A Nuffield Farming Scholarships Trust Report

Award sponsored by

The Yorkshire Agricultural Society

Herbicide-resistant weeds: investigating a sustainable future for arable farming

Richard Hinchliffe

July 2017

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A Nuffield (UK) Farming Scholarships Trust Report

"Leading positive change in agriculture. Inspiring passion and potential in people."

Date of report: July 2017

Title	Herbicide resistant weeds: investigating a sustainable future for arable farming
Scholar	Richard Hinchliffe
Sponsor	The Yorkshire Agricultural Society
Objectives of Study Tour	To investigate how farmers and agronomists are dealing with herbicide resistance around the world
Countries Visited	USA, Australia, Argentina, UK

Messages

- Herbicide resistance is a global problem
- Herbicide resistance is a direct result of farming practice
- Reliance on herbicides alone is not sustainable and weed control strategies should be based around cultural methods
- There is no single answer to herbicide resistance. Increasing the diversity of farming systems is required
- Stewardship of existing herbicides is vital, since no new modes of action have been discovered in over 20 years
- Farmers trust farmers! Allowing farmers to help communicate positive stories/messages can deliver great results

EXECUTIVE SUMMARY

"*Doing the same thing over and over and expecting a different result*" is often quoted as Einstein's definition of insanity. It could easily be argued that is exactly the practice that farmers and agronomists have found themselves following in recent years. This is because herbicides in the past were highly effective, cheap and easy to use. But reliance on herbicides alone has contributed to the widespread herbicide resistance problems that we are seeing today. If you look at the problem simply, herbicide resistance is nature's way of telling us herbicides alone are not sustainable and introducing more diverse weed control methods is required to disrupt the weed's life cycle.

With my study I aimed to see how farmers and agronomists were dealing with the challenge of herbicide resistant weeds. To investigate this further I visited the USA, Australia and Argentina as well as attending numerous events in the UK discussing how to manage herbicide-resistant blackgrass. I chose to visit the USA because by many it is seen to be the home of glyphosate, genetic modification technology, and vast acres of just corn and soybeans. Australia promised me world class herbicide resistance problems and also the chance to see Harvest Weed Seed Control in the flesh. I found Argentina to be one of the most intriguing countries that I visited. It gave me the opportunity of seeing how farmers will react to political decisions such as export quotas and tariffs on certain crops, and the result of this. It led to over 60% of cropping land being placed in soybean production and the rapid development of herbicide resistance in a number of weeds.

I found that farmers and agronomists were actively looking for better ways of dealing with herbicide resistance, with the momentum moving to more cultural controls of weeds rather than relying on synthetic chemistry. This is particularly important since no new herbicidal mode of action has been discovered for over 20 years, and even if a new mode of action was discovered today it would take many years to work its way through the regulatory process before reaching the market.

I also saw the value of effective communication when it comes to talking about herbicide resistance. This starts with effectively communicating new research on herbicide resistance in a format that farmers and agronomists can understand, right through to 'farmer to farmer' discussion groups where sharing and finding solutions as a collective is really working.

To put it simply: herbicide resistance is a problem that is not going to go away, but it is certainly manageable!

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1. About me

I'm Richard, an arable farmer from Yorkshire. Having grown up on the family farm you could probably say that farming is in my blood, and ever since I was old enough to walk and talk I knew that I wanted to farm.

In 1999, aged 16, I headed away from home to DeMontfort University in Lincolnshire to study for my National Diploma in Arable Mechanisation and after two years I returned to join the family farming business. I then went on to complete my education by studying part time for my Higher National Certificate in Arable Management at Bishop Burton College. I have since gained my BASIS and FACTS qualifications and carry out the agronomy on our own farm.

I married Rebecca eight years ago and we now have two young boys, William and Thomas. We are very lucky to live on one of our farms in a new farmhouse that we only moved into two years ago. Building a house for my young family was a very rewarding and character-forming experience, since it was the first time I had ever done anything different to farming. It was a little stressful at times but well worth all the effort in the end!

Figure 1: Me, Richard Hinchliffe, photographed with a palmer amaranth in a soybean field, Argentina

We farm 560Ha of combinable crops in East and South Yorkshire and are currently growing wheat (winter and spring), oilseed rape, faba beans (winter and spring) and linseed. Our soils range from grade 1 Blacktoft series silts through to some very heavy Foggathorpe series (magnesium) clay that is surprisingly grade 2 but also very challenging: with a tendency to be like concrete or porridge and nothing in between.

Our farm ranges from around 2-3m above sea level but is actually below high tide. All our land is under-drained and the water is pumped into the River Don that runs alongside our farms. The River Don has earth embankments to hold the water back and is still tidal for around another 6 miles inland.

Water management is a very important aspect of farming on our low lying, flat, fertile soils so I was pleased to be elected onto the Black Drain Drainage Board in 2014. The long term effects of sea levels rising through climate change could be potentially disastrous for our farm if the current river banks are not maintained or even raised in the future.

2. Background to my study subject

If you were to visit any arable farm in the eastern counties of England and were to ask what their number one farming problem was, then the most probable answer would be 'blackgrass'. That answer would be understandable once you consider that by 2013 blackgrass had spread to over 20,000 farms in the UK (Source: **Hull et al. 2014)**

Blackgrass (Alopecurus myosuroidies) is an annual grass weed that through its own brilliance has thrived under current farming practices. By its very nature it likes heavy moisture-retentive soils which make up a large proportion of the UK cropping area. Blackgrass is also a highly competitive weed in terms of light, space and nutrition. If that's not enough of a problem then its peak germination period is September through to November, at exactly the same time as the optimal drilling date for the UK's biggest combinable crop, winter wheat.

Some of the numbers and stats for blackgrass are also mind blowing. Each blackgrass plant can have on average 2-20 seed heads per plant with around 100 seeds per seed head if it is growing in a typical winter wheat crop. In bad infestations, populations can easily reach 1,000 ears per m^2 leading to a seed return of up to 100,000 seeds per m^2 and even with 40-60% viability you can end up with a seed return within the order of 40,000-60,000 viable seeds/m^2 (source: www.fwi.co.uk/academy/lesson/blackgrass). When you put that alongside a typical winter wheat seed rate of around 350 seeds/m^2 then it really does start to get worrying!

Figure 2: Blackgrass in flower. When a population reaches this level then you have a serious problem that cannot be ignored any longer! (Photo taken June 2016)

To stop an increase in blackgrass population you need to achieve over 98% control, which means - to be effectively reducing a population - you need to be getting over 99% control. Although blackgrass is such an impressive weed it does have one chink in its armour: it is a relatively short-lived seed with its viability reducing by around 30% per year, effectively giving the seed a 5-7 year lifespan before becoming unviable.

My personal interest in blackgrass and herbicide resistance goes right back to the start of my farming career, in fact even before it properly began. Back in the year 2000 the farming business bought the 150Ha farm where I now live. That was the first time that I had ever seen blackgrass on a field scale. It was everywhere! At home we have spent the last 17 years battling with blackgrass and have made giant leaps forward in understanding how best to deal with this most challenging of weeds.

Below is the combine map of one of our fields: Big Middle.

