NIAB TAG

Landmark

ISSUE 41
MARCH 2020

The rise of the faba bean

IN THIS ISSUE

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Brexit boost for plant breeding innovation

This issue of *Landmark* includes an article featuring Professor Giles Oldroyd, inaugural Professor of Crop Science at the University of Cambridge, and Director of the Crop Science Centre established jointly with NIAB. He describes his vision of a new agricultural revolution built on genetic innovation, and his hopes that promising new areas of research, including his own work on nitrogen-fixing cereals, can stimulate a different kind of discussion around GMOs.

There is undoubtedly a feeling in the air that Brexit marks the start of that new conversation. In his opening speech as Prime Minister, Boris Johnson singled out the need to liberate the UK's world-leading biosciences sector from the EU's anti-GM rules. He specifically referred to the GM blight resistant potato developed at The Sainsbury Laboratory in Norwich, which NIAB will be growing in trials, as an example of UK-led innovation in this area.

This in turn has sparked a new debate around the kind of regulatory framework the UK should put in place – EU trade arrangements permitting – to ensure a more proportionate and enabling environment for plant breeding innovation. Uncertainty over the impact of Brexit on trade, competition and farm support, alongside the challenges of climate change and loss of crop protection products, mean Britain's farmers need access to innovation more than ever before.

A pragmatic and rapid solution is required to realise the Prime Minister's stated ambition to free up regulation in this area.

If we stick with the GM regulatory system currently in place in the EU, it will become more functional simply because of Brexit – i.e. without the political intervention of 27 other member states. But I do fully support the Prime Minister's view that the UK should examine the system, and identify and remove those elements which cannot be justified from a scientific or risk assessment perspective.

While market acceptance for GM products is unlikely to be transformed in a short period of time, surveys of consumer attitudes towards gene editing in the UK and EU suggest that there is much less public concern, and even support where the techniques are used to address climate change objectives or tackle food safety issues – e.g. drought tolerance or coeliac disease.

I firmly believe that the initial focus for policymakers should be on regulatory action to set-aside the European Court of Justice ruling of July 2018 classifying new gene editing techniques as GM. Successive Defra Ministers have confirmed the UK Government's disagreement with the ECJ ruling as unscientific and unjustified, and that this should be an early candidate for regulatory divergence post-Brexit.

The EU position is out of step with how these techniques are being regulated in other parts of the world, such as the US, Argentina, Brazil, Australia and Japan. It is also at odds with the independent expert advice provided to the UK Government by the Advisory Committee on Releases to the Environment (ACRE). Brexit therefore presents an opportunity for the UK to re-align itself to the regulatory stance of other countries around the world. The UK is too small a market commercially to drive international regulatory change. It should seek to align itself with progressive agricultural economies outside the EU which do have functioning approval processes and whose farmers, consumers and environment are benefiting from access to the products of plant breeding innovation.

There is a relatively straightforward regulatory solution for this, which would be to change the current EU definition of GMO in the UK Environmental Protection Act for the definition used in the internationally recognised Cartagena Protocol – to which the UK is a signatory. This would re-focus GM regulation on the insertion of viable, heritable, foreign DNA, and would at a stroke remove

Blight resistant potatoes have been developed at The Sainsbury Laboratory, Norwich around 90% of gene editing applications from the scope of GM regulation.

This would send a clear signal that the UK is serious about supporting plant genetic innovation. At a recent Brussels conference a representative from Lantmannen – the €4.5bn Swedish food chain cooperative with plant breeding interests – indicated that such an approach could stimulate research investment in the UK by his company. He is unlikely to be alone in that view.

Should we see Brexit as an opportunity to create a completely new approach to authorising new plant varieties, based on the trait or product involved rather than the breeding method, giving GM and gene-editing a level playing field? Whilst superficially attractive, I would argue that we already have excellent, functioning, product-based regulations which have delivered safe and fit-for-purpose plant varieties over the years, and these regulations can embrace new breeding techniques without putting extra burdens on the industry.

We should recognise that plant breeders operate under the overarching requirements of UK food safety and environmental protection legislation, with an impeccable track record of safety.

The existing UK variety testing and registration system has served the industry well for more than 50 years. It has provided the foundation not only to assess the quality and performance of new varieties to ensure they match up to market expectations, but also to support the award of Plant Variety Rights which have underpinned investment and innovation in the plant breeding industry since the mid-1960s. Similar systems exist in many other countries, including within the EU.

The current variety registration system offers a proven vehicle to deliver the outcomes society expects from agriculture and crop production in the future. It is not set in stone but has evolved over the years to reflect changing market, agronomic and policy requirements. There are already discussions taking place, for example, over how to ensure the system reflects increased demands for sustainability, reduced input use, climate change mitigation and climate resilience. Which is, I am sure, where consumers would want the future focus to be – rather than on the methods we use to get there.

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The rise of the faba bean

EIT Food Favuleux:

The humble field bean, loved by many for the few brief weeks in the summer in its broad-bean form, yet reviled as a dried pulse and deemed suitable only for feeding livestock.

EIT Food

UNIVERSITY OF CAMBRIDGE

Despite featuring as a staple food in the UK since medieval times, the field bean, also known as a fava or faba bean has, over time, become marginalised as a foodstuff in Europe, with meat perceived to be the more discerning choice for the consumer. Currently two thirds of the crop is utilised as a high-quality source of protein and carbohydrates for monogastrics, poultry, aquaculture sectors and supplying seed markets. The remaining third commands a considerable premium when exported to North Africa for use in dishes such as ful medames and falafel, filling a niche in areas of the world where the crop can no longer be cultivated due to scarcity of water and the invasive parasitic weed *Orobanche crenata*.

But the faba bean has great potential as an alternative to dairy and less sustainable sources of plant-based proteins.

Pressure to live more sustainably may be positive for the UK pulse market; interests in alternative sources of protein have increased rapidly in recent years with growing rates of flexitarian, vegetarian and vegan lifestyles searching for more sustainable choices compared to animal and dairy proteins. The UK meat-free food sector is predicted to rise to £658 million by 2021, up from £539 million in 2017, according to Mintel research. Food manufacturers have responded to this demand by releasing of a wide range of innovative plant-based products including the well-publicised pea-based Beyond Meat burger and Burger King's soya-containing Impossible Burger.

Whilst this is a positive step towards reducing the amount of meat we consume, a large number of vegetarian and vegan products are reliant on imported South American soya.

Faba bean pods filling with seed in June

Although soya may have some improved green credentials compared to meat and dairy, issues with GM status and implications as a potential allergen favour the development of alternative sources of plant-based protein.

Legume benefits

The faba bean, high in protein and produced widely across Northern Europe, could offer a solution to help alleviate our over-reliance on dairy and less sustainable sources of plant-based protein. It is widely established that cultivating and consuming legumes like faba bean offers many benefits; pulse crops fix nitrogen that contribute to their own and subsequent crops' fertilisation, they act as break-crops for cereals and oilseeds to reduce the pressure from pests and diseases, are rich in micronutrients, have low glycemic index and excellent functional properties making them suitable for the manufacture of food ingredients. Unfortunately, despite being consumed as a foodstuff outside of Europe and a growing interest as a source of high-quality protein for sports nutrition sector, a stable supply of raw faba bean material still eludes processors and industry, leading to volatile pricing and preventing a wider uptake and exploitation of the crop compared to more stable commodities such as pea and wheat.

Through funding from EIT Food, a European food innovation initiative from the European Institute of Technology, NIAB has been working extensively with partners from academia and industry to trial innovative high quality varieties of faba bean in an effort to address problems of supply chain inability to deliver improved ingredients for diary or meat alternatives products.

Favuleux

EIT Food's Favuleux project has been targeted towards showcasing faba bean as a high-quality source of domestically produced plant-based protein with potential to provide a greener alternative to unsustainable animal-derived and soya proteins, and off-flavours associated with pea protein. The scheme connects core industry, agri-food start-ups, research centres and universities where consortia can bid for funding to finance projects in innovation, education, entrepreneurship and public engagement. EIT Food has established strategic priorities to overcome low consumer trust, create valued food for healthier nutrition, build a consumer-centric connected food system, enhance sustainability, to educate, to engage, to innovate and advance, and to catalyse food entrepreneurship and innovation.

The programme aligns a multi-disciplinary consortium, including Roquette Frères, Nestlé, NIAB, the Institute for Manufacturing and the Department of Plant Sciences at the University of Cambridge, to provide a field-to-fork approach, identifying suitable faba bean varieties, effective processing methods, novel prototype products and conducting a network and supply chain analysis. This will establish an effective pipeline for delivery of tasty, nutritious protein extracts suitable for manufacturing new, alternative solutions to dairy proteins.

Favuleux has been structured into three complementary work packages, including the cultivation, analytics, processing and prototyping and supply chain and network analysis, phased over two independent 12 month funding periods; the first year has focused on generating raw material and basic quality testing in a selection of diverse varieties, and the second on up-scaling and valorising the best one or two varieties for wider exploitation.

NIAB has been working with the consortium partners to provide knowledge and expertise on faba bean genetics, generate raw material for producing high quality protein extracts for human consumption, and implementing basic quality analytics. This has been achieved through the optimised selection and cultivation of diverse elite, experimental and land-race faba accessions at NIAB, with supporting characterisation.

Roquette Frères has been responsible for generating high quality protein extracts for subsequent testing for amino acid composition, taste and functionality. Nestlé then used the extracts to produce

Faba beans are both nutritious wholefood and an excellent source of sustainable high quality plant-based protein novel prototypes, showcasing directly with consumers in a series of taste tests demonstrating they can be utilised effectively as alternatives to dairy and other vegetable proteins, helping to promote consumer trust through transparency and co-design of new food products.

Supply chain

A key strength of the project has been the integration of supply chain mapping and network analyses by the partners from IfM, with an aim to identify key constraints affecting the supply of high quality faba bean for food production. Raising awareness of bottlenecks in the production pipeline with producers and industry, such as yield instability, crop seasonality, or quality issues caused by insect pests, will be essential in order to identify solutions to minimise their various negative impacts and reduce volatility in the supply and cost of faba beans.

Finally, information on how to grow food-grade faba bean and maintain sustainable farming practices has been used to create a learning platform to help growers and producers obtain knowledge to improve productivity and reduce instability in the supply chain.

The first year of Favuleux has been delivered successfully and the second phase has now been funded; during the initial phase the consortium identified useful levels of variation in protein content across diverse faba bean accessions, for which the top performing ones have now been selected for wider cultivation and testing. The project has identified effective extraction procedures and has generated a series of high quality food grade extracts that have been successfully prototyped in beverages, showing great promise as alternatives to current dairy and plant-based alternatives including soya and pea by demonstrating favourable functional and organoleptic profiles.

