Can anthelmintic resistance mitigation measures benefit the environment through the employment of grazing strategies and dung beetles?

A report for

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Executive Summary

Animal health is paramount in the livestock industry. Continual advances in management practices, technologies and medicines have brought a lot of positive attributes to the agricultural industry. However, as the demands for food increase, so too do the expectations of animal production. This puts more stress on the animals and, consequently, the environment.

We have had over half a century managing parasites successfully through the use of veterinary medicines. As these parasites would otherwise have a major negative effect on animal performance, these products have allowed the agricultural sector to produce food from pastoral systems in a very efficient manner. With the presence and rise of anthelmintic resistance and environmental concerns, and in keeping with the implementation of the new EU veterinary medicine legislation in Ireland, the HPRA have decided to label all anthelmintics in Ireland as POM from 1st Jan 2022.

The aim of this report is to gather and collate information from individuals with specialist areas of expertise and use this normally disconnected information in a collaborative way to achieve production outcomes that will benefit Irish farmers and industry in general..

The objectives of this report are to get a clear picture of the knowledge of parasites and management protocols currently being adopted on farms, gain an informed view of the risks and implications of anthelmintics resistance, investigate if anthelmintics pose a threat to the environment, establish if dung beetles have a role to play in parasite management, and assess whether the ecological effects of livestock faeces can have other attributes of value to the community.

Key findings:

- Parasites have been around for millions of years and the use of anthelmintics in animal agriculture is only a small bump in their evolutionary road. Anthelmintics resistance is now a serious problem and unless we can make significant reductions in the usage of anthelmintics, we are going to be back to the pre-anthelmintic era in terms of disease. We have some great resources at our disposal to make reduction possible.
- Anthelmintics have a negative unintended effect on biodiversity particularly on insects. Focusing on dung beetles, the report looks at the effects anthelmintics have on their populations and the effects that dung beetles have on parasites. This is where we can gain with a positive feedback loop.
- A healthy population of these coprophagous beetles reduces the parasite loading and in turn reduces the need for worming.
- Dung beetles have been accredited for their positive attributes to agriculture as the Australian government have invested millions of dollars introducing beetles to remove the faeces from pasture since the 1960's.
- Eco-system contributions made by dung beetles include soil and water quality improvement, increase in predatory bird numbers and reduced nuisance fly populations. In addition, we learn about increased herbage growth and community integration, especially through the involvement of school children.

All the findings in this report suggest that anthelmintic usage must be reduced. This is essential to preserve the efficacy of these products and ensure that animal production can continue without having to go through a systemic overhaul.

A unique selling point of Irish food produce on the world market is the eco-service contributions attributed to animal agriculture. With challenges in water quality and biodiversity loss, our reputation is coming into question and addressing these concerns will require unique approaches. We have all the resources, willingness and expertise to contribute positively to the environment, while benefiting animal health.

Implications for key stakeholders

- The relationship between the farmer and the veterinary practitioner needs to evolve towards a more open dialogue on parasite management rather than parasite control. Farmers and vets need to have a wide range of resources at their disposal and approach this area with an open mind.
- Policy makers looking at the EU Green Deal need to direct CAP funding to address issues such as biodiversity loss, water quality issues and cultural differences, public service for public goods.
- Processors, abattoirs, representative bodies and retailers would enhance their standing in the community and credibly enhance our green image by funding and facilitating educational campaigns, parasite diagnostics services and biodiversity enhancement programmes.
- To preserve the continuity of their business, pharmaceutical companies and veterinary retailers need to understand that the current volume of sales of anthelmintics is not sustainable.
- The work of ICBF has contributed significantly to the area of animal genetics and with additional relevant genetic information, breeding animals that have resistance to parasites is now possible.
- The stakeholders who stand to gain the most from the adoption of the recommendations are the next generation of farmers, our children. In the words of Sally-Ann Spence “It is up to us, our generation, to make the change”.

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Foreword

Having grown up on a mixed farm, I progressed on to study Automobile Technology and Transport Management in Cork Institute of Technology. With tuberculosis threatening the viability of our family farm I returned home to help restore our animal health status and herd numbers in 2001. I never left. Animal health having become my main on-farm focus, our increased usage of anthelmintics came under question with many discussions between my Dad and me. As our farm expanded and specialised in dairy, I realised that we were using higher volumes of anthelmintics overall. This brought my focus to resistance, both the resistance of the animals to the parasites and the resistance of the parasites to anthelmintics. As we strove to reduce our animals' exposure, we adopted a more targeted approach which led us to reduce our usage of anthelmintics.

A chance conversation with entomologist Dr Sally-Ann Spence about dung beetles piqued my interest in an area that I had previously been ignorant of. This conversation informed me of the role our native dung beetles had in parasite management and how with a reduction in anthelmintics we should be enjoying an increase in their abundance on our farm, undoing the downward spiral. I also learned that dung beetles are a food source for other species such as bats and birds and so realised that the decisions taken on my farm around parasite management could influence the wider eco-system, biodiversity and the sustainability of my farm. I am old enough to remember how headlights and windscreens on cars needed to be washed on a warm summer's evening to remove squashed bugs, so I realised something is happening which is reducing insect numbers.

For my topic, I will be focusing on dung beetles and how their interaction with animal faeces can have a positive impact on agriculture and the environment. With a lack of joined up information in this area, I decided to find out if there were possible gains to be made by interlinking the different areas of expertise. I was awarded a Nuffield Scholarship in 2019 to travel globally in 2020. I travelled to South Australia and Tasmania and was due to travel to numerous other destinations, but the global COVID19 pandemic cut my travelling short. With the benefit of online platforms, I was able to conduct numerous interviews with industry experts from different areas around the World. I was also able to trial novel techniques on my own farm which are now being adopted on other farms through my own dairy knowledge transfer group.

Using less anthelmintics is an area that farmers are particularly interested in with increasing production costs, questions of resistance and the possibility of unintended consequences – and of course new European legislation making the products 'prescription only' coming in from January 2022.

Acknowledgments

Firstly, I would like to thank all of my family and particularly my wife, Laura for supporting me through my Nuffield journey.

While I was away from my normal working position, Farm Manager Nicholas Berry, did a fantastic job of filling in and also adopted new practices on farm arising from my research.

Throughout my research, I enjoyed the mentoring of Kevin Twomey for keeping me focused and aimed in the right direction.

I would like to thank my parents for instilling in me the confidence to challenge the status-quo and for supporting me along the way.

I would like to thank both Tommy Heffernan MVB and Dr. Sally-Ann Spence for inspiring me and for advancing my knowledge, mindset and focus.

All of what I have learned and experienced with this journey would not have been possible without the support, guidance, generosity, trust and time invested in me by the sponsors and community of Nuffield Ireland to whom I owe a great deal of gratitude.

I would like to thank all the people who helped me in my research, from scientists to farmers, academics, veterinary practitioners, students, laboratories' and pharmaceutical companies' staff, business people, ecologists, advisory bodies, research institutions, environmentalists, and people who let me stay in their homes.

I want to thank James Allen for taking the initiative and to the rest of the **www.dungbeetlesforfarmers.com** team for including me in the creation of the website.

I would like to thank the farmers who gave up their time collecting beetles for "Operation Defecation".

I would like to thank Catherine Lascurettes of Cúl Dara Consultancy for editing my report.

Abbreviations

Acronyms

AHI: Animal Health Ireland

ASSAP: Agricultural Sustainability Support and Advice Programme, a multi-agency programme run by Teagasc to improve water quality through voluntary engagement by farmers.

BZ: Benzimidazole

CSIRO: Commonwealth Scientific and Industrial Research Organisation (Australia)

COWS UK-based Control of Worms Sustainably initiative

DAFM: Department of Agriculture, Food, and the Marine.

