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EXTRA JANUARY ISSUE ▪ EXTRA JANUARY ISSUE ▪ EXTRA JANUARY ISSUE ▪ EXTRA JANUARY ISSUE

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"Rather than cutting costs, it's increasing margin that makes a real difference."

Dave Dalye
Managing Partner of TWO Farms
and co-founder of The Farming Forum

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We create chemistry

cpm

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foreword

by Rosie Bryson

Time for the next Green Revolution?

The year 2016 has been an "interesting" and challenging one with 2017 unlikely to be easier. The shock of Brexit and the changes in the US, alongside other potentially destabilising influences across the world, suggest a seismic shift in the "world order". There is no longer such a thing as the "norm", and the impact on Europe, as a whole, remains to be seen.

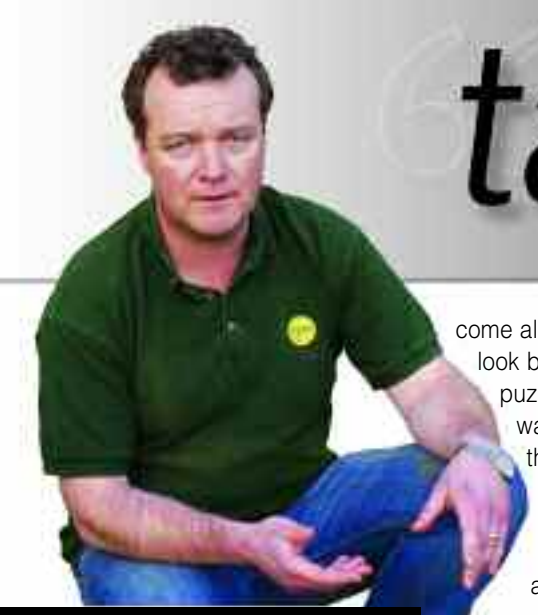
As always, agriculture lies at the heart of many political debates particularly when facing discussions on trade and market access alongside industry consolidations. The European pesticide legislation (1107/2009) has as a key objective to "maintain the competitiveness of European Agriculture" but it is hard to see how this will be achieved while the increasing stranglehold that this legislation is having on innovation continues. Alongside this, biology does not respect politics nor borders but adapts and changes using Nature's rules, not ours. The many millions of productive hectares across Europe will continue to be the lifeblood not just of our own region, but of the world.

It is no coincidence that when the plant pathologist and father of the Green Revolution, Norman Borlaug heard of his award for the Nobel Peace prize he commented that the committee had "selected an individual to symbolise the vital role of agriculture and food production in a world that is hungry for bread and peace". In his acceptance speech for the award he said "the Green Revolution has won a temporary success in the war against hunger and deprivation, it has given man a breathing space". He projected that the impact would last for about three decades, and that was in 1970.

In this series of articles commissioned by BASF, important topics facing European and UK agriculture are highlighted. They seek to pose questions which will encourage both thought and debate among *CPM* readers. The features cover diverse topics from the role of azoles and resistance management in Europe to how historic dog sacrifices were a precursor to our understanding of rust epidemiology. The Ukraine is explored as an emerging market and the threat to European sugar beet production discussed. Innovation lies at the heart of our industry's future and BASF, for the first time, unveil their new azole — Revysol.

Clearly, there are major challenges ahead but a bit like Nature, those working in agriculture are highly adaptable, innovative and know that food production in all its guises lies at the very heart of a peaceful and civilised society.

Dr Rosie Bryson is a plant pathologist based in Germany. She is the BASF team lead for arable fungicide development and is also chair of the Institute for Innovation and Knowledge Exchange.



talkingtilth

a word from the editor

Who has the biggest job?

If I'm honest, I was in two minds about BASF's 'Farming, the biggest job on earth' campaign when it first started.

On the one hand, it was kind of flattering that a large company wanted to spend quite a sizeable sum of money championing the job that farmers do. We constantly bemoan that the public doesn't understand where its food comes from, that there's a disconnect in society between those who work in the countryside and those who rarely even visit it. Here was a company that was going to put more resource into getting those messages across than farmers could ever hope to muster.

But the corporate alarm bells were ringing loud and proud. As farmers, we know we are tiny businesses compared with the multinational corporations we deal with, and that gives us a natural suspicion of everything they do. This led me to question the real purpose of this campaign, and whether those orchestrating it had the same aims for farming as me. What's more, I was intrigued to know how BASF was going to put forward messages about what it's like to deliver the biggest job on earth, when surely it's only farmers who truly know?

So I think many of us were happy to don the T-shirt, accept all the marketing gifts and come along for the ride. But if I look back, I for one was a bit puzzled about where it was heading and I don't think many of us knew where this campaign would end up, or even if it would achieve anything.

But if there's one thing that's changed in recent years, it's how I view the EU regulatory system. In the past, i've taken the tools we use in the fields for granted. I've always known it's a tough regulatory environment, but considered our job to be growing the crops, and someone else's to be jumping the regulatory hurdles.

That view's changed. The decisions made in Brussels have a direct effect on what we can achieve in the fields. I do now feel a part of that, and I want to feel part of the resolution, whatever guise that may take, to ensure farming has a positive future, is equipped to deal with its challenges, and empowered to reach its potential.

I don't know whether the BASF campaign brought about that change of view — there's been something of a sea change in the industry anyway. But the campaign has clicked into place — farming may be the biggest job on earth, but it would be a considerably harder one without its tools. BASF makes a number of rather useful ones that I routinely buy. Just as I should feel part of the determined effort to get a better deal in Brussels, I feel BASF is part of the job of getting productive, healthy crops to market.

So when *CPM* was approached about doing a whole sponsored issue, yes, those corporate alarm bells were ringing again, but I wasn't going to let them drown out my curiosity for what we could achieve together. And when the *CPM* team sat down with BASF and started to talk through some of the stories we all wanted to tell, it was surprising how much we had in common.

Enclosed in these pages are fascinating features you really won't find anywhere else. We've scoured Europe for an in-depth insight into some key aspects of farming, starting with innovation — not just the prospects it holds, but the real progress made in Brussels to get it recognised.

Plant-breeding is where there's real innovation potential, especially to bring on better disease resistance. We've explored the prospects and asked whether fungicide chemistry has held back or helped progress. Yellow rust is arguably one of farming's biggest challenges, and has been since the Roman times. We track its development and gather the latest from Europe's top researchers.

On azole chemistry, we bring a report detailing research that's thrown the spotlight on just how diverse the septoria-resistance picture is across Europe. We've looked in detail at the evolution of this 40-year old chemistry, that continues to hold its own as the fungicide mainstay. There's a World Farming report from Ukraine, exploring its incredible potential, and fascinating quirks. Finally, as quota-free sugar beet comes to Europe for the first time, we ask researchers and agronomists in five countries about the challenges their growers face.

CPM has deliberately taken a step back and given the broad, European view with this issue. I think you'll find it does offer a deeper understanding and greater appreciation of some of the challenges we as an industry currently face. Whether it ticks the campaign box for BASF, I really can't say. Nor is it clear whether the biggest job on earth campaign is going in quite the same direction as was first envisaged.

But I do feel as an industry we're travelling on this journey together, and it's a richer experience as a result. So I've two words to say to BASF: Thank you.

Tom Allen-Stevens has a 170ha arable farm in Oxon, and reckons the biggest job on earth is predicting when winter's dreary weather will make way to a decent spring.

tom@cpm-magazine.co.uk

Did the size of the T-shirts match up with the ambition of the campaign?

> *“Growers are becoming more innovative themselves, with many doing their own trials to look at what works best in their situation.”*

The future requires ingenious thinking

Technical Innovation

Converging technologies are fuelling innovations that could aid increased food production in a sustainable way. *CPM* finds out what fuels innovation and some of the things that get in the way.

By Lucy de la Pasture

We live in a world where technology is advancing at an unprecedented pace. Just 30 years ago, mobile phones were the size of bricks and barely mobile. Now we have smart phones that are wafer thin and light as a feather. Yet within their sleek exterior, there's such a powerhouse of functionality that most of the human race find it hard to be without one.

Smart phones are an example of successful innovation, explains Prof Sa'ad Medhat, chief executive of the Institute for Innovation and Knowledge Exchange in London. They tick the box when it comes to meeting the defining principles of innovation — generating economic value and providing a benefit to society — so much so, that any negatives are mostly overlooked.

“We all know that mobile phones increase our exposure to radiation and the long-term effect of this is unknown, but we continue to use them all the same,” he comments.

Public perception

On the other hand, the advent of green biotechnology and genetically modified (GM) crops was one of the most divisive innovations in agriculture. Met with public outcry and fears of ‘frankenstein food’, public perception effectively put the kybosh on adoption of the technology by growers and demonstrates that some innovations are more acceptable than others, he says.

Agriculture has one of the biggest challenges facing any industry. There's not just the predicted expansion of the global population to 9.1 billion by the year 2050. According to EU Commissioner for agriculture and rural development, Phil Hogan, in his recent speech at the World Food Day Conference, an extra 3bn people are predicted to become more affluent and join the middle classes in the next 20 years, which will put further pressure on food supply.

Sa'ad Medhat reckons the imperative nature of the food production problem will drive solutions through innovation.

Although part of the solution will be found in chemistry, Sa'ad Medhat reckons the imperative nature of the food production problem will drive solutions through innovation, but over a much wider platform than crop protection alone.

“There's a need to increase food production to meet the basic needs of people. But there are also numerous problems associated with doing this. In addition to the challenges of ▸

Five years after the implementation of 1107/2009, the first two active ingredients have just been approved through the new process, notes Paul Leonard.

▸ climate change and increasing severe weather events, land and water are both limited resources. Urbanisation continues to reduce land available for food production and increasing environmental degradation means that the bottom line is we'll need to produce more food from less land," he says.

It all adds up to an increase in world food production of 70% over 2005 levels and at a time when Europe is feeling the impact of Plant Protection Products (PPP) Regulation (EC) number 1107/2009. Under this regulation, pesticides are increasingly evaluated according to their intrinsic 'hazard' rather than actual 'risk'. This results in a loss of active ingredients and a slowing of the innovation pipeline, explains Paul Leonard, of BASF EU government relations, innovation and technology policy.

"A startling fact is that, five years after the implementation of 1107/2009, we have only just had the first approvals of two new active substances. Up until now, those approved were under the old 'risk-based' legislation. That's not a friendly timeline for innovation."

While there's been a slow-down in growth in the EU-15 in the past ten years, growth and technological innovation are accelerating in other parts of the world, particularly Asia and the Americas, he explains.

"It's partly due to the loss of active ingredients but also the conflicting demands of regulatory compliance and innovation which are being placed on R&D budgets. The more money which has to be spent addressing escalating regulatory requirements, the less money is available for real innovations," says Paul Leonard.

With the majority of actives only just entering the renewal phase, where they'll be assessed under the new regulatory cut-off criteria for the first time, the new regulations are only just beginning to show their teeth. The criteria for endocrine disruptors (ED) is currently being defined by the EU but the impact this will have on chemistry is still unclear, particularly for crop protection products, such as azole fungicides.

"These products could be considered to exhibit ED properties, based on their biochemical mode of action (aromatise inhibition), but that doesn't mean they are EDs. The EU criteria for ED have not yet been adopted and continue to be both scientifically and politically contentious," he comments.

ED criteria

"It's not known what impact ED criteria adopted by legislators will have on crop protection. We'll find out the extent to which azole fungicides may or may not trigger the ED criteria when they are finally defined, adopted and implemented in the regulatory decision-making process. In the meantime, it's a source of continuing concern, especially for farmers and countries which export agricultural products into the EU," he adds.

Azoles form a vital component of fungicide anti-resistance programmes, especially as partner products for SDHI fungicides. Hopes are pinned on a possible derogation to prolong the prospects of azole chemistry, where any potential risks can be proven negligible, but even this is currently looking doubtful, explains Paul Leonard.

And there's a problem with this approach, he points out. "Any legislation based on derogations is poor legislation and very bad for innovation and investment. A tricky regulatory environment leads to defensive R&D, with companies spending more money on compliance with legislation than on innovation, because compliance eats into limited R&D budgets.

"For example, EU legislation on particulate emissions in diesel tractor engines tied up 80% of tractor manufacturer's R&D budgets for five years to get engines to comply. The end result is less fuel efficient and more expensive to manufacture."

One of the biggest success stories in agricultural innovation in recent years is precision farming. In the past ten years, precision agriculture has moved from a position of good science to good practice with more than 70% of new equipment having some form of precision agriculture component inside.

But there are many other technologies being harnessed in food production and some of these are borrowed from other industries. Nanotechnology has applications in a range of areas from nutritional delivery to seed coatings. Robotics is used in crop production right the way through the supply chain and LED lighting systems are being used to accelerate food production in some systems. But what we're now beginning to see is a convergence in technologies underpinning the whole platform of innovation, explains Sa'ad Medhat.

Open-innovation, where skills are brought in from 'outside' and data shared, has been very successful in IT and expanding this concept in agriculture would help enable different technologies to come together, he suggests.

There's a huge opportunity for innovations in food storage and processing to increase shelf life and reduce waste. Currently it's estimated that for every 100 calories of food produced, only 35 calories are utilised, he points out.