The second phase of the project will run until 31 December 2020 and focus on up-scaling production of the selected faba bean accessions for wider prototyping and taste testing, assessments of performance across multiple production environments to understand potential effects on protein isolate quality. The future for plant-based proteins in the UK could be favuleux!

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The International Year of Plant Health (IYPH)

INTERNATIONAL YEAR OF PLANT HEALTH 2020

2020 has been declared the International Year of Plant Health by the United Nations. "International Years" or sometimes Days or Weeks, are instigated by one of more member states with the objective of raising awareness of, and promoting action on, a specific topic. The IYPH has come at a time when the importance of direct plant consumption in the human diet has never been greater, and when the essential environmental and social benefits of plants are recognised more and more. Similarly, the threat that pests and diseases pose to plant life, and the productivity of our crops, has achieved a much greater public profile, due to the ingress of pathogens such as ash dieback, sudden oak death, and the onward march in continental Europe of the bacterium *Xylella fastidiosa*, and its capability to alter ancient olive grove landscapes.

Most of the diseases which hit the headlines are quarantine or regulated organisms, where the objective is to keep them out of a country because of the devastation they may cause, and usually because of our inability to control them if they gain a foothold. However, the IYPH covers threats posed by any disease, including the many that are already well established in a country, and is thus relevant to all of NIAB's pathology work, including research on breeding for improved resistance, diagnosing problems in crops, surveillance of pathogen populations, Recommended and National List testing, and integrated management of pathogens on farm. Together, these activities contribute to the reduction of losses at a national scale.

One of the main objectives of IYPH is raising awareness of plant health issues, not just in industry or academia, but in the public mind as well, so during the year we will be contributing to several online outreach events and social media platforms. Whilst the main summer events season is now cancelled, we intend to continue showcasing further plant health related research projects at NIAB online and digitally where possible. Our international projects have a particular focus on improving disease resistance in staple crops and protein crops, aiming to reduce hunger and improve livelihoods in low and middle income countries.

Each edition of *Landmark* this year will have a focus article on how our work contributes to the objectives of the IYPH. Plants are the basis for the global supply of food, feed and fibre, as well as providing wildlife habitats and bringing pleasure to millions in forests, parks and gardens. The IYPH is a timely reminder that we need both fundamental and practical research to protect them, and our future, from the ever-present threat of pests and diseases.

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A new dawn in fungicide resistance management

Pathologists are usually obsessed with selection; how to avoid it, how to reduce it. We talk about reducing the number of sprays and reducing the dose applied, using mixtures of different modes of action, alternating modes of action – all in order to reduce selection – accepting that we may reduce efficacy with some of the measures employed.

In managing septoria resistance the risk/reward balance is perceived as: reducing the dose of an individual fungicide reduces costs and decreases selection but increases the risk of some reduction in yield in the current season. This risk can, of course, be offset by utilising varietal resistance. The risk of a serious yield loss due to septoria on a variety like KWS Extase is very small, whereas on KWS Barrel it is very likely, hence lower doses and fewer applications are possible on KWS Extase. The selection for resistant septoria will be reduced because the disease pressure is less and lower doses of fungicides can be used.

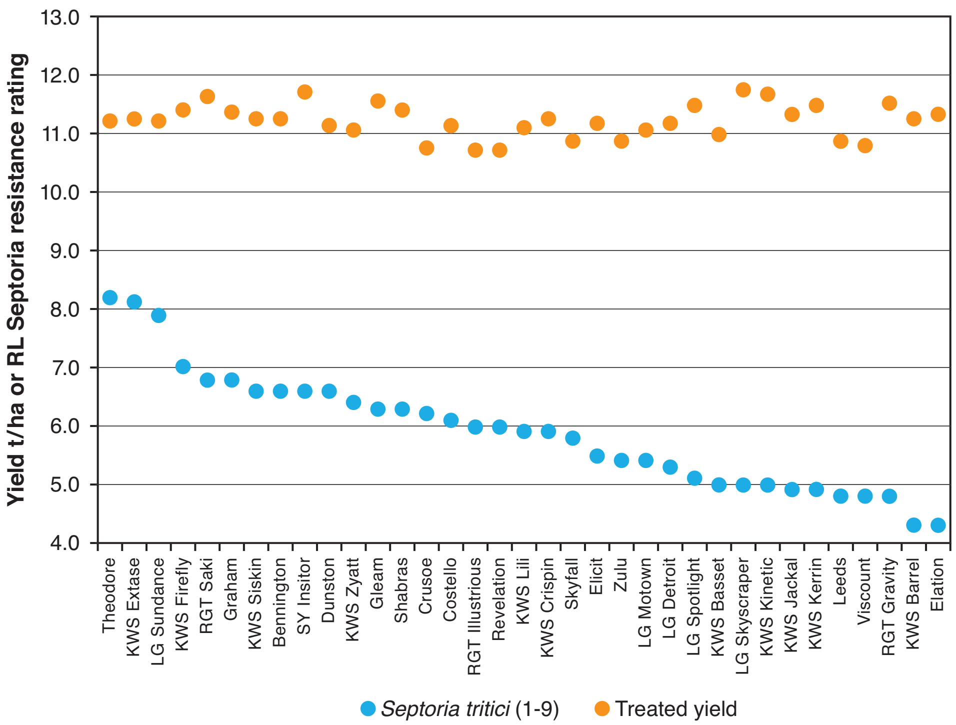
From the individual farmer's perspective there is no personal benefit in adopting an approach that reduces the efficacy of disease control, even though there may be a long-term benefit to the industry as a whole. So, the question is how to devise an anti-resistance strategy without the farmer suffering a yield penalty? For the past 20 years farmers have been using chlorothalonil routinely in wheat fungicide programmes, largely to improve the efficacy of their programmes, but with a nod to anti-resistance strategies as a multisite mixture partner for 'at risk' fungicides such as triazoles and SDHIs. It was cheap and effective – which encouraged its use as a foundation of septoria control programmes but EU legislation means that 2020 will be the last year it can be used.

A question on farmers' minds for 2021 is "how do we replace chlorothalonil?" It is not any easy question to answer. From an efficacy and resistance point of view, in wheat we are really only concerned with *Septoria tritici*. We have several fungicides with different modes of action and there are no issues with fungicide resistance in yellow rust or brown rust. Increasingly, we have better varieties on the AHDB Recommended List with good resistance to septoria. Of the thirty-five recommended varieties, ten can be regarded as high risk (RL rating 5 or less) and ten can be regarded as low-moderate risk (RL rating 6.5 or more), leaving fifteen intermediate varieties. The ten high-risk varieties require high fungicide inputs, with multiple timings and consequently pose the greatest risk in terms of fungicide resistance selection. The more resistant varieties tend to have lower disease pressure and so require lower doses of fungicide, which reduces the fungicide resistance selection.

Nowadays there is only a relatively small difference in treated yields between the 'dirty' and 'clean' varieties and there is not a good correlation between the septoria resistance rating and yield (Figure 1). Not so long ago the highest-yielding varieties tended to be very prone to septoria but this is no longer the case. This is a good argument for using varietal disease resistance as another tool in fungicide resistance management.

In 2020 there will be considerable pressure on farmers to use up stocks of chlorothalonil and it will inevitably be used throughout most fungicide programmes. However, in 2021 we will no longer have chlorothalonil but we will have more fungicide products on the market with one new mode of action. This includes Revysol, currently the most effective triazole against septoria, a range of SDHI fungicides including some new, more effective ones, and Inatreq. These three modes of action give us three fungicide groups that are very similar in their properties – they are all good protectants and good eradicants; they

Figure 1. Chart shows no relationship between the treated yields (i.e. the yield potential) of varieties and their resistance to *Septoria tritici*



are all systemic and persistent. We will also still have multi-site fungicides folpet and mancozeb. So, we will have several modes of action available from which to devise fungicide programmes that are both effective and give us a strong anti-resistance strategy.

Fungicide strategies

When developing a fungicide application programme for a particular crop/disease/fungicide combination, there are two key considerations:

i. **efficacy**: the treatment programme needs to provide effective control of the pathogen, and
ii. **resistance management**: consideration should be given to the selection pressure exerted by the application programme on the pathogen to evolve resistance to the fungicide's mode of action.

These two points can be translated into a number of practical decisions for a fungicide treatment programme:

a) variety choice – as a factor in determining strategy;
b) the number of applications that should be used per crop growing season;
c) the dose that should be used at each application;
d) suitable mixing partners.

All of these decisions are dependent on the perceived disease risk and the risk of economic loss from making the 'wrong' decision. The economics of yield loss from disease dictate that when disease pressure is high, yield losses and economic penalties can be very large. In contrast, the economic penalties of applying 'too much' fungicide in a low disease situation are very small. This leads to a risk-averse approach to fungicide planning, particularly by advisers.

From a resistance management perspective, there is a conundrum – the greater the number of applications and the higher the dose applied – the greater the selection for fungicide resistance. From a disease control point of view, the greater the number of applications and the higher the doses used will increase efficacy of disease control – and, more importantly, reduce the risk of economic loss. Consequently, there are opposing requirements for effective control and resistance management.

Generic guidance by the Fungicide Resistance Action Committee (FRAC) recommends avoiding repetitive use of a single mode of action, using appropriate mixture partners, limiting the number of applications and optimising the dose. These generic recommendations are now largely common practice – no informed farmer or adviser would apply a single mode of action fungicide alone, without a suitable partner. However, ensuring that the dose of a product is 'optimised' is more difficult. This recommendation is the least practically applicable as the dose of a fungicide applied to a crop canopy will vary as the spray penetrates the canopy, upper leaves receiving higher doses than leaves lower down the canopy. Following the spray application the fungicide will degrade on and in the leaf, reducing the dose present so the amount of active ingredient present declines over time. Thus, attempting to predict the optimum dose on the day of application is problematic.

Both the dose and the number of sprays required are determined by disease pressure. In practice, the effective dose of fungicide has a very small range so there is little scope to reduce fungicide dose without incurring greater risk of disease control failure. New varieties do offer some help in this regard, effectively reducing the risk of yield loss and margin from a reduced fungicide programme. Curiously, it is still easier to manage disease prone varieties as fungicide programmes can be pre-planned. More resistant varieties are more difficult to manage (in terms of assessing the number of sprays and dose required) but offer scope for reduction in fungicide use, both in dose and number of sprays, and pose less risk when fungicide programmes are sub-optimal.

Fungicides

Fungicide resistance in major pathogens is a fact of life. When new fungicides are introduced the question is always "how long will it be before we find fungicide resistance?" Despite our best efforts all we can hope to do is delay the onset of fungicide resistance and reduce the rate at which it develops in a fungal population.

We have no strategies to prevent fungicide resistance – other than not actually using the product. Our current strategies are widely applied but depend heavily on the use of mixtures of fungicides with different modes of action being used at appropriate doses. There is a conundrum in that many measures to reduce resistance selection invariably reduce efficacy. All efforts need to be made to maintain efficacy levels and reduce further resistance development. This relies on the responsible use of fungicide mixtures and the deployment of disease resistance offered by some modern varieties.

