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A Nuffield Farming Scholarships Trust Report

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Worming like a winner: A guide to a sustainable UK sheep flock

Miranda Timmerman

July 2023

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ISBN: 978-1-912059-98-0

Published by The Nuffield Farming Scholarships Trust
Southill Farm, Staple Fitzpaine, Taunton, TA3 5SH
Tel: 01460 234012
Email: director@nuffieldscholar.org
www.nuffieldscholar.org

A Nuffield (UK) Farming Scholarships Trust Report

Date of report: July 2023

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

Title	Worming like a winner: A guide to a sustainable UK sheep flock
Scholar	Miranda Timmerman
Sponsor	The Worshipful Company of Farmers with Savills and The Royal Welsh Agricultural Society
Objectives of Study Tour	1. Managing parasites without the use of anthelmintics. 2. Developing practical steps farmers can take to future-proof their farms and stock. 3. Using anthelmintics to prevent resistance occurring and to reverse the current incidence.
Countries Visited	UK, The Netherlands, Kenya, Saudi Arabia, Zimbabwe, New Zealand. Via Zoom: Norway, Australia
Messages	1. Anthelmintic resistance is a direct threat to the UK sheep industry's future survival. 2. Targeted selective treatment is crucial to slowing resistance. 3. Refugia is a key management strategy to reverse resistance. 4. Cheap tests are available to understand parasite levels. 5. The first step is to understand the farm's anthelmintic resistance status.

EXECUTIVE SUMMARY

Endoparasites have co-evolved with sheep but modern, intensive management techniques have increased their negative impact on productivity. Anthelmintics have been historically over-used, resulting in our current problems. The situation is concerning because anthelmintic resistance has the potential to stop sheep farming in the UK; however there are management changes that can be made to not only prevent anthelmintic resistance, but even reverse it.

Across the globe farmers and researchers are employing different ways to tackle this problem, from breeding beneficial genetic traits into their sheep to using appropriate rotational grazing and testing and implementing refugia, among many others. This report aims to collate the knowledge into a one-stop-shop for controlling sheep worms.

New Zealand farmers are taking the threat of anthelmintic resistance seriously as several have already discovered triple anthelmintic resistance on their farms. Implementing key ideas such as refugia and targeted selective treatments to reduce the reliance on chemicals is essential, alongside improving grass utilisation to increase the available nutrition, aiding the sheep's natural defences. The historical mixed farm is a successful way to manage parasites on pasture using different stock classes to act as vacuumers following contaminators. Ideally lambs should graze the clean pasture first, followed by ewes, allowing some refugia, then cattle to hoover up the parasites without becoming infected themselves. Genetics play an important role in flock susceptibility so understanding your ram breeder's direction on parasite management is also crucial. For the future, new and alternative ideas and products coming from outside the sector in Africa and elsewhere may provide additional alternative options.

When tackling on-farm resistance the first step is to understand what is happening in your business as without this appropriate changes cannot be made. Regular non-subjective test protocols, such as faecal egg counts, should be implemented monthly across the flock alongside understanding the main risk factors that lead to high parasite burdens. Parasite control should be developed on a farm-by-farm basis as the use of pasture and productivity aims are specific to each business. Therefore it is important to use tailored advice from properly informed advisors who understand the complexities of the system as a whole.

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Published by The Nuffield Farming Scholarships Trust
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Chapter 1 - Personal Introduction

Growing up in a rural village on the Welsh borders I had been determined to work in agriculture since I was a teenager. I graduated as a veterinarian from the University of Bristol in 2017 and worked as a mixed vet and farm animal vet in West Wales until 2021. I then locumed in practices across the UK and New Zealand as a farm veterinarian. During my veterinary studies I undertook an MSc with a dissertation focused on parasitology and while working in West Wales completed my AVP Certificate in Production Animals, focusing on sheep.

I am on the Sheep Veterinary Society and Welsh British Veterinary Association committees to steer policy around sheep parasites and the farm veterinary industry. I also run an educational Instagram account aimed at opening the farm veterinary profession up to a wider audience as well as educating farmers and vet students. Education is very important to me and I regularly speak at vet student and farmer conferences and open days as well as publish articles in both the veterinary and farming press.

I relish helping improve farm businesses through animal health and production across the globe and love collaborating and developing new ideas.

Outside of work I enjoy hiking and travelling, the higher and harder the mountain the better!

Fig 1; The author, Miranda Timmerman, investigating dung beetles in Zimbabwean ruminant faeces. Photo: Author's own

Chapter 2 - Background to my study subject

It is safe to say that the UK is at a crisis point with anthelmintic resistance. If we continue managing sheep, pasture and parasites the way we currently are there will be farms that are unable to keep sheep in the future, threatening livelihoods and altering the countryside and a way of life. This is not just a UK problem: across the globe farmers are realising that their wormers are not working. So what's next? New wormers are not an option. We need to look at the fundamental way we think about how we manage our parasites. We need to start farming our worms.

The most recent study on anthelmintic resistance prevalence in the UK was in 2015. This showed 94% of farms had resistance to Benzimidazoles and, more worryingly, 28% of farms had resistance to three anthelmintic groups[8]. That's a lot of farms with a drench problem. The cost of parasitic worms to the UK sheep industry is estimated at £42.3 million yearly while the cost of anthelmintic resistance is £3.15 million[10].

Across the world New Zealand is not faring much better and resistance prevalence has increased since 2016 with a similar profile to the UK (Fig 2)[3]. In contrast, Australian data show much lower resistance levels within their nematode populations[8,9]. I chose to focus on New Zealand as a more comparative production model to find ways we can improve our systems at home due to the similarities in much of our weather patterns and farming systems, rather than the dry and highly extensive systems in Australia.

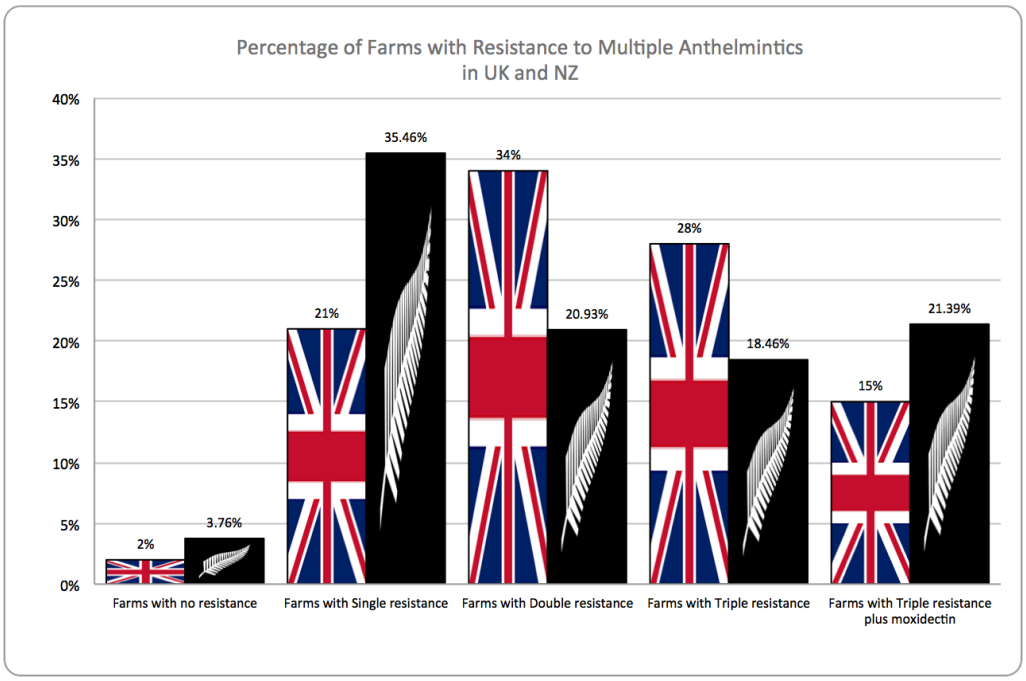

Fig 2; Percentage of farms with resistance to multiple anthelmintics in UK (2015 data) and New Zealand (2022 data)[3, 18]

During my work as a clinical vet in Wales, it was noticeable how endoparasite (parasites that live inside the animal) issues have been affecting farmers more, even over the last few years. I have always had an interest in gastrointestinal parasites and consequently focusing on a topic acutely affecting both farmers and vets seemed like the perfect middle of the Venn diagram.

In order to produce useful and specific actionable points for UK sheep farmers, I focused on gastrointestinal endoparasites, specifically sheep nematodes, rather than confusing the recommendations by also investigating the very different treatments and management for the other helminths; such as fluke and tapeworm. It is important to remember that some of the medicines used to treat endoparasites also treat ectoparasites (parasites that live on the outside of the animal) and consequently advice should always be contextualised and care must be taken to assess the impacts of using these medicines on non-nematode parasites.

Chapter 3 - My study tour

I took a different approach to my Nuffield travels compared to many scholars due to my working flexibility. As a vet I was able to work in New Zealand as a full-time staff member. This enabled me to fully immerse myself in their agriculture, understanding the challenges farmers are facing every day as well as undertaking many visits.