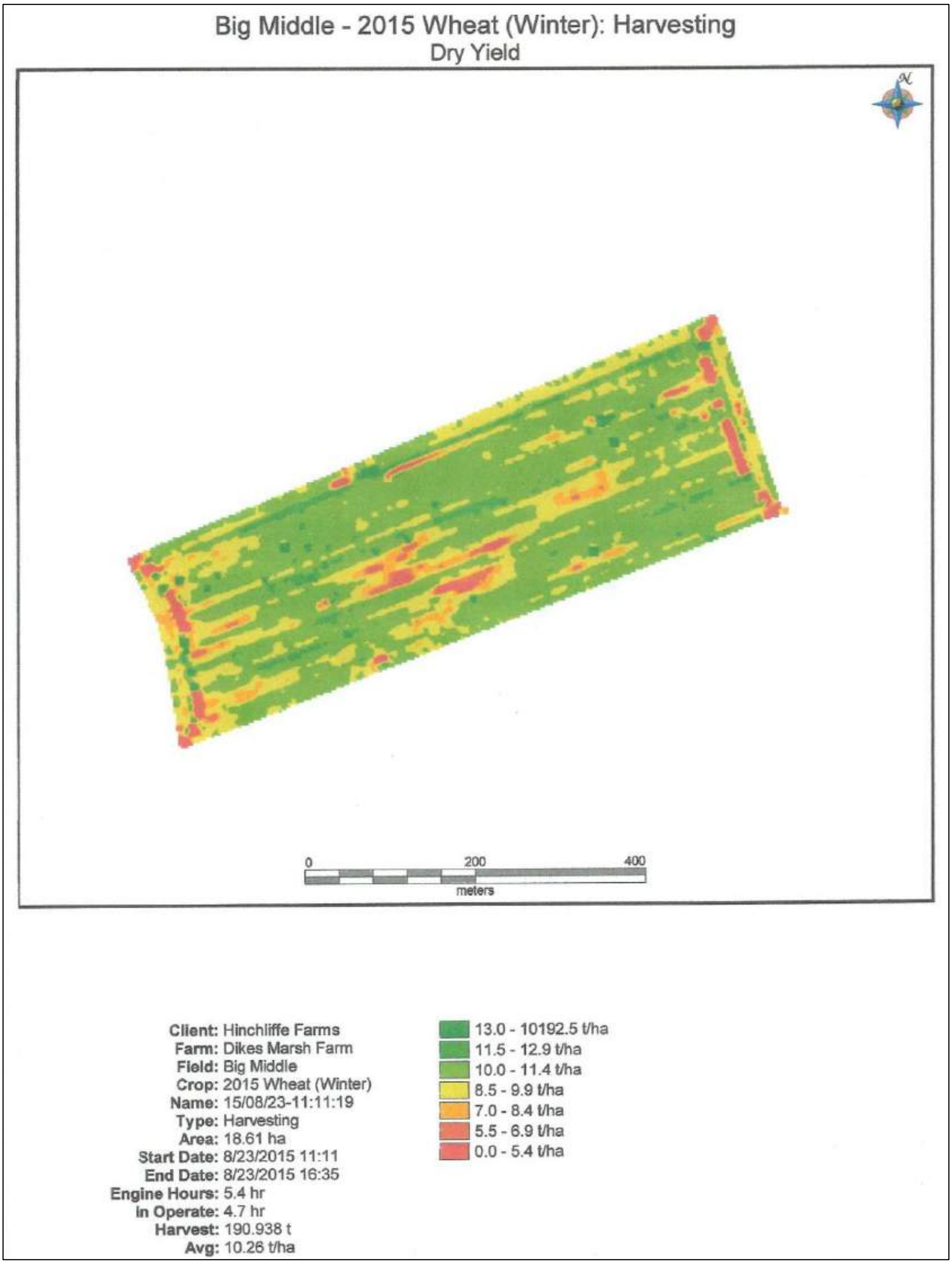

Figure 3: Big Middle field's combine yield map 2015, the poor areas exactly matching the blackgrass populations

But possibly the most important reason to really get serious about blackgrass, is seeing the impact on yield and therefore profitability. As you can see from the combine yield map in Figure 3 above, blackgrass can have a massive impact on yield.

When you consider the fact that no new 'blockbuster' herbicides are going to come on the market and help solve our herbicide resistance problems my natural curiosity to look beyond chemical control really inspired me to apply for a Nuffield Farming Scholarship.

3. Where I travelled

I went on four main trips, but I also visited a lot of blackgrass trial sites and attended meetings within the UK.

June-July 2016	**USA** 20 years of a Roundup Ready corn and soybean rotation in the Midwest. It is also home to the biggest GM plant breeding companies.
October-November 2016	**Australia** Harvest weed seed control was developed in Australia and had to be investigated. AHRI one of the world's leading centres of herbicide resistance research is also based in Perth.
March 2017	**Argentina** Investigating the long term effects of no-till on weed resistance
May 2017	**USA** I returned to the USA to visit the Global Herbicide Resistance Challenge 2017 in Denver, I also took the opportunity to visit the Rodale Institute in Pennsylvania to look more closely at organic no-till in action.

4. Herbicides and resistance

The accepted definition of herbicide resistance is the one given by the Global Herbicide Resistance Committee, which is:

> *"Herbicide resistance is the ability of a weed biotype to survive an herbicide application, where under normal circumstances that herbicide applied at the recommended rate would kill the weed. In contrast, plant tolerance to a particular herbicide is the inherent ability of that plant species to survive and reproduce after treatment with that herbicide."*

Herbicide resistance is broadly broken down into two groups: target site resistance and non-target site resistance. Herbicides work by binding onto enzymes and inhibit the metabolic process within the plant, leading to death. In target site resistance the binding site within the plant has been altered by mutations meaning that the herbicide can no longer bind to the enzyme and will lead to the plant surviving. Target site resistance is a total resistance and affects herbicides that are in the same chemical group. All other forms of herbicide resistance fall into non-target site resistance, and in the UK this most commonly comes into a group known as enhanced metabolism resistance, which is where the plant can detoxify the herbicide faster than it reaches the target site within the plant.

4.1. Herbicide resistance in the UK

Currently we have six different herbicide-resistant weeds that are an issue in farmland in the UK. Three are grass weeds: blackgrass, Italian ryegrass, wild oats; and three are broadleaf weeds: chickweed, common poppy and scentless mayweed. The most problematic and widespread herbicide resistance in the UK would be blackgrass, followed by Italian ryegrass, then wild oats. Although herbicide resistance is predominantly in grass weeds, the three broadleaf weeds should not be ignored since herbicide resistance in the broadleaf weeds is almost entirely down to relying on the same mode of action at reduced rates year on year.

Species	Farms	Counties
Blackgrass	>20,000	37
Ryegrass	>475	34
Wild-oats	>250	28
Chickweed	>50	13
Poppy	>70	9
Mayweed	12	5

Figure 4: Table 1: Herbicide resistant weeds in UK 2016. Data extracted from AHDB WRAG website.

4.2. Herbicides – weed control of choice for the last 50 years

Ever since people have cultivated soils to grow crops, farmers have had to deal with weeds. Weeds are an issue because they compete with the crop for light, water and nutrients. Prior to the introduction of the first herbicides in the late 1940s which started with 2-4D, a highly effective broadleaf weed herbicide, the only methods of weed control would be cultural methods such as cultivation, hoeing, rotation, rouging etc.

In this chapter I am going to look at all the various options of chemical controls that I have seen during my study tours. For the sake of simplicity I'm adding genetically modified cropping within this section.

4.3. Resistance testing

The benefits of herbicide resistance testing are obvious. Without testing for resistance to herbicides then you can never be 100% sure that you have resistance. Inadequate control of weeds from a herbicide can come from a number of factors involving poor sprayer set up, and can include: water volume, coarseness of spray, sprayer speed and boom height. Climatic factors also come into play, such as: temperature, soil moisture and speed of weed growth and growth stage.

These are just a few examples of what can lead to poor control from a herbicide and only by properly testing for herbicide resistance can you discount external factors and actually confirm herbicide resistance. Some of the benefits from testing are that you can find out which herbicides should still give a good level of control, thereby preventing unnecessary herbicide applications. Another good reason is to monitor the resistance situation within a field, or as a quick reference when taking on a new block of land. Some of the reasons given for not resistance testing include: cost, difficulty or time required to collect a sample.

Figure 5: Photo of herbicide resistance pot tests, Dr. P. Boutsalis (Plant Science Consulting & University of Adelaide)

Table 2 (on next page) shows the results from a blackgrass resistance test on one of our fields in 2015. It reveals a very high degree of resistance to both the ALS and ACCase group of herbicides.

We already knew from a previous resistance test that we had a very high degree of ACCase resistance and we had our suspicions that we now had a good level of ALS resistant blackgrass as well. As a result of this test we have now changed the chemical part of our blackgrass management strategy and removed the ALS from our wheat herbicide programme because we believed that it represented poor value for money.

See Table 2 on next page.

	Herbicide Resistance test results		
	Target site		
	ALS	**ACCase**	**Enhanced metabolism**
Field names	*R rating*	*R Rating*	*R rating*
Susceptible standard	S	S	S
Big Middle	**RR**	**RRR**	**S**

Figure 6: Table 2: Blackgrass resistant tests from Dikes Marsh Farm, 2015

The full report from the herbicide resistance test is given in Appendix 1 at end of this report.

4.4. What's all the fuss about Glyphosate?

When I met Professor Powles, Director of the Australian Herbicide Resistance Initiative and he told me '*Glyphosate was a once-in-a-century discovery'* you really sit up and take note! Yet glyphosate is the most used and probably most abused herbicide globally. But why?

The answer is probably the fact that since its introduction in the 1970s it has proven to be a very safe, broad spectrum non-selective herbicide that controls many difficult broadleaf and grass weeds. A large part of glyphosate's success is the fact that, by not having to control weeds through cultivation pre-drilling, it has enabled large areas of the globe to use non-inversion tillage techniques for crop establishment and the introduction of Roundup-ready crops saw a huge increase in glyphosate's usage.

Currently glyphosate is undergoing re-registration within Europe with a lot of lobbying against this re-registration. Also, despite a largely clean bill of health during its 40 years on the market, in March 2015 the IARC classified glyphosate as a Category 2A carcinogen, the same category as red meat.

Every farmer in every country that I visited still used glyphosate despite some of them having a level of glyphosate resistance on the farm. In the USA I saw lots of glyphosate-resistant broadleaf weeds, in particular palmer amaranth and waterhemp. In Australia, ryegrass and wild radish were resistant to glyphosate in places and in Argentina I saw a mixture of broadleaf weed and grass weed resistance to glyphosate including palmer amaranth and ryegrass.

Glyphosate resistance is a big concern of mine since, within the UK, it is the most effective herbicide we have against blackgrass and it is often used multiple times within a growing season, thus putting a lot of pressure on one active ingredient.

Its usage needs to be monitored and any decline in performance needs to be reported.

4.5. Genetically modified herbicide-tolerant crops and '2nd generation herbicide tolerance'

So what actually is a Genetically Modified Crop/Organism?

Genetic modification of a crop is a very precise form of plant breeding that allows individual genes to be transferred from one organism to another. Unlike in traditional plant breeding, these plants don't even have to be related species. This gives plant breeders more opportunity to find desirable traits from nature, like disease resistance, drought tolerance or herbicide tolerance to name a few. That trait can then be inserted into the crop they are developing.