FEC: Faecal egg count

GI: Gastrointestinal

HPRA: Health Products Regulatory Authority

ICBF: Irish Cattle Breeding Federation

ML: Macrocyclic Lactone

NCBI: US National Centre for Biotechnology Information

POM: Prescription Only Medicine

RSPB: Royal Society for the Protection of Birds

SCOPS Sustainable Control of Parasites in Sheep initiative

SP: Synthetic Pyrethoids

Aim and Objectives

Aim

The aim of this report is to look at the unintended effects of anthelmintics, including resistance, and to investigate specific alternative and/or complementary means of biocontrol around the free-living stages of the parasite, especially in the context of new European legislation and policy, and the need to improve the sustainability of farm practices.

Objectives

- To get a clear picture of the knowledge of parasites and management protocols currently being adopted on farms.
- To gain an informed view of the threat caused by anthelmintics.
- To investigate if anthelmintics pose a threat to the environment.
- To establish whether dung beetles have a role to play in parasite management.
- To assess whether the ecological effects of livestock faeces can have other attributes of value to the community.

Introduction

Since the mid-20th century, parasite management in cattle and sheep has revolved mainly around interventions in the life cycle of parasites through the prophylactic use of chemical formulations known as anthelmintics.

Anthelmintics are the second largest animal remedy expense on farms, according to IFA National Animal Heath Chairman Pat Farrell, and represent up to 27% of sales on the animal health market, which suggests widespread usage.

The combined loss in production associated with parasites on Irish cattle and sheep farms is estimated by J. Charlier of Kreavet in Belgium to cost over €181m annually. Added to this, treatment costs a further €56m, and resistance in the form of lower productivity and anthelmintic effectiveness loss add up to a further €8.5m. Parasites clearly pose a significant financial challenge to the industry. Cases of recorded resistance to anthelmintics are on the rise in both cattle and sheep, and Department of Agriculture Veterinary Research Officer John Fagan states that individual concerns around the effectiveness of a worming event often prove positive for resistance when investigated.

The implementation of new EU regulations in Ireland will require that all anthelmintics in Ireland become POM from January 1st, 2022. Ireland's HPRA has identified environmental safety risks for anti-parasitic medicines, and with evidence of widespread anthelmintic resistance, farmers will be faced with greater challenges to continued anthelmintic use.

Recent public debates have highlighted biodiversity loss. The EU Green Deal's Biodiversity Strategy which aims to restore biodiversity loss by 2030, will create a strong onus on agriculture to address a "declining population of dung associated fauna" according to Prof. Darren, Dr. Ceri Mann and Dr. Sally-Ann Spence of the UK's Dung Beetle Mapping Project (DUMP).

While we lack data on beetle populations in Ireland, one can only assume that a similar species list, climate and evolving agricultural landscape as the UK suggest we would have similar results here. Anecdotal evidence of older generations of farmers cleaning piles of geotrupes beetles from blocked roof gutters certainly aligns with this. The extent of the effects of macrocyclic lactones on non-target species for example are well documented and collated in a review paper published by NCBI and this chimes with the statement by Ciaran Lenehan, Technical Specialist at Chanelle Pharma, that we are seeing "an industry-wide increase in sales of wormers".

Chapter 1 - Gastrointestinal Parasites associated with Bovines and Ovines in a pastoral production system

Parasites, worms, helminths, nematodes, trematodes, cestodes are all organisms that live on or in their host. Most parasites can be divided into two groups, endoparasites and ectoparasites, respectively parasites that live within a host and parasites that live on a host. For the purpose of this report, I will be looking at the group of endoparasites associated with pastoral agricultural production, specifically cattle and sheep. The survival of these parasites relies on their host, while there is little evidence of the host gaining any benefits.

These parasites rely on the faecal-oral route to continue their cycle to a new host by attaching to herbage leaves or stems and by being ingested during grazing (Forbes A. B., 2021). These parasites have evolved over the last 240 million years from free living invertebrates (Dorris, De Ley, & Blaxter, 1999) until the appearance of ruminants 30 million years ago. With domestication approximately 10,000 years ago, ruminants brought the parasites with them. Animal resistance or resilience to these parasites would have been incidental to the main breeding objectives (Raberg, Graham, & Read, 2009). As we are breeding animals for higher output, we are placing more pressures on their immune system. Following lines of genetics with production as the driver has probably left us with animals that are more susceptible to infection. This is likely to have been accelerated with the introduction of parasite treatments in the last century, leaving the host species more dependent on human intervention. However, breeding for both resistance and resilience is now receiving some focus, particularly in sheep (Halleron, 2015).

The main endoparasites of livestock

The two most prevalent stomach worms for ruminants are *Ostertagia ostertagi* and *Cooperia oncophora*.

Ostertagia ostertagi

Figure 1 – Ostertagia ostertagi. Source: xxx

Starting off its cycle as an egg hatching in the faeces at pasture, the larva develop through 3 stages, L1 L2 and to L3 to become infective larva. This larva makes its way out of the dung pat, assisted by moisture and the splashing effect of rain hitting the pat and landing on the herbage. However, heavy rainfall can assist the washing off of the larvae on to the soil. (Pania, 2020)

Following ingestion, these L3 larvae move into the rumen and within 2 days pass into the abomasum and develop in to L4 Larvae. Here they develop in to L5 adults by day 16 (Forbes A. B., 2021).

As adults the worms now mate and the females lay eggs by day 21. (Ritchie, et al., 1966). Female Ostertagia can lay up to 5,000 eggs per day (Pania, 2020) and these eggs are passed out in the faeces.

By day 21, small lesions appear on the wall of the abomasum as it becomes inflamed. These lesions can take up to 90 days to heal post infection (Osbourne, Batte, & RR, 1960) which can be visible to indicate previous infection at post-mortems. It is important to note that the majority of adult cattle have lesions associated with *Ostertagia* when examined in abattoirs indicating the high level of exposure experienced on pastures.

As an immune response, the ruminant excretes a mucus or "gastrin" in the gastrointestinal tract. This mucus acts as a defensive mechanism against pathogens (Rinaldi, Dreesen, Hoorens, Li, & Clarebout, 2011). A side effect of this response is a reduction in appetite leading to a performance drop and subsequent immune suppression. Small infections have negligible effects. Clinical signs include reduced weight gain, decreased appetite, scour, poor coat and bottle jaw. (Pania, 2020)

In the period leading up to winter, *Ostertagia* eggs become predisposed to go into a state of hypobiosis. This is where the ingested infective larvae remain in their L3 state in their host for the winter period. These are known as *Ostertagia* type 2. A disease known as ostertagiosis type 2 is a syndrome whereby these latent *Ostertagia* can become stimulated and emerge en mass over the late winter causing disease. (Martin, Thomas, & Urquhart, 1957). The risk of this disease has been reduced through housing treatments associated with macrocyclic lactones.

Cooperia oncophora

Figure 2 – Adult Cooperia oncophora. Source: COWS initiative.

Cooperia is a parasite that lives in the small intestine of ruminants. Its life cycle is similar to that of *Ostertagia*. Animals develop immunity to *C. oncophora* quicker than with *Ostertagia* so that it is less of a problem in second season grazing animals and rarely in adult animals. (Bisset & Marshall, 1987).

Coincidence between *Cooperia* and *Ostertagia* is very common. (Forbes A. B., 2021). Larval challenges can be as high as 30,000 infective larvae per day for ewes at pasture. (Familton & McAnulty, 1997). In a study, it has been shown that calves graze for 105 minutes less per day (Forbes, Huckle, Gibb, Rook, & Nuthall, 2000) when infected with both *Cooperia* and *Ostertagia*. This subsequently lowered the average daily liveweight gain of the calves.