Country	**When visited**	**Why I visited**
The Netherlands	4/22	Cross-industry technology from medicine and cattle
Kenya	6/22	Alternative parasite prevention strategies from other areas of agriculture and control in challenging environments
Saudi Arabia	7/22	Large-scale farming management
Zimbabwe	10/22	Scholar-organised three-week tour across all sectors of agriculture
New Zealand	10/22-5/23	Sheep-focused visits and the Nuffield Triennial Conference
UK	22-23	Understanding how recommendations can be incorporated into the UK sheep farming industry given farmers' current challenges
Norway	Zoom Meetings	Discussing decoupling of veterinary practices and medicines sales
Australia	Zoom Meetings	Dung beetle importation and use, and the challenges of sheep farming

Chapter 4 - Introduction to parasites

4.1 Parasite lifecycle

Endoparasites in sheep is such a large topic that to use the Nuffield opportunity effectively I have concentrated on the most widespread and problematic gastrointestinal nematodes (worms that live in the intestines and stomachs): *Nematodirus* spp.*, Trichostrongylus* spp.*, Teladorsagia* spp. and *Haemonchus* spp.

Understanding their lifecycle (Fig 3) is key to developing management changes and reducing our use of control chemicals (anthelmintics). *Nematodirus* has a slightly longer lifecycle than the others but they essentially transition through the same stages (Fig 4). The free-living stage is shorter in warm and wet conditions rapidly increasing pasture burdens.

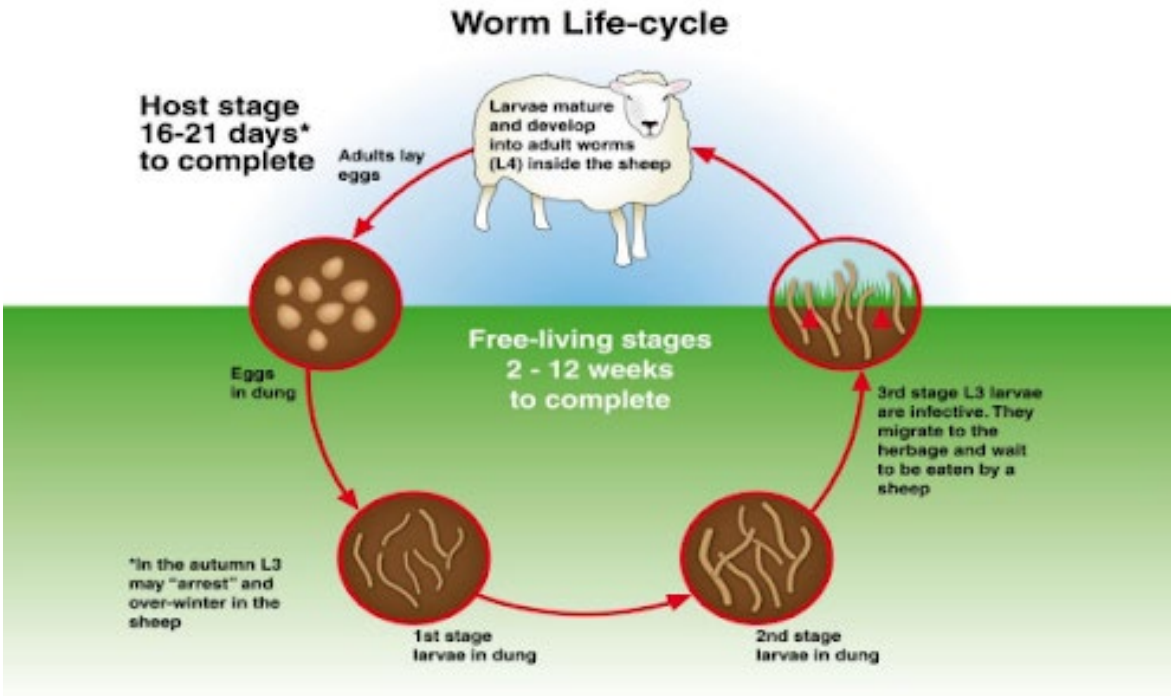

Fig 3; Lifecycle of Teladorsagia, Haemonchus and Trichostrongylus [13]

Parasite	No. days in host	Free-living stage	Key takeaways
Nematodirus	14	8-9 months	Only affects lambs in the first grazing season. Seasonal as they need a cold snap (10°C for 10 days to hatch).
Teladorsagia, Haemonchus and *Trichostrongylus*	16-21	2-12 weeks	Affects all grazing sheep.

Fig 4; Key differences in nematode lifecycles

So why do we care about endoparasites? Sheep worms can be fatal, particularly *Nematodirus* in lambs and *Haemonchus* in all sheep, but the impact of burden on productivity and profitability costs farmers daily. Different worm species cause different issues in the host: while *Haemonchus* causes anaemia through blood-sucking, the others decrease the host's ability to absorb nutrients by damaging the gut villi and competing for nutrients. *Haemonchus* is currently only present in the south of the UK as it needs a warmer climate; however with climate change it is progressing north so needs to be on farmers' radars.

Despite these negatives we are unable to eliminate parasites[4] from our sheep populations or pasture and efforts to do so have led to anthelmintic resistance (a reduction in the sensitivity of the parasite to a treatment, increasing survivability). Consequently we need to understand how we can effectively farm with parasites while managing the risks.

4.2 How resistance develops

Anthelmintic resistance is a genetic heritable loss of sensitivity in parasites passed on through breeding which enables them to survive a treatment. It is considered to exist in a population if more than 5% of the worms survive an anthelmintic treatment.

Resistance develops through exposure of parasite populations to anthelmintics: the selection pressure. Fig 5 demonstrates how resistant parasites become the dominant population after treatment, as non-resistant parasite populations are killed by the drench. If these treated sheep are then put on clean pasture, the ground becomes populated with resistant-only parasites, increasing resistance on the farm at an alarming rate. However, if they are put back onto an already infected pasture, the resistant genes are diluted by the resident parasite population, slowing the spread of the resistant genes in the parasite population across the farm.

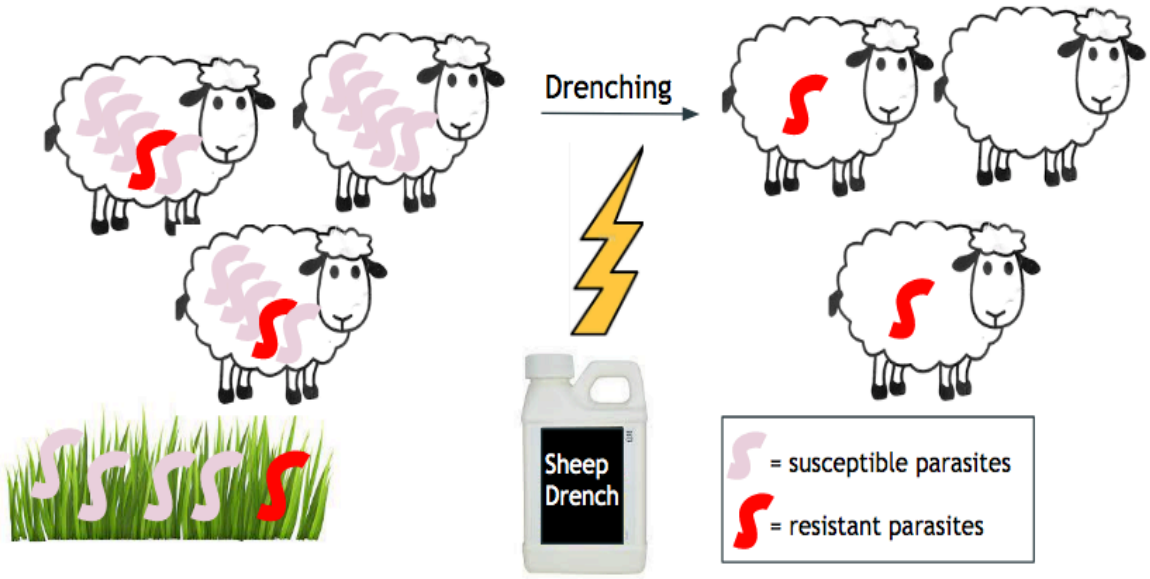

Fig 5; Treatment selecting for resistance. Diagram: Author's own

Key messages:

- **Understanding the lifecycle means you can alter management to avoid high worm burdens.**
- **Treating for worms is a selection pressure for parasites to develop anthelmintic resistance.**

Chapter 5 - Anthelmintics

5.1 Anthelmintic groups

The use of anthelmintics plays a crucial role in anthelmintic resistance, so understanding them is key. They are chemical compounds which kill internal nematodes when administered to animals, in this case sheep, and are grouped into five main anthelmintic groups (Fig 6) according to their active ingredient and mechanism of action (how they kill parasites). Although there are several different chemicals in each group, they can generally be considered the same (eg if a parasite is resistant to Oxfendazole it is generally also resistant to Albendazole), with some Group 3 chemicals, the Macrocyclic Lactone group, being marginally different. When deciding on the appropriate drench to use it is important to look at both the active ingredient (actives) and which group it is in compared to the other drenches you have been using.

