regions	Number of agronomists
Southern Scotland	1
North East	2
North West	0
Yorkshire and the Humber	3
East Midlands	3
West Midlands	4
East of England	3
South East	2
South West	5

By combining earlier flowering and maturing varieties with those with later timings, the demands on labour and machinery can be spread over time, despite a contracted drill window. In particular, the ability to extend the harvest window would be a clear advantage because of the upper limit on combine harvesting and the potential loss in grain quality due to delays in harvesting. By spreading key developmental stages, it may be possible to better manage the wheat crop and even increase capacity across the farm.

For farm management in northern regions, where lower temperatures and shorter days lead to even later growth stages, earlier flowering and maturity times were recognised as of particular benefit to be certain that varieties have enough time for grain fill and ripening. Furthermore, earlier varieties may also provide opportunities for catch and cover crops that may not be possible with later maturation times.

Avoiding pest and pathogen damage

Another potential benefit was the reduced risk of some diseases and pests, particularly those that infect in later summer. For the ergot fungus, which infects the ear at flowering and produces sclerotium and toxic alkaloids, risk is highest in later summer when the weather is warmer. Shifting flowering earlier may help to reduce this risk. For orange blossom midge, which feeds on developing grains, there is a relatively narrow window of a few days in which risk is extremely high and currently this window coincides with flowering of some varieties. Shifting FT earlier would help to avoid this window and reduce pest damage. However, there was also recognition that changing climates are likely to affect the life cycle of pests and pathogens as well, so any predicted reductions in risk will need to be combined with modeling of these factors.

Increasing the risk of frost damage

The only potential problem that arose was that of damage of earlier FT varieties from late frosts. Frost during flowering can be devastating to a crop, causing sterility in the ovary and/or pollen and underdevelopment of the ear. The French, early-flowering, variety Soissons was discussed by some interviewees in this context, as it was known to be particularly subject to late frost. The UK is generally thought to experience few frosts and warmer summers should lead to a greater reduction in late frosts. Climate change is also predicted to lead to an increase in extreme weather events, such as unseasonable frosts. However, these are difficult to predict and are perhaps best managed by growing varieties with different agronomic traits.

The yield sticking point

Yield is the overriding consideration of which wheat variety to grow, although the emphasis on its importance did differ between interviewees. Some suggested that yield penalties could be acceptable if the variety opened up other opportunities, although currently a new variety must yield 2% above the control varieties in order to make it onto the RL (96% of varieties sold in the UK are on the RL at time of purchase). As stated above, earlier FT varieties have a shorter growing period and therefore, in conditions where water is not limiting, they may be assumed to have a lower yield due to a shorter grain fill period. However, under drought conditions, there is expected to be a trade-off between the yield gained due to extending the grain fill period and yield lost due to drought stress. This is where an early FT variety could prove its worth. This could be boosted even further if the variety has high market value such as a milling wheat. An alternative strategy would be to breed early FT varieties with high yield by decoupling flowering time and maturity date in order to obtain a similar grain fill period to later varieties. As stated above, this will require more research into the link between these two developmental stages in order to find suitable genetic targets.

Overall findings

Early flowering varieties are clearly seen as a desirable option for UK farmers, particularly considering the limited choice that is currently available. The main advantage associated with an earlier FT, along with a likely earlier maturity time, is the benefit to the management of the farm by having multiple varieties with different key developmental timings so that demands on labour and machinery can be spread out. This advantage depends on the size of the farm with larger farms being able to grow more varieties and take advantage of this strategy. Drought avoidance is also seen as a clear advantage with early-flowering varieties. Drought is a common risk for many regions within the UK and with the effects of climate change on increasing temperature and extreme weather events, this risk is set to increase. The more options there are for flexibility and resilience, such as a wide range of wheat varieties with beneficial agronomic properties, the better.

NIAB outlook

Drought-tolerance and early flowering are the focus of ongoing research projects conducted by NIAB and in collaboration with other research institutes and breeding companies. NIAB is currently assessing 21 varieties and pre-breeding lines for agronomic performance under rainfed (water-stressed) vs. irrigated conditions as part of the BBSRC-funding Designing Future Wheat project. In these trials we aim to understand response to water deficit in lines contrasting for flowering time, height and root system architecture in order to inform future drought-resilience breeding.

Another ongoing project has measured key developmental stages related to flowering (GS39, GS55 and GS61) in the highly diverse 8-founder Multiparent Advanced Generation Intercross (MAGIC) population in order to find additional genetic controllers of flowering time. While major genetic loci that control flowering are relatively well-characterised in wheat, loci of minor effect are less well-studied but are promising targets for modulating flowering time. Several promising QTLs are being taken forward to determine how they interact with well-characterised loci and how they perform in elite wheat backgrounds with a view to delivering new, high-performing early flowering varieties in the next decade.

What about spring wheat?

The 2019/20 autumn-winter season saw exceptionally high levels of precipitation over the typical drill window (September-October) with a large proportion of the anticipated winter wheat drilling not carried out and replaced with spring crops. Because of this dramatic shortfall in winter wheat, we also asked whether the agronomists would recommend currently available spring wheats to their farmers.

We received a wide range of responses, from favourable to very negative. The positives associated with spring wheat are that they are good quality nabim Group 1 and Group 2 varieties that capture a higher market value than barley, the highest production spring cereal crop in the UK. These varieties also tend to be resistant to orange blossom midge. However, there were a long list of negatives including poor competition against black-grass, serious pathogen and pest issues including ergot and gout-fly, problems obtaining high and consistent yield, and that it is just not an option in some soils because it must be drilled relatively early. The positives in a higher quality crop with a higher market value, especially in a saturated barley market, may outweigh the perceived negatives for some but overall interest in new varieties was low. However, considering the number of perceived disadvantages, there may be a lot of room for improvement in targeted breeding of this crop.

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Is soil management the key to net-zero?

Of course, the simple answer is "No, not alone", but it does have a role to play.

What is the link between soils and greenhouse gas emissions?

Agriculture releases significant amounts of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) to the atmosphere (Figure 1).