Dictyocaulus viviparus (cattle lungworm, hoose, husk) and Dictyocaulus filaria (large ovine lungworm)

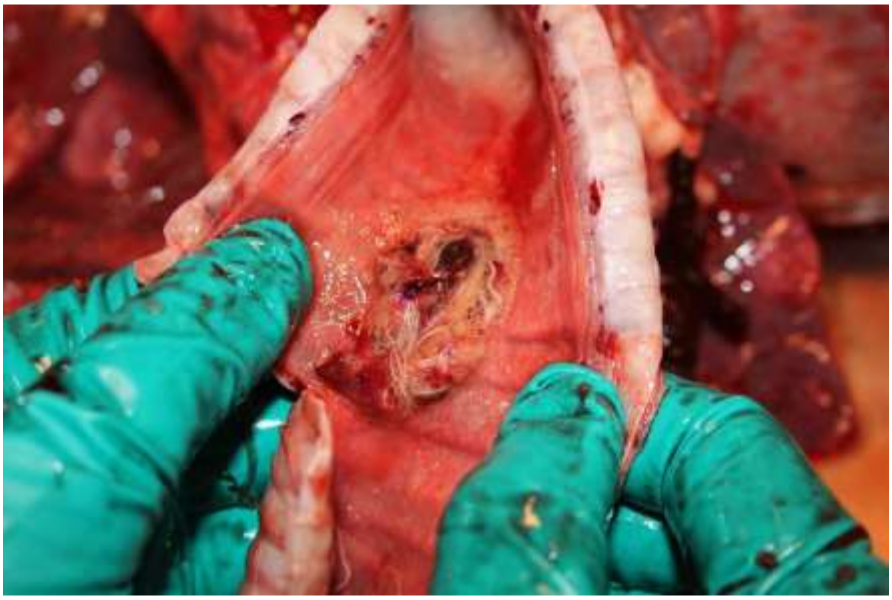

Figure 3 - Dictyocaulus Viviparus and lung damage in a young animal. Source: DAFM

D. viviparus is more common in northern temperate areas while *D. Filaria* is more common further South. Disease from lungworm is of lower concern in the southern hemisphere temperate regions (Charles, 1997). (Nilon, 2020). (Doube, 2020).

Starting the cycle with the egg in faeces on pasture, the nematode develops into stage L3 infective larva. This larva then either uses the splashing effect from rain to migrate from the pat on to the grass or, uniquely uses the sporulating fungus *Pilobolus* to propel itself out on to the herbage. Once ingested, these L3 larvae pierce the intestinal wall and move through the lymphatic and blood system to the lungs where it penetrates through the lung wall. These larvae mature into adults and lay eggs within 24-28 days post infection. These eggs are then coughed up due to irritation and swallowed to pass out into the faeces (AHI W. G., 2018). Host immunity is created rapidly with most of the adult larvae being expelled after 4-6 weeks. Female larvae can lay up to 25,000 eggs per day. (Forbes A. B., 2021).

Because of the required free living environmental conditions, and the route that the infective larvae take to get to their resting site, disease can come in quite rapidly with animals presenting themselves with bronchitis. Damaged lung alveoli are replaced by lesions and scarring as early as 7 days post infection. In severe cases, removal of the parasite leaving the damage behind may lead to continued disease or death (Jarrett, McIntyre, & Urquhart, 1957) (hoose pneumonia)

Animals create two lines of immunity to lungworm. The first is in the animal's gut where the immune response destroys the larvae in situ and prevents them reaching the respiratory tract, the memory of this defence is lost after six months (Forbes A. B., 2021). The second is an immune response in the lungs which results in the destruction and elimination of infective larvae before they get to mature into adult worms. This immune memory lasts two years or more. (Michel & Mackenzie, 1965).

Trichostrongylus **axei**

The adults of *T. axei* can be found in the abomasum of both sheep and cattle. It is not host specific and can be transmitted by a variety of species (Taylor, COOP, & Wall, 2007). This characteristic highlights the importance of biosecurity. Adult females can lay between 50 and 100 eggs per day. The resulting infection causes damage to the wall of the abomasum (Pania, 2020) affecting intakes, causing diarrhoea, weight loss and dehydration. (Ross, Purcell, Dow, & Todd, 1968). It is important to note that diarrhoea may be caused by a variety of factors in lambs, but less so in calves (Forbes A. B., 2021). Eggs start to appear in the faeces from day 21 post-infection and increase in numbers until day 35 when assumed acquired immunity of the host reduces the production of eggs (Gibson & Parfitt, 1975).

Nematodirus

Nematodirus is a parasite that mainly affects lambs but can also manifest in calves. The issue with *Nematodirus* is that clinical disease can be witnessed before the appearance of eggs, leaving early diagnosis to the skills of the flock manager. Larvae hatch into infective stage and make their way to grass in large numbers with a triggering effect from weather conditions lending to a wave of disease. (SCOPS, *Nematodirus* in Lambs)

Haemonchus **contortus**

This parasite can be found in the abomasum as a blood sucking worm. The large L5 stage adult worms can remove a large amount of blood from the host with infected sheep losing up to 250ml blood/day. Acute disease and death follow anaemia. Following infection, the L3 infective larvae quickly develop into adults in the abomasum in 14 day and adult worms can lay up to a massive 15,000 eggs per day. With a short hatching the complete life cycle of *H. contortus* can be as short as 20 days. These characteristics lend to acute disease. (SCOPS, *Haemonchus contortus*, 2020)

Although this parasite is more associated with warmer climates, it is now being reported more frequently in temperate areas, possibly as a result of climate change. (SCOPS, *Haemonchus contortus*, 2020)

Moniezia **expansa (Sheep) Moniezia benedeni (Cattle) – Tapeworm**

This parasite resides in the small intestine as an adult. This worm can reach lengths of up to six metres. From ingestion, eggs start to appear in the faeces at 35 days. Animal resistance builds up over four to five months. It is not particularly pathogenic. (Pomroy, 1997)

Fasciola hepatica (Liver fluke)

Figure 4 – Fasciola hepatica. Source: xxx

This parasite has an unusual life cycle as it involves an intermediate host, the mud snail (*Galba truncatula*). Adults in the bile duct lay eggs which pass into the gut and leave the host in the faeces. These eggs then hatch in shallow water into free living miracidia. These miracidia then infect the intermediate host, the mud snail. Over a period of 2-3 months these miracidia then multiply as they develop in to cercariae. These infective stage cercariae then encyst into vegetation ready to be ingested by the intended host. (Pania, 2020) Once inside the host the metaceraria makes its way to the liver and cause damage by burrowing through it. At about seven weeks post ingestion the fluke matures into an adult in the bile duct where it lays eggs.

Animals do not acquire resistance or immunity to *F. hepatica* and resistance is only genetic.