There is currently known resistance to all groups despite the most recent new groups (4-AD and 5-SI) only being commercially available in 2010. There are no new actives being investigated in this space so it is essential to preserve what we have.

Group 1 - (1-BZ) White

Product	Company	Chemical name	Parasites Covered	Use	Trace elements	Meat Withdrawal Period (days)
Albacert	Downland	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	5
Albenil SC 2.5%	Virbac	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	5
Albex 10%	Chanelle Pharma	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral		5
Albex SC 2.5%	Chanelle Pharma	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	5
Benzimole SC 2.5%	Mole Valley	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	5
Bovex 2.265%	Chanelle Pharma	Oxfendazole	Roundworm, Lungworm, Tapeworm	Oral		24
Endospec SC 10%	Bimeda	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	4
Endospec SC 2.5%	Bimeda	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	4
Ovidrench S&C 2.5%	United Farmers	Albendazole	Roundworm, Lungworm, Tapeworm, Liver fluke (adult only)	Oral	Co; Se	4
Panacur 10%	MSD AH	Fenbendazole	Roundworm, Lungworm, Tapeworm	Oral		15
Rycoben SC	Elanco AH	Ricobendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	3
Tramazole SC 2.5%	Tulivin Labs	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	4
Tramazole SC 10%	Tulivin Labs	Albendazole	Roundworm, Lungworm, Tapeworm, Liver Fluke (adult only)	Oral	Co; Se	4
Zerofen 10%	Chanelle Pharma	Fenbendazole	Roundworm, Lungworm, Tapeworm	Oral		21
Zerofen 2.5%	Chanelle Pharma	Fenbendazole	Roundworm, Lungworm, Tapeworm	Oral		21

Group 2 - (2-LV) Yellow

Product	Company	Chemical name	Parasites Covered	Use	Trace elements	Meat Withdrawal Period (days)
Chanaverm 7.5%	Chanelle Pharma	Levamisole	Roundworm, Lungworm	Oral		20
Levacide 7.5% injection	Norbrook labs	Levamisole	Roundworm, Lungworm	Injection S/C		15
Levacide LV 7.5% oral	Norbrook labs	Levamisole	Roundworm, Lungworm	Oral		21
Levacur SC 3%	MSD AH	Levamisole	Roundworm, Lungworm	Oral	Co; Se	20
Levamole	Mole Valley	Levamisole	Roundworm, Lungworm	Oral		20

The information in these tables was correct to the best of our knowledge at the time of printing (January 2023). Always check the data sheet before using any product.

You can check the most up to date information on the VMD website at: https://www.vmd.defra.gov.uk/ProductInformationDatabase/

Group 3 - (3-ML) Clear

* Injections: I/M = intramuscular S/C = subcutaneous

Product	Company	Chemical name	Parasites Covered	Use	Meat Withdrawal Period (days)
Animec	Chanelle Pharma	Ivermectin	Roundworm, Lungworm, Nasal bots	Oral drench	10
Bimectin	Bimeda	Ivermectin	Roundworm, Lungworm, Nasal bots	Injection S/C	42
Cydectin 0.1% Drench	Zoetis	Moxidectin	Roundworm, Lungworm	Oral drench	14
Cydectin 1% injection	Zoetis	Moxidectin	Roundworm, Lungworm, Sheep Scab, Nasal bots	Injection S/C	70
Cydectin 2% LA Injection (20mg/ml)	Zoetis	Moxidectin	Roundworm, Lungworm, Sheep Scab, Nasal bots	Injection S/C (base of the ear)	104
Dectomax	Elanco AH	Doramectin	Roundworm, Lungworm, Sheep Scab, Nasal bots	Injection I/M	70
Eprinex - Multi 5mg/ml pour-on (POM-V)	Boehringer Ingelheim AH	Eprinomectin	Roundworms (adults only), Lungworm (adults only)	Pour-on	2
Ivomec Classic Injection	Boehringer Ingelheim AH	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	37
Molemec Injection	Mole Valley	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	37
Molemec Drench	Mole Valley	Ivermectin	Roundworm, Lungworm, Nasal bots	Oral drench	6
Moxodex Oral 0.1%	Chanelle Pharma	Moxidectin	Roundworm, Lungworm	Oral drench	14
Noromectin Drench	Norbrook labs	Ivermectin	Roundworm, Lungworm, Nasal bots	Oral drench	14
Noromectin injection	Norbrook labs	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	42
Oramec Drench	Boehringer Ingelheim AH	Ivermectin	Roundworm, Lungworm, Nasal bots	Oral drench	6
Panomec injection	Boehringer Ingelheim AH	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	37
Paramectin injection	Norbrook labs	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	42
Paramectin Drench	Norbrook labs	Ivermectin	Roundworm, Lungworm, Nasal bots	Oral drench	14
Premadex Drench	Downland	Ivermectin	Roundworms. Lung worm, Nasal bots	Oral drench	14
Premadex 1% injection	Downland	Ivermectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	42
Zermex 0.1% Drench	Downland	Moxidectin	Roundworm, Lungworm	Oral	14
Zermex 1% injection	Downland	Moxidectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C	70
Zermex 2% LA injection (20mg/ml)	Downland	Moxidectin	Roundworm, Lungworm, Sheep scab Nasal bots	Injection S/C (base of ear)	104

Group 4 - (4-AD) Orange

Product	Company	Chemical name	Parasites Covered	Use	Meat Withdrawal Period (days)
Zolvix	Elanco AH	Monepantel	Roundworms	Oral	7

Group 5 - (5-SI) Purple (Derquantel not available as a single active)

Multi-actives

Product	Company	Chemical name	Parasites Covered	Use	Meat Withdrawal Period (days)
STARTECT Dual Active	Zoetis	Derquantel (5-SI) Abamectin (3-ML)	Roundworms, Lungworm	Oral	14

Fig 6; SCOPS - Know your anthelmintics[11]

5.2 Appropriate anthelmintic usage

Anthelmintics should be used to prevent disease, not infection. With 90-95% of parasites in the environment living on the pasture when we dose sheep we are only affecting the tip of the iceberg while providing selection pressures that promote resistance. All parasite management and anthelmintic use plans should always be done on a farm-by farm basis as there are so many complexities. However, there is some broad advice that can be implemented.

Inappropriate use of anthelmintics is a key driver of resistance developing, with four main aspects needing to be considered (Box 1).
SCOPS (UK) and Wormwise (NZ) are both great resources for in-depth explanations and advice in these areas.

Box 1: The four mainstays of appropriate anthelmintic use are:

1. Do you need to treat? (5.9)
2. Choosing the correct anthelmintic (5.6)
3. Correct dosing protocols (5.3)
4. Post-drenching management (5.4)

5.3 Correct dosing protocols

Animals should either be treated to the weight of the heaviest animal in the group or to the individual weight. If there is a wide weight range the group should be split into light and heavy sheep. This ensures no under-dosing as this would provide a subtherapeutic dose, promoting survival of resistant worms.

Te Pari, a large New Zealand farm equipment manufacturer, has an impressive sheep handling product range including an automatic drenching gun linked to a weighcrate.

Fig 7; Te Pari automatic weighing and sorting sheep squeeze crush at FieldDays, New Zealand. Photo: Author's own

This equipment weighs the animal and calibrates the gun according to the pre-programmed dose rate. Accurate weighing also decreases over-dosing which can be toxic at high levels and increases the cost per head for no benefit. Dosing guns should be well maintained and properly calibrated before use (see Appendix A).

New Zealand farmers often mix trace elements in their drench and administer together. Unless already mixed by the manufacturer this is something I would advise against because if the supplement and drench are not mixed properly the anthelmintic will either be under or over-dosed. The products in suspension often separate so need to be mixed constantly during the drenching process which can be easily forgotten when there are thousands of lambs to drench. Trace elements can be given at the same time as an anthelmintic, but through a separate dosing gun.

5.4 Post-drenching management

It is imperative that sheep are not moved to a new, clean pasture immediately after treatment. This is referred to as 'dose and move' and has been shown to increase the speed of resistance development on farm[7]. Instead sheep should be put back onto a slightly contaminated pasture for 24-48 hours to allow ingestion of a larvae population with susceptible genetics, causing dilution of any resistant worms left in the sheep's intestines.

5.5 Combination drenches - Kia ora triple

Combination drenches are products with two or more active ingredients targeting nematodes in one treatment. The UK differs from New Zealand and Australia regarding the options of anthelmintic products available. While the Australasian products are predominantly combination drenches, we only have one of these on the market in the UK for nematodes, despite having the same active ingredients available.

Triple anthelmintics or 'triples' are generally combinations of Group 1, 2 and 3 while 'doubles' are combinations of Group 1 and 2 (Fig 6) and are usually oral drenches. New Zealanders are surprised when told that UK sheep farms have no access to combinations because most information and advice in NZ has been based on the decades of research by Dave Leathwick into the benefit of combinations on decreasing the speed of anthelmintic resistance development[5,6]. The EU and Veterinary Medicines Directorate (VMD) has not licensed combination drenches due to efficacy concerns and consequently as an industry we have focused on managing parasites through single actives.