Carbon dioxide is released largely from microbial decomposition of plant litter and soil organic matter or during burning of crop residues. Methane is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, stored manures and rice grown under flooded conditions. Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available nitrogen (N) exceeds plant requirements, especially under wet conditions. In fact, 70% of the total greenhouse gas (GHG) emissions from agriculture are associated with N fertiliser; the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) showed that this resulted from a combination of CO_2 and N_2O emissions during manufacture and N_2O emissions, direct and indirect, from its use. Methane from livestock is the only agricultural GHG emission where soil condition and management play no role in the amount or timing of GHG emissions.

At the same time, there is a large quantity of carbon (C) held in the organic matter within the world's soils. It is estimated that the global stock of soil organic C (SOC) is in the range 684-724 Pg to a depth of 30 cm. This quantity of SOC in topsoil is about twice the amount of C in atmospheric CO_2 and three times that in global above-ground vegetation. Changes in this pool can contribute significantly to GHG emissions; for example, the IPCC estimated that the annual release of CO_2 from deforestation (coming from both vegetation and soil) was about 25% of that from burning fossil fuels.

Can agricultural soils lock away (sequester) more C?

During the last decade, much has been written about the possibility of slowing climate change through sequestering C in soil as soil organic matter. The "4 per 1,000" initiative was launched in December 2015 at COP21 and

Figure 1. Agricultural greenhouse gas balance

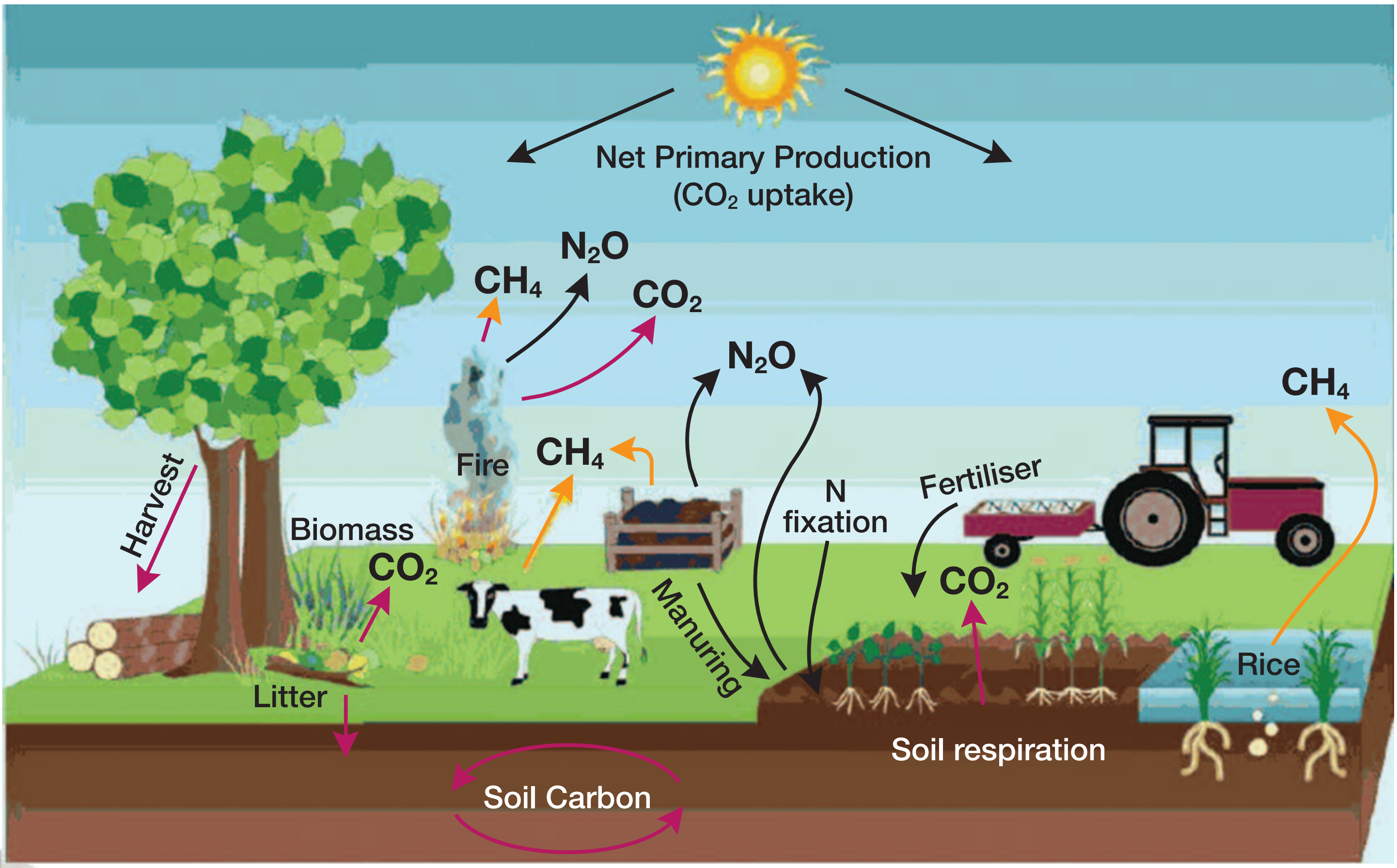
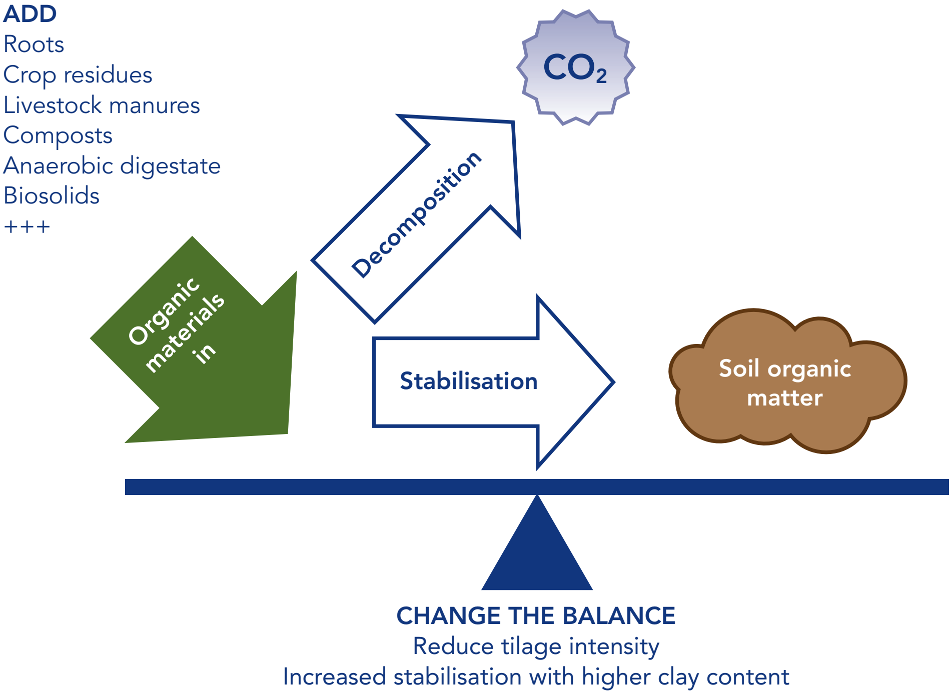