In bovines, *F. hepatica* is reputed to have a negative effect with host immunity to tuberculosis (Forbes A. B., 2021) and is reported to alter the host's sensitivity to the bovine tuberculosis skin test (Flynn, Mannion, Golden, Hacariz, & Mulcahy, 2007)

Paramphistomum cervi (Rumen fluke)

Rumen fluke shares a similar life cycle to liver fluke in that it also uses the same intermediate host to complete its cycle. Eggs pass through the faeces, hatch and infect the common mud snail. Developing in the snail into cercariae, the parasite then makes its way out onto herbage to be ingested by the true host. The infective larvae then attach themselves to the wall of the animal's intestine damaging it causing diarrhoea and weight loss. From here the larvae then make their way to the rumen and after several weeks or months start laying eggs that appear in the faeces. (AHI, Rumen Fluke-The Facts, 2021)

Eimeria-Coccidia

There are numerous *Eimeria* species that can affect cattle or sheep, but only a few of these are pathogenic. Oocysts (cysts similar to eggs) appear in the faeces and sporulate leaving them ready for re-infection. Once ingested these sporozoites penetrate the wall of both the large and small intestines. Here the ingested oocysts multiply into thousands of new oocysts ready to pass out into the faeces. (AHI, Bovine Coccidosis-the facts, 2015)

Disease is seen as animal unrest, dehydration, diarrhoea, poor appetite, and poor growth rates. (Forbes A. B., 2021)

Animals build immunity in the first grazing season, however oocysts of non-pathogenic *Coccidia* can be found in the faeces of adult cattle and sheep.

At the beginning of the grazing season, the available larvae would typically (but not always) have reduced over the winter due to the cold temperatures. These larvae from the previous season, if not injested, would further reduce in numbers with UV ligh from extended day time. However, once ingested these larvae mature into adults in the animals and start producing eggs that appear in the faeces and contribute to pasture fouling. See Fig 5.

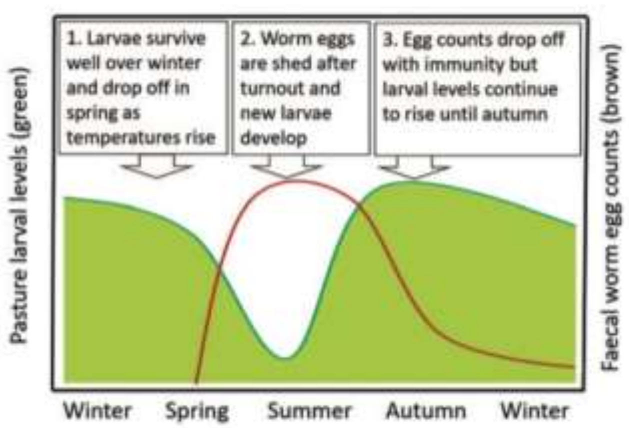

Figure 5 – Pasture larval levels and faecal worm egg counts for roundworms through the seasons. Source: COWS Initiative

Diagnostics

Diagnosis of parasite infection is an area that gets little attention. With more careful management of stock and the use of relatively inexpensive anthelmintics, disease from parasites has become a less prevalent issue. Diagnostics are not commonly used to determine if a group of or individual animal should be treated. Common diagnostics include:

- Faecal egg counts: This is where faeces from an animal, or pooled from a group, have a representative sample of eggs floated from the faeces, then the parasite is identified and counted to give a result showing the level of infection. Private laboratories, veterinary practices and regional DAFM laboratories provide this service. See figure 6 below.
- FECPAKG2: Eurion Thomas is the European Operations Manager of Techion who sell a device which brings accurate FEC diagnostics to the field with almost instant results. A prepared faecal specimen is analysed in their portable microscope. The device connects to laboratory technicians who can analyse the specimen 24/7 by connecting to the device through cellular data.
- Micron Agritech are a new start-up Irish company using an experimental flotation slide in a device to extract the parasite eggs while a mobile phone uses recognition software on the cloud to count the eggs.
- Blood antibodies: This involves testing animals for their reaction to exposure, and can be done by assessing the level of antibodies in their blood. This is especially useful when testing lambs for fluke as the result will not be affected by the previous season's

exposure. This would allow the herd owner to decide whether all the flock warranted an intervention.

- Bulk milk tank antibodies: By testing the antibody level in the milk for Ostertagia or fluke, the herd owner can assess the level of exposure his herd have had.
- Pepsinogen testing: This can be used in younger animals to detect abomasal damage caused by Ostertagia in particular. With the pH increase in the abomasum caused by Ostertagia, the conversion of pepsinogen to pepsin decreases, which leaves an elevated level of serum.
- Bronchial lavage: Water flushed in and out of an animal's lungs removes a sample of lungworm or inflammatory cells associated with lungworm, if present.
- Lower than expected weight gain: The increase in production of gastrin and the raising of the pH in the abomasum due to roundworm infection is associated with a reduction in appetite. With lower intakes, the weight gain of the young stock falls below expected levels. Monitoring the performance of young animals through weighing can be part of a diagnosis, but should not be relied upon exclusively.
- Post mortem at abattoirs or knackeries: A post mortem is an ideal and very accurate way of checking the liver, lungs, rumen and abomasum for parasites.
- Stockmanship: Tell-tale signs such as dirty tails, coughing, bubbles in very loose faeces, poor performance, irritated/unsettled animals, bottle jaw, poor coat, are signs that can be observed by any good stock person.

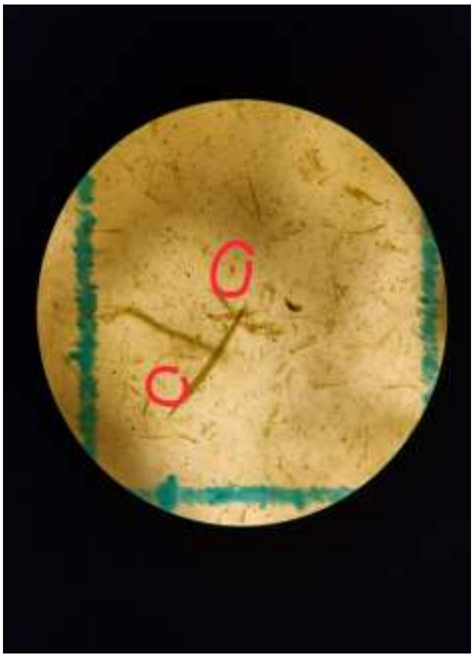

Figure 6 – Two parasite eggs identified using the McMaster method for counting eggs in a faecal sample.

Medical Treatment

With the advances in agriculture during the mid-20th century, we have seen the introduction of anti-parasitic medicines. For internal parasites there are numerous products, but there are three basic groups for cattle and two for sheep.

Group 1, Benzimadazole 1-BZ "White" Released in 1961, first recorded case of resistance in 1964.

Group 2, Levasamole 2-LV “Yellow” Released in 1970, first recorded case of resistance in 1979.

Group 3, Macrocyclic lactones 3-ML “Clear” Released in 1981, first recorded case of resistance in 1988.

Group 4, Amino-acetonitrile derivates 4-AD “Orange” Launched 2010, first recorded case of resistance in 2018.

Group 5, Spiroindoles 5-SI “Purple” Launched 2009, first recorded case of resistance in 2013.

With an increasing global food demand, stock numbers raised during the early to mid-20th century. With the extra production pressures, parasite control became a big part of stock management. As anthelmintics were developed they quickly were adopted as part of the parasite management, over time the relative cost of these products and their proven effectiveness made them the only parasite control on a lot of pastoral type farms. With little appetite and chance of new products being developed, it looks as though the above products are the last chemical stand to parasites as they remain an essential part of pastoral animal agriculture. We therefore need to ensure their future efficacy is paramount.

Anthelmintic Resistance

Anthelmintic resistance is the ability of a worm to survive a dose that should kill it. (Teagasc, 2020)

This trait is a genetically heritable trait amongst parasites and once it occurs, it persists. Resistance to one product within a class quickly transfers to all products within that class once it is detected. Once resistance is present, every time an anthelmintic is administered the percentage of genetically resistant parasites increases. Removing the parasites that are susceptible to anthelmintics gives the resistant parasites a genetic advantage.

Resistance is defined as when a worming event occurs that the anthelmintic fails to reduce the egg count in the faeces by 95%. Below this is defined as resistant. Even when an anthelmintic is administered on a farm where resistance is present, animals may show signs of performance improvement thus showing an economic value to using the anthelmintic without alerting the herdowner to the problem.