Fig 8; A farmer collecting triple drenches for his lamb flock (each drum is 20L), New Zealand. Photo: Author's own

Leathwick's research is mainly model-based but, despite this, the conclusions are important to consider, as multiple studies have shown that combination drenches slow the development of anthelmintic resistance compared to single actives, even without other management changes. This is due to combination drenches killing more parasites with each dose compared to those containing a single active[5,16].

A single active which is 90% effective leaves 10% of worms still in the sheep, whereas if each active in a triple combination is 90% effective the treatment leaves 0.1% of worms in the sheep. With 0.1% of parasites surviving the speed of resistance development is much slower than if 10% survive. Even rotating single actives every drench does not slow resistance as much as the use of combinations. However the additional efficacy of combination drenches breaks down when the parasites become resistant to individual actives in the combinations, which has been seen in NZ. Rotating single actives every drench does not have the same effect as using combination drenches and merely delays resistance development by a few years as worms do not discard their resistant genes quickly enough. The use of sequential combinations, where sheep are given two single active drenches one after the other is a valid strategy but the implications of using multiple drenches needs to be properly considered. No matter what drench type you use, in the absence of refugia even combinations have no benefit long term (8.2).

5.6 Choosing the correct anthelmintic - what works on your farm

Drenching is inevitable and decisions cannot be made without understanding the farm's resistance status in order to choose the correct treatment. The first step is to understand which anthelmintics work on your farm, as using treatments that parasites are resistant to is ineffective and a waste of time and money.

Treatment efficacy should be properly assessed every few years with a full faecal egg count reduction test (FECRT), ideally with speciation (identifying the types of parasites present), in order to understand which worm species are present and to what they are susceptible (Appendix B). FECRTs work by assessing each anthelmintic group individually to understand which treatments kill over 95% of the parasite burden (a threshold where it is considered the parasites have no resistance). Faecal egg counts (FECs) are taken prior to drenching and afterwards. The timing of the post-drench FEC is determined by the active used (Fig 9).

Anthelmintic Groups	**Time after treatment for FEC**
Benzimidazole and Macrocyclic Lactones	14 days
Levamisole	7 days
Monepantel (Zolvix)	10-14 days

Fig 9; Timing of post-drench FEC depending on drench active used[2,14]

FECs (see 5.9 and 7.1) can also be done as a non-paired post-drench check more regularly to continually check the success of treatment. However the results should be interpreted carefully.

Case study - Don't panic, Mr. Mainwaring!

Over-interpretation of non-paired post-drench FECs (drench check) is something I have seen in several practices across the globe. On their own they are not diagnostic of drench resistance, although may be indicative and point towards the need for further investigation. It is not a time to panic.

For example, a store lamb buyer had a pooled FEC seven days post-Monepantel (Zolvix) drench come back as 1,000 eggs per gram (epg), which is high (see 5.9), and Monepantel resistance was assumed. However this interpretation needs to be re-considered.

- Zolvix can only be checked 10-14 days post-drench; you cannot assume that the epg will only go up because you have taken an early sample.
- After discussion with the client it was discovered that some lambs in the mob were drenched with a triple combination as the farmer did not have enough Zolvix. Although potential triple resistance is also worrying you cannot be certain this is the case from this FEC.
- Without doing a pre-drench FEC of the same individuals you cannot assume it is drench resistance as you cannot calculate the percentage reduction. The pre-drench parasite levels may have been extremely high.

Although a less than 95% reduction in parasite burden is considered a resistant population, anthelmintics can be used down to about 80% effectiveness and still be a profitable use of time and money, if used in conjunction with appropriate pasture management.

Speciation of parasite populations can be done on pre-drench FECs to understand the species present as well as post-drench to understand which parasites are resistant. This can be expensive but enables farmers to alter management according to lifecycle, allowing risk period avoidance. *Nematodirus* is cheaply speciated by egg during the FEC (Fig 10) and is easily avoided with appropriate pasture allocation at key times of year.

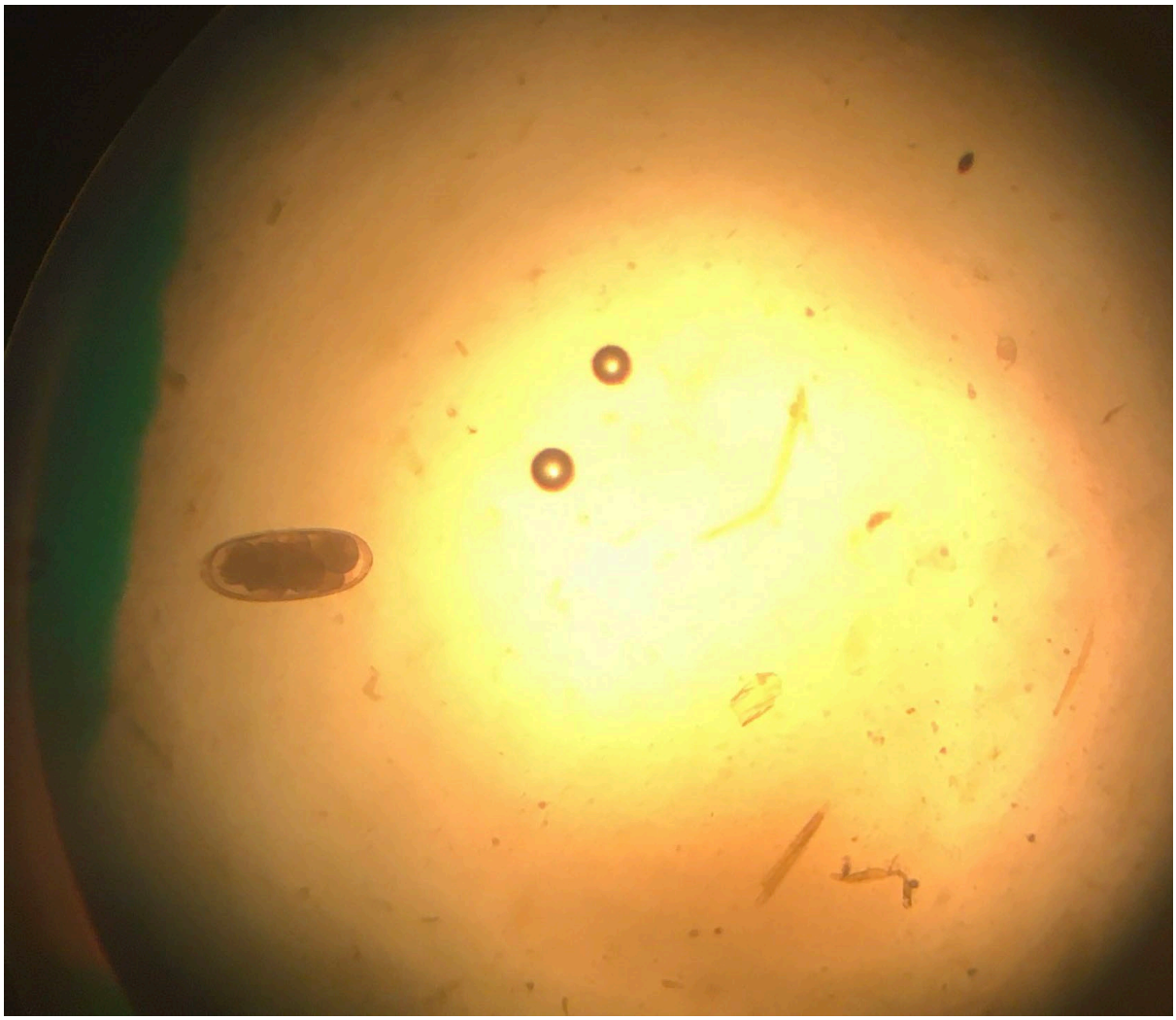

Fig 10; Nematodirus egg on MacMaster's slide. Photo: Author's own

5.7 Injectable or oral?

When discussing sheep endoparasite anthelmintics we have two application options, oral drenches or injectables, as sheep are unable to absorb pour-ons, unlike cattle.

When administering treatments it is crucial to follow the manufacturer's instructions. Different injectables have different adjuvants (the substance the active ingredient is mixed with) which alter the active ingredient uptake and elimination in the body so need to be administered correctly for the desired outcome and to adhere to withdrawal periods. This is particularly important and often ignored with Cydectin LA, which needs to be injected behind the ear due to the fat pad there which

allows a slow release providing the long-acting effect. If given in a different area this slow release may not occur and the chemical is often eliminated from the body more quickly.

All anthelmintic groups can come in both oral and injectable treatments which can lead to confusion. Discussing anthelmintic use with a farmer I found they had injected 250 calves with Dectomax (a group 3-ML) and dosed with an oral triple leading to a large 3-ML overdose.

Oral anthelmintics come in two forms, liquid and capsule (bolus). Generally speaking liquid forms are short-acting - the medicine is administered, absorbed and kills the parasites within 24 hours - while the boluses often have long-acting effects with a slow release of anthelmintic over the following weeks.

5.8 Long-acting or short-acting?

However the anthelmintic is given it is important to consider the length of action and what impact this has on the parasite population. Long-acting wormers continue to kill worms as they are ingested for weeks to months, removing the susceptible parasites and therefore the competition for resources. This allows resistant worms to breed more and increases their numbers on the pasture very quickly.