"Integration of innovative technologies will undoubtedly help farmers achieve increased yields but ultimately they'll also help the city ecosystem to become 'smarter'. Systems like vertical farming, urban greening and the development of smart cities, created with internet-of-things technologies, are possibly the future of urban living," he believes.

The importance of innovation to agriculture isn't being overlooked by the UK organisation whose vision is to empower growers to be more competitive and sustainable. The subject has been under much recent discussion within the Agricultural and Horticultural Development Board (AHDB), according to its knowledge exchange director, Susannah Bolton.

"One of our critical objectives is to provide growers with greater access to innovation in all its shapes and forms. Innovations can be new products or machinery but may also be novel ways of using an established technology or using a technology borrowed from another industry," she explains.

"We recognise that growers are becoming

Urban greening and the development of smart cities, created with Internet of things technologies, are possibly the future of urban living.

Loss of active ingredients

Assessing pesticides according to their 'hazard' rather than 'risk' in the EU has resulted in a slowing of the innovation pipeline.

**Results of study undertaken for ECPA and CropLife America by Philips McDougall, 2013*

more innovative themselves, with many doing their own trials to look at what works best in their situation. Part of our vision is to make innovation easier for growers by putting steps in that help make the decisions

There are now examples in crop production of the convergence in technologies that are underpinning the whole platform of innovation.

that facilitate change easier while removing some of the risk from the grower of adopting a new technology," she adds.

So how does she envisage overcoming some of the barriers to the uptake of technology and to innovators themselves?

Participatory approach

"From a research perspective, we're looking at a more participatory approach with growers when it comes to trialling and testing new technologies so the risk to growers is reduced. We can deliver this by developing farm excellence structures, such as the Monitor farms, but also by forming closer partnerships with the Agri-tech and established research centres," she explains.

"But a key element to making innovation more accessible is to relate it to a commercial farm practice. The impact on farm economics of adopting a new technology needs to be clear so we need to increase bench-marking activity to provide both the costs and benefits associated with any changes to farming practice."

On a wider scale, there's a move afoot in Brussels that may be good news for growers. The aim is to make Europe a less risky and expensive environment for innovators, explains Paul Leonard.

"The issue of increasing costs of compliance led to the proposal of the Innovation principle (IP) by the European Risk Forum, which states 'Whenever legislation is under consideration, the impact on innovation should be taken into account and addressed in the policy and legislative process'. Its adoption would help ensure the need to protect Europe's ability to innovate is not forgotten when writing or interpreting legislation," he says.

"The EU can't be globally competitive if

A key element to making innovation more accessible is to relate it to a commercial farm practice, says Susannah Bolton.

it's trying to eradicate technological risk and momentum is growing to ask the policy makers for a change in mindset. 22 CEOs of companies, across a range of industries, have signed up to the IP. With a combined R&D spend of €30bn and 1.5M employees, the people in Brussels are taking the IP seriously."

As far as growers are concerned, they're already making adjustments on the basis that chemistry will be lost and are turning to innovations in plant breeding as a way of dealing with the reduction in fungicide efficacy, says Scottish Agronomy's Andrew Gilchrist.

"The chemical 'prop' that existed a decade ago is diminishing so growers are being more innovative on farm and adopting a more holistic approach to growing crops," he says. ■

Brexit may help innovation flourish

The decision to Brexit means it's an interesting time for the UK, believes Paul Leonard.

"As much as fingers were crossed in Europe that the UK would vote to stay in, the decision to Brexit presents some important decisions to be made but also opportunities for the farming community. Legislation in the EU is presenting strong challenges and ultimately the UK won't be restrained to the same extent by EU policymakers and the debate in Brussels.

"Post Brexit, the UK will be able to choose the technologies that they're comfortable with. The country can become a first class 'laboratory', right on the doorstep of Europe. It's already a country with good soil, climate and scientific institutions and will have the opportunity to be the innovators of Europe — potentially an interesting scenario for investors as a proving ground for new technologies," he adds.

"The UK has always been a pragmatic partner in member state discussions relating to plant protection product regulation. For example, the UK didn't support the move to hazard-based systems for approval of PPP from one based on scientific risk evaluation. They didn't support the EU stance on neonics or glyphosate and were very supportive of green biotechnology, hosting GM trials.

"The UK will be able to make more decisions

Britain could potentially become more interesting for investors post Brexit as a country less constrained by the EU regulations.

as a pioneering Agri-tech country, free from many of the burdens which result from EU legislation," he believes.

Winning the race to stand still

> *“It’s unrealistic to suppose that present levels of food production can be maintained just by growing varieties with the best disease resistance currently available.”*

Technical
Plant breeding

Huge improvements have been made by plant breeders in the disease resistance of cereal varieties. But has fungicide chemistry helped its progress or stifled innovation? *CPM* assesses recent developments.

By Tom Allen-Stevens

Progress for a plant breeder may be a little like keeping up with the Red Queen in *Through the Looking-Glass*. No matter how fast the advances, all you’re doing is racing to stay in the same place. Despite continual improvements in the disease resistance of commercial wheat varieties, the key pathogens evolve and grow ever stronger.

“At the moment, it’s unrealistic to suppose that present levels of food production can be maintained just by growing varieties with the best disease resistance currently available,” argues Prof James Brown, project leader in crop genetics at the John Innes Centre.

“Significant progress in disease resistance has been achieved by breeders, but this takes time to develop. One of the main uses of systemic fungicides is to allow growers to achieve the genetic potential of a wheat variety, and control new and evolving pathogens, while the breeders are building in the defences that plants need to protect themselves.”

Balance in the field

It’s a balance that’s been played out in the field since fungicides were first introduced over 50 years ago, he says. “Previously, growers would either put up with a certain level of disease or grow crops that weren’t susceptible. Fungicides took the pressure off and allowed farmers to grow the food that consumers wanted at the level of production supply they demanded.”

But the pressure may now be coming back on, he fears. “If current regulations cause the number of fungicides or opportunities to use them to be greatly reduced, farmers won’t be able to respond to new diseases. What’s more, it’ll become much harder to control existing diseases effectively and combat unexpected outbreaks of disease on normally resistant varieties.”

Significant progress in disease resistance has been achieved by breeders, but this takes time to develop, notes James Brown.

There are a number of genetic factors that play into the mix and make breeding for disease resistance a very complex business, he explains. "When it comes to resolving a problem such as septoria resistance, there's the trade-off with yield, and breeders have to take that into account."

Recent research, supported jointly by industry and Defra through the Sustainable Arable LINK programme and carried out at JIC, traces this problem back to decisions made nearly 60 years ago. "What we found was that it related to wheat crosses made before septoria was ever even identified as a serious threat to wheat production," says James Brown.

He and a colleague Dr Lia Arraiano analysed resistance and susceptibility to septoria in wheat varieties grown in the UK between 1860 and 2000. Using a technique called association genetics, they found that the gene with the biggest effect on increasing susceptibility to septoria is very closely linked to one that increases yield and grain size.

"We discovered a small region of the genome that governs increases both in septoria resistance and yield. We traced it back to a variety called Heines Peko, which was used to breed for yield and rust resistance in the late 1950s."

Heines Peko was crossed with Cappelle Desprez, the major wheat variety in Britain at the time. This cross was so influential that all modern wheats bred in Britain are descended from it. "As wheat breeders selected ever more strongly for higher yield, susceptibility to septoria hitch-hiked along with it."

Breeders have discovered that introducing mutations of mlo result in broad-spectrum resistance to mildew.

Work is now underway to discover if the connection between the two traits can be broken. The research team has found ten other genes scattered throughout the genome with smaller effects on septoria. They also found that nearly half the variation in septoria was controlled by genes with effects that were too small to identify individually. "We know the genes are there, but we don't know where they are," says James Brown.

Durable advances

Focusing in on these genes will help commercial breeders make durable advances in septoria resistance without compromising yield, he believes, although significant progress has already been made. "For the past 10 years, no variety with a septoria rating lower than 5 has been added to the AHDB Cereals and Oilseeds Recommended List for winter wheat. There are now five varieties that combine septoria-resistance ratings of 7 with high yields," he notes.

There are other areas, however, where breeding achievements have resulted in undesirable trade-offs. "A major success in plant breeding for disease resistance is the broad-spectrum, durable control of powdery mildew in barley conferred by recessive alleles of mlo," notes James Brown.

Mlo is a gene in barley that causes a protein to interact with a plant in such a way that its natural defence is down-regulated. This makes the plant more susceptible to powdery mildew. So breeders have discovered that introducing mutations of mlo result in broad-spectrum resistance.

The mlo-11 allele is most commonly used and is currently present in around half the spring barley cultivars grown across Europe. Introduced from an Ethiopian landrace in the 1970s, this mutation results in very low levels of the MLO protein, which in turn confers very strong broad-spectrum resistance to mildew.

"It's been remarkably successful to the point that mildew is no longer considered a serious threat for spring barley growers," says James Brown.

"But there's a drawback. An undesirable side effect has been the rise of the leaf-spotting disease ramularia. Caused by the fungus *Ramularia collo-cygni*, this became a significant disease in 1998, but was little known before that. We now know that mlo makes barley more susceptible to ramularia although we don't know if that's what drove the rise of the disease."

The gene with the biggest effect on increasing susceptibility to septoria is very closely linked to one that increases yield and grain size.

This was confirmed in a study carried out at JIC and the James Hutton Institute and completed in 2014. Two doubled-haploid populations of spring barley were studied in field trials and in polytunnels. These showed the presence of mlo alleles increased the severity of ramularia, in both seedlings and adult plants.

In other laboratory experiments, mlo alleles have been associated with susceptibility to other diseases, including fusarium head blight and net blotch. "Although mlo mutations bring the benefit of mildew resistance in barley, there are alternative methods of control, such as systemic fungicides and breeding for partial resistance. Farmers have used fungicides to control ramularia and other diseases of barley. So even though mildew has been well controlled, farmers have not necessarily saved on fungicide inputs."

However, another observation of the mlo study was a large variation in susceptibility to ramularia across the populations in both the field and polytunnel trials. Further analysis of the genetics revealed other genes that conferred significantly less susceptibility to ramularia while keeping the benefit of mlo-11 to control mildew.

"The results here indicate that plant breeders should be able to combine mlo-11 mildew resistance and polygenic partial resistance to ramularia in spring ▸

Mlo makes barley more susceptible to ramularia.

barley cultivars. Indeed, that's what we've seen over the past 15 years as ramularia has grown in prevalence. Fungicides were relied on entirely to control this new disease in its early days, but now there are a number of varieties on the RL with good resistance scores for ramularia," he notes.

But has it been the RL and its focus on yield that has driven growers towards more disease-susceptible varieties and resulted in breeding for resistance becoming a lower priority? "I don't think that's a fair criticism of the process," counters James Brown.

"There have always been minimum standards for disease resistance and agronomic traits. Only varieties that have reached those minimum scores have made it onto the RL."

However, there has been a noticeable shift in recent years. "Clearly there's now a demand for growers for less reliance on fungicides, which may be driven by increasing resistance, as well as regulatory issues. There's also now a greater emphasis on disease ratings when selecting varieties for the RL — a high septoria score for example is given considerable weight in

Pre-breeding holds promise, but it's the long game

Pre-breeding research could be broadening the pool of genetic material available to breeders to build more resilient disease resistance into varieties. According to Dr Phil Howell of NIAB, there's no shortage of innovation nor determination to do so — it's simply a question of the right funding and enough time.

"In some ways, pre-breeding research has been a victim of its own success," he says. "We're capturing more diversity, but for this to be useful in commercial breeding lines, more interrogation of the material must be carried out, and there's no underpinning long-term funding for this work."

One on-going project underway at NIAB is MAGIC, a Multi-parent Advanced Generation Inter-Cross plant-breeding programme. This has taken eight well known varieties — Alchemy, Brompton, Claire, Hereward, Rialto, Robigus, Soissons and Xi-19 — and crossed them, every which way, to produce 1400 new lines, each containing combinations of genes from all eight parents.

This crossing has taken place over multiple generations, explains Phil Howell. "One difference between what we've done and what would happen in commercial lines is that we've kept every cross, and taken it to yield. What we're doing is shuffling and reshuffling the pack, and finding gene combinations that we haven't seen before. The genes themselves aren't novel, because they've come from parent material already in commercial lines, but there are some interesting new combinations."

Synthetic wheats mark a return to the original cross with wild goat grass which created hexaploid wheat.

One outcome he's confident is lying within these lines is a more durable yellow rust resistance, for example. "Single gene resistance is easy to track down these days with genetic markers. But the more durable multi-gene resistance relies on traditional breeder skills and selection to identify it and bring it to a stage where it can be introduced into commercial lines. We need time and resource to study the material to find out exactly what we have."

Arguably a more novel programme is NIAB's synthetic wheats. Researchers have returned to the original cross with wild goat grass which created hexaploid wheat some 10,000 years ago. "Modern varieties don't contain many of the genes that have been bred out over the ages, that could now be valuable in addressing today's breeding challenges. This programme gives breeders the opportunity to reintroduce that variation back into modern lines."