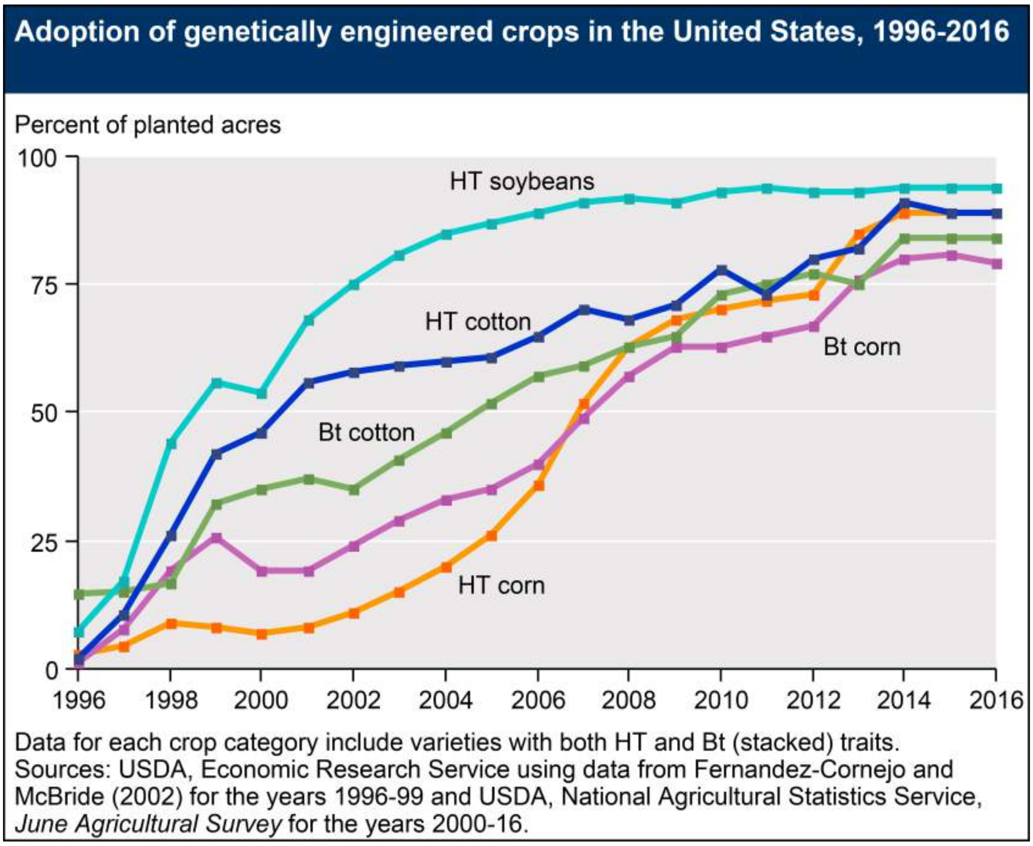

Figure 7: The speed of adoption for GM crops in the USA (*Source: USDA Economic Research Service*)

The first major introduction of GM herbicide tolerance was in 1996 with Roundup Ready (glyphosate tolerant) soybeans in the USA. You can see from the graph above that Roudup Ready soybeans went from 17% of USA soybean acreage in 1996, increasing rapidly to 68% in 2001, and reaching market penetration of 94% between 2014 and 2016: effectively the entire crop. The reason behind this meteoric rise was down to the fact that the system was amazingly simple and cost effective. Broadleaf weed control was a problem in a broadleaved crop; glyphosate-tolerant soybeans solved all those issues and were a very economic system (for a while)! The adoption of glyphosate-tolerant corn was not quite as spectacular as it was in soybeans because other cheap and effective herbicides were available, but Roundup Ready corn was still very widely adopted. So, by the turn of a new millennium, farmers in large areas of the USA (particularly South East and Midwest) had effectively created a situation where they were growing only glyphosate-tolerant crops, and using only glyphosate to control weeds. A recipe for disaster had been created!

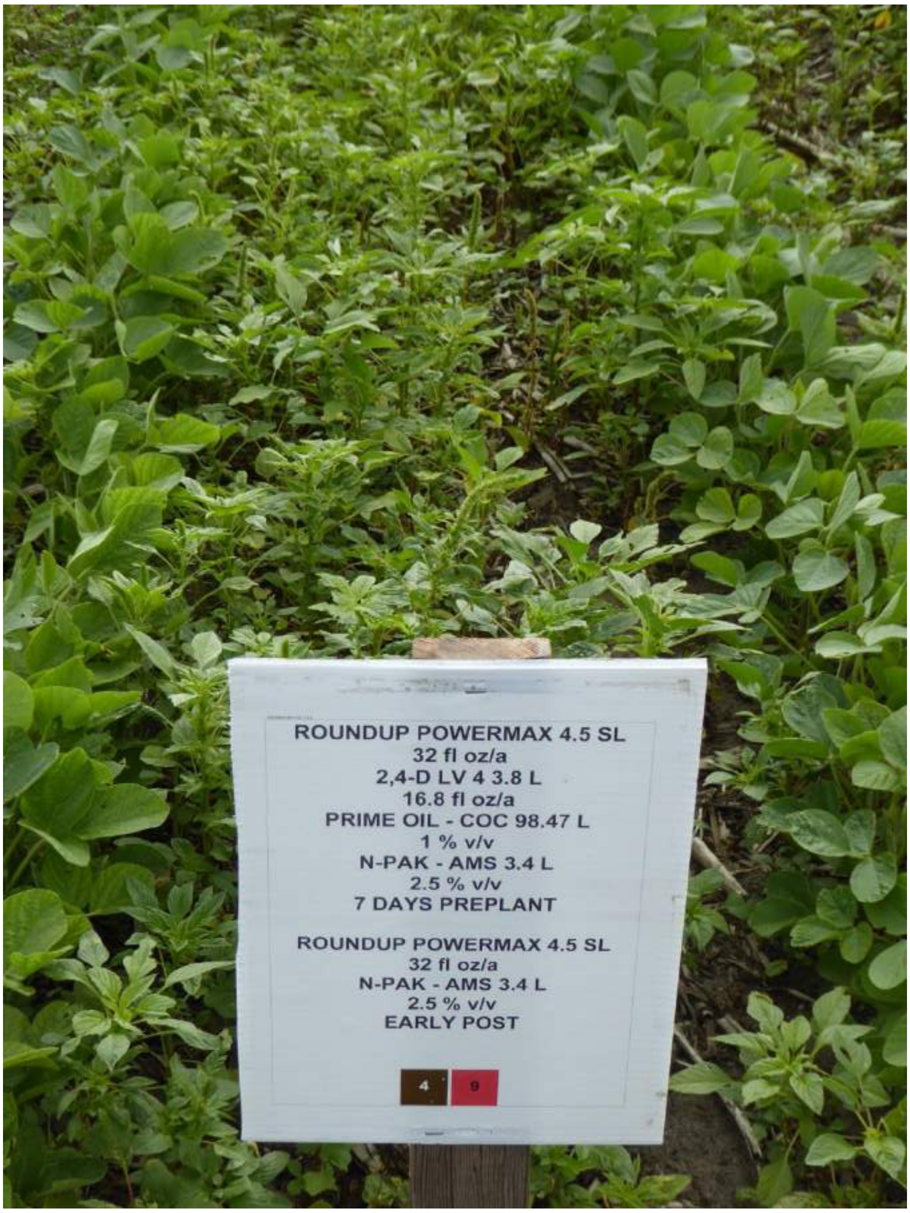

Figure 8: Relying on glyphosate alone post planting is not really an option any more, especially against the palmer amaranth pictured above (note only two modes of action noted at bottom of plot sign).
***Photo taken at a weed control open day in Indiana*.**

My time in the USA coincided with the commercial launches of some second generation herbicide tolerance to Dicamba (Roundup Ready Xtend by Monsanto) or 2-4D (Enlist by Dow) which are both synthetic auxins. These second generation herbicide-tolerance traits are 'stacked' with the current glyphosate tolerance, bringing levels of control back to those seen twenty years ago when the Roundup Ready system was first introduced. Hopefully farmers and agronomists will have learnt from past mistakes and will not abuse this new technology: and will follow best practice in the form of effective residual herbicide programmes, application and timing advice etc. But since the glyphosate part of the stack is delivering very little in terms of control with already-resistant weeds, then it's possible that if this technology is abused then it will break very quickly.

Some of the other issues with the 'second generation' tolerances are the fact that Dicamba and 2-4D are quite volatile sprays so there is some non-target movement to sensitive crops even with the newer 'vapour grip' type formulations. This leads to crop damage. Also, even though Dicamba and 2-4D are from the same chemical group, the two tolerances are not cross-resistant so mistakes are possible and crop damage can occur.

It is probably fair to say that these new herbicide-tolerance traits are not without their challenges and if abused then they may only be a temporary stop-gap to real cultural change when dealing with herbicide resistance.

Figure 9: Utilising Roundup Ready Extend alongside a good residual programme is capable of producing a very clean crop (note 5 modes of action at bottom of plot sign). ***Photo taken at a weed control open day in Indiana.***

Figure 10: Sign of Dicamba damage (leaf cupping) for volatilisation in sensitive soybean crop. Photo taken at Weed Open Day, Indiana.

Please see Figure 11 on next page.

Figure 11 : Demonstration plot showing total crop failure from directly spraying Dicamba on 2-4D tolerant crop. (Demonstrates lack of cross-resistance from similar GM traits). Photo taken at a Dow demonstration site in Indiana.

4.6. Chemical groups and labelling

Why should you ask: "*do you know and understand what mode of action you are using?*" To put it simply, the mode of action describes how an effective herbicide controls susceptible weeds through disrupting or blocking an enzyme in the weed. Therefore, to avoid herbicide resistance, alternating modes of action and not relying on one particular herbicide group is a very good idea. All herbicides that work in a similar pattern are grouped together by the Herbicide Resistance Action Committee (HRAC) or the Weed Science Society of America (WSSA) but, to add another layer of confusion, Australia also seemed to have its own system. HRAC and Australia use an alphabetical system to group herbicides and WSSA uses a numeral system! To see the HRAC mode of action poster please go to Appendix 2 at end of this report.