Figure 7 shows that with even a 90% reduction in eggs, there would be a great response in animal performance when an anthelmintic is used. However, every time an anthelmintic selects parasite for resistance, that product group will perform a little bit less resulting in very poor effectiveness over time. While 90% looks like a good result, the long-term effectiveness of the product will only decrease.

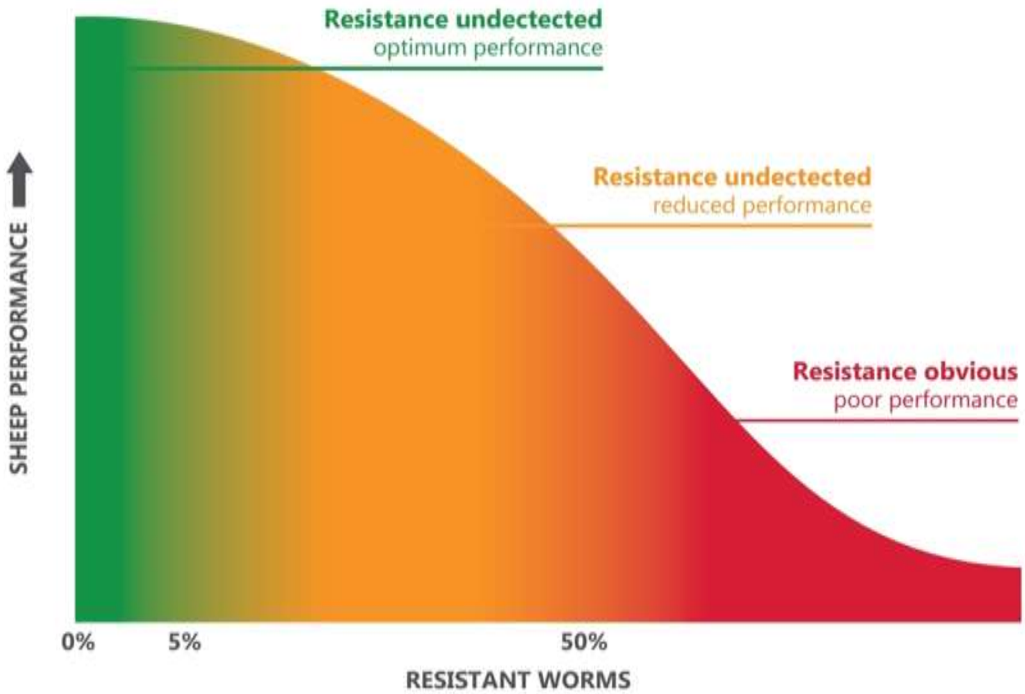

Figure 7 - Performance of sheep post drenching with different levels of resistance present. Source SCOPS initiative

Case Study – Dr Natascha Meunier, Epidemiologist, Animal Health Ireland - Getting farmers to reduce anthelmintic use through better diagnostics.

Farmers will have to reduce anthelmintic usage, overcoming their fear of parasites and their tried and trusted relationship with the drugs. This will require changes in their grassland management strategies. Resistant parasites in cattle are not generally as pathogenic as in sheep, though performance issues are starting to become evident, especially in dairy to beef cattle.

Testing for lungworm resistance is tricky due to the necessity to intervene at the early clinical signs and the sporadic nature of the parasite's reproduction. In 2020, anecdotal instances of ineffective lungworm treatment were reported, where farmers had repeatedly treated young stock on dairy farms. Not allowing animals to develop a natural immunity is leaving them naive into adulthood.

The milk PCR test can identify *Ostertagia* levels in a milking herd, though antibodies hang around for months after treatment. Automatic counter technology for faecal eggs is coming out of the lab and will soon allow for diagnostic the field. Genetics still has a way to go, but emerging research has shown that it is possible to identify resistant DNA in parasites.

Resistance was not a consideration when Ivermectin was first licenced, which is one of the reasons for subjecting anthelmintics to prescription. Long-acting products have been useful for farmers focused on production and labour efficiency. Under the new rules, a vet consult (or similar) would be a preferred option to support farmers in tailoring a parasite management plan to suit their farm.

The DAFM's sheep surveillance programme provides precious data, applicable to all cattle and sheep farms, as 90% of Irish farms are infected with liver fluke. As with the antimicrobial reduction through selective dry cow therapy, going through processors could be a good way to upskill farmers and vets to employ a diagnostics-based approach.

Case Study - Paul Nilon, Veterinary Surgeon at Nilon Farm Health, Australia - Using "Smart Grazing" to combat anthelmintic resistance

Australia, with lower rainfall, experiences greater anthelmintic resistance because at the time of dosing, few parasites would be on the pasture due to dehydration but there would be a high concentration in the sheep, thus a higher percentage of surviving parasites would have survived a drenching. There was little to no refugia on the pasture and selection pressure was increased. Australian sheep farmers carry out strategic drenches in the summer, at the start and end of summer, to decontaminate the pasture, then using sheep to graze a pasture, drench and move on. This strategy would leave a farm almost worm free.

"Smart grazing" is a strategy more suited to the damper Tasmanian and Victorian climate, to decontaminate paddocks ear-marked for winter grazing by Merino weaners. Larval collection on pasture would increase in winter due to wetter conditions and lower temperatures. Smart grazing increases the environmental decontamination of parasites on pasture and creates a safe bank of grazing for the most susceptible group i.e. Merino weaners. The farmer uses less susceptible animals to graze the paddocks first, he drenches them and lets them out to the smart grazed paddocks. These animals will now not be emitting any parasite eggs but will in fact be "hoovering" up the eggs on the smart grazed paddocks.

Tony Lovey is a farmer who has been practicing Smart Grazing for some years. Tony keeps approx. 3,500 head of Merino sheep on 800 hectares. Prior to implementing this grazing strategy Tony had been witnessing a lot of fatalities in his weaners from scour worms over the winter because of anthelmintic resistance. Tony stocks the smart grazed paddocks very heavily during the summer months to achieve a high grazing pressure. Ewes are drenched, let out to pasture and given one week's allocation of grass. The ewes are never on the pasture for longer than the 28-day cycle of the parasite. Should Tony not have the paddock grazed out in 28 days, he adds another group of ewes, drenches them, and lets them out on to the paddock to replace the first group. Tony has seen a dramatic drop in his fatality rate since he started using this technique.

Figure 8 – Vet Paul Nilon with sheep farmer Tony Lovey on his farm in North Tasmania where together they are reducing the effects of anthelmintic resistance through Smart Grazing.

Key points arising from this chapter:

- The free-living stages are necessary for the life cycle of GI nematodes and require faecal-oral transmission on pasture.
- Climatic conditions, seasons and grazing management are factors that can affect the level of exposure.
- Adult parasites lay large numbers of eggs.
- Young stock with no previous exposure is at the highest risk.
- All parasites pose a significant animal health risk and reduce performance.
- Animals have a great ability to develop immunity to parasites.
- Grazing strategies, refugia, diagnostics and considering the free-living stage of parasites are all tools that can be employed to prolong the effectiveness of anthelmintics.
- Anti-parasitic drugs are a crucial component of modern agriculture.

Chapter 2 - Anthelmintic Resistance, a Rising Problem

As we have learned from Chapter 1, parasites have evolved very successfully, but modern medicine has allowed us to manage them. With the efficient expulsion of these parasites from their host and the relative cheap cost and convenience of administering these drugs we have become almost completely reliant on these medicines. Animals that would not have survived in a system without anthelmintics have been adding to the gene pool of our herds and flocks.