The good news is that in the very near future we will have new fungicides with different modes of action, with complementary properties (eradicant and protectant activity, persistence, systemicity etc.) allowing us to create effective mixtures that will have a high level of efficacy and provide a good anti-resistance strategy (Table 1). These are very exciting new fungicides but all will need careful stewardship to prolong their useful life a key cereal fungicides for the future.

Table 1. New and upcoming fungicides for cereals

Active ingredient	Trade name	Company	Mode of action
mefentrifluconazole	Revysol	BASF	Azole
fenpicoxamid	Inatreq	Corteva	Picolinamide (QiI)
florylpicoxamid	Adavelt	Corteva	Picolinamide (QiI)
isoflucypram	Iblon	Bayer	SDHI
pydiflumetofen	Adepidyn	Syngenta	SDHI
metyltetraprole	Pavecto	BASF	QoI

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Oilseed rape: much to ponder

How bad can your oilseed rape be before ditching it?

With cabbage stem flea beetle problems currently seeming to be getting worse and no robust chemical or cultural controls available, more and more farms have to think about the future of winter oilseed rape as a crop in their rotations; at least in the short to medium-term.

New break crops that could act as an immediate alternative are currently not widely available for growing on the scale that winter oilseed rape is grown.

This is the focus of a current review by NIAB TAG, but in the meantime, what can we do now and what do we already know?

Why grow winter oilseed rape anyway?

Winter oilseed rape has only been a widely grown crop since the 1970s. A large potential market for the oil and the meal produced as a by-product of the crushing for oil process is the initial key factor that means a large area is grown.

In addition, the early harvest relative to most other combinable crops allows sowing of the following first wheat crop at a time that best suits the farm, rather than there needing to be a fast turnaround between harvest and sowing. Timeliness of sowing the following crop is probably the main reason that wheat yields following winter oilseed rape are often better than after other break crops.

Rather than just asking the question "how bad can the winter oilseed rape crop be?", it is perhaps better to also ask "how bad would the rest of my crops be without oilseed rape?"

Some rotation experiments in the 1990s (when set-aside was a break crop!) showed the benefit of oilseed rape to following first wheat crops. Interestingly, proving there is no such thing as a free lunch, some of the benefit in first wheat yield did not carry through to second wheats (Figure 1), most likely due to increased levels of take-all.

More recent work from the Sustainability Trial in Arable Rotations (STAR) project managed by NIAB TAG with funding from the Felix Thornley Cobbold Trust shows that wheat yields following beans can be better than following oilseed rape.

Before oilseed rape became widely grown, many farms, especially on heavy land, relied much more on continuous wheat, accepting the pain of going through 'the take-all barrier' – then basing crop income on the lower, but relatively dependable yields afterwards.

With stubble burning no longer an option for assisting weed control, and black-grass in particular having high levels of resistance to herbicides, a return to continuous wheat is more challenging.

On the plus side, improved machinery and a tendency for more open autumns, make waiting for suitable opportunities to sow later a more practical option – so long as nerve and patience hold!

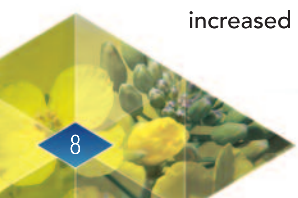
If we accept that although there are a range of other break crops that could be grown as alternatives to oilseed rape, virtually all either only have a comparatively small potential market (e.g. borage, poppies); they are currently not robust enough to deliver a reliable enough 'budget yield' more than about two years in five, even when grown in the most suitable geographic locations (e.g. sunflowers, navy beans, soya beans, lupins and chickpeas).

New markets and climate change may alter this, but only in the medium- to long-term. Also, with many potential alternatives being legumes (e.g. soya beans, lupins) they will not be the best crops to replace oilseed rape where other legume break crops such as beans or peas are already being grown.

Maize for AD plants has already recently become a much more widely grown crop. A comparatively late harvest and increasing problems with disease carry over (especially fusarium) as well as more maize-specific pests and disease build up (e.g. smuts and European corn borer) are likely to limit the area grown. The biogas/biofuels market is also highly exposed to political decision making.

In the short-term, maybe linseed is the best alternative? The winter-sown

Figure 1. Influence of break crop on first and second wheat yield (Cirencester 1989-1996)



crop does not suffer from flea beetle as spring sown crops often do – with control by insecticides again being difficult. But being in the ground for longer inevitably increases growing costs and reduces the opportunities for cultural control of problem weeds such as black-grass.

What might some typical gross margins look like? (Figure 2)

Using yields in t/ha as shown, with reasonable estimates of current prices and standard variable costs from the NIAB TAG 2020 harvest gross margin planner – it is easy to see why first winter wheat, winter barley, spring oats, spring beans and, where there is a convenient outlet, forage maize, are popular crop choices.

Equally, it is easy to see why winter oilseed rape is such a common choice of break crop. Although Figure 2 just shows particular examples of possible gross margins, it is generally accepted that for most crops yield is the main driver of additional profit. So if you know that you get better or poorer yields for any of the examples, it is easy to at least make a rough adjustment to the heights of the bars.

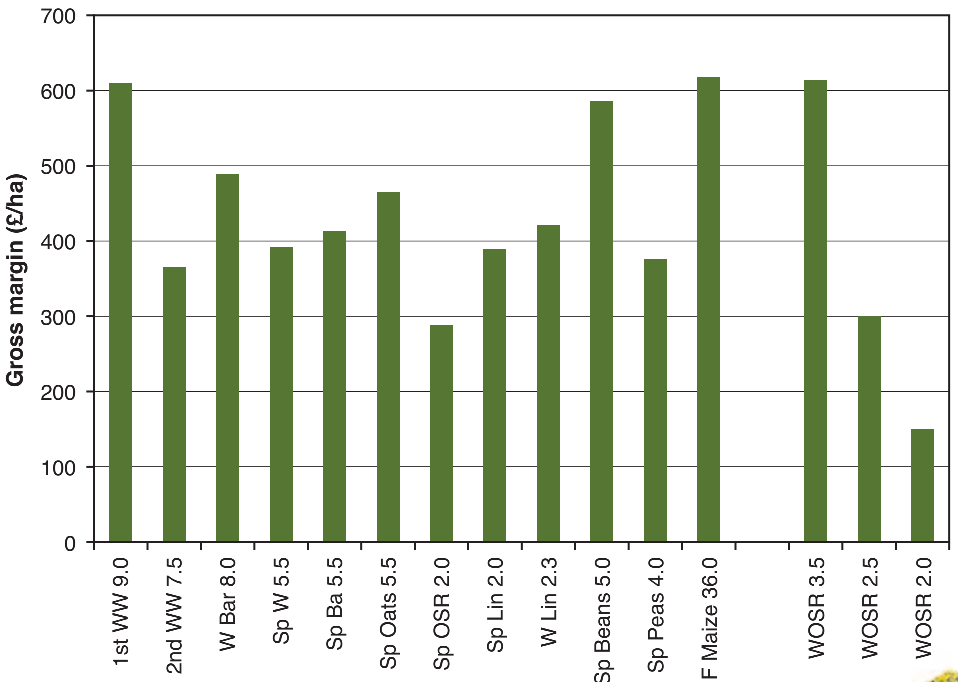
What you cannot tell from the Figure is all the practicalities and risks that go into growing crops in different geographic places and rotations. That is where grower experience and agronomist expertise come in!

But, looked at very simply, you can see that a 3.5 t/ha crop of oilseed rape competes well on straight gross margin. A 2.5 t/ha crop gives you quite a hit on individual crop gross margin, but most of that loss can be recouped across a rotation if it means you can avoid second wheats or an increase in spring crops, which are usually more variable in performance than winter sown crops. Once yield gets below 2 t/ha, unless you are also able to make significant cuts to input costs, the economics struggle to stack up.

This all assumes that oilseed rape does not fail to make a crop. This year, in some areas 30-40% of the area sown has already failed, forcing land to either be left fallow or re-sown with an alternative winter or spring sown crop. If this is your own situation, you probably need to pull down the margins shown by £100-150 ha to cover seed and establishment costs on the area lost. You are then looking for remaining area to yield above 3 t/ha for the crop to still pay its way compared to alternatives.

For some, growing crops for more lucrative markets and niche markets will be a way forward. For the many, is it time to return to continuous cereals?

Figure 2. Gross margin comparison



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Self-fertilising crops for the developing world

CROP SCIENCE CENTRE

Professor Giles Oldroyd is Professor of Crop Science at the Crop Science Centre, a partnership between NIAB and the University of Cambridge, based at the new NIAB Cambridge site. He leads an international programme focused on engineering nitrogen-fixing cereals, funded by the Bill and Melinda Gates Foundation, called Engineering the Nitrogen Symbiosis for Africa (ENSA) project. This article is adapted from an interview first featured on the University of Cambridge Fitzwilliam College website in January 2020 – *Fitz Fellow hopes to lead agricultural overhaul.*

Giles Oldroyd hopes his research in self-fertilising crops can increase yields for farmers in the developing world and reduce air and water pollution.

His research team aims to understand the signalling and developmental processes in plants that allows interactions with fungi and bacteria that help plants acquire limiting nutrients, thus eliminating the need for inorganic fertilisers.

The work has the potential to deliver more sustainable and secure food production systems, including delivering significant yield improvements to the poorest farmers in the world who have little access to inorganic fertilisers.

It can also help reduce the damage caused by the escape of such fertilisers to the environment, particularly in countries where fertiliser use is less controlled, with leaching into water systems causing eutrophication, endangering the biodiversity of aquatic systems.

"My long-term aim is to reduce as much as possible the use of nutrients in agriculture," says Giles.

"We can eradicate nitrogen, theoretically, by using nitrogen-fixing symbioses. And we can greatly reduce the amounts of phosphate, and probably potassium, growers need to apply by improving the fungal association. But more importantly, when fertiliser is applied, we can ensure growers are losing less into the environment."

One of Giles's main points is that many industrial processes have improved in their efficiency and sustainability, but agriculture across the world has some catching up to do. Additionally, there can be an acceptance of pollution events, and possible environmental consequences, because of the need to produce food.

He highlights that throughout the 20th century, agricultural problems were solved by chemistry. "In the 21st century, we have to replace most of those with biological solutions. Some may involve biotechnology, which some sections of society might not like, but if nitrogen needs removed from the environment, would society be willing to accept a genetically modified crop if it totally removes the need for fertilisers?"

There is potential to optimise agricultural production across developing countries far greater than it currently is. Giles, who spent some of his childhood in Zambia, believes the result in sub-Saharan Africa has the potential to be similar to that in telecommunications.