Figure 2. Levels of soil organic matter are a result of a balance between C inputs and outputs. A range of factors affects the processes of decomposition and stabilisation in different climates/soil types so the same inputs can lead to different amounts of SOC



highlights the fact that a small increase (0.4%) in the total amount of C stored in soils would be larger than the annual increase in atmospheric CO_2 in that year.

If environmental factors or management practices cause the SOC stock to increase over time, then the soil can be described as a sink because C is moving into it. On the other hand, if it is declining, it is a source because C is moving from SOC to the atmosphere. Bellamy *et al.* (2005; Nature 437: 245-248) analysed changes in SOC content in soils of England and Wales by using data from surveys conducted on two occasions (approximately 1978 and 2003). Overall, there was a decline in SOC (the soils were a source of C) but in soils with the smallest C content during the first survey (mainly long-term arable soils) SOC had increased by the time of the second survey and so were a C sink. This increase was probably caused by increased organic C inputs resulting from additional returns of straw following the cessation of straw burning in the UK. We have seen the same small increase in the long-term straw incorporation experiment at Morley.

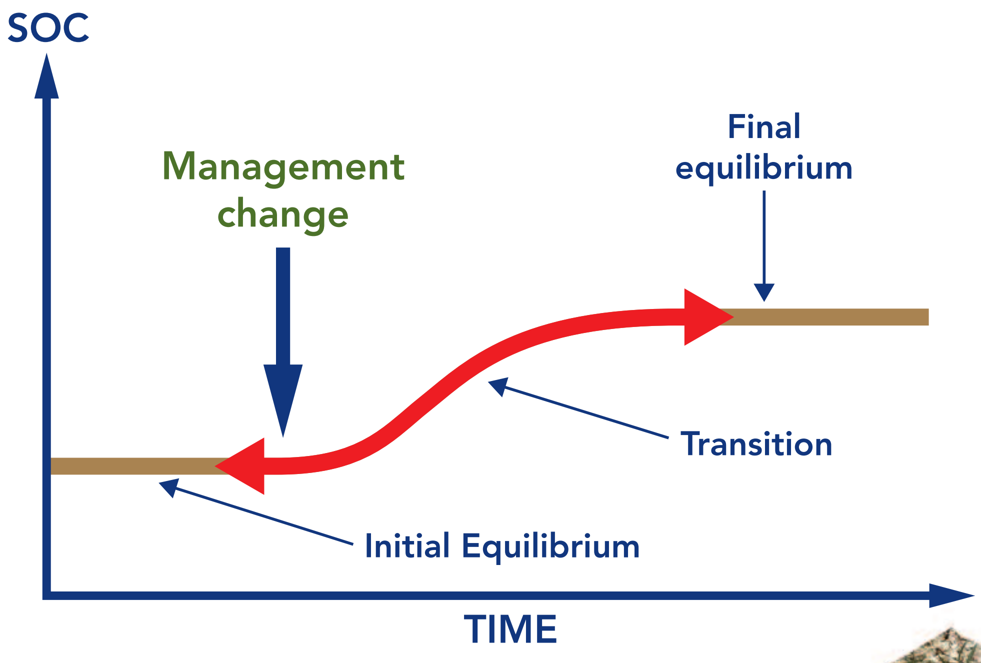
For areas with a low SOC levels there may be potential to accumulate SOC through altered management (e.g. including cover crops or leys in rotations) or land use (arable to woodland or grassland), thus creating a sink. However, in some cases, a low C content reflects a small potential for SOC accumulation, either because of soil type (for example, the sandy soils of Breckland have less capacity to stabilise C than heavier soils around Cambridge) or through limited plant growth resulting from climatic factors.

The general principle that applies to all soils is that if you add more carbon to the soil, then you build more organic matter (Figure 2). The levels of SOC in any soil are a result of the equilibrium between the inputs of organic matter and the decomposition of this organic matter by soil organisms. The disruption of soil aggregates during tillage changes the distribution and accessibility of SOC in soil and usually increase rates of decomposition; hence reducing tillage intensity can lead to more stabilisation of SOC.

In general, we see bigger changes where there is a change in land use or major rotational changes, rather than changes in management (e.g. reduced tillage, use of cover crops). But it is important to note that there are some general limitations to the effectiveness of C sequestration in soil or vegetation:

- The amount of C locked up is finite: the increase in SOC content ceases as a new equilibrium value is approached. The period of transition is often 25-40 years and is usually slower when SOC is increasing than when it is being lost. This principle is clear from long-term studies, which show that SOC does not accumulate indefinitely (Figure 3).
- The process is reversible: the change

Figure 3. Changes in SOC are slow, finite and reversible. To maintain the new equilibrium level in SOC the changed management must be maintained, even when there are no further increases in SOC



in land management leading to increased C in soil or vegetation must be continued indefinitely to maintain the increased stock of SOC. For example, if a new woodland is established, the C accumulated in trees and soil will be lost if the trees are felled. Similarly, if a grass or legume ley is included in an arable cropping system at least part of the SOC accumulated during the ley period is lost after ploughing for the next arable phase. Though there will often be some overall increase in SOC in the long-term compared with continuous arable cropping if the ley-arable rotation is continued (Figure 3).