Anthelmintic resistance is the ability of a parasite to survive a treatment. This ability is a mutation within the gene pool of the parasites and "once it has started, it is there for all time" as Paul Nilon, Director of Nilon Farm Health in Tasmania, puts it. This mutation can also occur outside of the host and any action that favours the resistant gene will give it an evolutionary advantage, as is revealed in the overview of anthelmintic resistance in Nordic Countries published by NCBI.

The effect of these resistant parasites starts off small and generally increases over time, ranging from no notable effect to completely ineffective worming, leading to pre-medical era parasite issues.

John O'Connell, a participant in the Teagasc BETTER Farm Sheep Programme from Leitrim, was concerned about the performance of the sheep in his flock and was focusing his attention on grassland management and mineral deficiencies before finding out that sub-effective anthelmintics were the problem. He is now diagnosing and documenting anthelmintic resistance on his farm with advice and expertise from DAFM and Teagasc to reduce anthelmintics usage and now obtains better animal performance despite resistance.

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SEARCH

BEEF DAIRY SHEEP AGRIBUSINESS MACHINERY TILLAGE PEDIGREE BUILDINGS PROPERT

Wormer resistance now a huge issue on cattle farms

Ciarán Lenehan looks at the growing threat of anthelminthic resistance in beef cattle.

Ciarán Lenehan
BEEF > MANAGEMENT
13 March 2018

Sheep and suckler farmer Kenneth Leavey from Oldcastle, Co Meath, dosing weanlings.

Anthelmintic (wormer) resistance occurs when worms are able to survive a normally effective dose of an anthelmintic. Within worm populations, resistance is heritable. So, new generations of worms on a farm with resistance will carry the trait too.

Figure 9 – A 2018 Irish Farmers' Journal article highlighting the problem of wormer resistance

Case study - Evidencing anthelmintic resistance in cattle – Dr James O'Shaughnessy and Orla Keane

Dr James O'Shaughnessy is a veterinary parasitologist with DAFM. He has conducted numerous trials on anthelmintic resistance in cattle. The rapid expansion of the dairy sector has put pressure on animal health and promoted an unsustainable increase in the use of anthelmintics. Test results – FECs, milk Elisa readings, autopsies, etc. - are not properly interpreted, and farmers tend to treat even where there is no performance loss.

Excessive treatment frequencies favour resistant worms. Leaving parasites behind on pasture means that the animals will get re-infected immediately, which reduces the selection pressure for resistant worms. Good young stock and grassland management should be favoured, enabling farmers to use less wormer in older stock. Wormers are only a tool, not the only option.

James was involved in the first trial which showed resistance in calves in 2014. Groups of calves in the Teagasc farms at Grange and Johnstown Castle were treated with levamisole, benzimidazole and macrocyclic lactone. Significant resistance was recorded to all wormers, with the macrocyclic lactones resulting in a parasite reduction of less than 40%. Other studies carried out since, including by Dr. Orla Keane, have found resistance every time.

Dr Orla Keane is a senior research officer in the Animal and Bioscience department in Teagasc, Grange.

Resistance is declared when anthelmintics fail to reduce the worm egg count by more than 95%. Sheep farmers are more likely to come forward with a parasite problem than cattle farmers, and testing for resistance in cattle has been more limited. The only two parasites that Orla's department have really been able to measure for resistance are *Cooperia* and *Ostertagia*. When performing a resistance test, Orla has found it is normally dominated by a >98% *Cooperia-Ostertagia* mix.

On a 2017 trial, the benzimidazoles were found to work better against *Cooperia* while *Ostertagia* was more resistant, whereas with macrocyclic lactones it was the other way around. 100% of the farms involved had resistance in *Cooperia*, with a surprisingly large number of farms found with resistant *Ostertagia*, which is more pathogenic. Levamisole is not effective against early immature larvae of type 2 *Ostertagia* before it goes in to hypobiosis, which leaves only two effective products. In 2018 Orla tested moxidectin and levamisole for resistance. The exceptional drought in Ireland in that year meant the parasite did not get the moisture needed to transport out of the dung pat on to the grass and was also killed off by UV light.

Startect and Zolvix are two new anthelmintic products which Orla recommends where animals are imported onto the farm, and for a once yearly use to help wipe-out resistant parasites – taking them out in animals, but not on pasture. Costs, the need for a prescription and the view from some farmers and vets that they should be kept till other actives become ineffective are barriers to this practice.

Lungworm is highly pathogenic and difficult to check for resistance. Calves start to show signs of disease by coughing, which brings up the eggs which are then swallowed, and so cannot be detected in dung. However, the concentration of wormer needed to kill lungworm is lower, and so presumably is resistance.

Key points arising from this chapter:

- A proper parasite plan used in conjunction with diagnostics can save farmers money in purchasing products while securing better animal performance.
- Resistance is hard to identify, because it starts with little or no notable loss in animal performance.
- Other issues, such as mineral deficiencies, are often blamed for anthelmintics failing to work.
- Resistance is now widespread in Ireland and is found each time it is tested for.
- Startect and Zolvix can help prolong the effectiveness of other wormers.

Chapter 3 - Anthelmintics and the unintended effects on the environment

Ever-increasing demand for food is putting pressure on our natural resources. Increased production output generally means increased inputs. With more animals on the same areas, increased production pressures on animals, shorter rest periods between grazings and more interaction between animals, we are seeing an annual increase in the sales of anthelmintics confirmed by Ciaran Lenehan, Technical Specialist at Chanelle Pharma. The unintended consequences linked to anthelmintics rise with increased usage.

In 2021, Damian Mooney published his doctoral thesis on a trial conducted throughout Ireland to assess the effect of anti-parasitic drugs as contaminants in Irish ground water. This found that 18% of the sites tested positive for anthelmintics residues, the most frequently found being from the BZ class.

On the Isle of Islay off Scotland, Gillian Gilbert, Senior Conservation Scientist with RSPB, investigated the decline in the native bird, the Chough. These birds rely heavily on the arthropods associated with the faeces from cattle and sheep. Over a two-year period, field trials were conducted, and it was found that when Triclabendazole (a derivative of BZ class) was used in conjunction with Deltamethrin, the reduction in dung invertebrates was as much as 86%.

John Finn, Research Officer - Biodiversity & Farmland Ecology Johnstown Castle, Teagasc conducted a laboratory trial which showed that Ivermectin from a treated animal did not decrease in the dung pat for 5 weeks after being expelled. The trial also showed that the probability of a dung beetle egg making it past its larval stages was 80% without Ivermectin but dropped to 15% where Ivermectin was present. Other negative effects on the beetles were discussed also.

In his paper *A Review on the Toxicity and Non-Target Effects of Macrocyclic Lactones in Terrestrial and Aquatic Environments*, Jean Pierre Lumaret of the University of Montpellier III suggests that, based on over 360 references, macrocyclic lactones have a big impact on a wide range of aquatic and terrestrial species. The results paint a startling picture of the lethal and sub-lethal effects that anthelmintic residues have.

Worryingly, over 50% of the UK's 60 dung beetle species are listed as being threatened to some degree as a result of anthelmintic use (Lane and Mann, 2016). As the species in the UK are very alike, with similar landscape and agricultural practices for the most part, it is reasonable to assume that there would be similar trends in Ireland.

Case Study – Dr Bryony Sands, Senior Research Associate, University of Bristol.

Bryony's interest is the control of livestock parasites using dung beetles. The cycle of using less wormers to encourage more dung beetles which reduce parasites is, she says, a "positive feedback loop".