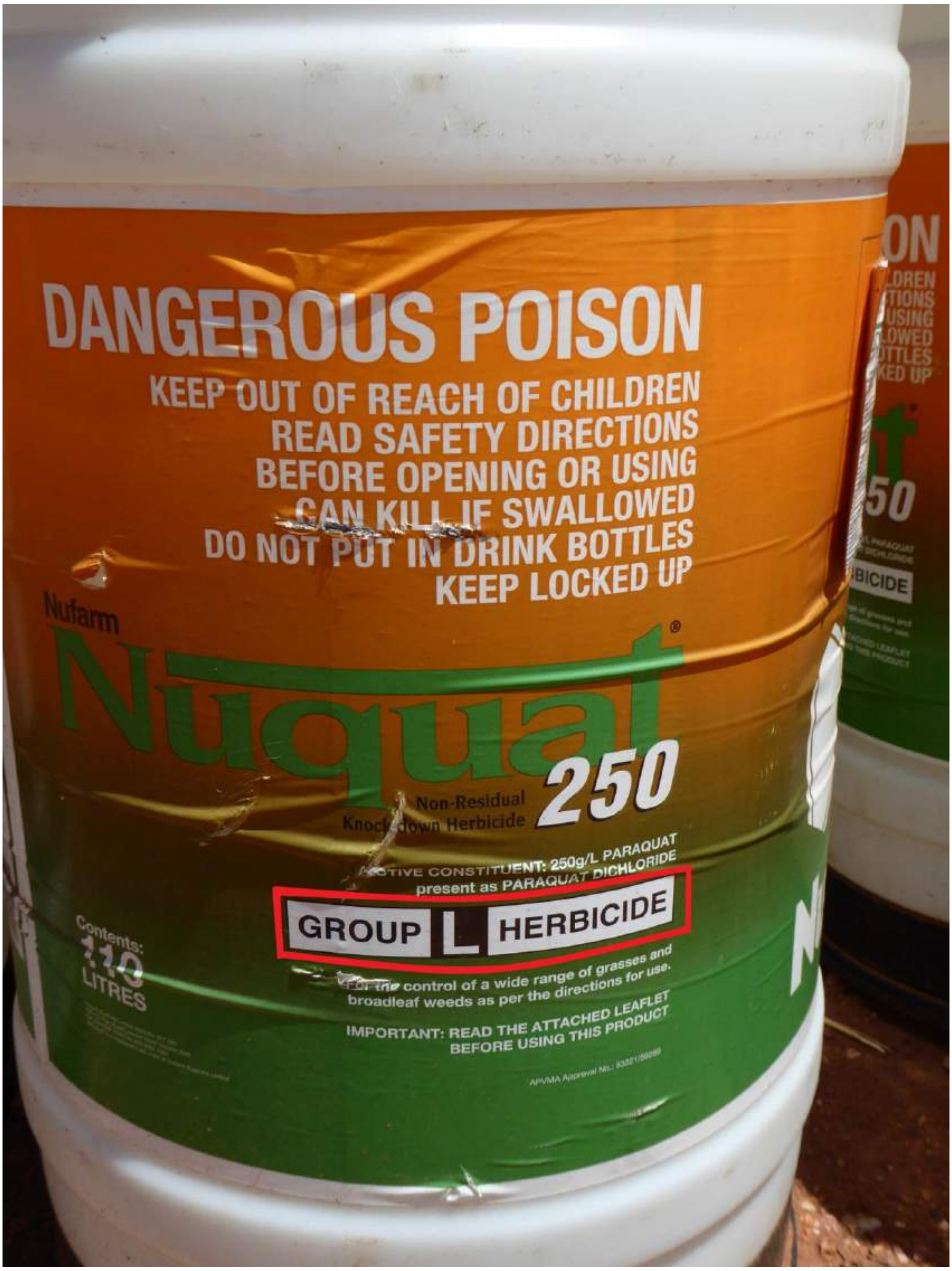

Figure 12: Diaquat label in Australia, clearly marked as a group L Herbicide

Figure 13: Artazine bag in the USA labelled as WSSA group 5 herbicide

One thing that was very obvious everywhere I travelled was how manufacturers in other countries put the herbicide chemical group on the side of the product. I was also amazed at the level of understanding amongst agronomists and farmers about the need to rotate as many different modes of action as possible within the rotation and not to rely on one chemical group alone because that hugely increased the risk of herbicide resistance. I think that by having this reminder on the side of the product helps keep the message of using different and multiple modes of action at the fore-front of your mind.

In the USA the Take Action on Weeds campaign (funded by a United Soybean Board levy) is very heavily focused on raising farmers' and agronomists' awareness of alternating different modes of action. One of the main focuses of the campaign is to produce yearly updates with all the different herbicides split into all the various modes of action and then cross referencing with the main brand names. This makes it easier for non-technical growers to be able to rotate modes of action and build a chemical programme with both herbicide resistance and rotating different modes of action in mind.

Figure 14: Selection of Take Action on Weeds educational material from USA

In Argentina they take this one step further and have developed a five-stage colour code system for pesticide containers and boxes, using green labels for products with the least environmental impact, through to red for those that have the greatest environmental impact. *See also photo on next page.*

4.7. Knock-knock it's 'Double Knock' from Australia

I am so envious of our Australian farming colleagues who have the ability to 'double knock' that I had to give this technique its own space in my report. The "double knock" technique was developed in Australia and it is the name given to a burn-down where you firstly spray glyphosate followed later (3-7 days) by paraquat. The idea is that the second paraquat spray should kill any survivors from the first glyphosate application; also by using a combination you're using complementary modes of action to help reduce the risk of resistance to either mode of action. The reason that a double knock using paraquat is not possible in the EU is that the latter was withdrawn from sale around 10 years ago after around 50 years of use; the reason being if not used correctly or mistreated then paraquat is a highly effective poison. I believe the double knock technique could help protect glyphosate from resistance developing in the future; it is a shame that farmers in the EU don't have another safe knock-down spray that works through a different of mode of action to add some much needed diversity to burn-down sprays.

Figure 15: Glyphosate can in Argentina with the MOA group top right and green environmental impact label at bottom.

4.8. Crop walking / scouting

As we haven't employed anyone on our own farm for crop walking for over 40 years and, having been on the BASIS professional register myself for 10 years, I hadn't really considered the value of what a really good agronomist can bring to herbicide resistance management. But everywhere I travelled farmers seemed to really value the opinion of a professional agronomist, even if it was often only for strategic and seasonal advice.

While visiting Santiago del Solar's farm in Argentina I was lucky enough to be involved in one strategic agronomic meeting, planning for the next season's cropping. Despite having to rely quite heavily on Santiago's translation, the conversation was wide ranging from the obvious gross margin implications of changing crop rotations to how changing rotation could influence cover crop options and the ability to rotate more chemical modes of action to improve weed control. In fact it could be said that weed control was one of the main drivers of the conversation after the obvious need to maintain profitability!

Chapter 4 Summary

- Herbicide resistance can only be confirmed through testing
- Glyphosate resistance is a massive problem globally
- The massive adoption of Roundup Ready crops and the lack of chemical diversity increased the pressure on glyphosate, leading to bigger resistance problems more rapidly
- Putting the herbicide group on the label raises awareness of the need to rotate modes of action
- Loss of certain herbicides through regulation impacts of herbicide resistance management through rotation
- Don’t underestimate the value of good agronomic advice

5. Cultural control

Cultural control of weeds encompasses everything that does not come out of a chemical can. Cultural and chemical controls are often combined and used together as part of an Integrated Weed Management form of approach.

5.1. Crop rotation

Changing and extending crop rotation was probably one of the first cultural controls that farmers were willing to change in the fight against resistant weeds; the major exception would be the Mid West USA where nothing could come close to matching the profitability of the corn and soybean mono-culture. When it comes to rotation planning the key is certainly that the more diverse the better, and avoiding mono-cropping systems that often lead to repeatedly spraying the same chemistry year on year.

While visiting Santiago del Solar in Argentina I learnt about how high export tariffs and low export quotas on wheat and corn (to protect domestic food prices) led to the dominance of soybeans which occupied 60-70% of cropped area. Only a couple of years ago, despite a 35% export tariff, soybeans were still the star performer for the Argentinian farmer. This was due to the fact that the Argentinians had very quickly adopted the 'perfect combination' of no-till establishment with Roundup Ready soybeans that produced good yields (around 4-5 T/Ha) at very low costs. This mono-culture was perfect for the development of multiple glyphosate-resistant weeds. However, with a change in government, and changes in regulation and currency, more crops became viable. Santiago currently grows 6 different crops: these are corn, soybeans, wheat, barley, sunflowers and a small area of sorghum. By extending his crop rotation he has been given different opportunities to tackle herbicide resistant weeds throughout the rotation, and rotate more modes of action, and not just rely on glyphosate as the main chemical control.

In Australia crops grown were very similar to what I would expect to see back home with wheat, barley and canola (oilseed rape) taking a lion's share of the arable acres. Various legume crops were also grown, depending on soil type and rainfall, and included faba beans, lupin, lentils and chickpeas. Typical current rotations would be one cereal crop followed by a break crop, mostly established by a no-till seeder. For example, the herbicide resistance capital of Australia is Western Australia; this is partly because it was the first State to move into more intensive cropping - and 80% of that was in one crop, wheat! This lack of cropping diversity led to repeat exposure of the same herbicides, meaning that in a ryegrass survey in 2010, 98% of ryegrass in Western Australia was resistant to at least one herbicide. Broadening the rotation has enabled usage of a more diverse range of herbicide mode of action and, in some cases, 'double breaks' are used to maximise that opportunity to mix herbicides up.