As short-acting wormers only kill the worms in the sheep at the time of treatment with no ongoing effects, their influence on parasite populations on the paddock is much less severe, allowing more flexible use. Historically UK farmers have been encouraged to give ewes a long-acting wormer pre-lambing to combat the periparturient rise (sudden increase in worm burden in ewes just before lambing due to a dampening of the immune system) and reduce parasite shedding onto pasture. Drenching ewes pre-lambing is now being advised against, but this advice should be assessed on a farm-by-farm basis.

NZ farmers are often used as an example of ewe drench reduction as many do not drench their adult sheep. Although our climates are similar in some ways there are many differences between the consistency of our climates and the way we manage our sheep. NZ farmers usually set aside pastures for set-stocked ewes to lamb on which have not had sheep on for six or more months, whereas UK farmers often use lambing paddocks which have had sheep on the previous autumn, and due to our mild winters, these are usually contaminated as most larvae can survive our winter. Ewes contaminate these further at lambing, especially those with high parasite burdens due to the periparturient rise, especially thin ewes and those carrying triplets and twins. By reducing parasite shedding from ewes when they are heavily contaminating pasture, though drenching, farmers can reduce the number of larvae accessible to lambs during the most susceptible time as they start to graze.

Although the non-use of anthelmintics lowers the selection pressure for resistance, not drenching at crucial times may be kicking the can down the road, causing lambs to ingest higher parasite numbers at an early age and therefore needing to be dosed more during their lifetime. Balance is key.

At lambing, especially if sheep are lambed inside, we can instead use a short-acting drench as they are turned out. This gives the benefit of a pre-lambing, long-acting drench without increasing a selection pressure for resistance.

Fig 11; A UK lambing shed. Photos: Author's own

5.9 Do you need to treat?

Drenching ewes can be further refined by only treating ewes that need it. This can be simply decided through BCS (body condition score), dag score or the number of foetuses, with triplets and thin twin-bearing ewes being treated and the others left.

With regard to treating lambs, historically vets in the UK have advised farmers to drench their lambs every four weeks, but we have started to move away from this advice and discuss targeted treatments for the lamb crop. However many NZ vets still advise the 28-day drenching regime (treating lambs every 28 days). What is the thought process behind this?

As with treating sheep pre-lambing to reduce the periparturient rise, the 28-day drenching regime is designed to keep parasite burdens low on pastures, ensuring lambs do not ingest many parasites rather than killing parasites once ingested. The thought process behind 28 days allows parasites time for their full 21-day lifecycle with flexibility for environmental impact, ensuring parasites are present in the gut at drenching. Long-acting boluses available for lambs in NZ also attempt to achieve low pasture burdens in the same way. Both methods have similar drawbacks with regard to quickly developing resistance. The NZ climate is more stable and predictable than the UK climate, which may be why this system is still advised in NZ, but it is inadvisable in the UK as the parasite lifecycle length can change remarkably according to the temperature and humidity.

It is possible to refine these treatment timings which gives similar benefits of limiting pasture parasite burdens but with less resistance-development opportunities. Targeted selective treatments ensure sheep are treated if necessary, rather than to a calendar timeframe. There are various ways to target treatments with different complexities. Not all animals need treating and allowing refugia (8.2) helps to slow anthelmintic resistance on the farm.

- Only treat thin or twin/triplet-bearing ewes pre-lambing.

- Monitor growing lamb FECs every 2-4 weeks and treat accordingly.
- Take pooled group FECs in growing lambs and only treat groups with medium or high epg (Fig 12).
- Treat lambs below a certain percentage of target daily liveweight gain (DLWG).
- FAMACHA can be used with *Haemonchus* to only treat sheep detrimentally affected[17] (Appendix C).

	Low	Medium	High
FEC (eggs per gram)	<250	250-750	>750

Fig 12; FEC ranges for treatment guidelines[12]

Using individual DLWG needs some investment with an EID reader and connected digital weighhead for the weighcrates capable of calculating immediate DLWG. This may be worthwhile as the profitability of drenching is limited if lambs are already growing close to the target weight and the approach reduces the numbers treated. However this will select for resilience traits if used for breeding stock (rather than resistance) so needs to be carefully considered (see 9.2). It is advisable if your lambs are only going for meat.

Farmers often see daggy sheep and assume they are carrying a worm burden so need to be treated. However this is not always the case as it can be due to nutrition such as sudden changes onto high-energy grass, faster gut transit time or historical gut issues such as coccidial gut damage (a gut-damaging protozoa) from when they were young. So it is imperative to understand what is happening before reaching for the drenching gun.

Key messages:

- **Know what works on your farm.**
- **Dose the sheep correctly and check the anthelmintics are working.**
- **Check treatment is needed before treating.**

Chapter 6 - Biosecurity and quarantine

Robust biosecurity and quarantine procedures are key in all livestock businesses. A visit to Victory Farms, a Tilapia fish farm on the banks of Lake Victoria, Kenya, really drove home how this could be successfully managed in difficult circumstances. In order to conserve the ecosystem and not contaminate the lake, Victory Farms are unable to use chemical antiparasitics. Strict protocols are in place at every stage of the breeding and growing process with no stock able to move pools or into lake cages without an assessment of their health and an investigation into potential parasite burden.

Fig 13; Victory Farms, Kenya. Photo: Author's own

One of the quickest ways to get anthelmintic resistance on farm is to buy it in with sheep. In order to prevent this any brought-in sheep should be:

- Drenched with a novel compound, usually Monepantel or Derquantel/Abamectin, as the parasites in the sheep should be susceptible to a medicine they have not been subjected to.
- Yarded on concrete for 48 hours to shed the parasite eggs.
- Turned onto dirty pasture previously grazed by the flock to dilute any surviving parasites.

Quarantine drenches are used in the UK in the autumn for finishing lambs before they go onto overwinter crops or cover crops on arable land. The use of these novel compounds removes most, if not all, of the parasite burden, and, as the lambs are then moved to clean grazing which will be ploughed and put into crops, the risk of developing resistance on the fields is minimal.

Key messages:

- **The quickest way to get anthelmintic resistance is to buy it in with untreated sheep.**

Chapter 7 - Diagnostics

7.1 FECs

We throw the advice of 'doing an FEC' around all the time, but what is an FEC and how are they used?

FECs are used to indicate the parasitic burden of the sheep. As well as the FECRTs mentioned earlier we can use FECs in a number of ways, the most common being to decide if animals need drenching. We have the option of doing either pooled or individual samples. An individual sample is a single faecal sample from an identified sheep: this tells us only what is happening in that individual, which is useful in single animal medicine, such as post-mortems of individuals to rule in or out parasitic burden as a factor for death.

Pooled samples are the most cost-effective way to indicate the group parasitic burden. Samples are taken from 10 sheep and a single count is given in eggs per gram, the average of all 10 samples. This is much cheaper than doing 10 individual samples (Fig 14). Generally 20% of the sheep carry 80% of the worms[1] so if one animal has a very high count the results can be skewed, making it seem that the group has an artificially high burden. This is where individual samples can distinguish outlying results.

Speciation is important as *Haemonchus* is extremely fecund compared to other parasites so produces a lot of eggs compared to the actual burden level. However if FECs are used to regularly monitor the trajectory of a group, suddenly high pooled sample results can be flagged easily and further samples can be done as a check before drenching.

Guide 2023 costs of pooled and individual samples in UK labs are:

	Cost (£)	Cost of 10 samples (£)
Individual sample	14-16	140
Pooled sample	40.00	N/A

Fig 14; Laboratory costs of FECs[15]

You can do 3.5 pooled samples for the price of 10 individual samples. The pooled samples, even if done every two weeks, give much more information than the single-time-point individual sample tests and at a much lower cost. You can know what is happening with a group for 1.5 months for the same price.

However, there are many challenges with FECs as they are not a direct measure of worm burden as is often assumed. They are highly correlated to feed intake, with increased feed intake increasing the amount of faeces and resulting in a dilution effect (lower FECs). Therefore the amount of grass available directly affects the FEC results.

7.2 FECPAK

In NZ I visited Techion, the company behind FECPAK, a digital diagnostics company focusing on digital microscope kits for processing sheep faeces for FECs both on farm and in their laboratory.

The FECPAK on-farm digital microscope gives farmers affordable access to fast laboratory-standard results to take control of parasites on their farm. It is very user friendly, with farmers only needing to mix a faecal sample and pipette it into a cassette which is then processed by the machine. A digital picture is analysed by artificial intelligence for a fast result, and assessed by a trained technician, supplying the farmer with a result within 30 minutes (if done within normal working hours). Farmers buy the kit outright and pay a yearly subscription which covers 100 tests.

Due to their decades of research in the diagnostic space FECPAK are often able to give advice regarding their results. Although they advise farmers to discuss this with their vets they are a well-placed company, trusted by farmers who own their products, and therefore have a role to play in anthelmintic usage advice.