Engaging with farmers suggested dung pats with lower beetle populations stay on pasture longer contributing to fouling and keeping the parasite habitat viable for longer. She attributes this to the use of macrocyclic lactones (MLs) and synthetic pyrethoids (SPs) which disrupt the ecosystem and believes farmers should step back and let nature take its course.

In a first trial, Bryony collected faeces from a farm that had a high FEC of parasites *Cooperia* and *Oestragia*. Using a clean grass field, she created cow pats, put cages around 1/3 of the pats to keep beetles out, allowed another 1/3 to be colonised naturally and added extra beetles to the final 1/3. 7 species of beetles were used in this trial, all *Aphodius* found locally. For 10 weeks, she cut the grass every two weeks, and counted any parasites from the herbage. The first count at the 2-week mark found more parasite worms on the grass beside the pats with beetles present. Bryony said the beetles oxygenate the pat by rummaging in them, speeding up hatching of the parasite eggs. However, for the rest of the 10 weeks of the trial, the pats with the beetles present consistently left fewer parasites on the herbage till they reached a count of zero. The beetles dried out and fragmented the pats which decomposed a lot quicker, stopping the parasites from hatching. The result after the 10 weeks was a 30% reduction in parasites on the pats with dung beetles and less again on those with increased beetle numbers. This could be significant enough to decide whether to worm the livestock or not.

In a second trial, she visited farms that used ML routinely, farms that only used SP and farms who used neither. She set up pitfall traps on these farms which she surveyed over the summer. She found that the farms that used SP and those that used ML had fewer beetles and lower diversity of beetles. Her research showed some beetle species were less susceptible to ML and SP, a significant finding as optimum dung decomposition and burial requires a diversity of beetles.

In further trials conducted in Africa, Bryony found that there were fewer beetle brood balls and poorly developed beetle larvae or unhatched eggs in barrels with the faeces of animals treated with SP.

Figure 10 - Dr Bryony Sands collecting a specimen for analysis in one of her trials.

Key points arising from this chapter:

- Some wormers have been proven to have a serious negative effect on not only dung invertebrates, but also on the wider ecology.
- Anthelmintics are not completely metabolised and persist in the environment for a considerable length of time moving out from the animal faeces into waterways.
- Some agricultural practices are having a negative effect on biodiversity.

Chapter 4 - Dung beetles, an anti-parasitic biological weapon

A critical stage of a parasite's lifecycle is the free-living stage, without which they would cease to exist when the host expires. Leaving thousands of eggs out on pasture dispersed in dung pats as incubators is a very sure way of securing the future of the species with a constant supply of hatched infective larvae making their way to a new host to complete the cycle. The focus of parasite management has been on expelling the parasite from the host but we rarely look at the free-living stages. This is where the dung beetle comes in.

Dr. Shaun Forgie of Dung Beetle Innovations NZ has been successful in campaigning since 2009 to introduce dung burying beetles into New Zealand to bring multiple benefits to the agricultural landscape. According to Shaun, these beetles decimate GI parasites in the faeces in three ways: they dry out the pat making it inhospitable to the aquatic infective stage larvae, they actually kill the parasites when making brood balls and they bury the eggs and infective stage larvae into the soil, removing them away from the host.

Figure 11 – Earth burrowing beetles (*Geotrupes spiniger*) hard at work in Australia.

CSIRO-The value of the dung beetle to the Australian landscape.

In the late 18th century when the first settlers arrived in Australia with their cattle and sheep, they were unaware of the value of the dung beetles that they had left behind in Europe. The dung pats produced by these new species were alien to the landscape and the native dung beetles which had spent thousands of years evolving along with the marsupials found in the wild. The lack of interest from the local beetles meant that the pats from these animals waited around for years to degrade.

As stock numbers increased through the early 20th century so too did the number of pats lingering around posing a number of threats. They contaminated water courses through run-off, covered potential grass and thus reduced growth, and acted as incubators for parasites. However, the most pertinent issue in the mid-20th century was an urban one: bush flies found in them an ideal breeding ground and so their populations flourished. In Canberra, outdoor dining was inhibited by the swarms. Jeremy Wilson, a farmer from Canberra, recalls “You couldn’t open a lunch box and put a sandwich in to your mouth without getting it covered in flies”.

People tried inventive measures such as tying corks to their hats to keep flies away from their faces. Dr. George Bornemisszza, a Hungarian entomologist working for CSIRO, soon noticed the huge volumes of animal faeces that was lingering around the pastures in Australia for much longer periods than he had witnessed in Europe. Dr. Bornemisszza realised that the missing dung beetles were the reason for this and so a programme was developed to import beetles, mass rear them and distribute them to the worst affected areas. This programme is still running under the supervision of Patrick Gleeson and his team in the Insect Collections Centre in Canberra and is currently on a five year $23m project. It is estimated that these beetles are contributing $1 billion annually to the Australian economy. Many of the beetles imported were from Europe with some of the most successful species being native of Ireland and the UK.

In addition to reducing the bush fly population, other benefits from the dung beetles’ activity are described. John Feehan “the dung beetle expert”, former entomologist of CSIRO and owner of Soil Cam was part of a team that introduced beetles to catchment areas where algal bloom was an issue. Dr. Bernard Doube (Dung Beetles solutions) is witnessing reductions in the necessity to worm animals and promises that with the newly imported *Onthophagus vacca* worming on the Fleurieu Peninsula (Adelaide) will become a rare event. Councillor Mellissa Rebbeck, Director of Climate & Agricultural Support Pty Ltd in Adelaide, is collaborating with farmers to use dung beetles to bury faeces from animals fed biochar to increase the soil carbon content and to gain carbon credits. Agricultural advisor and farmer Mark Higgins and his wife Laynette are noticing how the soil has become more porous. A pond used to collect surface run-off water at the bottom of their farm is decreasing in volume each year despite the same rainfall amounts. Mark attributes this to the bulk density of the soil lessening with the burrowing activity of the beetles.

The numerous problems beetles seem to help resolve focused the Australian agricultural industry on their benefits, and they are now enjoying a very healthy population of earth burrowing and dung burying beetles. According to Dr. Graeme Stevenson, 26 of the 57 imported beetles have flourished since their introductions between 1965 and 1985. Despite the very well documented negative experience regarding the environmental impacts of imported animal species in Australia, there have only been positive reports surrounding the importation of dung beetles.

Figure 12 – Dr. Bernard Doube surveying the effects that bush fires had on introduced beetles outside Adelaide. March 2020

Case Study - Dr Bernard Doube, Director, Dung Beetles Solutions, Adelaide, Australia

The purpose of visiting Dr Bernard Doube was to consider dung beetles as a commodity for sale to farmers, and to learn about in-field distribution and monitoring of colonies.

Bernard introduced dung beetles to Australia to control the bush fly. He supports the introduction of European beetles into Ireland, using some of the same species used in Australia. “Drugs and chemicals to control parasites versus the use of dung beetles. Compacted soil with low microbial activity needing more chemical fertilisers and mechanical intervention versus using dung beetles. Declining levels of birds and bats due to lack of feed versus feed them dung beetles. Increased methane levels from dung pats hanging around versus using dung beetles to bury them. Leave the current levels of run off continue to raise waterway nitrogen levels while leaving an economic loss, versus use dung beetles to lower the runoff”.

Bernard sees only positives in the introduction of beetles: they are unlikely to have any negative effects on the environment. He experimented adding dung to the base of vines in a plot to have beetles bury the dung. There was no negative impact on yield or quality of grapes at harvest, however, Bernard could measure that the bulk density of the soil had decreased which led to better water infiltration and less drought stress.

After the 2019 bush fires, Bernard carried out experiments to check the impact on beetles. Not only did the fires directly impact the environment and the beetle populations, but they resulted in animals being moved off the land or perishing, resulting in fewer dung pats for the beetles to feed and procreate.