Australian farmers (apart from the GMO-free South Australia and Tasmania) have access to Roundup Ready (GM trait) and the conventionally bred Tiazine-tolerant canola varieties that are used as part of a farmer's weed management toolkit.

5.2. Cultivations: 'To till or not to till'

All the countries that I visited were massively in favour of no-tilling, quite the opposite of what is the norm in the UK. Every farm I actually visited in Australia and Argentina was completely no-till and often had no-tilled for over 20 years. In these hot climates moisture conservation is key to establishing a successful crop. In the USA Midwest I saw a mixture of no-till and min-till establishment methods.

When it comes to weed control, cultivations can often be seen as either a blessing or a curse. This is because a tine cultivator sweep or a disc cultivator can do a really good job of chopping through the roots and cutting up existing plants, but can lead to another germination of weeds which, again, can be controlled out-of-crop with a non-selective herbicide or another cultivation pass.

Figure 16: Ridge till cultivator on the Moye farm in Iowa, inter-row cultivating the current soybean crops while building the ridges to plant the following corn crop.

I saw a really interesting system called "ridge till" for growing row crop corn and beans on the Moye Farm in North East Iowa. "Ridge till" is a system based around planting on the ridges produced whilst cultivating between the rows in the previous crop. The cultivation pass to build the ridges is also a good weed control pass. The system also allows the soil to warm and dry earlier in the springtime but the potential downsides are having to use the same wide-row widths for corn and beans, plus the lower stubble residue levels can possibly lead to higher erosion risk.

5.3. Cover cropping / brown manures

Planting cover crops is the 'fashionable' thing to be doing on farms in the UK at the moment, with some of the benefits including reduced erosion, trying to improve soil organic matter, holding nitrogen and 'mining' phosphate from the soil; and, by keeping roots living within the soil, improving mycorrhizal activity (depending on the species of cover crops planted) as well as trying to improve weed control through creating a mulch layer.

On my study tour I saw lots of people utilising cover crops for a variety of reasons, all of which are listed above. In the USA the majority of cover crops I saw were cereal rye single species primarily for reducing erosion on the gently rolling countryside. Once terminated this rye cover would provide a mulch that would slow down the emergence of weeds within the soybean crop. The issues in the USA were mainly about getting a good enough cover established before the continental winter hit, with the possibility of winter kill of the cover crop.

In Argentina the main driver decision for those who had started growing cover crops was to reduce the cost from out-of-crop herbicide sprays which had climbed up to US$40/ha (£30.50/Ha). The massive increase in glyphosate resistance meant that more herbicides had to be used to control out-of-crop weeds. In some cases this made cover crops cost-neutral because the reduced weed germination from the cover crop meant a cheaper cover crop destruction spray was required; and the farmers were starting to benefit from re-building soil organic matter again.

Figure 17: No-till cover crop field trial at the Bakehouse family farm in SW Iowa. Soybeans were sown direct into rye cover on the left, and straight into the previous corn stubble on the right.

Figure 18: Diverse cover crop including oats, beans and canola in Argentina. Photo courtesy of Santiago del Solar.

The number of farmers in Australia using cover crops was probably the lowest out of the countries that I travelled in, mainly because of the climate. The hot and dry summer months is when Australian farmers spend a lot of time on the sprayer trying to destroy any green cover to help preserve any moisture for the following crop. One of the exceptions was David Gooden who sometimes targeted a 'dirty' field to grow a legume brown manure crop (cover crop) allowing him to concentrate on growing cash crops of wheat, barley and canola. This cover has the benefits of providing ground cover in the summer therefore reducing weed germination, as well as giving a nitrogen boost to the following crop.

5.4. Roguing

Roguing could be up there with cleaning out grain stores as one of the most unpopular jobs on an arable farm in the UK, and it would be fair to say that it fell well out of favour once herbicides provided good levels of control. With the decline in control, increased herbicide resistance and plentiful willing labour from recent EU member countries, roguing is making a massive comeback.

Roguing is something that we never stopped doing as part of good faming practice on our own farm. In the past the emphasis was very much on pulling wild oats but in recent years the main target has moved on to blackgrass first, followed by other grass weeds. As I write this report in June 2017 we are about to conclude the roguing season in winter wheat, a task that totalled 170 hours this year. It is the first year that I have recorded man hours for roguing but by doing so I can calculate the cost of roguing winter wheat to be around £6/ha (if using a nominal labour cost of £10/hour) which works out cheaper than a contact herbicide in the wheat crop and with effective 100% control! Once we have finished in the winter wheat the spring wheat will be ready for roguing to commence.

Our roguing strategy has changed slightly in the last couple of years since our primary driver weed (blackgrass) has dictated this. We now commence roguing around two weeks earlier than we did traditionally, and we now use a knapsack sprayer with glyphosate throughout the season to spray out smaller dense patches that we have. We try to spray out these patches a week before the hand pulling commences so we can see any weeds that may have been missed; we also check the areas sprayed out for survivor weeds.

Figure 19: Roguing in progress on one of our own farms

Figure 20: The results of an afternoon's roguing on one of our own farms

Figure 21: Photo taken by a drone on one of our own farms. Glyphosate in knapsack sprayer is used to treat the denser patches before roguing

I was very pleased to see roguing on my travels but also at the same time a little surprised to see it happening. That is probably because a lot of the farms I visited on my travels were quite large in size making labour availability an issue. The move back into rouging is probably one of the biggest signs that herbicide resistance has developed to such a high level that farmers are returning to this most ancient of weed control methods: hand pulling and removal of weeds and their seeds. In developed agricultural countries, rouging is happening on a scale that probably has not been seen since before the start of the green revolution in the early-to-mid 20th century.

Since herbicide resistance started to take hold in palmer amaranth over the last 5-6 years roguing has had to become a very important aspect of cotton production in the southern United States. The biggest reason that herbicide resistance developed so quickly in cotton is the almost total adoption of Roundup-Ready cotton, resulting in no herbicide programme apart from glyphosate being used; and also the employment of poor rotations. In some cases continuous cotton has become the only viable crop to grow. I was told whilst visiting Tennessee that, in that particular region, less than 10% of cotton fields were actually in any sort of rotation at all, apart from continuous cotton!

Figure 22: Cutting gang hoeing palmer amaranth in Tennessee, and it was hot!!

The roguing of palmer amaranth (or cutting as the locals called it) is very similar to hoeing, and the cutting gangs walk down each row hoeing weeds and letting them wilt in the hot southern sun. One farm that I visited was spending over $85,000 (£65,000) a year on cutting gangs but when you also consider that the cost was spread over 4000 acres (1,600 Ha) it made the expense a bit more palatable at just over $21 (£16) per acre or £40/Ha. Only ten years ago, soon after the introduction of Roundup Ready cotton and with glyphosate working well, then herbicide costs were very cheap for these growers. Moving forward to now, where the same growers are having to spray a more complex and expensive herbicide programme and then having to employ a cutting gang, then it is easy to understand how weeds and the ever-increasing cost of weeds has developed into a really big deal for these farmers. Although I didn't witness any roguing in action in Australia, the Wilksch family farm has started to rogue its lentil crop for wild radish. A small gang would meet up every evening and pull radish from some of the biggest fields you could imagine; in fact the idea of working out the cost of roguing came from Randall Wilksch since he had costed out his lentil rouging to be around Au$5.5 (£3.30), while an extra herbicide would cost Au$15-40 (£9-25) making rouging actually a more economical option than a herbicide whilst also getting better control at the same time.

Figure 23: Roguing wild radish out of lentils in a 250Ha field at the Wilksch property in South Australia. (Photo courtesy of Randall Wilksch)

5.5. Organic

On my second visit to the USA I was fortunate enough to visit the Rodale Institute in Pennsylvania. I was particularly keen to examine the 'Farming Systems' trial that started in 1981, initially to investigate the process of organic conversion.

The emphasis is on corn and bean production to replicate what is actually happening in the mid-west, but the conventional and organic plots are in different rotations because of the need to build fertility within the organic system.

The different blocks within the trial include:

1) Organic, utilising manure from a local organic dairy and compost. A long rotation is used and production is based on grain and forage crops
2) Organic, legume based fertility. Legumes used within this block for fertility building.
3) Conventional farming system
4) No-till, introduced in 2008 each of the above plots was sub-divided to add a no-till plot of each of the three farming systems. The crimper is used for cover crop (rye) destruction in the organic plots.

The research at Rodale Institute has produced some interesting results. I was most surprised to hear that in the trials the organic plots were matching conventional yields and beating them in a drought season.

Figure 24: Investigating Rodale Institute 'Farming Systems' trial with Dr. Emmanuel Omondi

Figure 25: Crimper for cover crop destruction at Rodale

Figure 26: High residue cultivator for weed control in row crops at the Rodale Institute

Chapter 5 Summary

- Adjusting crop rotation is an easy, no-cost option for weed control but can have implications on gross margin
- Real thought needs to go into cultivations, ploughing WELL can reset the clock but cannot be overused as it loses that effect. Cultivations (if required) should be very shallow and drilling should be as low disturbance as possible
- Cover cropping is no solution to herbicide resistance; but it is a useful tool for building soil health which can bring other benefits such as better cropping options
- Roguing is one of the UK's secret weapons, because of our relative small scale production this can really be utilised to control surviving weeds.