Genome editing may hold further promise for pre-breeding research. One recent success has been achieved by a group at the Chinese Academy of Sciences Institute of Genetics and Developmental Biology in Beijing. Using TALENs (transcription activator-like effector nuclease) methodology, the scientists have managed to induce mlo mutations in wheat that confer durable resistance to powdery mildew.

While this was bred into barley in the 1970s, as wheat is a hexaploid, the mutation had to be created simultaneously across each of its three genomes, and then faithfully inherited. This makes it the first heritable mutation of its type in hexaploid wheat, and the first instance of successful simultaneous editing.

But the technology has its limitations, explains Phil Howell. "Genome editing can help you target what you're looking for in a cross, but you have to know what you're after in the first place. The difficulty with most traits is that they're determined by a number of different genes in a number of locations. Another problem with genome editing is that regulators may consider it a form of genetic modification (GM)."

More interrogation of the pre-breeding material must be carried out, says Phil Howell.

The jury's still out on this one, with most nations and trading blocks, in particular the EU, undecided as to whether the technology can be adopted into conventional plant breeding. "So the technology exists to make major advances in disease resistance. But the commercial reality is that it's still a long way off. We are getting better with conventional plant breeding, but we need to retain our fungicide chemistry — if we rely on varietal resistance alone, we'll lose yield."

But what of the argument that tighter regulation encourages greater innovation? "If you take away key fungicides, it'll cause upset, but there are plenty of innovators in plant breeding who'll find a way around the problem, and eventually we'll return to the same level of production. The question is how long that will take, and what we would have lost in the meantime. Perhaps growers should be looking towards other approaches within an integrated control strategy," concludes Phil Howell.

The RL may have focused on yield but only varieties that have reached minimum scores on disease have ever made it onto the list.

the overall evaluation."

This has resulted in an RL with a good selection of robust varieties, he believes. "While 20 years ago, many varieties had good resistance to most diseases, they were susceptible to one or two others, so still needed a robust fungicide programme. Now, a rating of 5 or higher for all diseases is the norm. It's a slow improvement, because breeding is a slow process. But over the last two decades, it's been a dramatic improvement."

But disease continues to bowl its curved ball, and even the most robust, broad-spectrum varietal resistance is vulnerable. "Yellow rust is a classic example of the Red Queen's race that breeders are running," points out James Brown.

Single gene resistance

"Brigadier was a variety with very good resistance when it came on the market, but this relied on a single gene. The pathogen soon overcame this and the variety quickly broke down. Breeders have become better at building in both single gene resistance as well as greater levels of multi-gene protection and such dramatic breakdowns were rare between 2000 and 2010.

"But there's a real question mark over the pathogen now and it's a considerable challenge for breeders. Since 2011, new races of yellow rust have arrived in Europe. They're more aggressive than the old races and harder to control. We have to understand what's happening at a genetic level and how to breed varieties with built-in protection. In the meantime, I hope the regulators have the sense to allow growers continued access to a well equipped fungicide armoury." ■

There's a real question mark over yellow rust now and it's a considerable challenge for breeders.

Breeding pipeline set on right path

Richard Summers has a cautious optimism about the future. "If you look at the varieties now grown in the field, I'd argue breeders have got a good handle on disease resistance and we're heading in the right direction. What we can't anticipate is an unexpected twist in the pathogens we're dealing with. While we select resistance sources of proven durability, it's inevitable that some resistance genes will break down."

As head of cereal breeding and research at RAGT, he's been involved in a number of publicly funded pre-breeding projects, but has mixed views on their outcome. "Some people say the breeding pipeline is broken. I'd say it's strong and working well, so long as new technology and genetic traits are provided in a form readily usable by breeders. When that is the case, we have an excellent track record in delivering the benefit to farmers with new varieties," he says.

"There are clearly some useful alleles that have been identified through NIAB's MAGIC lines, for example. It's one thing to observe a phenomenon, but we need robust analysis to nail its utility. Similarly, with the synthetic wheats, there was much excitement at first about the yield potential they could offer, but we're yet to see this transfer into practical utility."

He's enthused at how gene-sequencing technology has advanced to such an extent that it's now possible to work on a genome as complex as wheat. "Such research could not have been done by a commercial breeder alone, but through collaborations, academics have produced some powerful tools."

But he strongly denies that fungicides may have held back innovation in plant breeding. "Most breeders select from untreated lines. What's more, if you look at the RL today, the gap between untreated and treated yield has decreased compared with ten years ago, thanks to untreated varietal performance improving at a greater pace. Equally, you could argue fungicides are less effective than they were, but you still get a significant yield response from them.

"And that's the key — growers will always look to maximise profitability, and both breeder and fungicide manufacturer will look to build the tools that enable that. If we bring a variety forward with an exceptional yield and quality, but one disappointing disease resistance score, farmers can choose to benefit from the variety's strengths because the judicious use of fungicides will protect against the known disease weakness. Breeders will then use the variety in further breeding and attempt to improve the resistance."

So while it's unlikely varietal disease resistance will take a dramatic step forward, growers already have varieties in the ground with a strong resistance package, he assures, and this is steadily improving and becoming more durable. "Modern varieties have performed well against today's more virulent yellow rust races, for example, and high-yielding varieties with a score of 7 for septoria resistance are further proof we are producing robust material. But we can't react quickly to the unknown threat, and that's where growers will continue to rely on a diverse range of fungicides."

Richard Summers looks to build varieties to maximise profitability for the grower, but fungicides are needed to ensure they deliver on their yield potential.

The quest to quell the shapeshifter

> *We discovered there had been a complete shift in the genetic make-up of the UK yellow rust population.*

Technical
Yellow rust

There's a battle farmers, plant breeders and researchers have fought across the globe over three millennia, against an adversary that continues to take on new forms. *CPM* charts the progress in plans to outsmart yellow rust.

By Tom Allen-Stevens

Picture the scene: it's 25 April, and a solemn group has gathered about five miles out from Rome. An unweaned puppy is brought to a makeshift altar, its throat is slit and a masked priest murmurs a prayer as he performs a precise and well rehearsed ritual with the blood and disembowelled entrails.

This is crop protection in around 700BC. The sacrifice is to appease the Roman god Robigus, feared and revered as the deity that can bring a harvest of plenty or ravage the crops with rust. It's this very same disease that even today is a major concern for millions of farmers, from the Americas to the Himalayas, from the Green belt of Eritrea to the arable plains of southern Sweden (see map on page 14).

Greatest concern

The pathogen of greatest concern in Europe today is wheat stripe rust, or yellow rust, caused by the fungus *Puccinia striiformis*. These days it rarely causes an individual crop to lose more than 10% of its yield and existing chemistry provides adequate control, according to a study carried out by Dr Colin Wellings of the University of Sydney, Australia. But its reach and spread puts the estimated annual loss from the disease well into billions of US dollars.

What's more, it's evolving. Rust generally reproduces asexually and needs green plant material to do so, although the fungal spores may survive a couple of weeks on dry wheat leaves or on contaminated clothing. This means varietal resistance is the first line of defence, and breeders are credited with success at introducing genes with strong resistance to the pathogen.

But yellow rust has fought back. A small mutation in an isolate can render a resistant variety susceptible, with dramatic consequences — the breakdown in the UK of Rothwell Perdix in 1966, Joss Cambier in 1969 and Sleijpner in 1988 are well documented and enshrined in the memory of older breeders and trials managers.

As a result, breeders across Europe are striving to build in more durable, long-lasting forms of resistance that are less vulnerable to changes in the pathogen population and draw their strength from a number of genes, rather than just one or two. Genetic markers are used to identify and stack resistance from a number of sources.

But one recent development has stunned breeders and the research community and brought about a complete rethink on yellow rust: the Warrior race. "It's the pace with which Warrior took over," notes Prof Mogens Hovmøller of Aarhus University in Denmark. "It appearedacross wide areas of Europe and in many countries within the same season and dominated the population in just the first year of detection."

The development of this new appearance has been tracked by the Global Rust Reference Centre (GRRC), coordinated by Mogens Hovmøller. The centre draws from information and samples provided by a global network of leading research scientists and monitors progress of major ▸

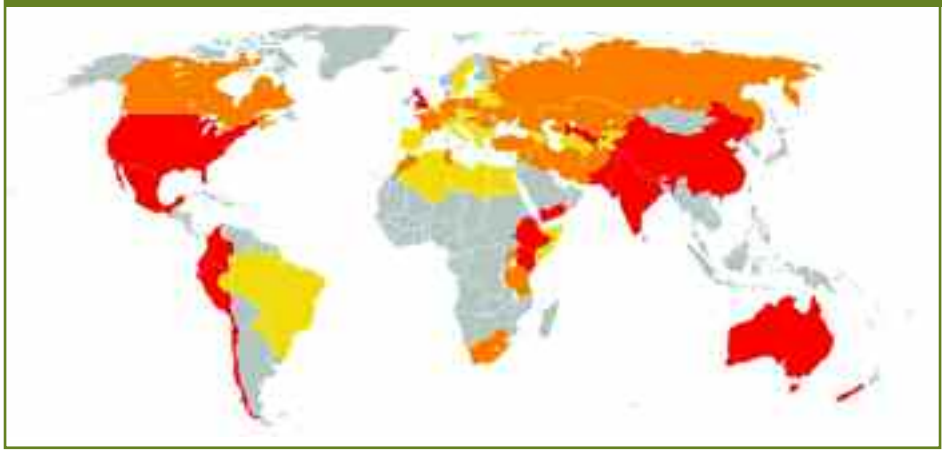
"When I test something it has to be my farm, my conditions, my soil."

Clive Bailys
Managing Partner of TWS Farms
and co-founder of The Farming Forum

BASF
We create chemistry

The Warrior race appeared across wide areas of Europe and dominated the population in just the first year of detection, says Mogens Hovmøller.

Current status of wheat stripe rust



Code	Incidence	Severity
	Rare	Negligible losses
	Localised, two in five years over 25% growing areas	1-5% crop losses
	Widespread two or three years in five over whole production region	5-10% crop losses

Source: CR Wellings, 2011, for period 2000-2009, from Euphytica vol 179

▸ rust pathogens around the world.

"The new race was then followed by Warrior(-), that's related but not the same, although we believe it's from the same source region. This currently dominates the population across Europe," he reports.

Other serious, recent incursions have caused widespread concern across Europe. "The Kranich race is one that's been found across much of Scandinavia and Poland, although few isolates have been reported in the UK. There are also two triticale races that have caused widespread damage."

One race was first identified in 2006. Once the race became widespread in 2009-2010, triticale crops thought to be resistant went from 0% to 100% infected in just a few days, causing yields to plummet to as little as 10% of the crop's potential. As a relatively young crop — a hybrid of wheat and rye — triticale hasn't benefited from the same durable rust resistance now built into wheat lines, notes Mogens Hovmøller.

"The epidemic hit organic growers particularly hard, although other varieties were then grown with better resistance. However, in 2015 another new triticale race appeared in many countries around the Baltic Sea and wiped out many triticale crops grown last year. As a result, Scandinavian organic growers are now switching out of the crop altogether. Fortunately, winter wheat varieties are resistant to these races, we believe, although they can grow well on spring wheat."

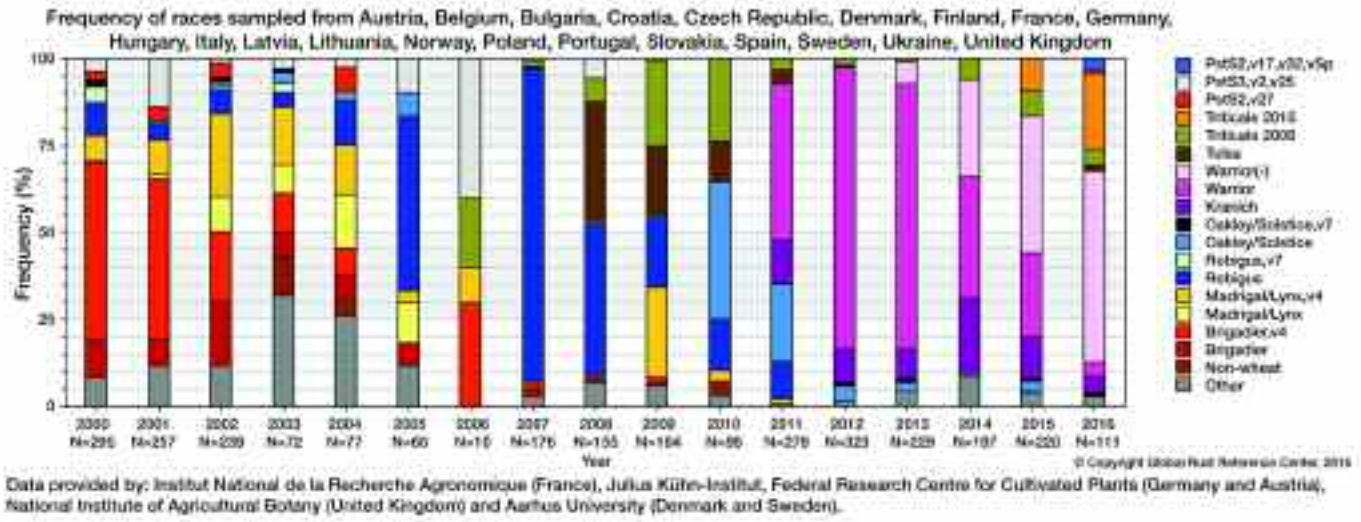
There are other developments in the rust population he's keeping an eye on, but that haven't been a concern — at least, not yet — to the majority of European growers. "There are two races, PstS1 and PstS2, that are causing considerable problems in N America, the Middle East and western Australia — places where yellow rust hasn't really been a problem before because they were considered too warm.