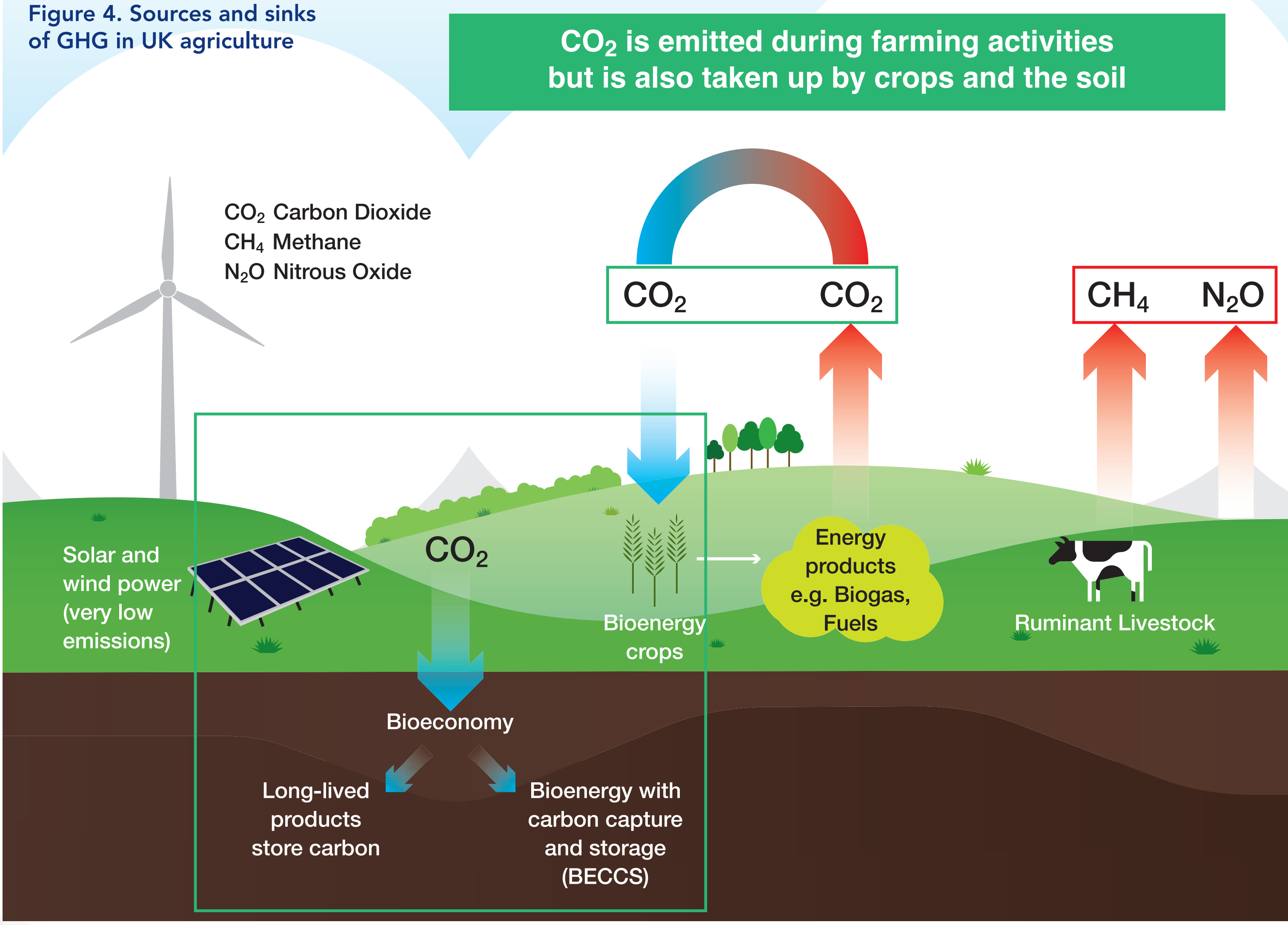
- Land management changes leading to increased soil C may increase or decrease fluxes of the other more potent greenhouse gases: N_2O or methane. Hence, it is essential to consider the full GHG budget not just the impacts on SOC.

Together with land use change and direct addition of OM, choice of crops and varieties may also affect the rate at which C accumulates in soil. Rooting structure, depth, patterns of root exudation and the extent of root associations with arbuscular mycorrhizal fungal all influence where SOC is stored in the soil profile and the balance between decomposition and stabilisation. PhD students (Emily Marr and George Crane) are working jointly with NIAB and the University of Cambridge to investigate some of these below-ground interactions.

Even with these limitations, sequestering additional SOC will contribute to climate change mitigation in the medium-term, depending on the options available for changes in management practices or land use. Practices leading to SOC accumulation can also start immediately without the need for development of new technologies. Even where there is no net additional transfer of C from the atmosphere to soil, and thus no climate change mitigation, increasing or maintaining the SOC is almost always beneficial for soil health and function, especially in agricultural soils.

However, experience has shown that improvement in productivity in arable systems after improved organic matter management takes some time to appear. Defra research has shown measurable benefits of improved organic matter management, in addition to any nutrient supply benefits, but these are often only realised after at least six years of implementation. Increased SOC has positive impacts on soil physical properties, including increased stable aggregates, decreased risk of run-off, erosion or surface capping, increased rate of water infiltration and increased water retention. It has been shown that even small increases in SOC can have disproportionately large impacts on aggregate stability, infiltration and the energy required for tillage.

Figure 4. Sources and sinks of GHG in UK agriculture



To deliver these benefits for production, ensuring that there are regular additions of organic matter to "feed" the soil is more important than achieving any particular measured value of SOC.

In UK arable farms, practices with positive benefits on SOC include:

- Reduced intensity of cultivation
- Increasing tree cover on farm
- Reduced area of cropping systems on peat and reversion to wetland
- No bare soil – continuous green-cover cropping systems
- Targeted steps to increase soil organic matter through managed additions of organic materials.

What about N fertilisers?