6. 'Harvest Weed Seed Control'.
Introducing the Australian farmers' answer to herbicide resistance

After travelling to Australia it is fair to say that harvest weed seed control really does demonstrate the 'can-do' attitude of the Australian cropping farmer. All of the six main "harvest weed seed control" techniques were developed by farmers who realised that they had to do something to stop the march of herbicide resistant weeds; the alternative (doing nothing) in the harsh farming environment of Australia could mean going out of business. It really was that simple!

Harvest weed seed control works as the final piece in the integrated weed management puzzle by dealing with the weed seeds at the time of harvest. For harvest weed seed control to be successful it is reliant on the weed species retaining their seeds till harvest. Luckily Australia's two biggest herbicide resistant weed problems Lollium rigidum (ryegrass) and Raphanus raphanistrum (wild radish) have a harvest seed retention rate of around 88% and 99% respectively.

6.1. Narrow windrow burning

It is easy to see why narrow windrow burning has been the most widely adopted of all the harvest weed seed management techniques in Australia. The reason behind its popularity is that it's the cheapest form of harvest weed control, which is always helpful when farmers are considering trying something new!

After the practice of burning had started on farm the researchers picked up on the idea and looked at the science to see what was required to achieve seed destruction from windrow burning and, according to Michael Walsh: "*To guarantee the destruction of the weed seeds you need temperatures greater than 400 degrees for 10 seconds for ryegrass, and 500 degrees for 10 seconds for wild radish."* To achieve this heat only a small amount of modification to the combine is required - by making a chute to concentrate all the swath into as narrow pile as possible (around 500mm) to help achieve the hot controlled burn required.

See a photo of a chute on next page.

The most difficult part of narrow windrow burning is probably the burn itself and keeping it under control, therefore it is often used as a rotational tool for the more manageable swaths in canola (oilseed rape) and legume crops.

Figure 27: Narrow windrow burning chute under construction at Gooden Welding (Lockheart, NSW)

6.2. Chaff lining

Chaff lining is another very simple and cost-effective form of harvest weed seed control, since it concentrates just the chaff element from the back of the sieves in a narrow band, very similar to the narrow windburn chute except the straw is chopped as normal through the combine harvester. The hope is that all the seeds retained in the chaff line will hopefully rot and mulch in there. I guess that the downside is that potentially you could be left with a very high concentration of weed seeds behind the combine in the following crop.

6.3. Chaff decks

Chaff decks are a more elegant solution. Although chaff decks worked on a very similar principle to chaff lining by virtue of the fact that they separated and disposed of the chaff in lines behind the combine wheelings, it felt a lot more controlled. Chaff decks work best if used within a controlled traffic farming system using very accurate and repeatable RTK GPS signals to keep all wheeling to the same place year on year.

The reason why that is so important is because everything is organised to work in multiples of the same width. In Australia the most common was the 3-12-36 system. Put simply, tractor/sprayer/combine wheel spacing worked at 3 meters, the drill/combine header was a 12 meter width, and tramlines were at 36 meters.

Figure 28: Chaff decks are integrated into a controlled traffic farming system on Trevor Syme's farm in Western Australia

It was an awesome system but, as a farmer coming from the UK with my narrow railway crossings and narrow bridges, it was very liberating to see a controlled traffic system done 'properly' with all the wheelings set at the same width. Using the GPS in this manner to control traffic to the same wheeling path every year meant that, if you did have weeds within your field, then they would be gathered by the combine and deposited back in the same wheelings again so as not to spread weed seeds across the field via the combine chaff spreader; with every third pass of the combine being a tramline anyway it appeared to work very well.

Interestingly enough the first chaff deck in the UK has just started field scale evaluation in Essex so I will be very interested to follow its progress through harvest into the following crop.

See pictures on next page of chaff deck in action in Australia.

Figure 29: Chaff deck in action in at Waddi Park, Goomarling WA, Australia

Figure 30: After same chaff deck had been used at Waddi Park, Goomarling WA (photos courtesy of Trevor Syme)

6.4. Bale direct

The bale direct system was also invented in the Australian herbicide resistance hotspot of Western Australia, by the Shields family. It basically is a Heston type baler directly attached to the combine and, unlike a normal baler that only bales the straw element, in the bale direct system the chaff element is combined into the bale. This means that all the weed seeds retained at harvest are removed from the field. This method is particularly useful if you can utilise the bales through livestock or as biomass heating systems, or even have a market for the chaff-containing straw bales.

6.5. Chaff carts

Another method that is gaining interest is chaff carts. A chaff cart is typically a large silage type trailer, often 60m³ in size, which is trailed behind a combine at harvest to collect the chaff fraction that contains most of the weed seeds. The earlier chaff carts used an auger and blower arrangement to deposit the chaff into the cart, which could sometimes block, but the newer chaff carts use a draper header belt to convey the chaff into the cart. When the cart is filled the contents are simply dumped. These chaff dumps then become useful feed for sheep during the Australian summer fallow period, making chaff carts an increasingly interesting option for mixed farmers. On farms without livestock the chaff dumps can be burnt instead.

Figure 31: Springfield Grenfell chaff cart ready for delivery in New South Wales

6.6. Harrington seed destructor: "Don't let the weeds call the shots!"

While touring Western Australia I was fortunate enough to tour the farm of Ray Harrington of Darkan, Western Australia. I must say Ray was possibly one of the most enthusiastic farmers that I have ever met and his passion for growing crops while managing weeds was intoxicating. In my notes that I wrote up every night on my travels the three that stand out to describe Ray are: 'Farmer, Inventor and Innovator', for Ray has spent his life coming up with all sorts of inventions to make his farm more productive and efficient.

Figure 32: Ray Harrington with his foot on top of the cage mill out of the very first Integrated Harrington Seed Destructor

The Harrington Seed Destructor project started around 20 years ago when Ray decided that he was going to have to change something radically if he wanted to continuously-crop without re-introducing livestock onto the farm, but he didn't want to burn because he returned all the residue to the field. After looking around at various options for a couple of years he saw a cage mill in action at a coal mine. After watching the coal go through the mill he decided that was the solution for him.

From that initial idea Ray built a stationary mill powered by tractor PTO to test the concept and put a lot of chaff through it that contained weed seeds. He then planted the processed chaff in his garden and no weeds grew so he knew that he could be on to something. After a chance meeting with Professor Powles he managed to secure a small amount of funding to build the first combine-trailed prototype, which led on to more testing for a number of years before the commercial introduction of a trailed Harrington Seed Destructor. After a further period of testing the seed destructor has been developed to a stage where it is now able to be integrated onto combine harvesters and powered by the combine's own hydraulics. The first commercial season of the Integrated Harrington Seed Destructor was the Australian 2016 harvest with a limited production run to ensure reliability with the hope of a bigger production run in the future. I can see the technology making a leap outside Australia very quickly since many American universities are trialling trailed and stationary units and, looking at the photos of the processed and unprocessed material, the initial results look promising.

Figure 33: This picture plus the one on next page: Difference in weed germination between unprocessed and Harrington Seed Destructor-processed soybean chaff is remarkable! (Photo taken at GHRC2017 conference Denver)

See another photo on next page

Figure 34: Difference in weed germination between unprocessed and Harrington Seed Destructor-processed soybean chaff is remarkable! (Photo taken at GHRC2017 conference Denver)

Chapter 6 Summary

- I feel chaff decks/lining and seed destructors would be the better option for UK because of their compact nature
- Harvest weed seed control probably has limited use in the UK because of the low levels of blackgrass seed retention at harvest, but could become helpful if bromes and ryegrass became a bigger problem

7. Education and Extension

I consider myself very fortunate to have visited some fantastic research organisations in the last 18 months, but half way through my Nuffield Farming Scholarship it suddenly dawned on me: what use is all this knowledge and data if it is not effectively communicated to the end user, in this case the farmer? Part of the issue seems to be with the research culture insomuch that funding is dependent on researchers doing just that, leading to the ‘publish or perish’ culture. But is that really in the farmer’s interest? Luckily on my travels I saw a few amazing exceptions to this ‘publish or perish’ culture.

7.1. Australian Herbicide Research Initiative (AHRI) & Weedsmart

The Australian Herbicide Resistance Initiative was founded in 1998 and is based at the University of Western Australia in Perth. The current Director is Professor Stephen Powles. Although the research at AHRI is world class, the most exciting thing I found there was the way that they actively communicate with growers and agronomists though the Weedsmart Initiative.

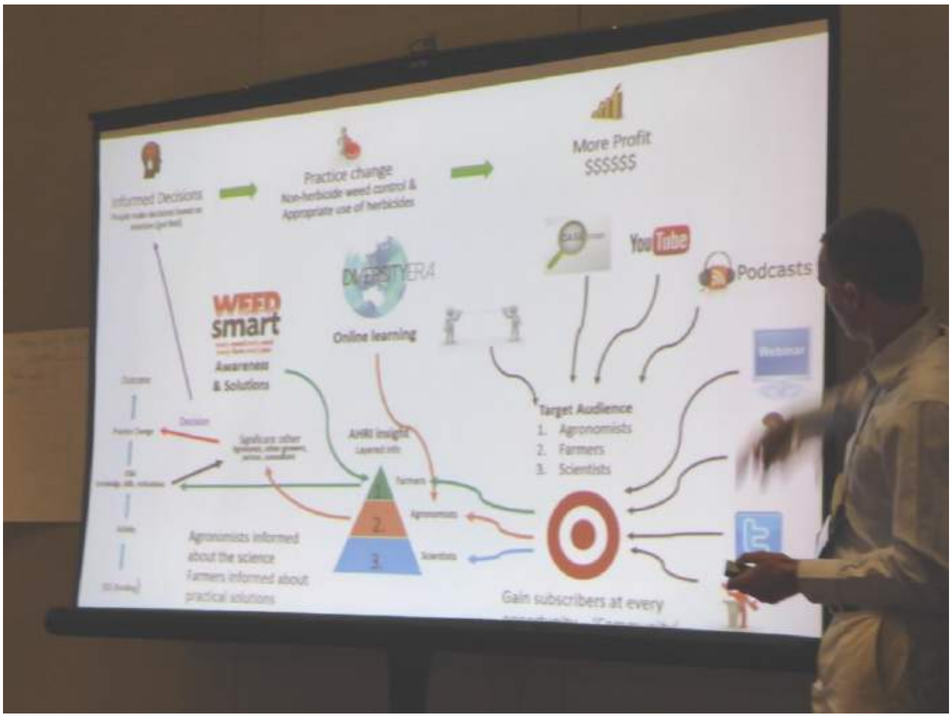

Figure 35: Peter Newman, explaining all the avenues of communication at AHRI and Weedsmart

Peter Newman is the Leader of Communications at AHRI where his primary role is to communicate the research carried out at AHRI to the Australian grains industry: although one the first things I learnt is that effective communication does not come cheap and Weedsmart soaks up around 30% of AHRI’s total budget!