"We're particularly worried because these races are aggressive and adapted to high temperatures. We haven't seen them much in Europe, and believe that 95% of varieties here are resistant to them, but they could still be a threat if the pathogen changes."

Unknown origin

Hereford is another new race and its origin is as yet unknown. "We've only found it in Sweden and in wheat varieties with Hereford in their parentage. It's a concern because three of the most grown varieties in the country are susceptible, and the variety's

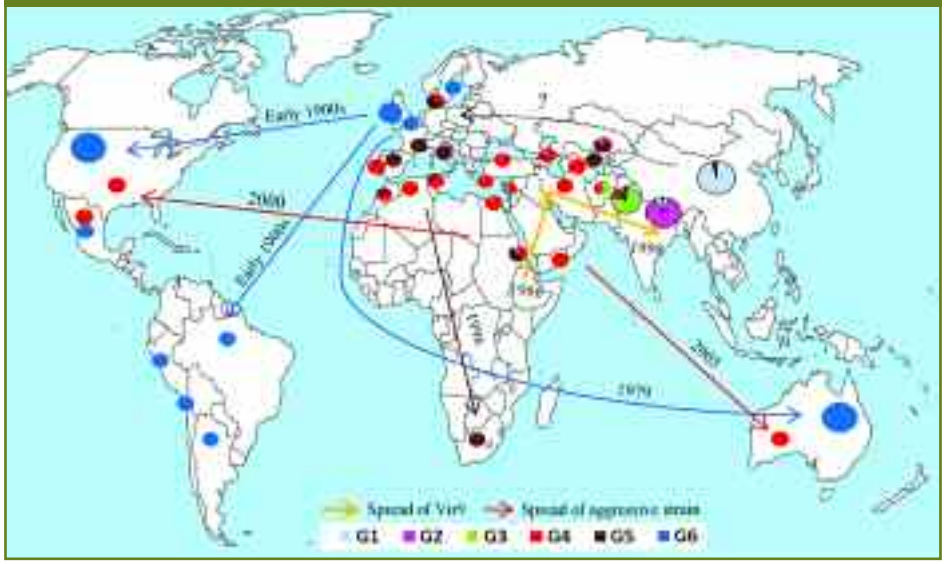
The evolution of yellow rust in Europe



Source: Aarhus University (DK), Global Rust Reference Center, 2016 (www.wheatrust.org)

Rust isolates may have evolved complex mutations, but they originate from a few distinct clonal lineages.

Migration routes of wheat yellow rust populations



Source: Ali S et al, 2014

used in breeding lines across Europe."

It may also be a worry for the UK, as seven out of 11 new winter wheat varieties that have just joined the AHDB Cereals and Oilseeds Recommended List also have Hereford in their parentage.

The overall picture on yellow rust has changed, confirms Mogens Hovmøller. "The turnover is more rapid, and new races become established over wider areas much faster. In the past, mutations would cause one or two varieties to become susceptible. But these isolates are more virulent and hit scores of varieties — its time of arrival and impact is completely unpredictable."

He believes changes in climate and growth patterns have combined to create a perfect storm and the ideal environment for yellow rust to thrive. "Right across Europe, wheat crops are now established earlier in the autumn, providing a green bridge for the pathogen. We've also seen a succession of mild autumns — if the night-time temperature in Sept and Oct is around 10°C and you have a dew during most of those nights, you couldn't ask for more perfect conditions for yellow rust to establish."

The origin of these new, more virulent races has quite profound implications, too. "Warrior and Kranich originate from the pathogen's centre of diversity in the Himalayas — genotyping has confirmed they are similar to isolates found in that region. How they got here, and whether they came in one go, with travellers for example, or wind borne in several stops, is unknown. That's significant because we now know sexual recombination is taking place in that region, producing a more diverse population."

Until recently, the rust population in Europe, although diverse, has been genetically very similar. Isolates may have evolved complex mutations, but they originate from a few distinct clonal lineages. In fact, it wasn't until 2010 that it was established that the pathogen could reproduce sexually.

To do so, teliospores, produced late in the season, must colonise an alternative host, such as common barberry. There they pass through a series of different spore forms, ending with aeciospores on the secondary host that then infect a wheat crop the next year. The new recombinant strain can ▸

These foreign incursions have the potential to take out a number of resistant genes at the same time, says Diane Saunders.

Which race is which?

Race	Also known as	Significance
Warrior	Warrior 1, Ambition, Cluster I (pink)	Took over and dominated population in UK and Europe in 2011. Now largely disappeared.
Invicta	Warrior 3, Cluster III (blue)	Found only in UK and first identified in 2015. Behaves like old Solstice race, but more closely related to Warrior.
Warrior (-)	Warrior 4, Cluster IV (red)	First identified in 2013 and currently dominant in UK and across Europe.
Kranich		Found extensively in Scandinavia and Poland, but not elsewhere, apart from two isolated UK cases.
Triticale 2015		Found in N Europe. Replaced Triticale 2006 and has wiped out many triticale crops.
Hereford		Currently found only in Sweden in three main varieties with Hereford in parentage. The variety's widely used in European breeding lines.
PstS1/S2		New, more aggressive and virulent isolates that tolerate higher temperatures, found in Middle East, USA, Australia, but rare in Europe.

Quite a few varieties are susceptible to Invicta, notes Sarah Holdgate, including Britannia, Leeds, Myriad, Reflection and Zulu.

▸ have a very different genetic make-up, which could affect its virulence and aggressiveness.

In theory, recombination in Europe is possible, but no evidence of this has yet been found. What's more, to survive, a new strain would have to compete with European strains that are regarded as the most virulent in the world.

Genotyping work at the Earlham Institute in Norwich is now providing researchers with more detailed information, characterising the recent dramatic changes in the wheat yellow rust populations in the UK. "Our new field pathogenomics method, developed in collaboration with NIAB, uses sequencing technologies to generate high resolution data quickly for describing the diversity in a pathogen population directly from infected field samples," explains the institute's Dr Diane Saunders.

"What we discovered is that there had been a complete shift in the genetic make-up of the UK yellow rust population. The old races have been replaced by Warrior and other new exotic races."

The significance, she says, is in how varieties have broken down. "Previously, you'd see a breakdown of one resistant gene as a strain evolved virulence to it. But these foreign incursions have the potential to take out a number of resistant genes at the same time. So what used to be a relatively gradual change is now increasingly unpredictable."

All varieties should be monitored, and if unusually high levels of rust are seen on one that should be clean, inform UKCPVS.

Genotypically, the new Warrior race is very diverse, and isolates found in the UK have now been classified into distinct clusters (see table on p15). "We're currently analysing the data for the 2016 season — we saw a slight change and an increase in the diversity, but more detail will be available in the New Year."

The lab now takes in samples from all over the world to help establish the potential origins of some of today's problem rust races. "We can provide a much faster turnaround on genetic information than researchers could access previously. We're developing these methods with the aim of being able to deliver a high resolution digital profile of a sample in just a single week. The technology is also getting cheaper, and we hope in the near future to fully integrate our techniques into the UK Cereal Pathogen Virulence Survey (UKCPVS)," says Diane Saunders.

New UK race

What it has revealed is the genetic make-up of Invicta, a new race in the UK population, reports Sarah Holdgate of the UKCPVS. "It was first detected in 2015, and behaved like the old Solstice race. Quite a few varieties are susceptible at the seedling stage, including Invicta — after which it is now named — Britannia, Leeds, Myriad, Reflection and Zulu. But we now know it's more closely related to Warrior, so isolates sit in the Warrior 3 group."

The impact of Kranich in the UK is as yet unclear, she says. "We picked up an isolate in Oxon in 2014 and one in Scotland in 2015 and that's curious in itself. Results from 2016 have so far been inconclusive, but there's been a definite shift in varietal resistance. We're not yet sure whether that's entirely down to Invicta, or whether another race, such as Kranich, has played its hand.

"My personal suspicion is that there was more than one race doing the damage, but our adult lines in plots inoculated with Invicta were swamped by the background population, so we don't have reliable data."

There's no evidence that current races are more aggressive, however. "If that was the case, growers would have to tighten the interval between sprays to less than the current two weeks. Having said that, anyone who's spot on with their timings and is having problems should let us know," notes Sarah Holdgate.

"So there's no change in sensitivity to fungicides — current chemistry is still highly effective. But correct timing is essential, because if this virulent rust gets into a susceptible crop, it'll do damage and will be tricky to eradicate."

Information from UKCPVS on varietal susceptibility has changed, with adjusted ratings taken straight onto the RL before the new list was launched in Dec. "The ratings are also now based on one year's data, which gives a better picture of how a variety will perform."

The main advice is use resistance ratings with caution. "Even varieties with a score of 8 or 9 should be monitored. Most wheat crops get a little bit of yellow rust, but if you see unusually high levels on one that should be clean, we want to know — KWS Crispin, KWS Siskin and Costello in particular should be spotless."

Mogens Hovmøller points out that one advantage for European growers in the battle against rust is that the legacy of virulent races has encouraged European plant breeders to focus on the development of varieties with relatively good durable resistance. It's a luxury not afforded to growers in other parts of the world, where breeding lags behind so they rely solely on chemistry to quell new virulent races.

"The years of diligence and skill invested by European breeders has paid off and the result is a fairly high level of background resistance, especially in adult plants. But a very early onset of the disease will cause substantial losses, even in resistant varieties."

He's now aiming to bring in a new early warning system for European growers, and is putting together a bid for funding under the EU's Horizon 2020 programme. "This will build on what we've achieved with the global network, but it'll have more of a European focus," he says.

"We need shared facilities, so we can test more rapidly and uniformly. Importantly, we want to be able to test a range of varieties from across Europe against a new strain we find and deliver the results quickly back to breeders, growers and extension services.

"Hopefully we can tighten up the time lag, and get reliable, definitive information on threats to specific varieties out to growers before Christmas. That way, before the spraying season even starts, growers will have a good idea of the pathogen they're tackling and how much their crop is at risk." ■

The question of selection

> *“It’s been very inspiring to have a helicopter view of what is around us, not just what we find in our own backyard.”*

Technical
Azole resistance

As each year passes, septoria becomes less sensitive to azoles, but the pattern across Europe varies. *CPM* reviews aresearch programme that’s explored this and assesses the implications for fungicide programmes.

By Tom Allen-Stevens

Be honest — peering over the hedge at what your neighbour’s doing is probably a pastime you enjoy more than you’d care to admit. When it comes to fungicide use, the marvellous reality is that you have a good excuse — your neighbour’s practice and how that’s affecting the population of septoria making its way into your wheat crop has a direct influence over how you might put your own control programme together.

So imagine how revealing it could be to peer into the fields and the practices of all your European neighbours. That’s exactly what a group of scientists, led by Lise Jørgensen at Aarhus University in Denmark, have done. They’ve spent the past two years comparing notes on the efficacy of different azoles and the effect they’re having on mutations in the septoria population.

Known as the Eurowheat project, funded by BASF, it’s thrown up some interesting results, says Lise Jørgensen. “It’s been very inspiring to have a helicopter view of what is around us, not just what we find in our own backyard. The main finding is the diversity that exists across Europe — it was a real surprise to me.”

Eurowheat extended the work of the Endure network. This was a collaboration of 15 agricultural research, teaching and extension institutes from across Europe with a special interest in Integrated Pest Management (IPM). Funded by the European Commission, the network came together from 2007-2010 to tackle the complexities of helping European farmers meet the challenges of the EU regulatory framework.

Useful network

“It’s always been a very useful network and we’ve stayed in touch and worked together on a number of projects since,” notes Lise Jørgensen. “It was at a meeting two years ago when we were discussing disease resistance that we came up with a plan to collaborate on some trials.”

The gradual erosion of azole performance and the increasing complexity of the septoria population were common threads in discussions between the partners. “The specific aim of the project was to look at the performance of azole fungicides and to profile this against frequency of CYP51 mutations.” This is the enzyme in *Zymoseptoria tritici* that azoles target — a mutation here confers a level of resistance for the pathogen.

The trials were carried out over two years, with 26 in 2015, across different locations and climate zones, from Ireland to Lithuania, Denmark to Hungary. There were a further 14 trials in 2016. Moderate to susceptible cultivars were chosen and sprayed with fungicides supplied by BASF at flagleaf emergence. In some cases, an early multi-site spray was applied to keep disease at acceptable levels.

The diversity in the how different azoles performed across Europe surprised Lise Jorgensen.

The major outcome of the project was the huge variability in how the various azoles performed across Europe. “There were some general trends, however,” she notes.