The FECPAK team advise farmers to monitor FECs monthly. They advocate 'Oh FEC it's Monday!' encouraging farmers to run pooled faeces samples every Monday and rotate round their sheep management groups so each group is sampled at least once a month. These results are useful in two ways: as pre-treatment FECs to detect if the sheep need treating, and to provide information as to the trajectory of the parasite burden in the groups, and consequently what is happening on the pasture.
Farmers using this technique ideally use spreadsheets to map the FEC results taking into account the management groups and fields the animals were on, providing information on pasture parasite burdens.

FECs are most cost-effective when used to prevent treatments or as an indication to treat before gut damage has occurred. Therefore understanding the trajectory that groups and pastures are undergoing can enable anthelmintic treatment to be given when there is a high enough worm burden but before the parasites have damaged the sheep's guts.

While working on the South Island of NZ, I was able to encourage farmers to bring in FECs before drenching, with many FECs below 250 epg four weeks post-drench in growing lambs. The farmers then brought in FECs every two weeks and the intra-drench interval was extended by an average of three weeks (many were able to drench every 6.5-7.5 weeks). This saved the farmers both money and time, given that most NZ drenching treatments take two days, one to muster the lambs off the hill and another to drench the usual 5,000 lambs on a NZ sheep farm (if not more).

7.3 Nemobiome

Laboratories are able to sequence the parasites' genome to detect which anthelmintics different species are resistant to. In the near future this will be commercially viable with the potential of pen-side resistance testing able to revolutionise drench resistance testing, enabling farmers to understand their on-farm situation more quickly, easily and cheaply.

Key messages:

- **FECs are key tools to understanding and controlling the parasite burdens of the sheep.**
- **Oh FEC it's Monday! Routine monitoring of FECs should be done throughout the grazing season.**

Chapter 8 - Avoidance

8.1 Pasture management

Despite all our diagnostic abilities the future of parasite control does not come in a drum. There are many aspects to pasture management when discussing parasites. Animals with healthy BCS have the energy to use their immune system to counter their parasite burden. Consequently, pasture management is about managing both the pasture parasite levels and the nutrition requirements of the animals.

Rotational grazing is a staple of the NZ sheep farming system. NZ farmers focus on their dry matter per hectare while UK farmers generally focus more on the number of sheep per acre. This shows how the farmers think about their work: NZ farmers concentrate on growing as much grass as possible, with the animals being a tool to utilise the grass; while UK farmers focus on the animals, often set-stocking and therefore not growing as much grass as the land could manage with rotations.

Rotational grazing has many benefits, such as putting fresh feed in front of animals regularly, encouraging them to eat more and, therefore, grow faster. The length of rotation is also important when considering parasites. After five days sheep should be moved off pasture as this is when the newly hatched parasite larvae start to become infective. As infectious larvae can survive on pasture for months, the longer the rotation the better. This also allows the grass to grow, ensuring the sheep are not eating too low on the sward and consequently reducing the number of parasites they ingest. In addition, rotations stop fresh leaves constantly being eaten immediately and increase the amount of dry matter grown compared to set-stocking.

Moving sheep off the pasture after five days is important as although ewes try and avoid grazing near very fresh pats, by four to eight days the 30cm around pats have the highest larval burden of the pasture and the new grass here tempts ewes to graze, increasing their parasite burdens if not moved off pasture.

The type of sward grown can be beneficial to managing parasites as well. Larvae are most dense at the bottom 2.5cm of the sward and climb up leaves to be ingested when grazed, therefore grazing longer grass avoids the dense larval areas. Larvae need moisture within the sward to move so environmental conditions are crucial for this migration. Ryegrass is very easy for larvae to crawl up while bioactive forages, such as chicory and plantain, have challenging structures which inhibit larval migration, survival and development, especially if the sward is above 5cm tall. High tannin plants such as birdsfoot trefoil and chicory also act as natural anthelmintics in the sheep's gut, helping kill parasites, while white clover has high protein levels, boosting the sheep's immunity and bettering their plane of nutrition. These forages can be grown as single species stands for clean grazing for lambs or as part of a mixed herbal lay with ryegrass. Sheep on a pasture with a high larval burden reduce their bite rate, bite mass and bite depth, meaning that lambs eat less while increasing their parasite burden[18].

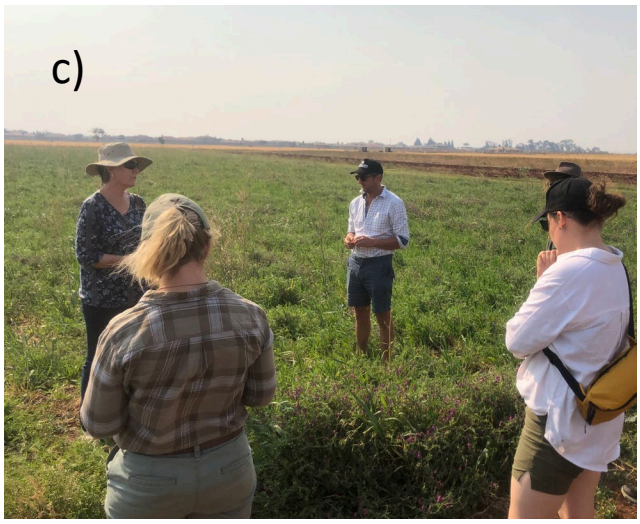

Fig 15; Mixed grazing swards in a) New Zealand and b) Zimbabwe, c) UK, Canadian and Zimbabwean scholars discussing regenerative practices. Photos: Author's own

Alongside grass swards many farmers keep some stock on winter brassica crops. This is useful when managing for parasites as they allow little to no larval migration and are often treated as 'clean pasture' in the rotation. However, farmers can easily be caught out in assuming that there are no parasites on this type of forage as there are always headlands, hedgerows or run-offs that have grass, and therefore parasites. Very high worm burdens can be seen in lambs wormed onto winter crops.

Another type of clean pasture is silage aftermath. This grazing can be rocket fuel for lambs, helping boost their daily liveweight gain and shorten the time on farm and therefore lessen the stock numbers more quickly while still being profitable.

When managing pastures for parasites the stock groups used are crucial. Lambs should be allowed to graze first (as the contaminators) as they need the least contaminated feed due to their poorer immune systems. Lambs should be followed by ewes as net vacuumers and to aid with refugia (if the ewes are undrenched) and then, ideally, followed by cattle to hoover up the now contaminated pasture and parasites. Co-grazing is an historic practice across the world and is used in Zimbabwe to manage ticks on cattle (Fig 16).

Fig 16; Cattle and wildlife co-grazing. Photo: Author's own

8.2 Refugia

Refugia is anthelmintic resistance's Achilles heel and the key to preventing co-adaptation (where resistance genes stop having a fitness cost)[5]. It is generally considered to be the most effective approach we have to prevent resistance developing and can even be used to reverse resistance on farms. Refugia, in its most basic form, is leaving some parasites in the population not exposed to the wormer. The higher the parasite population in refugia, the slower resistance develops. A simple way to do this is to leave some animals undrenched in the group.

In order to understand and implement refugia on farm it is easiest to think of animals as either net vacuumers or contaminators. Lambs in their first year and ewes in the third trimester of pregnancy are contaminators (they shed more worm eggs than they ingest) as they have a lower immune system response so cannot suppress the worms. Adult stock for the rest of the year are net vacuumers, as are cattle. Although cattle are a useful tool for vacuuming pasture parasites, they do not contribute to refugia as most parasites do not cross species: to create a refugia population the parasite eggs need to hatch and become adults. Cattle's most useful ability are as parasite hoovers to reduce pasture burdens.

Fig 17; North Island, New Zealand, ewes with lambs at foot on lambing pastures. Photo: Author's own

Weaned lamb groups are the most challenging population in which to leave animals undrenched as this can affect their growth rate, sometimes fatally. One way to avoid this is to alter the group slightly and run some two-toothed ewes (two-year-olds) with the lambs and not drench the two-tooths. Farmers regularly want to give their lambs the best grass covers and not 'waste' this food on older sheep, in order to fatten the lambs as quickly as possible. However, if the poorer two-tooths are run with the lambs they will hoover up more parasites but with the good feed in front of them will also put on weight and therefore get up to appropriate BCS for tupping, alongside the priceless benefit of slowing anthelmintic resistance. It is generally considered that the two-toothed numbers should be about 5-10% of the lamb numbers in the group to be effective on pasture.

8.3 Nutrition

Nutrition may be the most important and overlooked area of parasite management. Production is a drain on protein and therefore a drain on immunity but well-fed ewes in the correct BCS get in lamb,

have little trouble lambing, have enough milk to rear twins, and often grow them fat by weaning. They also have enough energy to service their immune system and dampen the parasite burdens in their guts. Poor nutrition reduces the capacity of sheep to cope with these challenges.

Unless animals are well fed it is much harder to distinguish their inherent genetic traits of resistance or resilience, as a reduced protein and energy environment does not allow sufficient exhibition of these traits.

Poor lamb nutrition reduces growth rates so lambs stay on pasture for longer. This increases pasture parasite burden with nutritionally stressed, highly susceptible animals contaminating for longer.