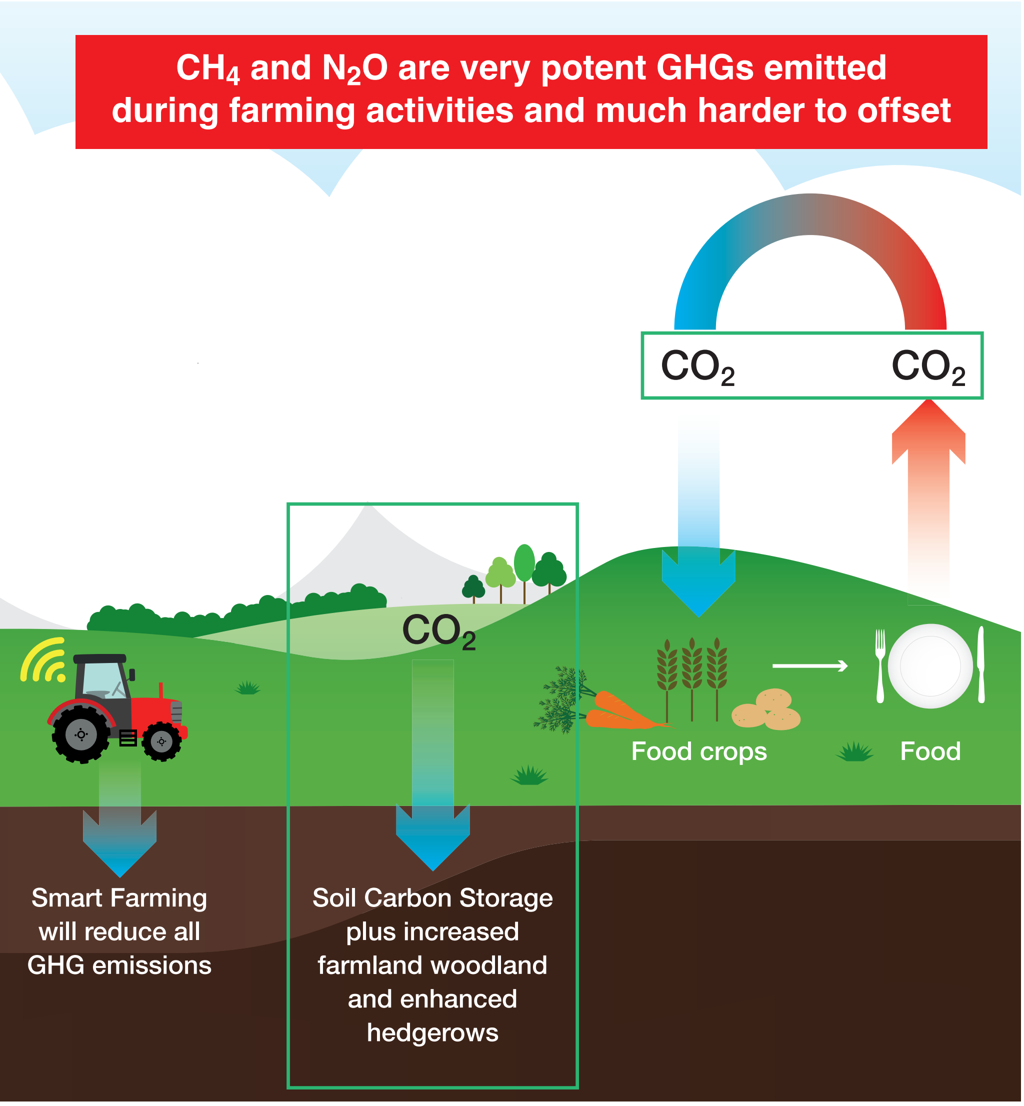
Work with farmers has highlighted that the easiest soil management step to implement that will help mitigate climate change is, in fact, an increased focus on nutrient management, in particular, steps to improve N use efficiency within a farm-specific N management plan.

Any benefits of N fertiliser for crop productivity (and increased root and residue returns that increase C inputs to soil) can be offset by higher emissions of CO_2 from fertiliser manufacture and losses of N_2O from soils. Plants take up N from the soil solution as ammonium (NH_4^+) and nitrate (NO_3^-); these pools of N in soil are regularly replenished by the decomposition (mineralisation) of organic matter. In unfertilised systems, these pool sizes tend to be low, as plant and microbial uptake empty these pools, almost as fast as they are filled. N fertilisers add NH_4^+ and NO_3^- (or their pre-cursors e.g. urea, organic manures) and hence higher pools of mineral N (NH_4^+ and NO_3^-) are found immediately (and for a few weeks) after fertiliser application. N_2O is released during microbial processes of both nitrification and denitrification. Ammonium is rapidly nitrified to nitrate (NO_3^-) in a two-stage microbial process by the action of chemoautotrophic bacteria; this process releases some N_2O as a by-product. Denitrification, (first observed by Humphrey Davy at the beginning of the 19th century) is the release of nitrogen gas during microbial decomposition and is a relatively small flux in comparison with the rate of fertiliser addition in many aerobic agricultural soils. However, N_2O is produced during the stepwise sequence of microbially mediated reducing reactions and these losses are higher when soils have high microbial activity and a high proportion of water-filled pores. So early spring fertiliser (or autumn N, e.g. to oilseed rape) is at increased risk of loss.

Practices that improve N use efficiency (and may also directly reduce N_20 losses) include:

- adjusting application rates based on precise estimation of crop needs (e.g. precision farming);
- removing any other constraints to growth whether pH, other limiting nutrients or disease, or planning N applications to take account of the change in yield potential (e.g. due to drought/pest attack);
- avoiding time delays between N application and plant N uptake (improved timing);
- placing the N more precisely into the soil to make it more accessible to crops roots;
- using slow-release fertiliser forms or nitrification inhibitors;
- avoiding excess N applications, or eliminating N applications where possible;
- improving soil structure to improve both rooting and water holding capacity thereby increasing N use efficiency even when spring is dry (which seems to increasingly be the norm in the UK);

Together with agronomic practises, choice of varieties may also affect GHG emission. Cereal varieties that benefit more from higher N conditions tend to have been selected over the years, however adding N fertiliser is not always an efficient process. Work is underway in NIAB to investigate genetic differences in N responsiveness in cereal crops (Stephanie Swarbreck), which may inform variety selection in the future.



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Is eating less red meat really a win for our health and the planet?