“Overall, the best control was achieved with epoxiconazole (EPX) or prothioconazole (PTZ) used alone or the co-formulations EPX plus metconazole (MET) and tebuconazole (TEB) plus PTZ.” (see panel on p18)

That’s largely as growers may expect, she points out. But what the researchers weren’t prepared for was the variation between ▸

Eurowheat involved members of the Endure partnership, who compared notes on the efficacy of different azoles and the effect they're having on mutations in the septoria population.

▸ countries. "Of the single azoles, TEB performed best in Belgium and MET achieved the best results in Ireland and France. TEB also performed fairly well in Ireland but poorly in other countries."

All treatments resulted in yield benefits. The co-formulations and EPX treatments gave the highest yields, while MET and TEB trailed behind.

The CYP51 values and EC_{50} values (the dose in a lab required to give half the maximum response) correlate with the results found in the field, reports Lise Jørgensen. "In Belgium, we got good field performance with TEB and a low EC_{50} value, indicating high levels of sensitivity.

"In some places, you don't see the nuances any longer, especially where the frequency of CYP51 mutations is high. This seems to be the case in the UK and Ireland to a certain extent, where there were relatively high EC_{50} values, while Hungary had much lower values."

Intensity of azole use is the main driver, she says. "There seems to be a gradient as you move across Europe — the further west and north, the more azoles are used, and the greater the frequency of CYP51 mutations. Away from the more intense areas, azoles are performing very differently, and this strengthens the case to retain a diverse range of azole fungicides."

Gradual shift

The trials in 2016 largely confirmed the results found in 2015, although performance of all azoles dipped slightly, which correlates with the gradual shift in performance over time, she points out. "Co-formulations again outperformed straights. Some mutations are more sensitive to certain azoles than others. By mixing complementary azoles, you hit a wider spectrum of septoria isolates."

The trials highlight the importance of appropriate dose, she points out. "Growers shouldn't be too keen to keep the leaf clean. Where mutation frequency is lower, you can apply a lower dose and make fewer applications. In Denmark, for example, good control can be achieved in most years by applying two 40-50% doses at the T2 and T3 timings. Sometimes you may need a T1 azole, but it's better to increase the dose than the frequency."

The situation in the UK is somewhat different, notes Dr Neil Paveley of ADAS. "What's clear from the Eurowheat data, particularly on frequency of mutations and EC_{50} values, is that the UK septoria population is less sensitive than elsewhere in Europe."

That fits with AHDB Cereals and Oilseeds fungicide performance data, he notes. "We're getting lower efficacy than elsewhere, and that's the result of how wheat has been grown in the UK.

"Historically, growers have chosen high-yielding varieties with poor disease resistance, such as Riband, Consort and KWS Santiago, in an environment very conducive to septoria. So in the UK, we apply three and a half fungicide treatments to wheat crops, while elsewhere in Europe it's just over two. It's no surprise, then, we're selecting very hard for resistant strains."

Using products with different modes of action is the main resistance-management strategy, emphasises Neil Paveley. "But it is helpful to have a diversity of azoles available so we can use different ones throughout the programme. If regulation removes some azoles from use, we'll select much harder for resistance against those that remain."

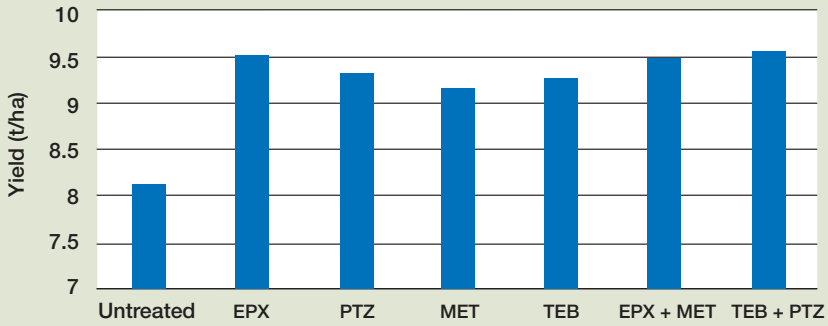
Previous research has shown that increasing the dose or the number of sprays applied, or splitting the dose, all increase selection for resistance, he continues. "Whereas adding a mixture partner of a different mode of action or alternating can reduce selection."

When building programmes, he believes it's essential growers and agronomists look to protect the efficacy of the chemistry they have. "Start with multi-sites and make best

The distribution of CYP51 mutations can be found on the Eurowheat website (www.eurowheat.au.uk).

Control of septoria on leaf two across Europe in 2015 (%)

Country	Untreated	EPX	PTZ	MET	TEB	EPX + MET	TEB + PTZ
	-	125g/l	200g/ha	90g/ha	250g/ha	112.5 + 82.5g/ha	125+ 125g/ha
Denmark	72.5	76	79	62	55	83	75
Denmark	58.8	60	52	45	43	60	53
Denmark	40	75	63	47	47	71	56
Poland	5.3	45	59	62	62	69	50
Poland	17.5	90	63	56	62	91	65
France	79.7	58	48	69	57	81	72
Germany	30	80	93	77	50	87	73
Ireland	74.9	60	38	84	69	86	77
Belgian	35.5	28	63	46	72	85	74
Belgian	28.3	56	70	57	58	64	66
Hungary	45	83	56	47	11	89	58
Hungary	50	72	60	67	70	90	75
Average	44.8	65	62	60	55	80	66



Source: Eurowheat, 2015; EPX - epoxiconazole; PTZ - prothioconazole; MET - metconazole; TEB - tebuconazole; Red - disease severity of untreated plots (%); Green, yellow, orange - high/medium/low treatment effect. For treatment effects in the table, read left to right.

use of those. SDHI chemistry is where growers should be most careful. Unlike elsewhere in Europe, the UK allows up to two applications of SDHI in a season, but that should be the exception, rather than normal practice."

He believes there's also opportunity to slow the azole decline by cutting down on their frequency of use across the programme. "The question is: where do we have a bit of wriggle room to reduce the selection for resistance? We don't want to mess with the T2 spray, but if we look at T3, particularly if it's a septoria-resistant variety in a year with a low fusarium risk, we should ask ourselves whether we really need an azole there.

Is an azole really necessary for a septoria-resistant variety at the beginning and end of the season in a low risk year?

"At the other end of the season, again if you have a septoria and rust-resistant variety, the multi-site may be enough to protect the crop at the T0 timing, while strobilurins can cope with low levels of rust."

But frequently these choices revolve around the disease resistance of the variety. "With the exception of Group 3, there are now plenty of varieties on the AHDB Cereals and Oilseeds Recommended List for winter wheat with a 6 or 7 rating for septoria resistance and manageable yellow rust resistance. They are more forgiving varieties in terms of dose, number of treatments and timings," says Neil Paveley.

While growers need to keep disease under control, he stresses it's also important not to push the septoria population too hard and select for the more resistant mutations. "We want to avoid building such a sophisticated population that we put the new chemistry under pressure.

"One of the main reasons for this is that in a couple of years' time, we will hopefully have a new azole, Revysol. It could prove to be a game changer because we still have a septoria population that's largely sensitive to it. This could take programmes to a stronger position in terms of performance as well as protecting other chemistry. We need Revysol to arrive into a good place in terms of the septoria strains we're asking it to control, and care taken over fungicide programmes now will help ensure that," concludes Neil Paveley. ■

UK growers have chosen high-yielding varieties with poor disease resistance, which has driven resistance, says Neil Paveley.

Luck of the Irish keeps septoria at bay

Septoria control has been good for the past two seasons, reckons Irish independent agronomist Eoin Jordan, based in Co Carlow, south west of Dublin. But he feels that's as much to do with luck as good management.

"Weather plays such an important part in how septoria is kept under control," he says. "Growers are now more aware of what needs to be done and focused at getting on at the right time. But with the chemistry we have, while azoles still work well preventatively, if you move into a curative situation, it's a slippery slope and you're fighting fires with a very poor fire extinguisher."

The results of the Eurowheat research aren't a surprise in terms of the make-up of the population, compared with the rest of Europe. "Irish growers have known for a few years that we're tackling a difficult septoria population, and that sticking to one azole isn't the solution. Anecdotally I've heard about the performance of MET, and plan to look at this in 2017, but I'd be nervous about relying on TEB at a key spray timing."

But one change he's made to help protect the chemistry is to largely remove the azole from the T0 spray timing. "I've found that you may have some septoria in the crop by GS32, but an early dose of chlorothalonil (CTL) keeps it at bay. If you apply an azole early, all you do is select out the trickier strains that then move up through the canopy and present a tougher challenge later in the season."

T1 is when Eoin Jordan likes to "hit septoria hard", and this will always include CTL onto which he'll generally build a straight SDHI fungicide. The azole element is usually Gleam (EPX+ MET). "Sometimes we'd go with Adexar (EPX+ fluxapyroxad), but we've found a co-formulation of azoles with a straight SDHI works well, and you cannot compromise. We keep rates of azoles at 80-90%, while SDHI should be up at around 80%, too."

At T2, he'll use a "good SDHI", such as Imtrex (fluxapyroxad) with the CTL base. "This is where I'd look to change around on azoles, so perhaps use PTZ, if I'd used Gleam at T1, and/or possibly TEB. I've heard about good results with Librax (fluxapyroxad+ MET) which I plan to investigate in 2017.

"But choice of product is really a secondary consideration for us. Far more important is to get the timing right with an application that has a good spread of modes of action."

By the time the T3 comes along, Eoin Jordan hopes to have a crop with a clean canopy, and fusarium would be the focus. "Generally, a TEB plus PTZ co-form would be the norm. Often we'll add a strobilurin plus CTL."

As azole performance has slipped in recent years, he doesn't regard them as the primary elements of a programme — they're there to protect the chemistry and bolster performance, but it's a strategy built around CTL and SDHIs.

Azoles still work well preventatively, says Eoin Jordan, but if you move into a curative situation, you can be fighting fires with a very poor fire extinguisher.

"We're getting good results from SDHIs. That struck home in 2015 — those who compromised rates or left out an SDHI got clean crops, but they ran out of steam and didn't deliver the high yields achieved by growers who'd made the extra investment.

"It's only after a season has ended that you can review it and say you could have cut down on an azole here or reduced dose there. But that's a risky strategy. I'd far rather maintain doses and retain a choice of products in the armoury," he concludes.

Farming a land of plenty

Features
World farming

Agriculture in Ukraine is on the up. *CPM* gains an insight into the 'bread basket' of Europe, where size is everything and full production potential is yet to be fulfilled.

By Lucy de la Pasture

Although Ukraine's economy is undoubtedly struggling, agriculture's the one sector providing growth and attracting investment.

The country shot into the limelight in late 2013 when political unrest erupted in the streets, leading to the deposition of the then-President. At the heart of the crisis was a set of trade deals — one with the European Union and the other with Russia which marked a choice of Cold War importance. Ultimately Ukraine aligned with the West, signing an Association Agreement which has led to reduced and suspended tariffs on trade with the EU and increased quotas for selected items from Ukraine.

But despite the subsequent annexation of Crimea and the ongoing turmoil in the south-east of the country, Ukrainian agriculture is booming. Britain Mike Lee works as a freelance consultant, agronomist and crop-touring blogger, providing independent information on farming, agri-business and associated issues in the Black Sea region, including Ukraine, Russia, Belarus and Kazakhstan.

While the conflict in the east of Ukraine is serious, it doesn't impact that much on the day to day life across the rest of the country, he explains.

Deep, fertile soils

Known as the 'bread basket' of Europe, Ukraine boasts deep, fertile soils and some 32 million ha of prime arable land. More than half the soil is 'chernozem', a black coloured soil that contains a very high percentage of humus (3-15%) along with phosphoric acids, phosphorus and ammonia.

With soils up to 1.5m deep, Ukraine can grow almost any crop producing around 60M tonnes of grain and is one of Europe's leading producers of wheat, with 26M tonnes harvested in 2016, he reports.

For the adventurous minded and agribusinesses, Ukraine offers a wealth of opportunity, believes Mike Lee. He has a long association with Eastern Europe, having managed large farming operations in Ukraine and Russia and he currently operates a Black Sea 'crop tour'.

The crop tour isn't exactly a bus load of farmer tourists, more an appraisal team which scouts the potential of crops in the ground by travelling a route across the country, planned to give a representative flavour from the different cropping regions, he explains.

Ukraine agriculture has been punching well below its weight, but Mike Lee believes farming is only going to get bigger and better.

This autumn, wet weather has hampered drilling, with the wheat area 1.4 million ha down on the initial forecast figure, according to the latest figures. One of the problems with forecasting yield in Ukraine is that the crop can be greatly affected by winter weather conditions, explains Mike Lee.

"Winter kill rates are difficult to assess with certainty but it's generally accepted they're normally around 3-5% although they can be as high as 10 or 15% in a difficult year."

Because the flow of accurate information from official sources can be scarce —

> *It's going back to basics and it's exciting.*

typical of a former-Soviet Union country — accurate reporting of crop condition and production prospects is largely lacking. That's why the crop tour provides such valuable feedback for his subscribers — largely commodity traders — on the state of the crops in these Black Sea countries, where weather conditions can have massive influences on production, he explains.