Trace elements are particularly important in growing lambs, with cobalt deficiency being a major issue on farms I worked with in Wales, often associated with high parasitic burdens as it increases susceptibility. Cobalt supplementation helps the immune system and parasite resilience. Many NZ drenches have the major trace elements pre-mixed into their drenches as this is such a problem in their soils.

8.4 Reversion of resistance

Despite many naysayers, resistance on farm is reversible and has been proven in NZ. It is not an easy process and often needs drastic management changes, but can mean the business continues to be able to farm sheep in the future.

Refugia is the key to reversing resistance by mixing stock classes on all grazing areas and providing appropriate nutrition, often needing to be done through reducing stock numbers. Getting lambs off pasture as soon as possible is crucial to all of this, to allow grass recovery. If this means selling the lamb crop early for a few years it is worth the sacrifice to reverse resistance in order to keep farming.

Key messages:

- **Refugia is the most powerful way to prevent and even reverse anthelmintic resistance.**
- **Well-fed sheep have lower parasite burdens.**
- **UK farmers can follow NZ pasture management practices and integrate rotational grazing.**

Chapter 9 - Breeding

9.1 Genetics

There is variation in an animal's response to a parasite burden depending on age, previous exposure, nutrition and genetics. NZ breeders have been breeding for sheep unaffected by worms for decades to good effect.

It is a challenging and expensive trait to select for, complicated by taking a few months for lambs to start being exposed to parasites, with FECs of 21-week-old ewe lambs being an accurate predictor of adult output[1].

Although focusing more on heritable lameness reduction in Merinos, Ben Todhunter at Cleardale Station showed how powerful genetics can be. Cleardale 171230 is a stand-out ram in this area, being in the top percentiles for many important traits in the fine wool business including the FEC. It goes to show how an individual can suddenly boost your farm genetic stock, putting Cleardale on the map for Merino genetics.

Fig 18; Cleardale Station, New Zealand. Photo: Author's own

9.2 Resistance or resilience?

Confusingly, we talk about anthelmintic resistance (the worm not being killed by the wormer) and breeding resistance in sheep (sheep being able to kill the worm). We want the latter, not the former.

When breeding sheep there are two schools of thought: those who are breeding for resistance and those breeding for resilience (sometimes called worm-tolerance).

Resistance:

- Sheep use antibodies to fight worms and do not shed many eggs on pasture.
- Sheep channel their energy into the immune system to defend against parasites.

Resilience:

- Sheep shed lots of eggs on pasture but still grow and produce. These sheep tolerate parasite burdens.

There is much debate which is the better camp, with advocates of resilience disliking resistant sheep putting energy into fighting the parasites which can lead to reduced growth rates. However, we need to look at long-term gains rather than the short term. Over years of grazing and breeding resilient sheep on the same pastures the ground becomes heavily contaminated with parasite larvae at a rate that the sheep genetics cannot keep up with, leading to higher parasite burdens than the sheep can tolerate.

So how do you know what your breeder is breeding for? Many ram breeders will advertise breeding for coping with parasites but the way they are monitoring and how they choose their breeding sheep matters.

Breeding for Resistance:

- Breeding from animals with low FECs after a parasite challenge.
- 30% heritability.

Breeding for Resilience:

- Breeding from high growth rate or high-producing animals despite high FECs.
- Many breeders will select on high DLWG and not perform individual FECs.
- 15% heritability.

There are several approved schemes that breeders sign up to in order to meet the appropriate criteria to sell their stock under official regulations. In NZ, WormFEC Gold is the top criteria achieved by flocks. When buying breeding stock EBVs (Estimated Breeding Values) and genomic tables should be consulted. However breeders are able to manage their own EBVs with different attributes weighted and contributing to their parasite EBV score so it is important to understand how this is done. In the UK, Signet standardises traits but breeds cannot be directly compared.

There has been some recent interest in the use of CarLA and serum and plasma IgA testing in sheep, a standard practice in the NZ deer industry in relation to parasite tolerance[19]. These look at the immune system's reaction to parasite burdens but have shown poor correlation to parasite burdens in the UK. However, this area is likely to expand in the next few years.

A particularly outstanding visit to Allan and Sonia Richardson at Avalon Station, NZ, cemented some key messages for farmers in the UK. Worm-resistant sheep are feasibly bred from a 'normal' flock in four years with some management and ram selection changes, although it can be achieved quicker by buying in worm-resistant ewe lambs.

Fig 19; Avalon Station, discussing ewe traits. Photo: Author's own

- Change the ram team to highly worm-resistant rams.
- FEC ewe lambs and breed from low FEC animals.
- Graze resistant sheep on separate pasture to non-resistant sheep or they will perform worse as they are hoovering up the worms others put onto pasture.
- Resistant sheep kept together work together as all individuals decrease the burden on pasture.

Breeding takes time and planning so the sooner you start the sooner results are seen.

Key messages:

- **Breeding for resistant sheep is a long-term genetic strategy.**
- **The way the breeders select their animals changes how the sheep react to parasites.**

Chapter 10 - Alternatives

10.1 Integrated pest management

Farmers are looking to move away from synthetic chemicals to control their pests in all areas of farming, both livestock and arable. Integrated pest management (IPM) relies on understanding the pests' lifecycles and environmental interactions in order to reduce their impact on the crop using targeted management practices and biocontrol agents rather than potent and potentially environmentally damaging synthetic chemicals. This has historically been used consistently and effectively in several arable crops. The more controlled the environment the easier IPM controls are to integrate but I believe this is an important future area of livestock parasite management. This is a space that Dudutech, Kenya, is thriving in, specialising in cut-flower-market pests. There is massive potential for the use of nematode predators which are able to target the free-living larval stage of the nematode lifecycle, an area that anthelmintics do not affect. The team at Dudutech also work on proliferating beneficial fungi targeting plant parasitic nematodes, which has the potential to be used on sheep nematodes on pasture as there are fungi that target sheep parasites. However, the application is still very much in its infancy.

10.2 Dung beetles

There has been much talk about the benefit that dung beetles bring to pasture, soil and parasite reduction in the last few years. Dung beetles are an amazing free tool in the UK to help control parasite larvae on pasture, spreading the pats around the pasture and bringing the faeces down into the burrows, aiding in desiccation of the larvae and reducing pasture burden. Dung beetles are so valuable that Australians pay to import them as there are no natural ones there (Fig 20). The anthelmintics we use are detrimental to many insects, including dung beetles, killing them and reducing their breeding abilities. Group 3, the MLs, are the worst anthelmintics for this, especially Ivermectin, as they last in the soil and continue to kill dung beetle populations.

Fig 20; Dung beetle nursery on a sheep farm in New South Wales, Australia. Photo: Jessica Conlan

10.3 Vaccination

Vaccinations for parasites are in their infancy although there is one currently on the market for *Haemonchus* and a lungworm in cattle. Research centres are investigating this area but it will likely be several years before being commercially available.

Key message:

- **Dung beetles are a natural parasite control that are killed by anthelmintics.**

Chapter 11 - Conclusions

1. Anthelmintic resistance is one of the biggest threats to the future of the UK sheep industry.
2. Chemical and non-chemical control should be carefully integrated on a farm-by-farm basis.
3. The most important first step for farmers is to understand what parasite species they have on their farm and what levels of resistance they have.
4. Refugia is the most powerful tool for preventing and reversing resistance.
5. Non-subjective consistent monitoring of parasite burdens with FECs provides priceless information allowing educated management decisions.

Chapter 12 - Recommendations

Sheep Producers - Implement three fundamental practices:

1. Use genetic selection to breed resistant sheep.
2. Alter grazing practices to counter pasture parasite burdens.
3. Use monitoring technologies to direct appropriate anthelmintic use.

Vets - Familiarise yourself on the pasture management options in order to better provide appropriate tailored advice.

Levy boards - Provide easily accessible information and access to well-informed consultants.

Chapter 13 - After my study tour

Nuffield Farming has given me the opportunity and confidence to approach those people and institutions that I previously believed were not interested in hearing from a (relatively) young clinical vet. What does an ordinary vet have to add to these powerhouses of research and policy making? It turns out, quite a lot!

The experience of meeting people in agriculture across the globe is phenomenal. Farmers and business owners who run large successful enterprises are keen to sit down and have a chat and the network Nuffield provides opens a lot of doors.

Having the freedom to live and work in another country with access to their experts and advice has given me different points of view to bring back to the UK. I hope to use this experience and knowledge to provide holistic sheep consultancy advice focusing on parasite management and sheep performance.

Acknowledgements and thanks

I am very lucky and grateful that I have a hugely supportive family who have enabled me to make the most of the opportunities the Nuffield Scholarship has provided. To Rupert, my husband, who has moved countries, kept our wedding planning on track from the other side of the world and put up with my constant talk and investigation of any ruminant faeces I find! Thank you to my parents for giving me the confidence to move across the world and especially to Marilyn for reading my report so many times over. Also to Nic Snell, my mentor, who has resolutely kept me on track despite regular time zone challenges.

Thanks to both my sponsors, The Worshipful Company of Farmers with Savills and The Royal Welsh Agricultural Society, who have made this opportunity possible. I really appreciate their support.