"Due to the prohibitive cost of the landline infrastructure historically no-one used the technology. But when mobile phones arrived, the technology was far more accessible and affordable. Now, everyone has one and is connected. We have to do something similar with agriculture, with a much more sustainable production system which is accessible to a smallholder farmer."

Giles' research focuses on improving the yields of smallholder farmers, but he is also interested in how mass produced crops, such as maize, wheat and rice, can be made more sustainable.

"If we can get these systems working it can only be good for smallholder farmers in sub-Saharan Africa. You could at least double, possibly triple, yields. But you can't get the same yield from microbial delivered nutrients as you can from fertiliser delivered ones, so for UK growers the argument becomes one of sustainability. Are you willing to accept a 10% to 20% yield penalty in order to gain the sustainability of the system? From an economic perspective, that's an interesting challenge.

"There's a lot of drive now towards sustainability across the food chain. But to achieve sustainability there will be a cost, otherwise it would be happening now. What level of cost are we willing to accept?"

Giles believes the yield penalties would be less severe than those in organic farming, where the product is more expensive, but the answer to his question is one for the future.

Karolina Golicz, Cranfield University

Smartphone technology in modern agriculture

Karolina Golicz believes that the agricultural sector is underusing the potential of smartphones to act as powerful, multi-purpose tools in farming throughout the world. Here she explains why…

Worldwide, today more people have access to mobile phones than to clean water. Smartphones are increasing in number year-on-year, first disrupting, and then subsequently integrating completely within almost every industry. Agriculture is firmly at the forefront of this technological revolution.

Our adaptation and rapid response to changing conditions will be key in safeguarding worldwide food production systems to a projected nine billion people by 2050. In order to provide sufficient quality nutrition to the growing population, we need to hasten the uptake of efficient, information-driven and sustainable agricultural practices. However, the full potential for utilising smartphone technology in informing agricultural management decisions at local and international level remains largely unrealised.

The role of smartphones

Powerful, portable microcomputers, demanding little IT literacy, smartphones provide the means to access information at will. From acting as irrigation decision support tool in Colorado to connecting farmers in Ghana, and fine-tuning fertiliser recommendations in Thailand, they have a potential to contribute to the development of a new generation of agriculture-oriented information technology architecture, where data is instantly received, recorded and either shared between interested parties or stored in the cloud.

Farmers have been engaging with mobile technology since its inception. Especially in the developing world, where mobiles and agriculture-oriented apps have been repurposed to act as tracking systems, mobile payment terminals, farmer-oriented helplines, and for operating trading platforms.

Apps that make use of inbuilt smartphone sensors are capable of equipping farmers with real-time and site-specific assistance, providing a portable soil testing capability, improving irrigation scheduling or modelling nitrogen losses.

Hundreds of farming-oriented apps are available in the various app stores (Figure 1). Choices exist between high quality methods, which are often not publicly available, or apps developed by unknown parties with no evidence of thorough testing. Scientifically sound testing and government-mediated quality standards of apps should be a priority given the pressing public and scientific interest in developing smartphone technology to enhance agriculture.

The dissemination of information involving agricultural practices and farm management could be advanced through easily accessible, quality-assured and user-friendly apps. Ideally, those apps would emphasise connectivity and the ability to transfer knowledge and agricultural innovation on a person-to-person basis, rather than focusing solely on passive information transfer. They should be widely accessible across the world and in multiple languages.

Schemes aimed at improving agricultural productivity while enhancing sustainability have failed frequently over the years with knowledge intensive practices being less likely to be adopted. However, in such cases the lack of technological solutions has rarely been identified as the chief barrier. Instead, socio-economic problems are highlighted, rising from linear transfer-of-technology and top-down approaches that did not account for innovative systems that constitute elements of feedback loops, iterative interactions and learning processes. Employing elements of communication technology within such approaches could help foster agricultural innovation systems, replacing top-down extension approaches, and could further act as a medium for the introduction of climate change adaptation and mitigation strategies.

Figure 1. Google Play Store showing a search of the term 'Agriculture'. India is at the forefront of agriculture-oriented app development, having developed 59% of the first 100 top rated (4*) apps and downloading them over 1.6m times. Countries such as India and Malta use apps as a way to provide extension services and trading platforms. However, a lack of suitable frameworks impedes smartphone app incorporation into agricultural management across the world

What does this all mean?

There is little doubt that smartphones will become more widespread and that their adoption into agri-business will increase and deepen. However, the success of smartphone apps as multi-purpose tools, able to collect and share financial, environmental and social data, will depend on suitable conditions, which make scientific, business and social sense.

Firstly, the smartphones ought to be viewed as tools, acting to support the development of efficient and data-driven precision agriculture. As such, they require well thought-out architectural designs, which account for challenges likely to be encountered in the agricultural sector. For example, intermittent internet access, bandwidth fluctuations, and energy conservation necessary for prolonged in-field use. Secondly, there must be a clear link between the needs of the user and the app being developed. Thirdly, it is important to recognise that isolated development and meticulous cross-examination of smartphone apps will remain solely an unconnected endeavour if they are not made widely available and updated regularly.

Furthermore, app availability and usefulness needs clear communication to intended users. This requires a certain level of trust to be established between the technology developers and its users, and can only be achieved through well-established extension services or intermediaries. Finally, integration of frameworks that can ensure quality standards and improved accessibility will remain of paramount importance. This level of integration requires a robust and dynamic collaboration between individual farmers, governmental organisations, and related industry.

By increasing engagement with agriculture-oriented information technology, the collaboration between farmers and the tech industry will surely push the future development of high-quality apps, ensure their continuous updates, and hasten the uptake of information-driven agriculture throughout the world.

Laura Harpham, NFU

Celebrating ten years of CFE

CFE celebrates ten years of a unique partnership encouraging and supporting farmers to incorporate industry-leading environmental management into productive farming businesses.

Established in 2009 as the *Campaign for the Farmed Environment*, CFE encourages and supports farmers to demonstrate the agricultural industry's commitment to environmental management on farm. The Campaign initially focused on voluntary measures, adopted as part of day-to-day farm management, which worked within a productive farming business.

Measures included management practices that offered benefits to both the environment and the farm business. These included taking awkward field corners out of production – to benefit wildlife as well as streamline cultivation – and establishing grassy banks in fields to prevent soil erosion and support beneficial insects. CFE also encouraged farmers to retain beneficial management practices if they were coming to the end of a scheme agreement such as ELS.

During the ten years since its inception, CFE has engaged thousands of farmers and farm advisors across England, with the support of partners from agricultural, environmental and governmental organisations. Farm visits and events have highlighted the great work many farmers do to care for the environment.

Relaunch

In February 2019, the partnership was relaunched as *Championing the Farmed Environment*. The relaunch included a refresh of the resources available at cfeonline.org.uk and saw CFE guidance develop beyond the 'voluntary measures' which formed a significant part of CFE since its launch.

The new guidance focuses on farming practices that protect and enhance the environment while working for the bottom-line of a farming business, regardless of whether-or-not these are externally funded.

In some cases, unfunded management practices offer business benefits, such as efficient nutrient use that reduces wasted costs on unnecessary inputs as well as the risk of pollution. In others, the practices may have funding attached to compensate farmers for income foregone, including payments through a Countryside Stewardship or Capital Grants schemes. The new CFE direction does not draw a line between 'voluntary measures' and funded activity – it promotes good environmental management in whatever way works best for a farmer and their business.

Farm walk

Celebrating success

In November 2019, we celebrated the successes of CFE since its launch through a 'Champions of the Farmed Environment' Awards event. These awards celebrated farmers who champion good environmental management in their farm businesses and highlight what can be achieved to others in the industry and the wider community.

Winners from the four core themes of CFE showcased how it is possible and profitable to farm in a way which works for the farm business and the environment. They are:

Air category – Phil Latham, Brook House Farm and Kelsall Hill, Cheshire

Phil farms 1,000 acres across two sites. The diverse farm business include an equestrian centre and 500 head herd of Brown Swiss cattle. Phil's holistic approach to nutrient management, recognised through CFE's partner initiative Tried & Tested, combines the economic benefits of effective nutrient planning and application with reducing environmental risk.

Soil category – Jonathan Boaz, Mill Farm, Worcester

Jonathan's 600-acre arable and sheep farm in Worcestershire is a great example of how care of the natural resources on farm works hand-in-hand with managing a productive, sustainable business. Jonathan has been farming his land for more than 50 years and in that time he has seen first-hand the impact on the land of intensive, high output farming.

He approaches environmental management from a pragmatic stance; if you are taking a lot from the land through what you grow, it is important to put back enough to maintain the balance of healthy soil and a resilient environment.

Water category – Rob Atkin, Atkin Farms, Uttoxeter

Atkin Farms manages over 1,200 acres of largely arable land, with a small beef herd on low-lying meadows in the River Blythe catchment. They work closely with South Staffordshire Water as part of a project supporting farmers in the area to adopt catchment-friendly farming practices that work within their productive farming systems.

Atkin Farms epitomise the win-win opportunities which good environmental management can offer for farm businesses; the actions around water quality on farm show just how much can be achieved when people and businesses with shared goals work together.

Wildlife category – Patrick Barker, Lodge Farm, Suffolk

Patrick manages the family farm of 1,300 acres with his cousin Brian. The integration of measures for wildlife through the entirety of this modern, intensive arable enterprise makes Lodge Farm a very worthy winner.

Ten years of HLS followed by a Higher Tier Countryside Stewardship scheme set a strong baseline for the fantastic habitat management and creation on the farm. Lodge Farm is an exemplar for what a love of wildlife combined with the best possible use of agri-environment scheme support, and a commitment to go above and beyond, can deliver.

There was also a special 'Distinguished Service Award' presented to Jim Egan of Kings, formerly of GWCT, for ten years of dedicated commitment to delivering CFE messages to the industry.

Phil Latham – Air category winner

Jonathan Boaz – Soil category winner

Rob Atkin – Water category winner

Patrick Barker – Wildlife category winner

Jim Egan, winner of a special Distinguished Service Award

What does the future hold?

The policy landscape in which CFE is operating has changed significantly since 2009. The new challenges on the horizon, including the new Environment and Agriculture Bills, the phasing out of BPS and the introduction of ELMs, will place good environmental management into an ever-more central role within all farming businesses.

CFE will play its part in offering guidance and support to the agricultural community of its partners' members. The role of partnership becomes increasingly crucial in a world in which many organisations are offering excellent advice and resources on an array of topics. As the original partnership between agricultural, environmental and governmental organisations, CFE is well versed and well placed to support the collaborative, integrated working that will mean the best guidance is accessible to the widest audience.

We will work with the expanding partnership to continue championing the great work farmers are already doing to care for the farmed environment, while supporting those farmers who lead by example to highlight the value of British farming to the public and policy makers.