Agriculture in Ukraine is pyramidal in structure, with a few large businesses (agro-holdings) farming land banks which make the largest UK estates look like mere plankton in the agricultural pond. Typically, agro-holdings lease land banks from 10,000-500,000 ha in size — it's farming on a scale that's mind-blowing.

A step down from these massive farming companies are holdings more comparable in size to the largest UK enterprises but at the other end of the spectrum. "There are still peasant farmers who operate them with horse and cart and are largely self-sufficient," he explains.

For the adventurous minded and agribusinesses, Ukraine offers a wealth of opportunity – you can grow anything.

At first glance, the dichotomy that exists between Ukrainian farming businesses appears surprising for a former Soviet-block country, but it's that heritage that makes it possible to have farm holdings that are vast in size.

Moratorium on land sales

When the collective farms were closed down in the 1990s, after Ukraine gained independence, the seven million former farm employees were given a pai or land share, on average around 4ha. There's a long-standing moratorium on land sales in Ukraine, recently extended to 2018, which means land can't be bought or sold. But in spite of this, the majority of land has fallen into the hands of a few because of land leasing, which in effect means land is easy and cheap to come by.

"Anyone could go farming in Ukraine tomorrow, leasing land at a pittance in comparison to the cost of land in the UK. Land leases cost key money in the region $200-600/ha and run for a minimum of seven years, with the leaseholder having the right to renew and the first right to purchase. Annual rents are payable at approx. $100/ha but is often paid to the local landlords in grain rather than cash."

Typically, agro-holdings lease land banks from 10,000-500,000 ha in size – it's farming on a scale that's mind-blowing.

Mike Lee believes Ukraine promises an exciting adventure for western Europeans prepared to leave their western business values at the door.

"There's a lot of talk about corruption in Ukraine, but it's not a problem if you take local advice and build a rapport with the local administration," he explains.

"When I managed a holding in Ukraine, I soon learned to employ a Ukrainian national to deal with the local administration. It wasn't unusual to be visited by the fire brigade and be presented with a spurious and enormous fine. When you get to know how things work, the real reason behind the visit was the local administration were short of funds to pay their wages bill, so were trying to ▸

Fleets of the biggest Claas Lexion combines, one behind the other, together cut a 100m swathe of crop at a time.

bridge the gap," he explains.

It's a very different business culture, but if you're prepared to help out the local community and administration, then you'll find they return the favour, he explains.

"You're more likely to receive a phone call when one of the tractor drivers has evidently had a little too much vodka than find they've been carted away by the police."

One of the things Mike Lee loves about farming in the Ukraine is that it makes you think. It's not a case of just transferring the agronomy practiced in the UK, but more about using its fundamental principles to find solutions.

"Local agronomists are a step-up from a tractor driver in Ukraine. It's a legal responsibility to employ one agronomist per 5000ha and they're responsible for spray application. It's very different to the type of agronomist we have in the UK."

As a consequence, over-application of pesticides has been common practice and it's a problem Mike Lee has come across. He discovered the locally trained agronomists would apply insecticide each year when a May bug swarmed into wheat crops in the spring.

"When the bug arrived, I went into the

Efficiency at heart of farming giant

The Mriya Agro Holding land bank is 175,000 ha, with land in six regions of western Ukraine — Ternopil, Khmelnytsky, Lviv, Ivano-Frankivsk, Chernivtsi and Rivne regions — and employing a staff of 2000 people. The company also owns seven modern elevator complexes and four grain storage facilities.

Mriya grows winter wheat and OSR, with a planned planted area of 94,400ha, and the remainder due to be sown with spring crops — sunflower, corn, soybeans, barley and potatoes — in 2017. Sugar beet is also set to join the rotation, with an area of 3000ha.

The company aims to simplify the logistics of managing such a large area by grouping the different crops into clusters.

"There'll be about 10-12,000ha of each crop in a region, rather than pockmarked fields and a "chessboard" effect, and there'll be one crop per area which will take turns," explains Victor Kuharchuk.

"By structuring the rotation this way, I think we can add approximately 60% to the machinery output efficiency. It's more efficient for logistical purposes and we'll be able to gain more advantages from it. The better we can do our field work the more intensively yield will increase."

A land holding of 175,000ha means several state of the art storage facilities are needed

Talking to Victor Kuharchuk, it soon becomes very clear that his business is structured with lowering the costs of production as the major emphasis.

"The main challenges we face are uneven surfaces and weeds. These are simple basic things that if resolved, will allow us to reduce production costs," he says. "For the second consecutive year, we're intensively working on levelling the fields, because an uneven surface makes producing high yields impossible.

"We made a decision to create a land leveller, which is proving to be very efficient. It works by cutting the ground from the 'hills' and moves it along the field, filling in any 'holes' along the way. The land leveller works across the field 3-4 times in different directions and, as a result, we get almost perfectly flat field surfaces with the added advantage that the Mriya leveller is very economical and doesn't require costly repairs," he says.

There has been increasing drought in Western Ukraine over the past two years. Even rainfall events or periodic reductions in temperature can't compensate for the extremes that accompany climate change, believes Victor Kuharchuk.

"We consider it isn't appropriate to plough or work soil at a depth as primary tillage, because of the lack of moisture in the ground and the consequently higher costs of repair to the equipment because it's working such dry land. We can't allow a reduction in machinery performance or loss of soil moisture, which impacts on the yield.

"So, we're looking for the best combination of technologies which can add value and we're considering the possibility of using strip-till or precision planters. Last year, for the first time in the history of Mriya, we started using min-till and no-till technology.

Crop production in the Ukraine isn't just about costs, it's about people, says Victor Kuharchuk

"We seeded winter wheat with spreaders, and then seeded spring barley in the same way but we've gone even further. We've just scattered grain around and didn't disc it after seeding, so the seeds were just lying on the ground surface. They turned out to be some of the best fields for the company. But if you choose a non-traditional technology, it's very scary."

But crop production in the Ukraine isn't just about costs, it's about people, says Victor Kuharchuk.

"The responsibility of people has the greatest impact on efficiency. Regardless of the amount of money invested into technology, irresponsible people will always bury it firmly and deeply. Everything is possible with the right people."

** Photographs and interview supplied by Latifundist.*

Sunflowers are a major crop in Ukraine, so high-clearance sprayers are in big demand.

crop and watched. I saw that most of them were actually mating, with very little crop damage from grazing. So I made the decision that it wasn't necessary to spray and could justify that decision on the basis of my observations and agronomy experience. It's going back to basics and it's exciting," he enthuses.

Oilseed rape was being routinely sprayed in the autumn for phoma and light leaf spot because the culture was to see the disease in the field and spray. There was no concept of thresholds, so a lot of spraying being done wasn't necessary.

"Because of the importance of the flag leaf timing in the UK it's easy to apply the same thinking here. But in Ukraine, septoria isn't the same yield robber because it gets very dry in the summer. On the other hand, one of the major threats to wheat is fusarium ear blight because of the mycotoxins they produce.

"We're currently debating whether the T3 spray is more important than the T2 and we've done trials looking at the margin over fungicide costs to help us decide where to best target spend," says Mike Lee, adding that crop producers are going to get even savvier with their agronomy over the next few years.

In recent years, crops have improved and spray applications are becoming more targeted. "When I started working in Ukraine, I was frustrated by the lack of progress in crop production, but they've transformed production systems in the past few years. Many people like to think that it's US, Canadian and Western European companies and their advisors who've made this difference, but I think that it's Ukrainians doing it for themselves."

One thing's for sure, Ukrainian agriculture has been punching well below its weight, but things are moving forward now in a very positive way, believes Mike Lee.

Policy decisions

"The Ministry of Agriculture seems to have got its act together and is making good policy decisions. Ukraine is struggling economically but when money does eventually come into the country from foreign investors, the yield potential is here," he says.

He firmly believes agriculture in Ukraine is only going to get bigger and better. "Ukrainian growers are currently producing wheat yields averaging approx. 3.5t/ha. But some of the better growers are achieving 6-7t/ha, which gives some idea of the potential production. Water availability will be the limiting factor, so growers have to be careful not to overspend," he adds.

Keeping a close eye on costs of production is an important part of agricultural business thinking, believes Mike Lee.

"I work with a farmer in the south of the country who has come over from Australia, so he's familiar with growing crops in a dry climate. He reports his yields in terms of kg per mm of available water, so he's able to calculate his yield potential in relation to water availability. He can then adjust his inputs accordingly during the season to take this into account. That means he keeps control of his costs of production when water is limiting and maximises his return."

Ukraine boasts some of the richest and deepest black soil in the world.

The most popular self-propelled machines have a 3-4000 litre capacity, with twin-fold 27m or 30m booms.

The lower yields in Ukraine are offset by the costs of production which are comparatively low, and a move towards low or no-till systems is further reducing costs. Big land areas warrant big hunks of machinery — huge 500-600hp tractors, 12m seeders running in tandem and fleets of the biggest Claas Lexion combines, one behind the other, together cutting a 100m swathe at a time.

Many farms are investing heavily in technology and machinery because of a recent change in tax policy by the government, explains Andrei Botnari, Household's export manager. Any profits are now going back in to the farm to avoid being taxed.

Household's have been working in Ukraine for the past 4.5 years and are expecting sales of sprayers to continue to grow. One of his observations is that the most successful foreign businesses working in Ukraine all employ local nationals.

"It's important to understand the language and the culture to make sure you can fully understand the needs of Ukrainian businesses. We've modified our sprayers for the Ukraine so that they fit the needs of the farmers. Because sunflowers and corn are widely grown, the main requirement is for high-clearance equipment. The OSR varieties being grown also tend to be tall," he adds.

"There's a niche for every sized sprayer in Ukraine but the most popular self-propelled machines (approx. 70%) have a 3-4000 litre capacity, with twin-fold 27m or 30m booms. But some large holdings have massive boom widths of 54m and sprayer tanks holding 8-10,000 litres.

It may be a tyre-kickers paradise but the sheer size of farming operations highlights a crucial factor in crop production — the power of logistics. One of the strengths of Ukrainian farming is they understand what needs to be done and how to get a job done on time. ■

Going back to the future?

Features
Azole fungicides

They may have been with us for the past four decades, but the history of azoles is a remarkable story of innovation and success. *CPM* explores the surprises they may still hold in store.

By Tom Allen-Stevens

"Do you have anything new up your sleeve?" The question, posed in 1977 by Prof John Lucas, who at the time was running the Crop Protection course at the University of Nottingham, was innocent enough.

Len Copping, who was leading a tour for the students of research facilities at what was then the Crop Protection Discovery facility at Boots, shrugged his shoulders. "There is this new coded material that shows some activity on mildew," he said.

Widely used products

He was referring to prochloraz, that was one of the earliest azole fungicides introduced, and became, as Sportak, one of the most widely used products on commercial arable crops. "Azoles have been in practical use for more than 40 years, and yet they've retained their pivotal role in the fungicide armoury," notes John Lucas.

"They are curative, durable and have very interesting properties across a wide range of pathogens. They still account for around 30% of global fungicide sales

The strength of azoles is that they target the CYP51 enzyme and stop it functioning, which severely compromises the growth of the pathogen.

> They are curative, durable and have very interesting properties across a wide range of pathogens.

— more than any other fungicide class."

But it may have been the early indications of resistance risk to older chemistry that brought them to prominence in the early days. "Growers had MBC fungicides, so there was little perceived need for new chemistry. Then MBCs went down to resistance, just after prochloraz was launched, and interest switched to azoles in a big way. The whole chemistry has a common target site, but there's a lot of variety in the properties of the various molecules."

This target site is the 14α-sterol demethylase enzyme, commonly known as CYP51. John Lucas has worked on resistance mechanisms since the 1970s and believes that this is the key to the success of the chemistry.

"It's proved to be an extremely effective target, as without a functioning CYP51, the growth of the pathogen is severely compromised. It's also a highly conserved protein, so it can't change that much without affecting its function. Whether by good chance or good judgement, it quickly became clear this was a very good target to inhibit, and this paved the way for a succession of azole fungicides, all with slightly different properties."

Reduced sensitivity

Throughout the 1980s and early 1990s, a large number of agricultural azoles and triazoles were introduced onto the market. "The different ways the azoles behave has affected the way resistance has developed. It's not true there's no cross-resistance — there is. But within the reduced sensitivity shown by pathogens, there's wide variation in the extent to which different azoles are affected," he explains.