Having met many amazing people throughout my travels who have given their time to host and meet me I am unable to name them all. However, a special thanks to Allan Richardson, Ben Todhunter, Greg Mirrans and Tracy McHutchon, Ginny Dodunski, Dave Leathwick and Neil Sargison for making me really think and for providing feedback on my report. I look forward to continuing our interactions.

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Appendices

Appendix A – Drenching Protocol[20]

Drenching protocol

- "Weigh a random sample of animals (40 suggested) and if there is a narrow variation then drench to the heaviest weight – not the average. If there is wide variation, draft the group into light and heavy animals and dose to the weight of the heaviest in each group.

Drench gun protocol

- Ensure all equipment is in good condition.
- Check the drenching gun by placing your finger over the end and pressurising the trigger. This way you will find out if there are leakages or back flow.
- Replace washers and valves if necessary.
- Calibrate the drench gun by squirting ten x 10 ml squirts of the drench into a calibrated measuring cylinder. The volume should read exactly 100 ml.
- If not, adjust the dose setting and check again.
- Use the actual drench you will be administering rather than water in this test.
- Check the drench gun nozzles for damage and ensure there are no rough edges that could damage mouths.
- Keep new valves and washers on hand as spares.
- Keep more than one drenching gun – clean and in working order – on hand.

Filling the backpack

- Ensure product is in date and has been stored correctly.
- Shake well to ensure suspensions are evenly mixed.
- Check the setting of your gun to ensure that you have calculated and selected the correct volume to administer for the required weight.

Drench administration

- Do not rush. This is a skilled job and rushing or cutting corners will reduce the effectiveness of the treatment.

Oral drenches

- Hold the animal firmly with the head horizontal.
- Carefully introduce the nozzle of the drenching gun into the side of the mouth and over the back of the tongue.
- Administer the drench and withdraw the gun.
- Release the animal when it has swallowed.
- Check accuracy of gun again after drenching 200 animals.
- Drench gun injuries to the throat, or drench that enters the lungs, can be fatal.
- If using 'hook' in larger cattle, take care to avoid damage to mouths, and ensure each animal swallows the full dose.

Injectable drenches

- Before starting, check the gun is delivering the correct dose by squirting a set number of doses into a measuring cylinder or calibrated medicine cup.
- Animals must be dry and clean before being injected.
- Use new sharp needles and change to a new sterile needle after every 50 animals.
- If the product is for subcutaneous administration inject under the skin in the anterior neck, so the injection is not going into muscle.
- Careless injection can cause infections, residues or carcass damage resulting in downgrading at slaughter.

After drenching

- Clean all equipment. Replace any damaged items.
- At regular intervals, dismantle and thoroughly clean drenching guns.
- Record all drench use in an appropriate documentation system.
- Monitor the effectiveness of your drenching programme."

Appendix B - Faecal egg count reduction test protocol[18]

Taken from DrenchSmart® Protocol[18]

Anthelmintic types	Possible wormer product name	Active ingredient
Benzimidazoles (1-BZ)	Rycoben SC 2.5% (oral)	Ricobendazole
Levamisole (2-LV)	Levacide 3% (oral)	Levamisole
Ivermectin (3-ML)	Oramec (oral)	Ivermectin
Moxidectin (3-ML)	Cydectin 0.1% drench (oral)	Moxidectin

Procedure

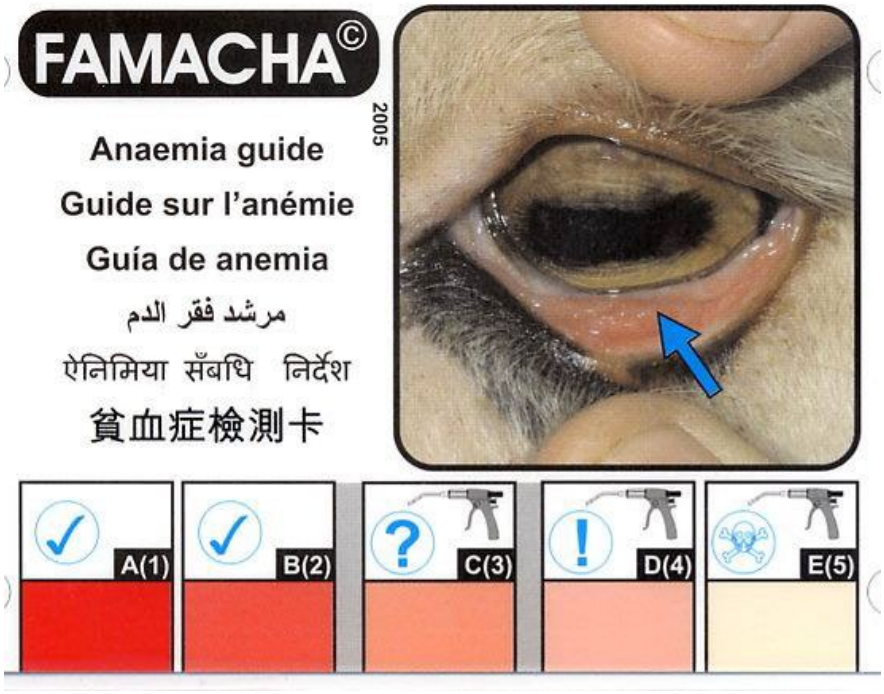
- Mob counts to be monitored to ensure sufficient challenge before the FECRT is started.
- Strongyle egg counts need to be 500epg or higher.
- Ideally 10% of the group should be sampled, but no fewer than ten random lambs are needed for each anthelmintic group assessed with one control group. Group 3 anthelmintics are split in two between Ivermectin and Moxidectin.
- Mark and treat the animals in each group accordingly.
- Collect faecal samples from each group:
    - Fresh dung is essential, ideally less than one hour old.
    - Gloves should be worn.
    - Each individual sample should be bagged separately and labelled with the appropriate group. The lab will pool these samples ensuring same weight per sample.
    - Sheep should be healthy and have full access to pasture.

- Collect one overall mob faecal sample for larval culture.
- Ideally 10% of the group should be sampled, but no less than 10 random lambs.
- Individual samples to be collected from the same animals each time, marked for each drench group.
- Post-treatment collection from the same animals as follows:
    - 7 days later for Levamisole (2-LV).
    - 14 days for other three treatment groups and control.
    - 12 individual samples to be collected from each group (to allow for some sheep that don't give appropriate samples).
    - 1 mob sample per treatment and control group is collected for larval culture.

- FEC counts on pooled samples for pre-treatment with individual FECs done on post-treatment samples.
- Larval culture and speciation to be carried out on samples collected before treatment and from groups where a drench failure is detected.

Appendix C – FAMACHA[17]

FAMACHA – for *Haemonchus contortus* control



- Mucus membranes of the eye are examined.
- Sheep are treated if too anaemic (see colours on bottom of card).

Glossary

Active ingredient - biological active for treatment or prevention of disease

Adjuvant - ingredient used to increase or modify the activity of the active ingredients

Anthelmintic - medicine used to kill helminths (parasitic worms)

Antiparasitic - drug to treat infections caused by parasites

BCS - Body Condition Score, practical way to assess the impact of nutrition

Bioactive - have an effect on a living organism

Clean pasture - grazing that is free from parasite burden

Coccidial - coccidia, a protozoa which affects the gastrointestinal tract

Daggy sheep - sheep with faecal staining on the wool around the anus

Desiccation - drying out through removal of water

DLWG - Daily Liveweight Gain, the amount of weight gained in a day

Dose - measured amount of drug

Drench - a measured amount of anthelmintic

Drench check - a faecal egg count test performed after an anthelmintic treatment has been given

Ectoparasites - parasites that live on the outside of the animal

Endoparasites - parasites that live on the inside of the animal

Enteric - related to the gut

FAMACHA - a test of anaemia to decide if an individual sheep should be treated in relation to *Haemonchus*. Named after Dr Faffa Malan, the inventor

FEC - Faecal Egg Count, the test performed to detect worm burden in ruminants

FECRT - Faecal Egg Count Reduction Test, the series of FECs performed before and after drenching to understand drench resistance

Fecund - producing an abundance of offspring

Fitness cost - cost of an organism's ability to replicate and survive in a competitive environment

Gastrointestinal – the digestive system from the mouth to the anus

Headland - New Zealand term for the sides of a non-grass field which have grass on them

Helminth - a genre of parasitic worm of which includes the phylum Nematoda

Nematode - a worm of the phylum Nematoda. Usually used in this report to mean gut parasitic worms of sheep

Parasite - organism that lives in or on host species and benefits at the host's expense

Pen-side - tests that can be done next to the animal

Periparturient rise - increase in parasite burden just before lambing due to immune suppression

Plane of nutrition - quantity and quality of food intake

Refugia - proportion of total parasite population not exposed to antiparasitic chemical treatment

Resilience - the ability to withstand or quickly recover from a negative event

Resistance - the ability to not be adversely affected by something

Run-off - grass that sheep have access to when on winter crops

Selection pressure - external agent which causes the population to genetically change through natural selection

Set-stocked - fields that have a specific number of sheep per acre for an extended period of time

Speciation - determining the species present in the faecal egg count

Sward - grass field

Wormer - chemicals given to animals to expel parasitic worms

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