Communication comes in many forms including:

- Having its own Twitter account @WeedSmartAu
- A fortnightly email called ARHI Insight that has over 3,200 global subscribers with a 40% open rate
- Podcasts. These are very regularly downloaded and listened to on the tractor while working. It probably helps that in rural Australia the choice of radio stations isn't always great.
- Webinars
- You-Tube Videos
- On-line short courses such as 'Herbicide Resistance 101' and 'Harvest weed seed control 101'.
- Weedsmart Week, a three-day week looking at all things 'herbicide resistance' with indoor presentations and farm visits.

Figure 36: One of my Nuffield highlights was meeting and discussing herbicide resistance with AHRI Director & herbicide resistance legend Professor Stephen Powles.

7.2. USA university extension services

In the USA knowledge transfer tends to take a different route, primarily led by the land-grant universities. Land-grant universities were mostly established in the late 1800s by the relevant federal state gifting land to be sold or farmed for profit. Therefore, while focusing on teaching practical agriculture, science and engineering, funding to run the establishment could be created.

Of all the land-grant universities that I visited the most impressive university extension service was probably Iowa State University with a good number of extension agronomists relaying information to the grower; although this approach to information was sometimes a 'one stop' shop for grower information. At the same time these agronomists were key to keeping up to date on the latest product releases and changes in the federal American system.

7.3. CREA

In Argentina I met up with farmers who were members of CREA. The acronym translates in English as Regional Consortiums for Agricultural Experimentation. CREA was founded in 1960 and now has over 200 groups that are formed locally and are sector-specific. Each CREA group of around 10 farmers employs an agronomist/consultant to help with the running of the group and offer advice. Each month the group has a meeting on one of the members' farms, with the main objective of the meeting to help the host farmer through his farming and business problems as well as organising and running group trials.

The ethos behind CREA is '*getting in the field and seeing for yourself*' and '*no secrets, just farmers helping farmers*'. It was a very strange concept to me as I don't think that I would personally feel that comfortable sharing that level of business detail with my neighbours, but in Argentina where the economic climate has been more unstable then here in the past, then the ability to talk through your businesses challenges with your neighbours seems to create a sense of security.

Chapter 7 Summary

- Research is useless if it isn't communicated to farmers
- Communication needs to be well funded
- Farmers trust farmers!

8. Looking back on my study

During my Nuffield Farming journey I would say that the overwhelming message I've heard time and time again is: 'Diversity, diversity, diversity' - the more things you can change the better! The fascinating thing about nature is its ability to take advantage of things staying the same, so if you keep changing your farming practice by constantly 'mixing it up' then it cannot adapt quickly enough to the new environment that has been created.

Unfortunately chemical diversity is not as easy within the EU as it is within some other parts of the world because a lot of herbicides that would be of use dealing with herbicide resistance have either been banned because of environmental or toxicological reasons, or have even failed to get registered for the same reasons in the first place. The situation with genetically modified crops is similar in that the cultivation of these crops is not possible. However, with the UK due to leave the EU in 2019, the decision on what plant protection products or GM traits to authorise will then be in the hands of the UK government. I am not suggesting that products that were banned in the past will be making a re-appearance or that the floodgates to GM cropping will open, but these are conversations that will have to be had and debated in the future.

I think cultural diversity is probably where we will see more immediate gains here in the UK. Some of the more implementable cultural controls probably include:

- **Make a plan, but be flexible**
  If you have made a plan then you have taken the first step in 'owning the problem' since herbicide resistance does not go away if ignored. It will only get worse. Also by thinking about fields in isolation you can work your way back to the root of the problem and think of the most appropriate solutions. Be prepared to change the plan if necessary but be patient at the same time because reducing a weed population can be a slow process.
- **Soil health and cultivations**
  Healthy soils that are well drained and have higher organic matter contents give you so many more options with cultivations, cropping, etc. Go back to basics ensuring drainage schemes are working and if mole ploughing would be appropriate or would help.
  Consider what cultivations are appropriate or if they are appropriate at all! Ploughing is a great method of weed control, but it cannot be done on too regular a basis otherwise you just end up mixing all the seeds throughout the soil profile. Ploughing is also a very skilled job and modern ploughs often don't do a really good job of inversion. Other cultivations should be kept as shallow as possible with all drilling operations being as low-disturbance as possible. On land clear of weeds, or in years of good weed control, no-till should be maximised so as not to bring fresh weeds to the surface.
- **Attention to detail**
  Factor the implications of weed control into all your farming decisions. Time spent roguing weeds is very well spent if the population is low enough to allow, also taking the time cleaning down cultivator and combines in field gateways is often time well spent.

Finally, I would like to say that until I undertook this Nuffield Farming Scholarship I had probably undervalued what a difference really good communication can make and despite this new 'post-truth' age we now live in it's reassuring to know that farmers still trust farmers.

9. Conclusions

1. Herbicide resistance is a global problem
2. Herbicide resistance is a direct result of farming practices
3. Reliance on herbicides alone is not sustainable and weed control strategies should be based around cultural methods
4. There is no single answer to herbicide resistance; increasing the diversity of farming systems is required
5. Stewardship of existing herbicides is vital, since no new modes of action have been discovered in over 20 years
6. Farmers trust farmers! Allowing farmers to help communicate positive stories/messages can deliver great results

10. Recommendations

1. Better education of herbicide resistance and communication has a vital role in resistant weed management

2. Industry recommendations for dealing with herbicide resistance needs to come from 'one voice' similar to the Weedsmart initiative in Australia, with funding from growers' AHDB Cereal & Oilseeds levy and the agrochemical industry. This approach would reduce confusion among farmers and avoid mixed messages

3. Herbicide boxes and labels should have the Herbicide Resistance Action Committee (HRAC) classification group shown on them to aid herbicide rotation

4. The agrochemical industry should help educate farmers and agronomists about the HRAC group classification system

5. Glyphosate is still the keystone to successful reduced tillage and no-till farming in the UK even after 40 years of use. I feel it is time to re-educate farmers and agronomists on glyphosate to sustain its future use

11. After my study tour

Over the last 18 months I have travelled to three different continents studying herbicide resistance but, more importantly, looking and asking how farmers are dealing with their own herbicide resistance problems, while listening to what measures they are putting in place to deal with it. At the same time as investigating herbicide resistance I was lucky enough to visit some of the world's biggest no-tilling countries; no-till and conservation agriculture is a real farming passion of mine and having the opportunity to learn from farmers who have not cultivated in some cases for over twenty years was a priceless experience for me.

As a result of my Nuffield Farming Scholarship I would say that the changes on our own farm are more evolutionary than revolutionary. This is partly because even though we have some highly resistant blackgrass on our farm the level of infestation would be considered acceptable for some. Having 'good enough' levels of control of blackgrass is no longer good enough because I'm conscious of possibly being only one or two mistakes away from a far more serious blackgrass problem. I feel this will be the case until I'm confident that the seedbank is fully depleted.

The most important change to our farming system is a firm zero tolerance to blackgrass when, in the past, we may have tolerated low levels on our historically worst blackgrass farm. All our winter and spring wheats and linseed are rogued for blackgrass with no exceptions. Even though we had never stopped the practice of hand roguing we now prioritise the worst fields and patches rather than leaving them to the end and running out of time and having the risk of seed shedding.

The farms' crop rotation has changed since the start of my Nuffield Farming journey. For a number of years we had run two different crop rotations depending on the soil type. On our better and more productive land we were growing two wheat crops followed by oilseed rape or spring beans; on the farm with heavy magnesium clay soil our typical rotation would be wheat, oilseed rape, wheat and winter beans. These were hardly the worst rotations in the world; they were good and profitable rotations but only around 10% of the land was in a spring crop each year. There was no spring cropping on the most challenging land that also has the potential to have the worst blackgrass problems. We have changed this by adding a degree of flexibility into our crop rotations. On the better land we have introduced spring wheat before the spring bean crop to create a double spring break, and have also re-introduced a small area of linseed back into the rotation. Our aim now it to have around 30% of our farm growing a spring crop every year. On the heaviest land we are trying our best to have some spring cropping in the rotation with spring barley looking to make a re-introduction for harvest 2018.

As is the trend in arable farming at the moment we are also having a try with cover cropping. Although I'm no cover crop zealot I do think it has a place especially if land is to be left undisturbed over winter since I think it does bring some soil health benefits. It helps increase soil organic matter, whilst mopping up any available nutrients. As a personal rule, with cover crops I try to plant species that are unrelated to what I grow as a commercial crop since I'm still unsure of any potential disease or pest carryover into our cash crops, but the aim is to establish an even, low density cover to give enough light and space for any blackgrass to grow amongst it so that it can be controlled out of crop. It is a lot easier said than done especially with my own personal limit of around £20/Ha on cover crop seeds.