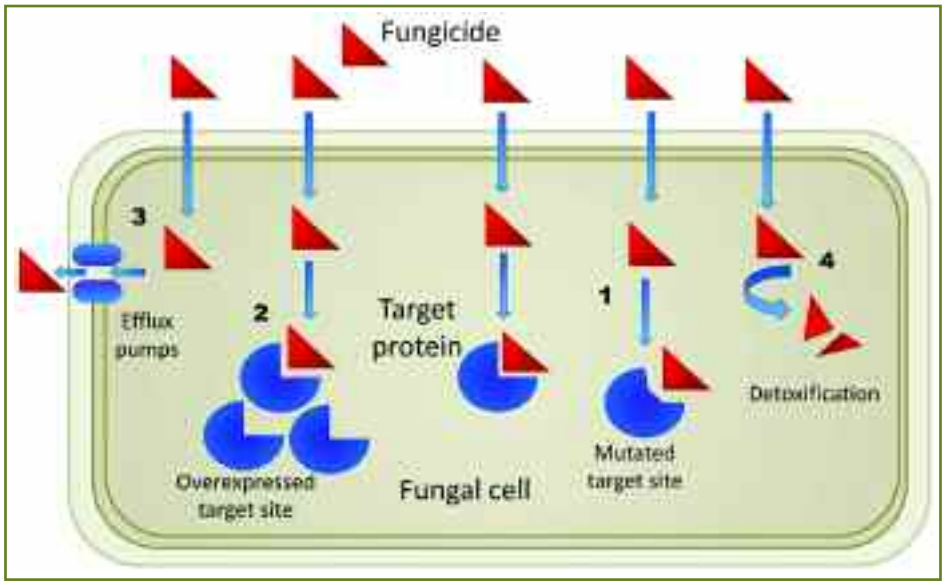
"So some mutations that cause resistance to tebuconazole actually increase sensitivity to prochloraz, for instance. In *Zymoseptoria tritici*, the early azole chemistry has become a lot less effective, but it's been a gradual erosion, rather than a collapse. We now know a lot about how that has happened."

The demethylation inhibitors (DMI) fungicides, which include the azoles, work by inhibiting the biosynthesis of the key CYP51 enzyme. Resistance to them began with mutations in the target site. These prevent the molecule from binding to it, illustrated in (1) in the diagram below.

"Initially it was a simple story, but from the mid-1990s, there were further mutations, and these combined with the previous changes. Today you can find some mutated isolates with eight to ten multiple changes. Some of these mutations don't directly affect resistance, but may help the protein to function in the presence of other changes," says John Lucas.

Azoles have been in practical use for more than 40 years, and yet they've retained their pivotal role in the fungicide armoury, notes John Lucas.

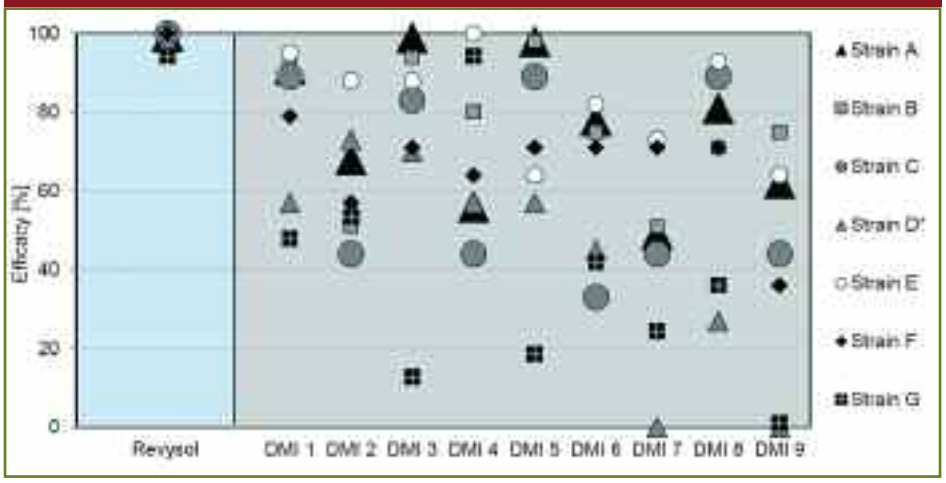
It's now a complex picture with a mixed population of isolates developing that have varying degrees of resistance, but some might be less fit and so are less competitive. "You do get highly resistant isolates, but so far they haven't predominated. To a certain extent, that's saved the azoles, which is why we see a gradual rather than complete breakdown in efficacy." ▸



Resistance to azoles began with mutations in the target site (1), while some isolates overexpress the CYP51 gene (2). Efflux pumps (3), enable the cell to expel the fungicide, while it can also detoxify the chemistry (4).

Revysol has a unique isopropanol moiety, says Jens Bruns, that seems to open the binding site, so potentially there's less chance of mutations happening.

Efficacy of various DMI compounds



Highly adapted strains A to G of Zymoseptoria tritici *were treated in the glasshouse with a 33% registered dose of ten DMI compounds, including Revysol and assessed one day after inoculation. *Strain D=MDR phenotype.*
Source: BASF

▸ Other resistance mechanisms exist, however. Some isolates overexpress the CYP51 gene, so provide more of the target site for the molecule to bind to (2). "It adds another increment, and if you have an isolate with mutations and overexpression, that puts resistance on a higher level. Fortunately, this is relatively rare, however."

Another mechanism, known as efflux pumps (3), enables the cell to expel the fungicide, while it can also detoxify the chemistry (4). "These mechanisms have been shown to affect sensitivity in lab tests, and they're not specific to a mode of action. But there's less evidence that they're contributing greatly to resistance in the field," notes John Lucas.

"So there's the potential nightmare of multiple mechanisms developing, and an evolutionary arms race taking place in the field. They now face even greater challenges with the new hazard-based regulatory system in Europe. But one encouraging aspect about azoles is their remarkable history of innovation and success. This is why the introduction of a new molecule in the class is particularly significant."

Azoles now face even greater challenges with the new hazard-based regulatory system in Europe.

In March 2016, BASF unveiled Revysol, its new "blockbuster" azole. It's not due to hit the market until 2019, but there are high hopes for this new active. "I'd be very surprised if it didn't have a few tricks up its sleeve. Septoria is the big issue, and it will need to prove itself against resistant isolates."

Regulatory environment

But John Lucas has concerns about the regulatory environment into which it'll be introduced. "One of the aspects that's kept azoles so successful is the different properties they have. To limit the effect of resistance, we need as much diversity as possible, and if regulation limits the number of products on the market, that'll put an extra strain on those that remain."

Dr Jens Bruns, BASF European product manager for Revysol, reveals the company also has high hopes for the new azole. "We're excited, but we're also worried. If it arrives and there's nothing to protect it, it'll come under huge pressure, especially if SDHIs have started to lose their efficacy.

"With Revysol, we've shown we can innovate, but increasingly we're spending a lot of our resources conserving what we have, although if it wasn't for the legislation, we may not have come up with a solution that's as good as Revysol."

All azoles are characterised by a triazole ring, and it's this that does the binding to the target site. With Revysol, it sits on the neck of a slim isopropanol, which allows it to form a hook. Lab tests show this blocks the site of the enzyme and binds 100 times better than other azoles, according to BASF scientists.

"It's this unique isopropanol moiety that seems to open the binding site, so potentially there's less chance of mutations happening," explains Jens Bruns.

With pesticides facing new regulatory demands in Europe, BASF has taken a fresh approach to screening new chemistry. "It's one reason why no new azoles have been launched in the last ten years. We've established a new screening method — a new active needs not just high activity but also no potential downsides that could prove a regulatory challenge."

But it's where Revysol sits in the resistance management story that may be of most interest. "In our tests, Revysol is controlling all strains of septoria. That's very good control, not only of existing, shifted isolates, but includes those with overexpression and efflux pumps," reveals Jens Bruns (see chart above).

Out in the field, this translates to noticeably improved performance. NIAB technical director Bill Clark has seen the chemistry perform in trials against prothioconazole where a single application of each azole was made at GS39. "We know that prothioconazole is giving good protectant activity, but it's not such a good eradicant," he notes.

"So in the trials, leaf 1 in both cases was clean. In the prothioconazole trial, there was septoria present on leaf 2. But in the Revysol plots, leaf 2 was clean. This shows good eradicant activity has been restored."

John Lucas feels such performance may just be the start, and that new technologies have a lot to offer this

Bill Clark says field trials show good eradicant activity has been restored with Revysol.

40-year-old group of chemistry. "CYP51 has proved to be an excellent target, and we now have genomics and very elegant 3D modelling. So we can look in great detail at genetic variation and how different chemistry interacts with the protein.

"With gene editing, we can introduce mutations to see how they impact efficacy and understand more about resistance. We can use these technologies to revisit what we know about the old chemistry. This means we can understand better the mutations that exist in the population and how to configure mixtures to defeat them.

"But the real possibility here is that we can design resistance-busting azole molecules. No single compound will be the complete answer, but Revysol is a step in the right direction. And while the Holy Grail remains a novel mode of action, it's clear we shouldn't abandon the old valuable friends yet." ■

With new technologies, scientists can revisit what's known about the old chemistry.

Persistent friend against the fungal foe

If there's one cereal disease that's shaped Jon Birchall's farming career, it's septoria. But throughout, there's been one class of chemistry that's always proven to be an effective weapon against it.

"Septoria has always been a problematic disease, but the introduction of azoles was a huge step forward, and probably the most significant addition to the fungicide arsenal. In the 1980s and 1990s, there was always new material coming forward, offering kickback and protection — it just didn't seem to be an issue to control fungal diseases, and we managed to remain one step ahead," he recalls.

His first experience of using azoles was in the mid-1980s, as farm manager on a large estate in Oxon. "Prochloraz and propiconazole were probably the earliest ones I used, alongside MBCs. There was also flutriafol that was so systemic it tinged the leaf tip and the whole field looked as though it had been scorched. But it was very effective."

In those days, a two-spray programme was enough to protect a 10t/ha wheat crop. But by the early 2000s, Jon Birchall was adding in an ear spray. "I'd moved to the Kings Walden Estate at Hitchin, Herts, where we were growing milling wheats and needed to keep the ear clean. Tebuconazole was the product of choice."

By the end of the decade, he'd moved to Shrewsbury, looking after around 1200ha of combinable crops for Balfours. "By then, the T0 spray was coming in," he notes.

"Where we are in that part of the West is a rain shadow — we only get around 65cm. So we don't suffer too much from rust, which is a distinct advantage for milling wheat. But septoria is very much a concern, and early in the season, you can always find some kicking about."

With the triazoles becoming less effective against the disease, a little-and-often approach became the adopted practice. "In the early days, we'd apply a T0 on a case-by-case basis. But it's now a routine part of the programme."

For Jon Birchall, there are two azoles that stand out in the armoury. "Opus (epoxiconazole) was a game changer when it came in. The other one is prothioconazole. We're heavily dependent on both."

But they form part of a varied programme. He starts the season with a "cheap and cheerful" T0 spray, mixing chlorothalonil with cyproconazole and propiconazole. A straight SDHI is used at T1, mixed with epoxiconazole and folpet.

"My favoured flagleaf spray is Imtrex (fluxapyroxad) with Osiris P (epoxiconazole+ metconazole) — it's priced well and is highly effective at keeping the flagleaf clean. At T3, prothioconazole is well regarded for keeping fusarium at bay, and I'd add in a strobilurin primarily for the greening."

A key aspect of his programme is combining products, particularly those with a different mode of action. "When I started my career, no one had even heard of resistance. But it's now essential to use a broad range of effective chemistry."

And his favoured strategy includes five different azoles. "I do think it's crucial we retain our ability to use a number of different products. If the current thinking on endocrine disrupters results in the removal of a number of effective plant protection products, we'll be in serious trouble. I'd happily accept tighter controls on the products we have than lose some from the armoury," he says.

Jon Birchall reckons the introduction of azoles was probably the most significant addition to the fungicide arsenal.

"But looking forward, I think the interesting aspect about Revysol is that it's been created from day one on the premise of how it would operate against resistant septoria. It's not just another triazole — it's been selected intelligently."

And he too believes this chemistry may have more to offer. "Strobilurins have been defeated, and SDHIs have a question mark over them. But azoles are still here and provide the basis for most spray programmes. I hope a resistance-busting azole is achievable, because if it was, it would be the best weapon we could have."

Brave New World for sugar beet

> *“If we don’t have epoxiconazole, it won’t be easy to control cercospora.”*

Roots
Sugar beet

Is EU regulation threatening the viability of sugar beet production as the era of market protection comes to a close? *CPM* canvasses expert views from around Europe.

By Lucy de la Pasture

The arrival of 2017 marks a landmark for sugar beet production. The new campaign will be the first after the abandonment of EU production quotas and the minimum purchase price. It’s a move that will expose sugar beet producers to market forces they’ve been protected from for decades.

“Sugar beet growers will have to deal with global competition and most probably there’ll be a negative effect on their income,” believes BASF’s Jörn-Fried Johannsen. “To compensate for this, growers have to increase both yield and quality in order to successfully continue to compete in the global sugar beet market.”

It’s something the EU sugar industry has been restructuring towards for years, its reform programme resulting in the loss of many sugar beet factories and a 53% reduction in the number of sugar beet growers across Europe. Production is now concentrated in five countries (France, Germany, Poland, the United Kingdom and the Netherlands), which have an approximate 73% share of the total area of sugar beet cultivation in the EU, compared with 62% in 2004, according to European Parliament statistics.

Higher efficiency

This increased specialisation and concentration of sugar beet production in Europe has led to higher efficiency and yield potentials but is in sharp contrast to the sugar cane industry, responsible for 80% of world sugar production, which has been growing rather than becoming more concentrated.

A report requested by the European Parliament’s Committee on Agriculture and Rural Development to study the post-quotas EU sugar sector, published 2016, concludes that the sugar sector is of strategic importance and CAP market policy should include instruments that allow the maintenance of sugar production.