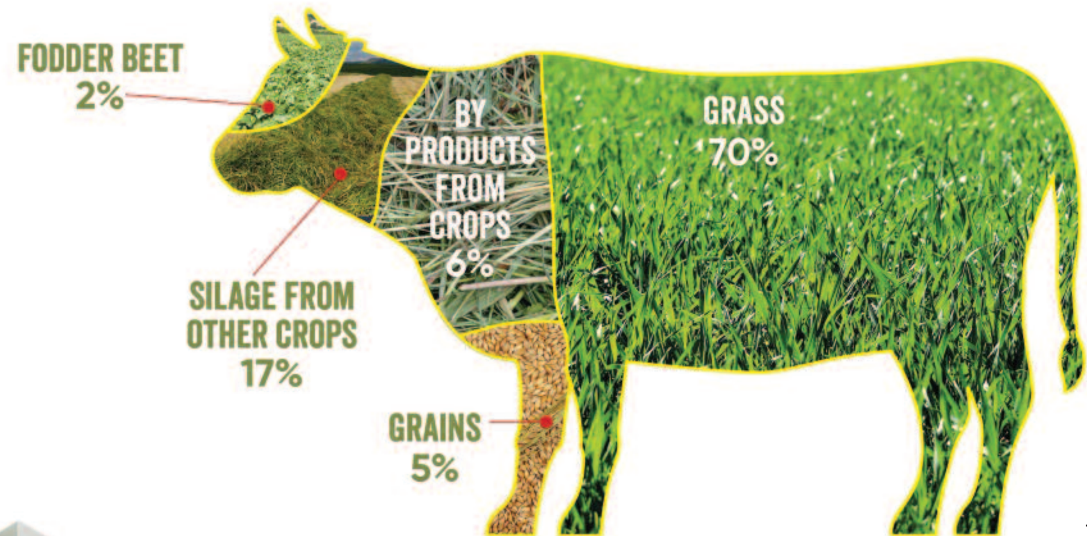
Adapted from materials published by AHDB Beef and Lamb

The report produced by the Intergovernmental Panel on Climate Change (IPCC) last summer on the impacts of global warming re-ignited the crusade against eating meat, specifically on this occasion, beef. However, the real messaging of the report appears to have been twisted to suit the needs of headline writers and single-issue campaigners. From Parliament to dinnertime chat at home, the perceived impact of livestock farming on the environment is the hot topic. The BBC's interpretation of the report fed the fire of anti-meat rhetoric, suggesting the report should lead viewers to question whether meat-free diets could be a long-term solution to climate change.

However, what the report actually stated was: "Balanced diets, featuring plant-based foods, such as those based on coarse grains, legumes, fruits and vegetables, nuts and seeds, and animal-sourced food produced in resilient, sustainable and low-GHG emission systems, present major opportunities for adaptation and mitigation while generating significant co-benefits in terms of human health." Doesn't sound very anti-meat does it? In fact, it backs the common sense notion that responsible livestock farming is part of the solution to climate issues, not the biggest offender.

Even as reporters tried to drive an anti-meat line in the press conference, experts from the panel repeatedly pushed back to say the analysis was not suggesting people turn away from meat – or any other food stuff. This did not stop the media creating their own story with the IPCC report as yet another nail in the coffin of eating meat. Just a couple of days later, we had the announcement that Goldsmiths University of London has withdrawn beef from their menu on campus in a stance to tackle their own negative impact on

Figure 1. The miracle of British cows – turning grass into tasty food



the environment. This decision was, we are led to believe, partly steered by the messaging from the IPCC report.

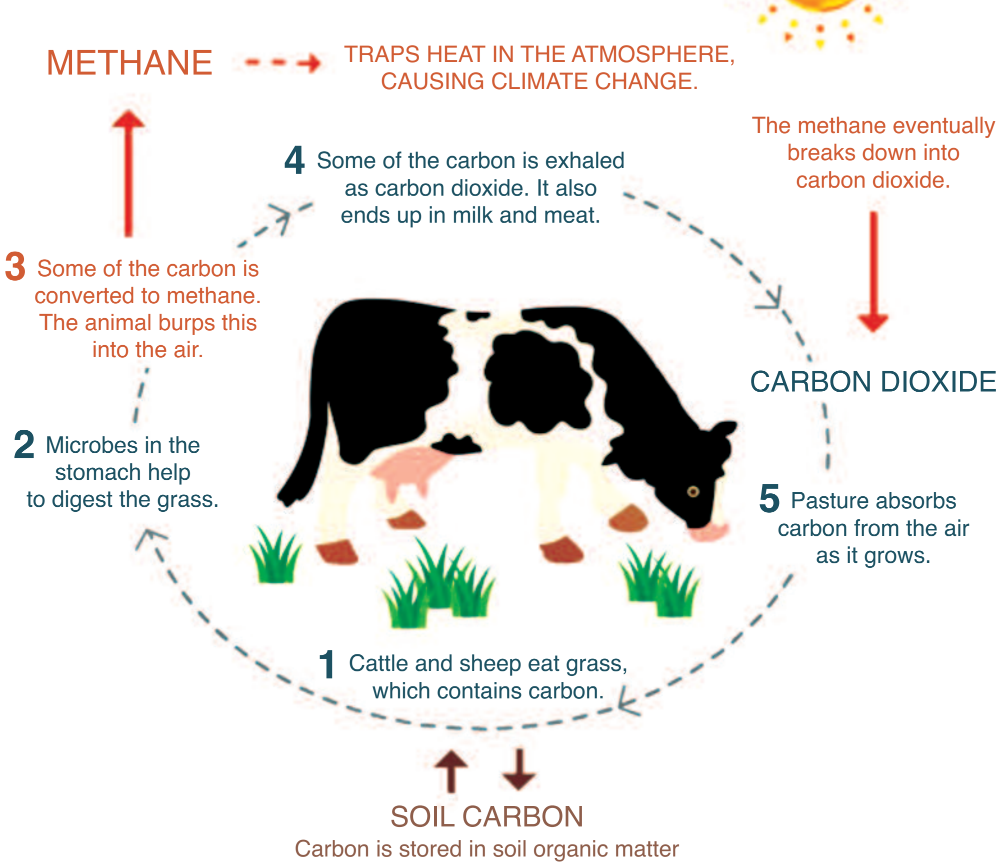
Along with other industry bodies, AHDB has been supporting farmers to highlight a key fact missed in almost all reporting on emissions and livestock farming: meat and dairy production in the UK is among the most sustainable in the world. We have clear standards on animal welfare, increasingly, farms have right grass management systems in place, we have plenty of rain to make naturally occurring grass growing which grazing animals eat to create protein for humans with very few additional inputs needed. It is a natural cycle that also returns fertility to soils through manure (Figure 1).