Since starting my Nuffield Farming Scholarship and looking more at no-till during my travels it has given us the confidence to fully embrace no-till across our entire farming area. We have been opportunist no-tillers for a number of years, typically with our Horsch Sprinter drill after bean crops that would typically go on to produce the highest yields the following harvest. But in 2012 we dipped our toe in the no-till camp a little further and purchased a 4 meter John Deere 750A single disc no-till drill and have drilled some fields since then using only the John Deere drill, so we have seen it produce consistent crops throughout the rotation. As our confidence over the drill's abilities has grown we have rolled the system out throughout the entire farm and harvest 2017 will be our first harvest from entirely no-till sown crops. We were so confident that the John Deere drill can do all that we ask of it that we did the deal to upgrade our two 4 meter drills (Horsch Sprinter & John Deere 750A) to a single 6 meter John Deere 750A while I was undergoing my Nuffield Farming study tour in Australia. It was a different experience getting the spec of the drill right with my dad through the magic of Twitter's Direct Messaging feature! I feel that the low disturbance nature of the drill will be of benefit regardless of whether we were no-tilling or not, and the added benefits of increased low disturbance drilling capacity will engender more confidence to hold off drilling to as late as we dare. A wider drill offers less compaction through fewer wheelings while also better utilising an existing John Deere 7820 (185hp) tractor. Despite the move to a no-till based establishment method we appreciate this may not always be the case and value the importance of mole drainage and, where appropriate, selective sub-soiling with low disturbance points. We have also retained our Horsch FM cultivator to use as required.

Figure 37: Our new 6 meter John Deere 750A drill, ready for work after a few user modifications!

Personally I think taking time to undergo a Nuffield Farming Scholarship was probably one of the best professional decisions that I have made during my career. It has given me a completely different outlook on how I view our industry, as well as widening my list of contacts from around the world and making some fantastic new friends.

My Nuffield Farming experience is something that I will treasure for ever more.

Richard Hinchliffe

July 2017

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Jonathan and Tiarnee Dyer, farmers, Vic
John and Brooke Stevenson, farmers, NSW

David Gooden, farmer, NSW
Jamie Wright, farmer and chaff cart manufacturer, NSW

Argentina

Fernando Frugoni, CREA weed project leader
Robert Bunge, farmer
Rubén Berardo, farmer
Santiago del Solar, farmer
Maria B. (Pilu) Giraudo, Ministry of Agriculture, Argentina.

UK

Dick Neale, Hutchinsons
Dr Paul Neve and the Rothamsted Research team

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And if there's anyone I have inadvertently forgotten to mention – my grateful thanks to you too.

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Appendices

Appendix 1. Hinchliffe Farms 'Big Middle' full resistance test, 2015.

BLACK-GRASS RESISTANCE TESTING

Farm: Hinchliffe Farms
Field name/ sample reference: Big Middle

Sample code: 2013BASF64

Dear Sir

You submitted a sample of black-grass seed for testing for resistance. The test involves two parts. The first test measures enhanced metabolism resistance and ACCase target site resistance using a Petri-dish assay. The second test is a glasshouse pot test which measures ALS resistance. You have already received your results for the petri-dish assay but they are repeated here with the results from the ALS target site resistance test for your convenience.

Herbicide Resistance test results

	Target site		**Enhanced metabolism**
	ALS	**ACCase**	
Field names	*R rating*	*R Rating*	*R rating*
Susceptible standard	S	S	S
Big Middle	**RR**	**RRR**	**S**

The information below provides details and a summary on interpretation of the results and a photograph of the ALS test is attached for reference. Please contact me if you have any other queries.

Yours sincerely,

Lynn Tatnell
Research Scientist, weed biology

Summary

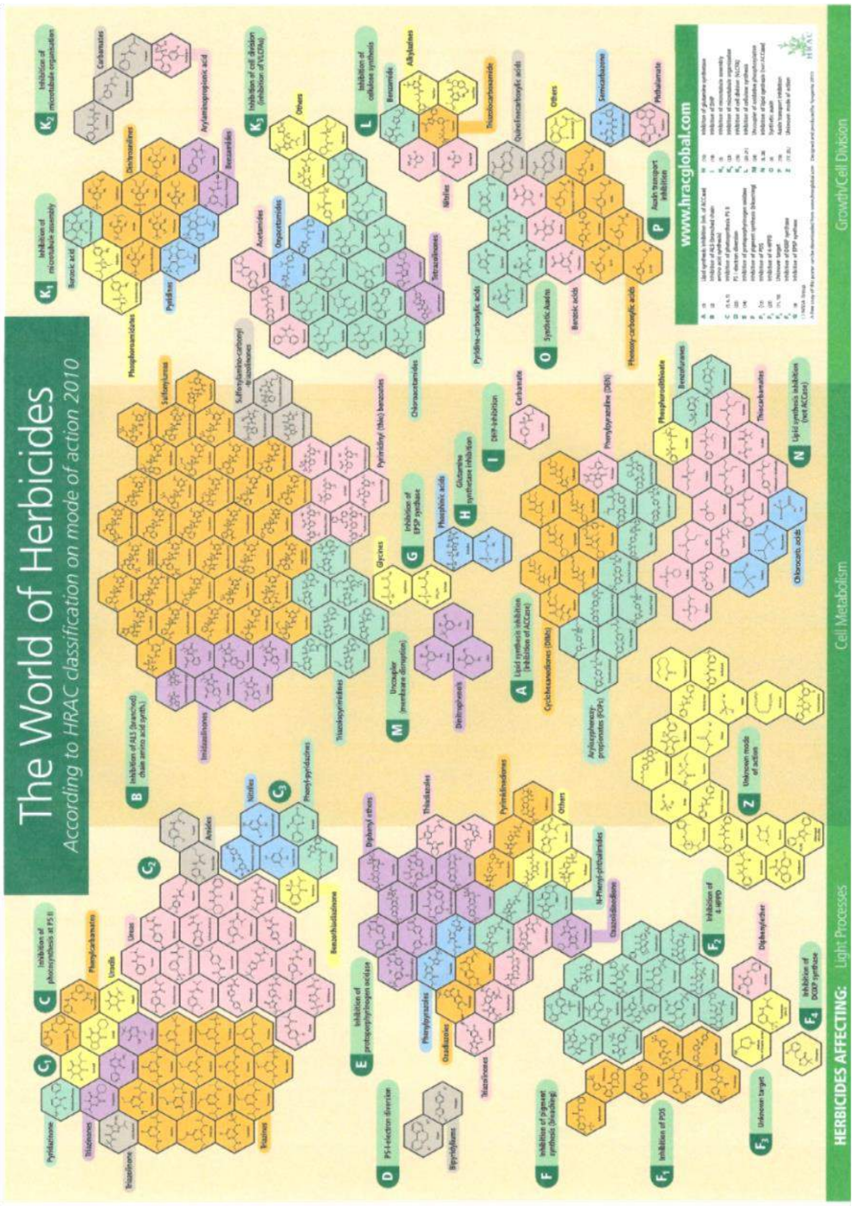
Type of resistance	**EMR**	**TSR – ACCase**	**TSR - ALS**
Examples of herbicides affected	Almost all – notable exceptions include propyzamide and carbetamide	‘fops’, ‘dims’ and ‘dens’ (e.g. clodinafop, fenoxaprop, fluazifop-P, propaquizafop, cycloxydim, clethodim, tepraloxydim and pinoxaden)	Sulphonylureas (e.g. flupyrsulfuron, mesosulfuron/iodosulfuron) and pyroxsulam
Speed of development	Develops slowly	Can develop rapidly	
Incidence and impact	Very common, but only very severe cases result in almost total loss of control	Common, in severe cases loss of control can be significant	Less common than ACCase but increasing, in severe cases loss of control can be significant
Maximising herbicide performance	Ensure application in optimal soil and weather conditions	Ensure application in optimal weather conditions Use correct nozzles, water volume and timing. Smaller and actively growing black-grass is usually better controlled	
Implications of test results for management:			
S	Herbicide use should lead to effective control. If control is poor consider: • Were product choice and timing correct? • Was weather poor at application? • Was black-grass too large? • Was sample representative of the field?		
R? or RR rating	• Herbicides will have some activity. • Pre-emergence application is essential and beneficial, • Aim to apply in optimal conditions to maximise efficacy. • Reduce risk through inclusion of some cultural control options	This is level is a cause for concern and action needs to be taken to prevent an increase. • Herbicide use is likely to result in sub-optimal control. • Herbicides will still give control of the portion of the population that is susceptible, but resistance may develop rapidly through selection. • Integrate other modes of action and timings into herbicide programmes	
RRR rating	• High likelihood that herbicide performance will be affected in most seasons. • Use a range of actives with different modes of action.	• Poor levels of control are very likely, especially when this mode of action is used alone. • Vital to integrate other modes of action into strategies • Inclusion of several cultural control options will be essential to contain populations	

	• Inclusion of several cultural control options will be essential to contain populations	

Adapted from www.agricentre.basf.co.uk

Figure 38: The plant on the left is untreated whilst the plant on the right (Big Middle Sample) has been treated with 0.4kg/ha Atlantis + 1.0 l/ha Biopower.

Appendix 2. Herbicide Resistance Action Committee modes of action poster



Source: Heap, I. The International Survey of Herbicide Resistant Weeds, online