We look forward to working with two new partners – Agricology and NIAB – at the Soil Pit at Cereals 2020, and details of the free CFE partnership events delivered by our network of regional coordinators can be found at cfeonline.org.uk/our-work/events.

Finally, 2020 will see the rollout of the second stage of our recently launched 'Climate Change Mitigation' guidance, with input from the partnership in the following months. Visit cfeonline.org.uk/climatechange to view the new pages.

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Cabbage stem flea beetles: oilseed rape crop damage survey Autumn 2019

Having endured the worst autumn for flea beetle crop damage in winter oilseed rape since the neonic ban took effect in 2014, we need to be positive and remind ourselves that as recently as 2017, with good rainfall at the right time, we experienced almost perfect establishment, nationally. What we saw last autumn was the combined effect of a large beetle population and two years of dry summers. With the water table well and truly restored, we can hope for better things in autumn this year.

Big response to the 2019 survey

Firstly a big thank you for the 1,127 responses received last autumn, easily the most that we have had since we started our surveys in 2015. We asked you to drop a pin onto the map and tell us whether you were seeing little or no damage, mild damage, moderate damage, severe damage or crop failure in winter oilseed rape. We also asked you to respond if you had given up oilseed rape growing because of the beetle, so that we could map that as well.

Crop damage estimates showed a stark comparison with 2018, which was the worst year for establishment up to that point (Figure 1). The whole emphasis of the damage reports had swung towards crop failure, with 30.4% of the reports in 2019, compared with 12.9% in the previous year. We should be wary of simply taking this at face value, since we would anticipate that growers and agronomists with the worst problems will have been most ready to report them. Nevertheless, we know from general discussion in the agricultural media that the picture that we present is pretty close to what has happened in England and Wales. Very few reports came from Scotland and we would deduce that flea beetles are not a major problem there.

The geographical damage distribution was already well

Figure 1. Comparison of oilseed rape crop damage reports in 2018 and 2019

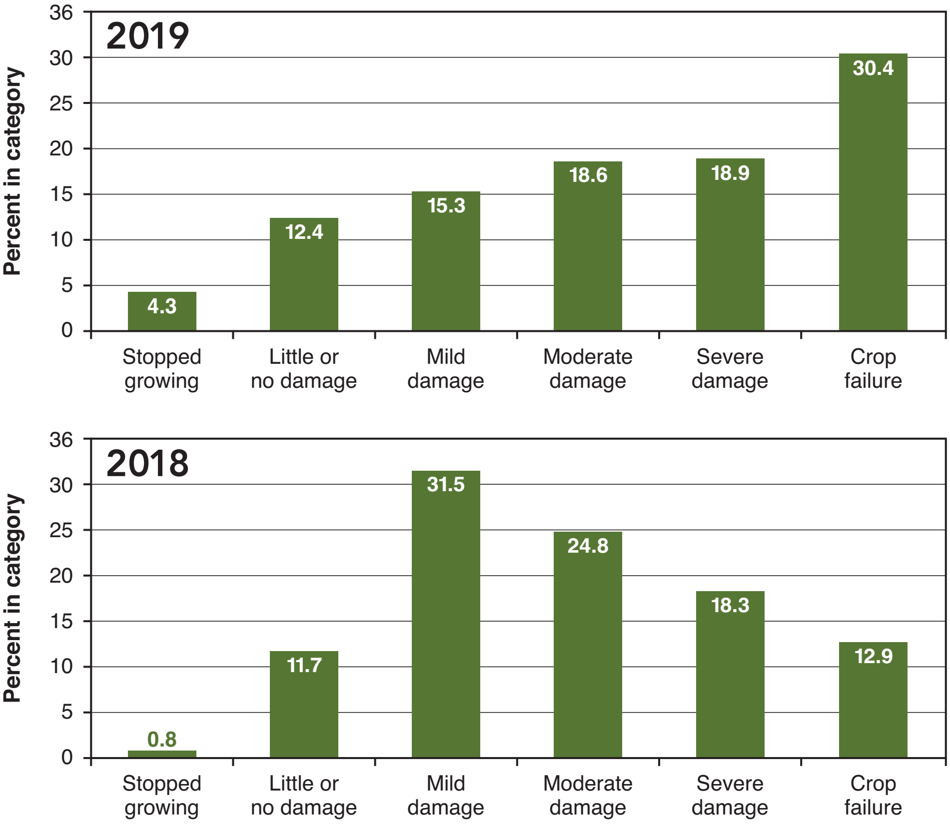
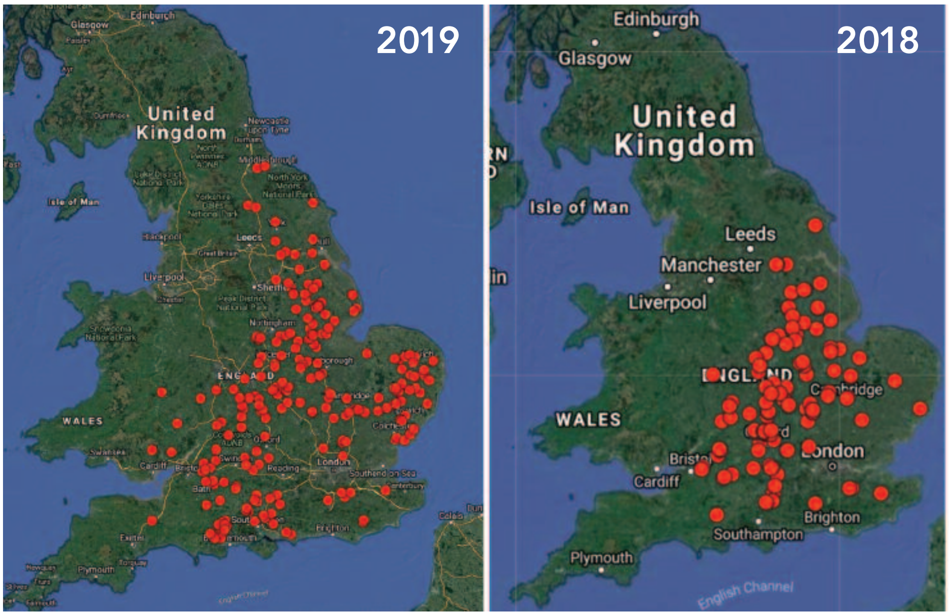


Figure 2. Distribution of crop failures reported in 2018 and 2019



established when we reported on the interim survey data for the December edition of *Landmark* (No. 40; p12). We showed how interspersed and overlapping the levels of damage were across the whole of the England and Wales oilseed rape growing area, with lower damage levels only emerging in the far south-west and as we go up into Yorkshire and beyond. Here we compare the distribution of crop failures in 2019 and 2018 (Figure 2). There has been a marked intensification of crop failures across in East Anglia and down into Hampshire and Dorset as well as a general spread towards the west and to the north. The proportion of respondents who have given up growing oilseed rape has now risen to 4.3% of the total, compared with less than 1% last year.

Survey questionnaire

We asked a series of questions to identify the circumstances at play for each of the crop reports, looking at sowing date, cultivations, variety type, seed treatments, insecticide sprays. We also enquired about factors other than flea beetle damage that might have contributed to establishment problems. The responses are summarised here.

Sowing time and moisture availability

The distribution of drilling dates showed a similar pattern to 2018 (*Landmark* No. 36; p 8) with the last week in August having the most sowings but the complete set being somewhat more skewed towards earlier sowings, including a small number in July (Figure 3). Within the main six-week period from 5 August to 15 September, there was a clear pattern of declining establishment success (Figure 4). As with last year's survey analysis, because of the subjective nature of the flea damage assessment, we have grouped the 'little or no damage' and 'mild' damage and compared these with the 'severe damage' and 'crop failure'.

This link between increasing crop damage with time of sowing tied in well with the flea beetle migration data, published in December's Landmark, where numbers built up during early September, with a substantial peak in the last week in September. This was somewhat later than in 2018, when many of us can recall devastating damage to newly emerged crops over the late August Bank Holiday weekend. In 2019 these migration flights would have been well timed to infest and do maximum damage to slowly emerging crops sown from late-August sowings onwards. In addition to direct insect pressure, drought was identified by the majority of respondents as a major contributory factor to crop damage levels, with 50% of reports even for the 'little or no damage' implicating drought in reduced early growth. This rose steadily to 85% for the 'crop failure' response (Figure 5). All this will relate to our recollections of an intensifying drought which only broke in the last week of September, leading into very wet conditions for the rest of the winter.

Figure 3. Number of sowing reports per week from weeks beginning 8 July to 30 September

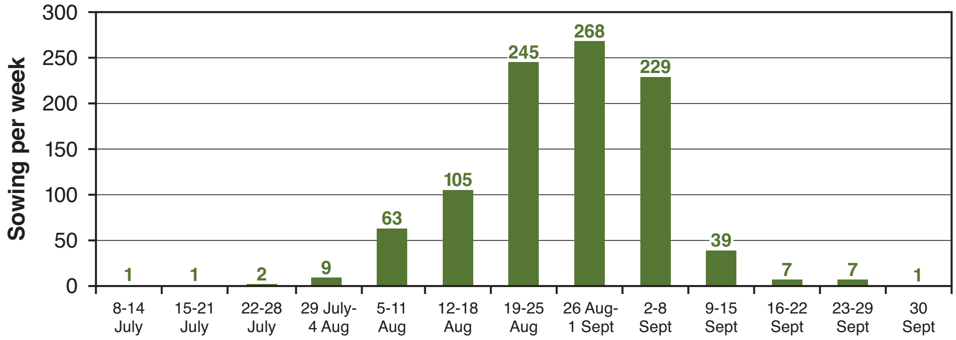


Figure 4. Sowing date and damage levels: comparison of severe damage and crop failure with mild damage and little or no damage for winter rape sowings – 2019

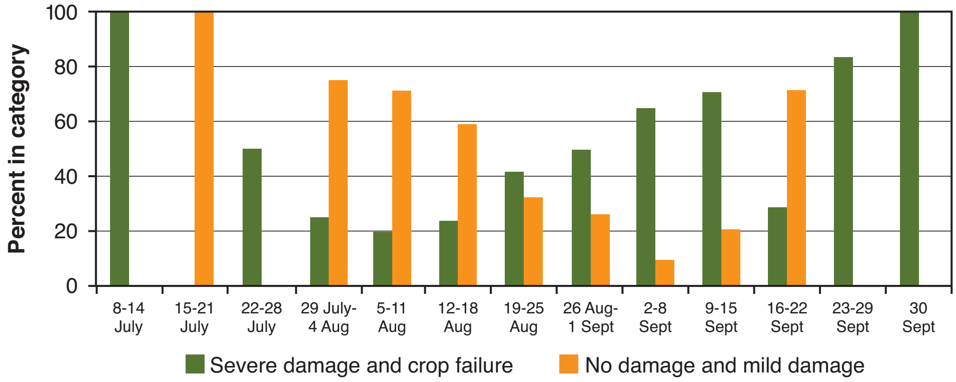


Figure 5. Proportion of responses implicating drought as a contributory factor to limiting early growth and establishment and to subsequent crop damage