There is a lack of understanding about British beef production and the distinction between it and production elsewhere in the world. With British livestock grazing in grass-based systems, the greenhouse gas (GHG) emissions are 2.5 times smaller than the global average. In fact, latest figures for the Committee on Climate Change (CCC) acknowledge that emissions from farming amount to 9% of the national total, with 47% of that (so less than 4.5% total) from livestock digestion.

There is also some confusion about how the climate impacts of methane emissions should be assessed. Natural methane emissions arise from microbial decomposition in anaerobic conditions in wetlands. Around half of anthropogenic methane arises from fossil fuels – natural gas is emitted in the process of extracting coal or oil and from leakage in the storage and distribution of natural gas as a fuel. 44% of the anthropogenic methane is released through agricultural activity; two-thirds is from the enteric fermentation in the ruminant gut, with a small amount arising from manure handling, and one third from paddy rice cultivation. Much of the emitted methane (around 80%) is broken down to CO_2 in the lower atmosphere.

But there is some confusion about how agricultural methane is counted. The methane-derived CO_2 comes directly from the livestock feedstuffs, so the CO_2 emitted is essentially

Figure 1. The role of livestock in the production of methane



replacing the CO_2 fixed through photosynthesis. The CO_2 emitted through respiration (from humans and livestock) is not counted as an additional CO_2 source, so this livestock methane does not need to be counted as additional (Figure 2).

Of course there is work to do to in livestock systems to improve manure management systems in place and to research into genetic improvement of livestock, especially selection of breeding lines with lower lifetime methane emissions. AHDB support farmers with a number of campaigns to combat both of these issues including work to neutralise slurry and improvement in genetic evaluation for livestock producers to help them identify sheep and cattle with superior breeding potential.

Combatting environmental degradation is without doubt in everyone's interest. However, the UK is very different to other places on earth and, because of our natural environment and the weather, remains one of the most sustainable places in the world to produce red meat. In fact, without grazing cattle and sheep, as much as 60% of agricultural land in the UK would be taken out of food production, due to the fact it is not suitable for cropping or growing produce other than grass. This would also significantly change the cherished landscapes we have in this country which livestock help to manage efficiently and naturally.

Amidst the slating of the beef industry for its environmental impact, there has also been a re-emergence of claims that red meat causes health problems, with headlines such as 'Red meat raises risk of breast cancer in women' and 'Swap beef burgers for chicken cuts'. However, the evidence continues to support the position that red meat plays a vital role in a healthy, balanced diet.

So, the message when we are speaking to people about these challenges on welfare and red meat, is to look behind the headlines and seek out the facts. Plus, always remember, all foodstuffs have an environmental footprint of some kind and perhaps talk about the water demands of avocado farming or nut production for a change?

It should be all about balance.

Dr Stéphanie Swarbreck

Post-anthesis N uptake as key trait underlying high wheat grain protein

While there is great emphasis on producing high wheat yield, achieving a high grain protein content (GPC) is a very close second. Wheat grain protein, of which gluten protein accounts for 70-75%, is one of the main criteria determining the grain quality and downstream use. For example, GPC of 13% and above is necessary to reaching the breadmaking requirements, while lower GPC of 11-11.5% is suitable for biscuits and cakes.

Variety selection together with good agronomic practices are necessary to achieve both high yield and high GPC. As nitrogen is a major component of protein, a good management of N fertiliser applications is critical. Increasing N availability leads to significant increases in GPC. However, this can come at great cost both to the farmer and to the environment, since N leaching leading to eutrophication of aquatic ecosystems or volatilisation of N_2O (a potent greenhouse gas) is more likely to occur under high N conditions. Targeted N application especially later in the season (close to flowering time) can help reaching high GPC, so long as climatic conditions are favourable and varieties able to efficiently uptake and assimilate N at this late developmental point.

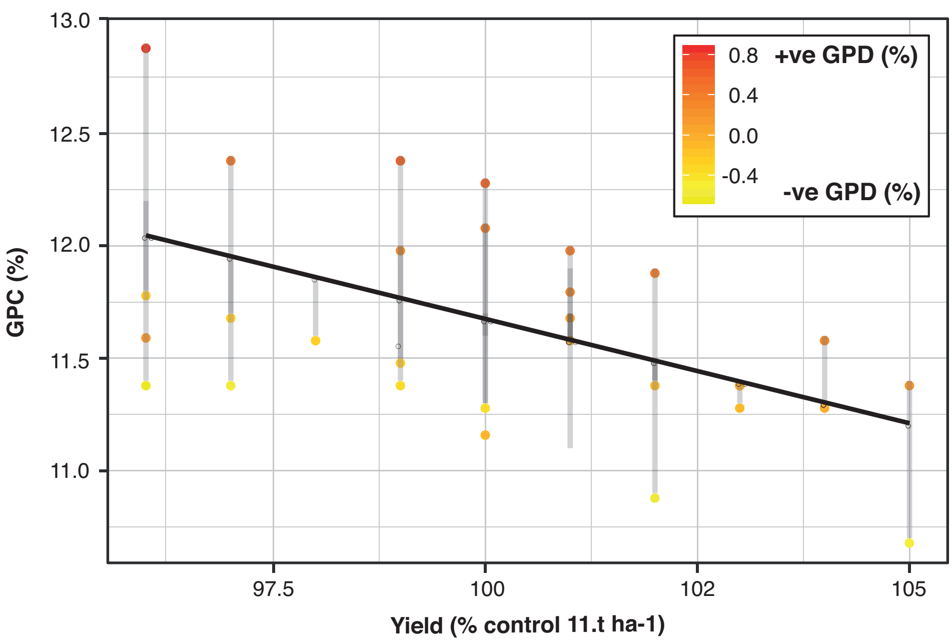
Selecting wheat varieties that can achieve both high yield and high grain quality is a challenge for breeders. There is a strong negative correlation between yield and GPC, i.e. the higher the yield the lower the GPC (Figure 1). Interesting varieties are those that show a positive grain protein deviation (GPD), i.e. varieties showing a significantly higher GPC than expected given the negative correlation between grain yield and GPC. The basis for a negative correlation between yield and GPC is currently not clear. Studies can find no negative relationship between quantitative trait loci (QTLs) for yield and GPC, suggesting that it is possible to select varieties with both characteristics. Understanding the biological processes that specifically lead to high GPC even under high yield production and how these are regulated can support the selection of varieties with positive GPD.