Ironically, there’s a regulatory threat looming to a key active ingredient from the azole fungicides that could severely hamper beet production in some areas if its approval isn’t renewed. That active ingredient is epoxiconazole, which is widely considered to have the best efficacy against the most important foliar disease in Europe.

“The main disease in sugar beet in Germany is cercospora (caused by *Cercospora beticola*) which can cause high decreases in yield and quality,” explains Jörn-Fried Johannsen. “Yield losses of about 15-30% are reported in the literature and seen in practice.

European sugar production is now concentrated in five countries, which have an approximate 73% share of the total area of sugar beet cultivation in the EU.

“As a consequence of global warming, the cercospora infection in recent years has been occurring about a week earlier than it used to. Therefore, the sugar beet is under stress earlier in the season and bears the risk of higher yield and quality losses,” he says.

Epoxiconazole is the most widely used azole fungicide across Europe for the control of cercospora, and has shown the best field performance of all, he says. In Germany, 334,000ha of sugar beet were cultivated in 2016 and 68% of the national crop was treated

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with fungicide. Of the fungicide applied, 74% of applications contained epoxiconazole, points out Jörn-Fried Johannsen.

Cercospora is also the most important foliar disease in Poland, one of the big three sugar beet producers, lying just behind France and Germany with a sugar beet area of 203,000ha in 2016. The disease is of particular importance in central and southern Poland, explains Jacek Piszczek, associate professor at the Polish research organization, IOR-PIB.

"The climate in southern Poland is a little different than in the rest of country. There's more rain and the temperature is usually a little higher, resulting in higher humidity. In the central part of Poland, we have much more drought intervals during the summer.

"Because of the increased disease pressure in the South, fungicides are applied up to four times for cercospora control, compared with approximately twice in central parts," he explains, adding that disease pressure depends on the weather.

"The first symptoms occur from the middle of June to the first ten days of July in the south of Poland. In the central part, it's usually 10-14 days later and in the north, later still in the first part of Aug.

According to Jacek Piszczek, farmers know that they'll achieve the best results when they spray as soon as the first symptoms appear, so they usually aim to apply fungicide at this time.

"The problem is that very often this occurs at the same time as cereals are being harvested. That means some farmers don't have enough time or forget about their sugar beet because of that. Another problem which can affect the fungicide timing is the weather — it's not always possible to apply at the proper time because of rain," he says.

The consequences of missing fungicide timings where cercospora is active can be severe, he explains. "If you don't pay careful attention to sugar beet you can lose about 2-3% of sugar content and about 40% of root yield, dependent on the weather."

Most effective azole

Of the 37 fungicides registered for use on sugar beet in Poland, more than half contain epoxiconazole. As the most effective of the azoles on cercospora, it's often used, says Jacek, which means an anti-resistance strategy is necessary. He first started to look at the sensitivity of cercospora strains to fungicides in 1996.

"The first resistance I found was against benzimidazoles. About 80-100% of fungus isolates are still resistant to this group of fungicides now. I found the first isolates with a reduced sensitivity to epoxiconazole in about 2000."

Jacek begins his research into resistance at the end of each season, isolating fungus from leaves collected from infected fields in Sept. In the 2015 season, Jacek found 10.5% of the isolates he tested from central Poland had resistance against tebuconazole and not one against epoxiconazole. In contrast, 76.2% of tested isolates from south-east Poland had resistance against tebuconazole. 42.9% showed a slight shift in sensitivity to epoxiconazole, though there was no fall off in field performance.

"We've observed lower efficacy of protection with azoles especially in the south of Poland when farmers spray too late. It's very difficult to keep leaves in good condition in such cases. It isn't easy to keep tabs on it — we only hear from farmers that sometimes they do apply sprays at the proper timing and yet fungicides haven't worked well. But you can't always be sure they've applied them at the correct timing," he adds.

Of the 37 fungicides registered for use on sugar beet in Poland, more than half contain epoxiconazole, says Jacek Piszczek.

As a consequence of global warming, the cercospora infection in recent years has been occurring about a week earlier than it used to, says Joern-Fried Johannsen.

"If we don't have epoxiconazole, it won't be easy to control cercospora, especially in the south of Poland. We need a very effective active ingredient for this area. The shifting in sensitivity in this region means we also must have the chance to change fungicides within the programme, and use alternative triazoles, especially in the four spray situations. It's essential to maintain a choice of fungicide to help prevent cercospora from developing resistance more quickly," he believes.

"Probably in the first year it wouldn't be so bad. But a limited number of effective fungicides will have a negative influence on the pathogen population. Active ingredients which aren't so effective will be used much more often and the fungus will create resistance to them faster. Then the effectiveness of chemical control will be reduced per se," he warns.

"I advise farmers to use any active ingredient only once a year as part of their anti-resistance strategy. If they need three or four applications, I advise using a mixture with copper oxychloride or mancozeb (in Poland) for the second or third spray to reduce the risk of selecting for resistance."

Plant breeders may provide part of the solution to cercospora control in the future but even if better varieties are bred with good resistance, fungicides will still be necessary.

"So far we know 5-6 genes which are responsible for resistance to cercospora but the problem is that they're correlated ▸

There are some very good reasons why we need to keep epoxiconazole in Europe to produce sugar competitively with the rest of the world, notes Mark Stevens.

▸ with genes responsible for yield and sugar content. It's possible to have very highly resistant varieties but such varieties will give no more than about 30t/ha of roots and the sugar content is about 14%.

"In comparison, the average sugar beet yield in Poland over the past five years is 62t/ha with an average sugar content of 16%. Hopefully this problem will be resolved in the future," he adds.

"Looking at the susceptible, resistant and highly resistant varieties, you find that the best yields are achieved with well protected, susceptible varieties. There's a little less yield from varieties with a higher resistance to cercospora and the yield for the most highly resistant varieties is the worst.

"It's good to protect varieties with resistance but they also need protection against cercospora. So we advise farmers, if you do protection against cercospora well then sow a susceptible variety, but if you aren't good at it — use a resistant variety. The yield of resistant varieties is only higher than a susceptible variety when there's a lack of effective fungicide protection."

But Jacek Piszczek points out that growing a resistant variety doesn't mean that it won't succumb to cercospora infection at all.

Resistance to some azole fungicides is now showing up in cercospora isolates tested in central and southern Poland.

"These varieties can also suffer from cercospora infection, it depends entirely on the pressure of the pathogen," he says.

Cercospora is also the major foliar disease for sugar beet growers in Spain, says Dr Julián Ayala of AIMCRA (Asociación para la Investigación Mejora del Cultivo de la Remolacha Azucarera).

Spain grew approx. 33,000ha of sugar beet in 2016 but Julián believes the production area is likely to increase with the end of the quota system.

"There's a big gap between Spanish production, c.500,000t and sugar consumption of 1,300,000t so there's the opportunity for growers to produce more sugar beet to meet domestic need.

Main disease

"In Spain, there are two regions that grow sugar beet. In the south sugar beet is autumn planted and in the north it's spring sown. The three main diseases affecting the crop are cercospora, powdery mildew and rust, with cercospora the most important," he says.

In the south, 50% of the sugar beet area is affected by cercospora in a normal year, with severe attacks due to the high levels of humidity that occur in the region. In the North, approx. 30-40% of the sugar beet area is normally affected.

The only fungicides approved for control all contain azoles, for example pyraclostrobin plus epoxiconazole, which we advise is applied in tank-mix with the contact fungicide, mancozeb.

"For effective control, it's critical to apply fungicides at the appearance of the first spot and repeat applications every 21 days," says Julián Ayala. "It's also very important to adopt strategies to delay the emergence of resistance and make applications correctly. If the same product is applied continuously, then you run the risk of selecting and multiplying resistant strains, negating the effectiveness of the product in a short time."

Two to three fungicide applications are normal in an average year and Julián Ayala advises using a product with good efficacy and alternating with other products throughout the fungicide programme to maintain the yield potential of the crop.

Climatic conditions in the UK mean that cercospora doesn't currently pose the same threat to sugar beet producers as in other parts of Europe, comments BBRO's lead scientist, Dr Mark Stevens.

"I've seen more cercospora infection in the UK this season than ever before, which is a timely reminder of the possible effects of global warming — the importance of some

Half of the sugar beet area in southern Spain is affected by cercospora in a normal year, says Julián Ayala.

diseases can certainly change with time."

To illustrate that point, Mark Stephens found a field during 2016 in north Norfolk with stemphylium infection, which marks a return of the disease which first appeared in the UK in 2014 but then seemed to disappear in 2015. He says this shows that the dynamics of the disease are potentially changing in the UK.

Stemphylium is a major problem for Dutch growers and can cause losses in sugar yield of up to 42%. Dr Bram Hanse of the IRS, Institute of Sugar beet Research in the Netherlands, has been researching the disease since it first appeared in 2007 and has found the fungicides registered for use in sugar beet have precious little activity against stemphylium.

The situation is very different to cercospora where the disease can still be managed by alternating fungicides with active ingredients belonging to different groups. In 2014, the Netherlands gained approval for the use of Retengo Plus (pyraclostrobin+ epoxiconazole) in sugar beet, which has some activity on stemphylium and is the only product registered for use in the crop that currently does so, though his research also shows that stemphylium can be managed once the fungicides he tested with a higher degree of efficacy are registered.

Although epoxiconazole isn't the UK's mainstay fungicide for foliar disease at the moment, maintaining choice in the fungicide armoury is just as important to British sugar beet production, believes Mark Stevens.

"It's important to maintain a wide range of fungicide products so we have options when the importance of a disease changes as a response to climate change or resistant strains develop. Becoming reliant on a smaller fungicide portfolio would be worrying." ■

lastword

by Lucy de la Pasture

Let's look beyond the hazard

The gradual loss of active ingredients has been a discussion point for several years now. The first to go weren't really a big surprise — most of those that were harder to defend lost their approval in the first wave under the 2009 EU directive. Since then there's been a steady decline as a trickle of active ingredients have bitten the dust.

In 2017, however, things start to get serious as the future of some of our most trusted active ingredients comes into question. Among those awaiting a final judgement on the hazard they could (arguably) pose, are some of the azoles that are still crucial partners in many fungicide programmes, not least for their role in anti-resistance strategies, as research scientists from around Europe have reported in this special issue of *CPM*.

The EU has spent years trying to come up with a definition for the controversial 'endocrine disruptors' (ED) and their criteria are still being tinkered with around the edges. That seems to indicate that the criteria themselves won't be easy to apply — hence the huge degree of uncertainty regarding the future.

It's one of the idiosyncrasies of the EU that, on the one hand the hazard-based regulation it has adopted could threaten the efficiency of its sugar beet growers, while on the other hand the importance of supporting the sugar beet crop in post-quota Europe is being highlighted in a study commissioned by the European Parliament. No doubt it's contradictions in policy like this that led many UK growers to opt for Brexit.

Whether the UK regulators will abandon the hazard approach to regulation is another matter but it does seem that a bit of pragmatism wouldn't go amiss at times. As things currently stand, active ingredients are assessed on their hazard without taking any account of what the risk of exposure may be. Let's face it, there's a hazard we could get wet socks and suffer from trench foot every time we walk into a soggy field but we can engineer away the risk of that happening by donning a pair of decent wellies!

As the legislation stands, the burden of proof lies on the chemical manufacturers to produce the science that will convince the regulators that even if there is an ED effect, it isn't harmful to non-target organisms. It's no wonder that products have stopped popping out of the pipeline on a regular basis as funds are inevitably diverted from true R&D, as we found out in the article looking at innovation.

This may be a debate best left to the politicians — politics is a funny old game at the best of times. But are we all guilty of thinking someone will always do the lobbying on our behalf, and relying too much on the NFU or the chemical manufacturers? Perhaps we should get a little bit more noisy rather than take it on the chin and stoically keep calm and carry on farming.

The danger here is that there's a lot of pseudo-science in the hands of very powerful lobbyists that would prefer a chemical-free world. A casual observer of farming, for instance, who gleans their views from Facebook, is told bees are being slaughtered to the point that there won't be an orange left on the planet and it's all the fault of nasty pesticides. It's presented as fact so it must be true. "How terrible," thinks the right-minded citizen. "I must sign the petition."

Whatever your view on the matter, it's dangerous misinformation and I've yet to see a post putting across the other factors that could be causing bee mortality. It's not an equal playing field out there!

The fact is, there's not one farmer who'd really want to be using any pesticide that would risk harming the environment. The soil and everything that lives in it is their growing medium — it's the very basis of their business and for the generations that will follow them. Bees are crucial and so are natural predators — especially where some insecticides don't cut the mustard anymore. They're the farmers' friends and it's wildly misleading to suggest any farmer would deliberately endanger them.

So 2017 doesn't have to be the year that agriculture lost its azoles. It could be the year that the European parliament saw sense and recognised that farmers are responsible enough to manage hazards on their own holdings. This is the time that innovative talent could be given the encouragement it deserves to help European farmers be more competitive as agriculture blossoms in other parts of the world.

This is an industry that responds positively to the challenges presented, and while we need to work together to protect the chemistry we have, the good news is we've a new azole to look forward to.

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Are farmers doing enough to promote their positive approach in the face of damaging misinformation and an increasingly hostile regulatory environment?