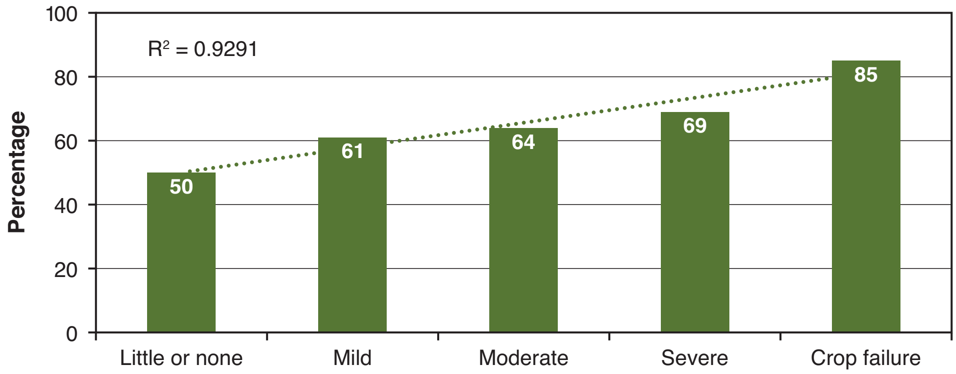
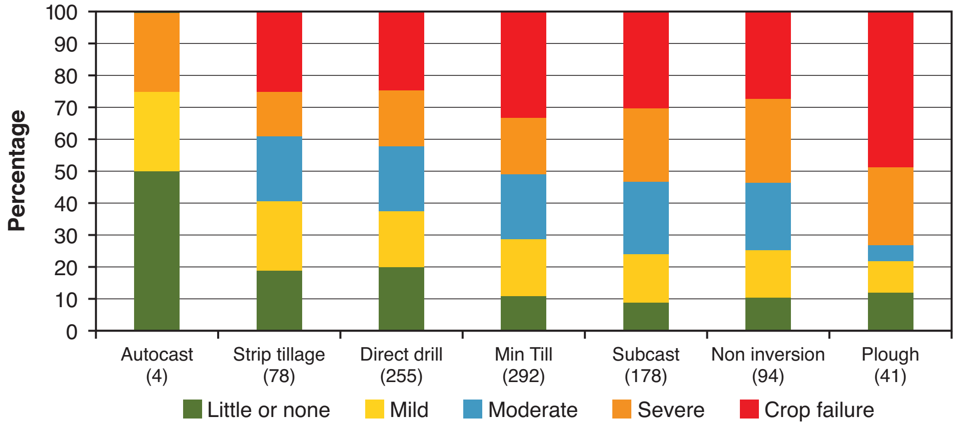


Figure 6. Crop establishment method crop damage levels – 2019 (sample numbers indicated over columns)



Crop establishment method and moisture retention

The best overall level of establishment was associated with the very small number of autocast crops (Figure 6). It would be easy to dismiss the significance of this were it not for the fact that this has been the pattern in all five years that we have conducted surveys. Autocasting has the advantage of early sowing into the stubble as the cereal crop is harvested, zero soil disturbance and minimum moisture loss. It is very far from precision agriculture and the devotees of this practice tend use very high seed rates to achieve a decent stand. After autocasting the proportion of badly affected crops increased with strip tillage<direct drilling<min till<sub-casting=non-inversion<ploughing. Ploughing was conspicuously the worst option for the season, with 75% of crops showing severe damage or failing presumably because of excessive moisture loss. Of course, there are situations where ploughing might be exactly the right judgement call, because of compaction or the need for deep cultivation where sulphonylurea herbicide residues pose a threat to the following rape crop.

Variety type

There is much discussion over the relative merits of the higher seed rates usually budgeted for conventional varieties and the generally better early vigour of hybrids. Of the 930 respondents who specified variety type, 54% drilled conventional varieties, with 32% standard hybrids and 14% Clearfield hybrids. The conventional variety crops appear to have fared somewhat better than the hybrids (Figure 7) but we need to do more work to untangle this from other background effects of geographical location and cultivations.

Seed treatments and insecticide sprays

Of the 870 responses to our question on seed treatments, 86% had used untreated seed, 9% Lumiposa-treated and the remaining 5% had used seed treated with other products, generally under the classification of biostimulants (Figure 8). With such a mismatch between the proportions of the three options we cannot begin to draw definitive conclusions on the efficacy of the treatment approaches but neither appeared to offer an advantage in the conditions of moisture stress and insect pressure that were experienced. This is not to say that, under more benign set of conditions and a more general use of the insecticide seed treatment, progress cannot be made towards controlling cabbage stem flea beetle population numbers. Sadly, because of chemical loading restriction regulations, Lumiposa is not being applied to seed of conventional varieties, because of the assumption of their higher seed rates.

Insecticide sprays appeared to achieve very little, but interpreting the data supplied by 909 respondents is not straightforward and at first glance it would seem that more applications resulted in more damage (Figure 9). This is the wrong logic of course and, in reality, growers with the worst problems will have been drawn into spraying more often. 18% of the crops were unsprayed and these were associated with the highest proportion of 'little or no damage' reports and the smallest combined number of 'severe damage' and crop failures. The majority of crops received one (34%) or two (29%) insecticide applications, while 16% received three sprays. In their turn, these were associated with correspondingly worse crop damage. The crop reports for four, five and six spray applications were too few to compare properly but one wonders whether there was a light-bulb moment, for the sole respondent on six treatments, when the realisation dawned that a seventh spray probably was not going to do the job. My own instinct is to stop using pyrethroid sprays, to allow the beneficial invertebrate predator and parasitic species to come into balance with the flea beetle population but we realise that this is a difficult message to accept when you can stand in your emerging rape crop and hear the beetles rustling around at your feet and see your livelihood disappearing.

Companion crops

There were only 91 reports of the use of companion crops, predominantly mixtures including berseem

Figure 7. Crop damage levels associated with different variety types

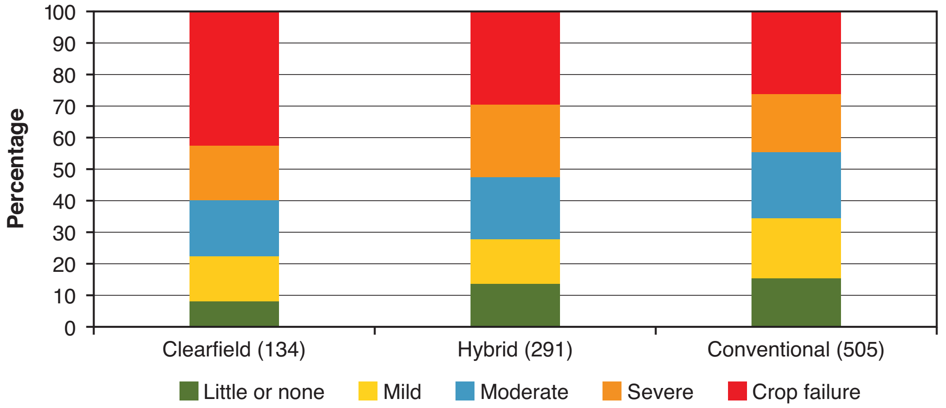


Figure 8. Crop damage associated with seed treatments

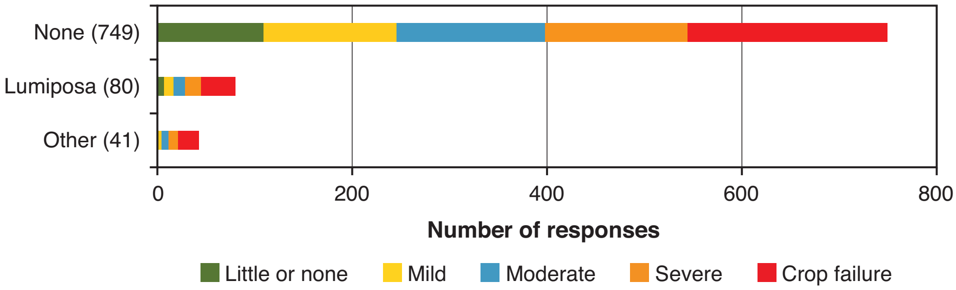


Figure 9. Crop damage associated with number of insecticide spray applications

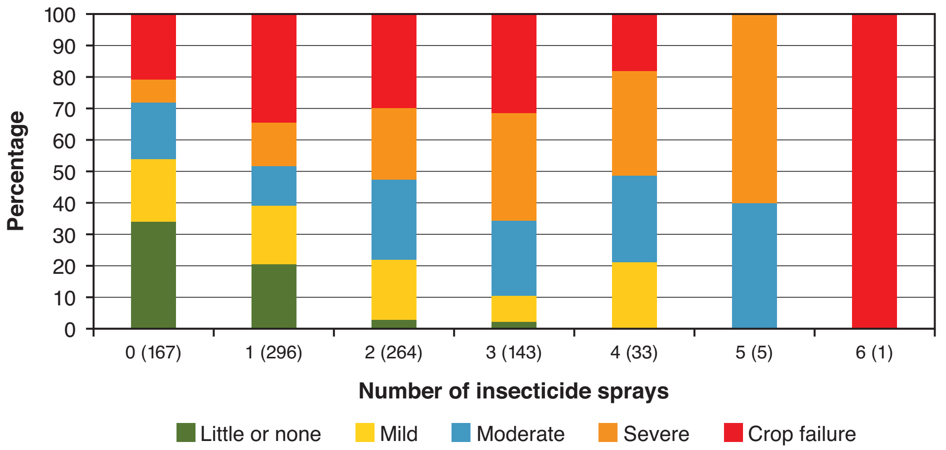
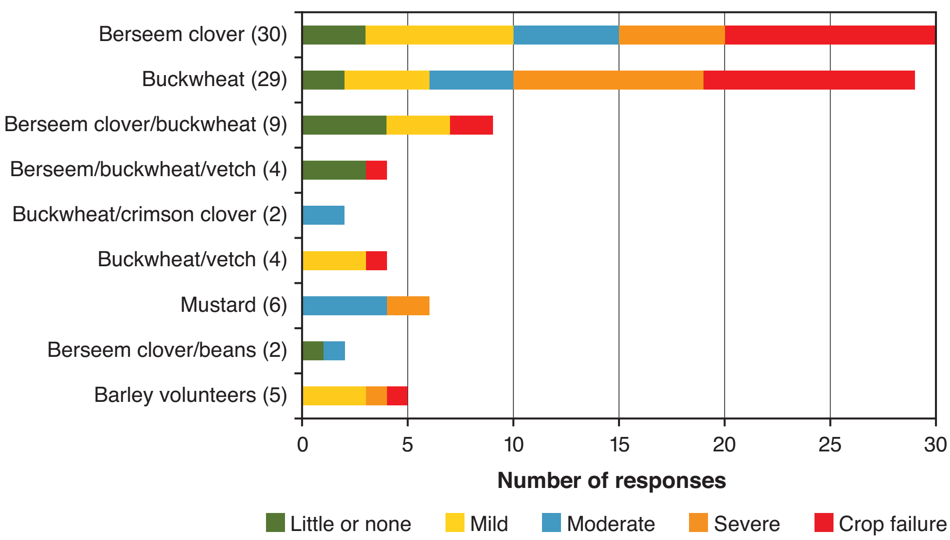


Figure 10. Crop damage levels reported for different companion crop combinations



clover and/or buckwheat (Figure 10). Our own experience of testing these species, in small plots and tramline experiments, is that most of them contribute little or nothing, especially from later sowings and under severe beetle pressure. The chart does nothing to dispel this view but there are strong advocates out there. The value may come from these mixed canopies, when established early, and when weed suppression and enhanced soil fertility will be added benefits. Companion crops may also decrease the flea beetle larval burden in the developing oilseed rape crop.