Nitrogen accumulated in vegetative tissues as a N source for the grains

In wheat grains, protein bodies are located throughout the starchy endosperm and these accumulate throughout the grain development, N start accumulating in the developing grain from about five days post-anthesis. Plants take up N from the soil mostly in the form of nitrate and ammonium which are then assimilated in amino acids and proteins for metabolic activity and storage. One of these key proteins is RuBisCO which is the enzyme responsible for the photosynthetic fixation of atmospheric CO_2 into sugars in the leaf. In wheat leaves, RuBisCO is a significant N store representing ca. 45% of the total N. To achieve high GPC, high levels of N must be taken up, assimilated and stored in vegetative tissues then transferred to grains.

Vegetative tissues, and leaves in particular, are sinks for carbon and nitrogen while they are growing and maturing when photosynthetic carbon fixation is high. Gradually leaves shift from being a sink for N compounds to being a source. For the flag leaf this

Figure 1. Negative correlation between wheat grain yield (expressed as percentage of control for the UK 11.2 t/ha) and GPC for 35 AHDB Recommended List (2020-2021) winter wheat varieties. The black line represents the regression. Each dot represents a variety with colour indicating a gradient of GPD, yellow corresponds to negative GPD while orange corresponds to positive GPD



occurs after flowering and before any external visible signs are noted (yellowing and loss of chlorophyll occurs at later stage of senescence). The metabolic processes occurring in the leaf-sources are different to those occurring in the leaf-sink. In particular, the processes involved in breaking down the proteins inside the leaves into compounds (small peptides or amino acids) that can be transported through the phloem to the developing grain are heavily upregulated. The importance of strong remobilisation from vegetative tissues towards the developing grain has been demonstrated using both physiological and genetic studies. A QTL located on chromosome 6B was reported to explain 66% of the phenotypic variations in GPC, the positional cloning of this QTL identified a NAC transcription factor (NAM-B1) involved in nutrient remobilisation towards the grain.

Nitrogen in the soil as additional N source for the grains

Previous studies investigating the physiological underpinning for high GPD have identified a positive correlation between post-anthesis N uptake and GPD. Post-anthesis N uptake can contribute from 5-40% of the total grain N in winter wheat and is dependent on N being available in the soil during the grain filling period as well as favourable climatic conditions. So far, the physiological determinants for post-anthesis N uptake are less well understood and merit further study given the potential opportunity in improving GPC without affecting yield.

To fully assess the contribution of post-anthesis N uptake it is critical to measure it accurately. Assessments in the field have so far involved measurements of total N at anthesis and total N at maturity. However, this is a rough estimate as some level of N is volatilised from the leaf as ammonia, especially under high N conditions. As part of the CINTRIN project, we have used ^{15}N isotopes (a stable non-radioactive isotope that occur naturally at very low level) to measure post-anthesis uptake over a few days for plants grown in pots and in the field.

Figure 2. CINTRIN opti-plots were run for two years, each trial included testing over 50 varieties and pre-breeding material under six nitrogen treatments (0, 70, 140, 210, 280, 350 kg N/ha)

The procedure involves adding ^{15}N labelled ammonium nitrate to the soil and collecting plant samples at later time point (samples were collected two days later and at maturity). The level of ^{15}N in the plant tissues are then precisely measured using mass spectrometry. The advantage of this method is that we can get a measure of post-anthesis uptake over a shorter time period compared to what is achieved by comparing N at anthesis and then at maturity. As part of the CINTRIN project, we established an opti-plot field trial where wheat varieties were grown under six different N treatments established with the addition of 0 to 350 kg N/ha (Figure 2).

The physiological basis for post-anthesis N uptake remains largely uncovered. Is the N taken up by the roots post-anthesis directly transported to the developing grain? Some level of nitrate reductase activity (a necessary step in the process of assimilating nitrate into amino acid) has been measured in both the grain and the surrounding tissues (glumes). Using the ^{15}N method, we could show that the developing kernel is a much larger sink of N taken post-anthesis than the leaf. Nitrogen circulates a lot in the plants during grain filling and it is not clear whether N was first taken up in the leaf through the transpiration stream, then remobilised towards the grain.

While research has shown that GPD was related to post-anthesis N uptake independently from anthesis date and total N at anthesis, other studies have shown that under high N conditions post-anthesis N uptake (PANU) was reduced compared to low N availability. Using the ^{15}N isotope method, we could also show a decline in PANU under high N conditions both in plants grown in pots and in the field. There is a negative correlation between N present in the grain and the level of uptake. It is unclear at this point what leads to the down-regulation of post-anthesis N uptake under high N conditions. Is it the N content in the leaf or that of the grains and glumes? Additional questions remain about the interplay between remobilisation and post-anthesis N uptake. For example, can efficient remobilisation early during the grain development lead to lower PANU?

To conclude, being able to select varieties that can produce high yield, and high-quality grain, given the resources available, is critical to ensure a sustainable food supply. Considering post-anthesis N uptake as significant contributor to GPC and one that can be targeted for improvement opens new avenues to explore.

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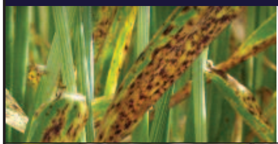	Accurate identification of diseases for successful control in barley	**Devised by:** NIAB TAG's Bill Clark
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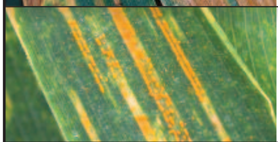	Accurate identification of diseases for successful control in wheat	**Devised by:** NIAB TAG's Bill Clark
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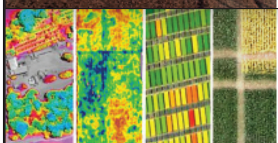	Using remote sensing data for higher yields and profits	**Devised by:** NIAB TAG's Bill Clark with input from Eric Ober and John Cussans
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