In our own investigations, white mustard has sown the greatest potential, with its faster emergence than oilseed rape, attractiveness to the flea beetles and its ability to withstand their damage. To minimise competition with the crop the mustard needs to be sprayed off by late October, or as soon as the oilseed rape is developed enough to withstand grazing.

A separate strand of discussion covers the spreading of manures and slurries to deter the beetles and accelerate early growth. The survey produced little on this and growers that we have spoken to have had wildly different experiences. Our view would be along the lines of "What harm can it do? Try it!"

Summary

2019 was a very poor year for oilseed rape establishment over most of the UK rape growing area, with more extensive damage to the south, west and north of the central/eastern region most usually affected. Early sowing is beneficial in establishing crops before the main cabbage stem flea beetle migration in late August/early September. Establishment methods should be selected to avoid soil moisture loss. Variety selection remains a critical judgement decision, balancing the use of high seed rates of conventional varieties with the generally more vigorous early growth of the standard hybrids and the specialised use of Clearfield hybrids in some companion crop combinations where early removal of some companion species is required. The survey produced no evidence of the value of the currently available insecticide of growth stimulant seed treatments, nor of the benefits of companion crops.

Oilseed rape remains an invaluable component of our arable rotations. We must hope for a better weather pattern this summer and autumn and, above all, rain to get emerging crops away. And we must seize all the indications from research and our own instincts to make small, incremental improvements in oilseed rape crop establishment.

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

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.

Undertaking a Nuffield Scholarship was an opportunity to gain a wider view of the horticultural industry, and develop a deeper understanding into how scientists may work to improve productivity and sustainability in the soft-fruit industry in a rapidly changing world.

Intensive tomato production routinely yields upwards of 650 t/ha (and in some cases upwards of 1,000 t/ha). This pattern is similar for other protected crops, such as peppers and cucumbers. Strawberries are around 10% of this, with many of the best growers producing 65 t/ha under similar glasshouse systems (Figure 1).

The strawberry breeding programme at NIAB EMR has some extremely high yielding lines, with acceptable fruit quality, yielding upwards of 2 kg/plant, with some at 2.5 kg/plant although these rarely, if ever, make the cut for market acceptability. Further research found growing systems with plant densities of up to 200,000 plants/ha, three times more than current systems, giving a potential yield of around 500 t/ha.

So, my Nuffield study set out to assess:

- What further research is needed to reach this potential maximum
- What are the barriers to adoption of new technologies
- How sustainable, including energy use, would intensification of production be
- How will the UK's changing position affect the agri-food sector, in particular fresh fruit production, and will it increase or decrease the need for intensification.

It became clear that the final two points were the most important.

Viewing and studying 'lifecycle analysis' of current production systems, it became increasingly clear that urgent action is needed to shift to more sustainable patterns of production for some of our most important horticultural crops.

The report, currently in the final stages of publication, is framed around the changing global patterns of wealth and prosperity and how this drives the challenges of sustainable production, influenced in a large part by my travels in South Africa. The steps required for truly sustainable intensification are outlined, including a system in which genetic innovation and renewable energy are harnessed, net emissions of greenhouse gases are zero, and the negative externality costs of our current food system are internalised.

The five key conclusions, each with an aligned recommendation, will be a focus for this series of articles across the next few issues of *Landmark*. The first conclusion is:

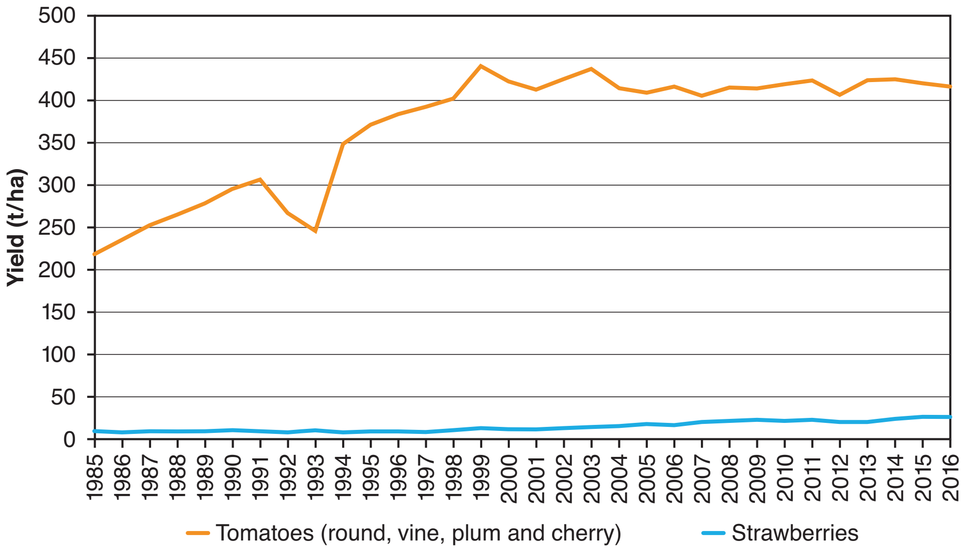
Conclusion 1

Genetics is an easy way to make environmentally sustainable yield gains – there are more tools than ever before and the UK is well placed to lead in this area.

Genetic innovation in all crops is important, as we find ourselves in a world where more must be produced with less and more sustainably. Ensuring the wealth of scientific knowledge reaches the field in the form of new varieties requires different technologies to come together in an affordable way. There are five major technological advances in soft fruit breeding programmes that are driving forward innovation in a way that provides a route to faster genetic progress:

a) **High throughput phenotyping** – phenotyping (measuring observable

Figure 1. National average UK yield. UK tomato production has shown large increases in yield over the past thirty years. In contrast, strawberry yields are increasing, albeit from a much lower base. Raw data from Defra Basic Horticultural Statistics 2017



characteristics), at multiple scales with a minimum of human labour, is crucial if multiple different characteristics are to be combined through selective breeding. For most crops this is still carried out by manual field recording across multiple years in multiple environments, though increasingly the use of UAVs in-field and other techniques such as 3D imaging are playing a more important role (Figure 2).

b) **Low cost genome sequencing and genotyping** – the ability to measure the DNA-level variation in an individual seedling is crucial to measuring its genetic potential. It is only in the past five years that the cost of DNA sequencing and DNA profiling technologies have reached a point at which this becomes an affordable proposition in a crop such as strawberry. Despite its high value to the global economy (around $16 billion per annum) until recently, investments in strawberry genomics were hampered, both due to the relatively modest size of many global breeding programmes and the lack of genomic resources for strawberry. Strawberry is a complex 'octoploid', which was derived from the fusion of four ancestral genomes, much like the steps that led to hexaploidy in wheat. The additional issue of high levels of genetic variation within individuals due to both the outbreeding nature of strawberry, plus that it is a recent hybrid of two wild octoploid species, has meant that sequencing the genome has been technically very challenging. Many global efforts have been focused on generating genetic resources for strawberries. A BBSRC-funded NIAB-led initiative, collaborating with domestic and international strawberry breeders and AHDB, has led to the sequencing of over 200 unique varieties and lines of strawberry being sequenced. This will in time lead to new low-cost methods for cheaply measuring the inheritance patterns of key traits and the estimation of genetic performance.

c) **Genomic selection** – with the advent of low-cost ways to genetically profile individual seedlings at many regions in the genome comes the opportunity to

Figure 2a. UAV phenotyping of resistance to *Verticillium dahliae* in field-grown strawberry plants, measured through the calculation of the normalised difference vegetation index (NDVI). These data were subsequently used to identify regions of the plant genome controlling resistance

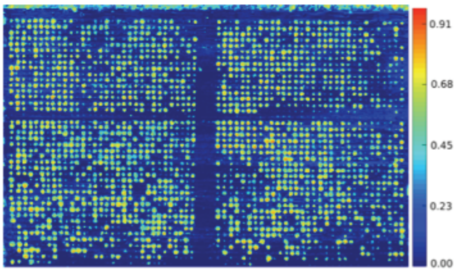


Figure 2b: 3D imaging of strawberry fruit to determine a range of characteristics. These data were used to identify key genomic regions controlling fruit uniformity

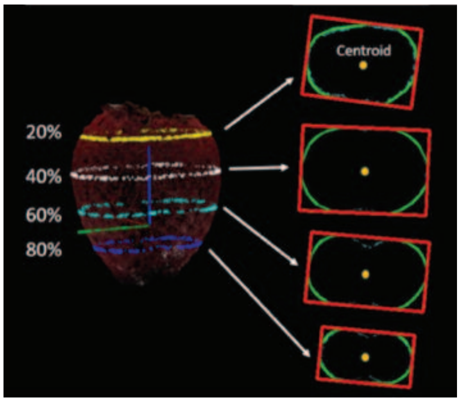
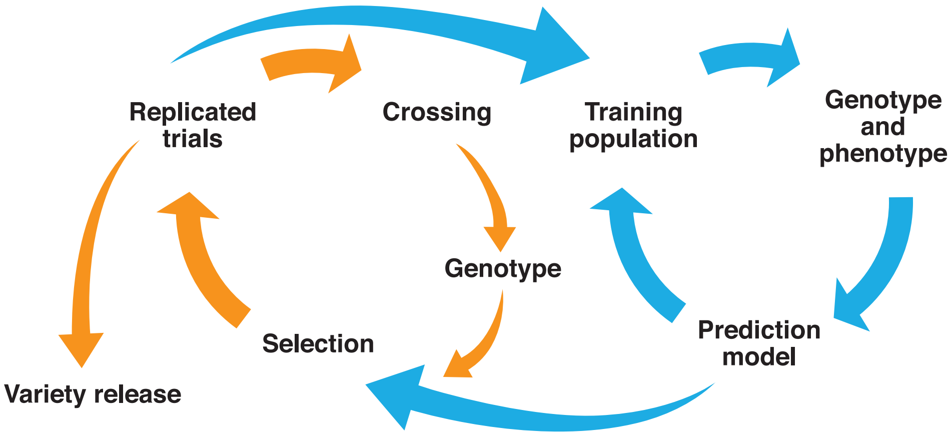


Figure 3. A schematic for genomic selection in an outbreeding crop such as strawberry. The crucial amendment to classical breeding is the use of a training population to predict performance of seedlings prior to measuring their observed characteristics



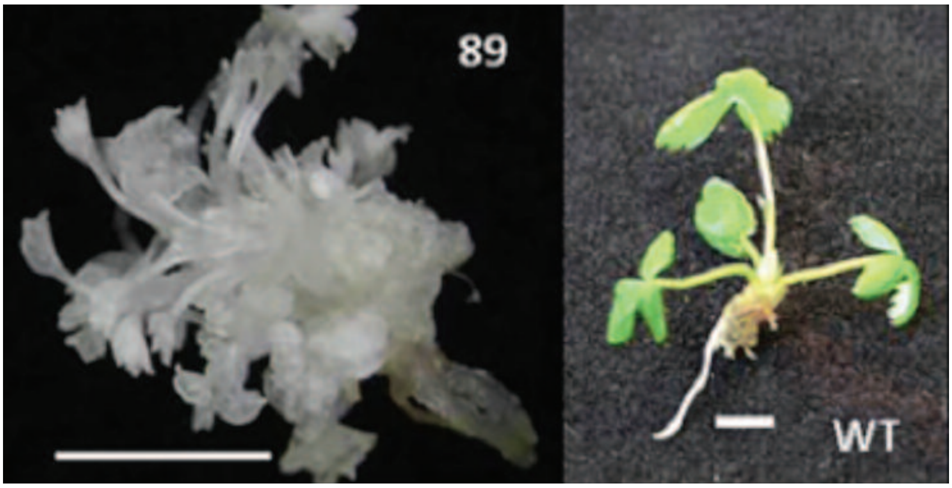
innovate breeding programme designs. The massive opportunity of new breeding programmes is the ability to decouple prediction of genetic performance from the measurement of performance through phenotyping (Figure 3). By using a 'training' population that is densely phenotyped for all important traits and genotyped to high-precision, a mathematical model can be fitted allowing estimation of performance of un-phenotyped offspring that have been genotyped (often to a lesser extent). In practical terms, this saves many years of waiting (in tree fruits often seven to eight years) before evaluating the performance of a particular parental cross.

d) **Speed breeding** – coupling together the technologies above with an emerging technique known as speed breeding, means that genetic gain per-unit of time can be even faster. The pioneer of this approach in wheat, Dr Lee Hickey, has shown that as many as six generations of wheat can be grown in a single year using this technique. Speed breeding involves using highly controlled plant growth facilities to optimise the growth cycle of the plant to rapid reproduction. This involves many of the same technologies used for vertical farming and is rapidly being adopted across crop breeding programmes (Figure 4).

e) **Gene editing** – has an enormous role to play in the future, both through the generation of novel genetic variation and through the targeted removal of disadvantageous mutants. Again, within the last five years, the translation of a raft of gene-editing approaches into speciality crops has rendered the technology affordable and usable in crop

Figure 4. Demonstrations of novel 'microherb' production at the World-HortiCenter in the Netherlands, using LED lights and controlled environment growing systems

Figure 5. Proof of principle demonstrating gene editing of strawberry. Mutation of the PDS gene leads to an albino phenotype (left panel) through impairment of chlorophyll, carotenoid and hormone biosynthesis



improvement – regulation permitting (Figure 5).

It is clear that the combination of these technologies can make more affordable and rapid progress towards improving genetic gain. If the combination of high-throughput phenotyping and genotyping, genomic selection and speed breeding were turned towards more crops and deployed at scale in breeding programmes directed towards the targets of whole-system input-reduction through yield and productivity enhancement, it is easy to see how sustainable yield gains can be made possible. One practical example of this is the use of genomic prediction in the deployment of disease resistance, though there are a raft of other targets that would be equally valuable, such as breeding for robotic harvesting, breeding for extended shelf-life, breeding for enhanced beneficial microbial associations and many others.

With the addition of gene editing into the toolbox alongside the wealth of genomic tools that allow us to understand the exact genetic variants in crops that control key desirable traits, the opportunities for rapid improvement of our crops have never been greater.

Looking to the future

The UK is in a leading position from a technical perspective, but needs more start-up activity to translate into commercially-viable products. Some of this could be accomplished through simply encouraging greater linkage between academia and industry – something which NIAB excels at, but it also requires people with the drive and ambition to innovate in this sector.

Looking to the future there is a much greater role for modelling in designing cropping systems of the future. Part of this will be modelling at the crop level to design new crop architectures and behaviours to suit new growing systems which can then be selected using the full range of tools that we have at our disposal. This is an emerging discipline which sits at the intersection between crop breeding, crop physiology, data science, artificial intelligence and systems engineering, and one that NIAB will drive forward in the coming years.

However, the risk of failure in pushing at the frontiers of crop science is high. Nothing that I saw on my travels under active development in the commercial sector was (in my opinion) ambitious enough to fully address the challenges we face in making intensive horticulture, or indeed wider agriculture, truly sustainable.

We exist in an uncharted territory. To date, no business or person has ever been asked to fully internalise the 'negative externalities' (the true cost to society) of their activity. Yet, this is what is really being asked of us now, net zero is just the first step in that direction.

There is a role for the state in funding 'future' crop breeding for future markets. The combination of fundamental and translational interdisciplinary research in a broad portfolio of crops could harness the full power of genetic innovation to direct performance in cropping systems that are designed with sustainability as a primary outcome, and development of 'climate-friendly' crop production should be the focus of much greater attention across UKRI and other funders.

Recommendation 1

At least half of the increases in yield potential for strawberry could come from genetic innovation. Continuing to fund the pipeline that takes fundamental research into practice is crucial. However, accelerating this to develop varieties that do not match current market demands is challenging. The UK government should consider directly funding breeding or pre-breeding for 'future' crops, as this is unlikely to be met by near-market industry funding.

Craig Livingstone, Lockerley Estate, Hampshire

The benefits of membership

When Craig Livingstone took over managing a 1100 ha farm between Stockbridge and Salisbury in Hampshire, one of the first things he did was become a NIAB TAG member. But why?

Here Craig tells us about the farm he manages, and just why NIAB TAG membership is right for him.

Craig Livingstone (far left) and his team

Four years ago, Craig took over managing the Lockerley Estate farm in Hampshire. Prior to that he was an Agronomist. 'Coming from an agronomy background, I knew how well respected NIAB are in the industry. So I became a NIAB TAG member, as I wanted a forum where we could look at trials, get access to the results and meet farmers. NIAB offered all of that, so it was an easy decision to join' says Craig.

The Farm

Five miles outside Stockbridge, and near to Salisbury, sits Lockerley Estate, owned by the Sainsbury family. Craig is part of a small team and they largely do everything themselves: 'I believe in training our own staff rather than buying the expertise in, apart from NIAB TAG membership, of course!'

Craig adds: 'The total area farmed, including contract farms, is 1100 ha. Of this the majority, around 800 ha, is under arable cropping, with a 215 ha woodland working forestry business. There is a huge variety in soils on the farm – around half the farm is Hampshire chalk, but there is also some heavy clay cap. The remaining area is used for livestock, with 1000 sheep on site. The sheep are used as a tool in our system to manage cover crops, which allows natural fertility building and significant reduction in glyphosate use. 30% of the farm is under some form of conservation management.'

Conservation

Craig uses a seven-year rotation and is always looking to improve soil health and fertility. He believes that it's about the overall value of rotation rather than individual crop. OSR is now unviable on the estate due to the area historically grown. Battling huge brassica weed problems and early signs of clubroot combined with 100% resistant CSFB, Craig opts for two-year fertility building clover grass leys.

It all stems from the landowners – the Sainsbury family – and their vision for the farm underpins everything: it has to be sustainable and resilient but equally doing the right thing must pay. It recently became a LEAF demonstration farm.

How does being a NIAB TAG member support this?

'The best thing is the dialogue with other farmers' says Craig. 'The opportunity to have discussions and talk through different options is helpful – I'm not alone! I can pick up the phone and talk to other farmers in a similar situation.

'I like getting the strategy options. I feel that it empowers me to make decisions without actually selling me something. It's invaluable – if you divide the cost across the hectarage of my farm, it's definitely worth it. It gets me looking at things in different ways and you get a lot of data and knowledge.'

How has being a NIAB TAG member impacted your farm?

Craig estimates that membership has helped him reduce pesticide spend by 22%, and fungicides by 13%. 'It gives us the confidence to be brave, we can pick the right variety for our farm and then match it to the right agronomy. I like the risk scorecard we are sent. It's very useful to go through it and see where your variety is and what you'd spend on a crop. You can then change it if you feel there is a more suitable one for you.'

What would you say to someone who is considering becoming a NIAB member?

'Do it! The value for what you get is unrivalled.'

We welcome your feedback – email ***clare.leaman@niab.com***

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BASIS NRoSO National Register of Sprayer Operators
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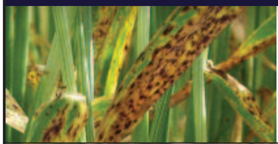	**Accurate identification of diseases for successful control in barley**	**Devised by:** NIAB TAG's Bill Clark
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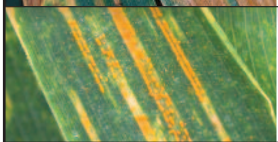	**Accurate identification of diseases for successful control in wheat**	**Devised by:** NIAB TAG's Bill Clark
	**Building arable rotations for soil fertility, yield and resilience**	**Devised by:** Ron Stobart and Chris Winney
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	**Purchasing and storing professional pesticides on farms**	**Devised by:** Dr. Aliona Jones, Business Development Coordinator at BASIS Registration Ltd
	**Better black-grass control to reduce threat to yield and profit**	**Devised by:** NIAB TAG's John Cussans
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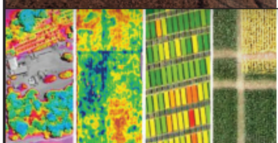	**Using remote sensing data for higher yields and profits**	**Devised by:** NIAB TAG's Bill Clark with input from Eric Ober and John Cussans
	**Nematicide Stewardship**	**Devised by:** NIAB TAG's Douglas Hobbs and Steve Higginbotham, Stewardship Limited

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Edited and published by NIAB TAG. Designed and produced by Cambridge Marketing Limited, 01638 724100