Bernard and the author visited a dairy farm where Bernard’s company was in the process of introducing a colony of beetles. Farmers Shane and Kylie Mieglich’s top priorities are animal welfare and attention to detail, with a low level of drug intervention. This was the motivation behind their purchasing the beetles to use as fly and parasite control while improving soil health. Having found a species of beetle best suited for the climate on their farm, *Bubas bubalus,* collected for CSIRO through European partners from higher, cooler ground in Spain, they set about breeding them progressively to introduce them in large numbers into the farm environment. They found that different species are best used in combination based on different environments, geography and to create as long a presence as possible through the seasons.

Key points arising from this chapter:

- Dung beetles are an effective and vital component in the control of pests and parasites associated with livestock.
- Introduced dung beetles have had a very positive effect in Australia.
- With an increased prevalence of dung beetles, farmers are able to reduce their anthelmintic usage.

Chapter 5 - Dung beetles, a positive for the community

So we have seen the benefits that beetles bring to the natural environment and to the health of livestock, we have seen the success these beetles had in Australia in removing flies that are a nuisance for humans, but what other attributes do the beetles bring to the community? Dr Bernard Doube of Dung Beetles Solutions also champions CSIRO's work in tackling algal bloom in catchment areas using dung beetles to bury the nutrient-filled dung pat at the roots of the grass away from the risk of running to waterways in times of heavy rainfall. However, beetles contribute in even more ways to the wider eco-system.

The beetles themselves are a food source for predators such as wading birds, garden birds, birds of prey, badgers, foxes, etc. A good healthy population of beetles is an intrinsic part of a healthy eco-system service in which livestock is central. Quantifying the input that dung beetles bring to agriculture, Dr. Sarah Beynon owner of **The Bug Farm** estimates that they save the UK's cattle farming industry £347 million per year (Beynon et al. 2015). In her report, Dr Beynon shows these savings arise from the reduction in purchased fertilisers, additional grown herbage, increased liveweight gains and milk yields, higher animal welfare, reduced nuisance flies, reduced anthelmintic usage, biodiversity loss mitigation, improved water quality, reduced GHG emissions and tourism attraction.

As consumers become increasingly detached from food production, educating children on the sources of their food has never been as important. This is not only essential to ensure the appreciation of the resources and efforts involved in producing food, but it also improves their engagement with their community.

Andrew Doube, horticulturalist and childcare worker in Hobart, Tasmania, is taking children out of their classrooms. On a pilot scheme in Claredon Vale Primary School, Andrew used practical sessions of collecting and mass rearing beetles in the school's garden to demonstrate the life cycle of dung beetles while also performing written reporting, mathematical calculations and learning biology. Pupils with learning difficulties were initially selected and had a curriculum engineered to accredit them for their participation.

James Gilmartin, Science teacher at St Clare's post primary school in Manorhamilton, Co. Leitrim, facilitated his transition year agricultural science class to perform a dung beetle survey across a number of farms. The students asked the farmers questions about wormer usage. This project, when collated, educated the children on the importance of the responsible usage of wormers, the importance of dung beetles and the wider contribution that animal agriculture makes in land management.

Dr Graeme Stevenson of Tasmania under a voluntary umbrella organisation Landcare colourfully engages with children by telling the story of nutrient recycling in classrooms all around Tasmania: He describes how "Sally the sick soil" is being prescribed "Beetle pills" by "Dr Splutter Grunt". He has even sat down in front of the children with a plate of "delicious" cow faeces and a knife and fork pretending he was about to eat it. On his "Adopt a farm" school programme, Graeme brought children from schools to farms to learn all about the balancing the ecology of Tasmania through the introduction of dung beetles.

Figure 13 - three-day old dung pat completely buried removing the potential of parasite issues, surface water run-off and nuisance flies. Tasmania March 2020

During the 1970's, with the introduction of exotic dung burying beetles, CSIRO took the initiative to promote good practices on farms to encourage beetles to flourish by investigating what advantages they would bring to agriculture. In one such experiment, Entomologist Dr.

George Bornemissza discovered that buried dung had a very positive impact on not only the volume of grown herbage, but also the feed quality. The positive effect of dung burying beetles, which make naturally occurring nitrogen available to the plant roots, was very plain to see on poor, overgrazed land.

Dr Bernard Doube also explains in detail how more grass grows in a field trial with dung because the soil was found to have higher levels of phosphate, organic carbon, and lower bulk density which increases its water penetration capacity.

Max Anderson, PhD student at the University of Sussex, describes dung beetles as being "a barometer for environmental health". He explains that these beetles are a food source for birds, bats and other terrestrial animals. Changes to grazing management effects both the diversity and abundance of dung beetles, which in turn has a bearing on both the quantity and species of bats. In 2020, the author undertook a beetle reconnaissance mission with almost 40 farmers who helped him search for beetles on their farms. These were to be handed into the national collections centre in the autumn, however the prolonged restrictions due to the pandemic meant that this was not possible. The group, however, gained a valuable education about the dung beetles on their farms.

With the vision and technical expertise of James Allen from Heritage Graziers, a website was born on 1st Jan 2021: **www.dungbeetlesforfarmers.co.uk** . The team behind this website include a conservationist, a farmer member of the Pasture for Life Association, an ecologist, entomologists, a large animal vet and a conventional farmer (the author). With the growing demand for information on these invertebrates and a lack of cross-speciality expertise, James brought these professionals together to form a hub of pragmatic, informative and practical advice to make the information available to people who take an interest in dung beetles. The team took a stand at the 2021 UK regenerative agriculture show and conference Groundswell 2021 and managed to engage 200 people to each of their "Dung Beetle Safaris" during the event.

Figure 14 - Dr Graeme Stephenson digging for earth burrowing beetles that he helped introduce into Tasmania.

Figure 15 - Dr. Splutter Grunt, Dr Graeme Stephenson's comic alter ego.

Case Study – Dr Graeme Stephenson, Tasmanian Senior Australian of the Year, Retired Senior Research Officer with the Agriculture Department. Landcare Developer. Organic Certifier.

Dr Stephenson has extensive knowledge of dung beetles, and why they have been a success story in Tasmania. He has contributed to raising awareness and appreciation of beetles in Tasmania. Graeme loves educating children about dung beetles and poo in schools. He would bring cow pats into the classroom; his "adopt a farm" campaign where pupils went out to see their "farmer hero"; his "Dr Splutter Grunt" act which sees him cure "Sally the sick soil" by prescribing her "dung beetle pills". Children get to discover "the magical world of creepy insects and unmentionable poo".

Tasmania now supplies beetles for other parts of Australia. Graeme receives 60c for each dung beetle that he catches. *Geotrupes spiniger* AKA the Blue Bomber, is a success in Tasmania due to its suitability for cooler areas, its ability to move large amounts of dung, to migrate a distance to find dung and the fact that it is well suited to captive breeding. This beetle is very similar to our Dor beetle, *Geotrupes stercorarius* in appearance and behaviour. Four out of 13 species introduced have become well established.

Graeme believes a certain level of parasites is needed to aid digestion in ruminants. The dung pat replaces nutrients removed by grazing, and earthworms digest the pat and make it available to the plant after the beetles bury it. Earthworms concentration is higher in the soil around a pat within days of it being deposited. The females *Geotrupes spiniger* dig the tunnels while the males bury the dung and make the brood balls into which the females lay their eggs. A typical female will lay 80-200 eggs over the space of a season. After the eggs are laid, the tunnel walls are lined with dung. An adult beetle can bury up to 200 times its own body weight every day at peak. Only early-stage beetle larvae actually "eat" the dung which is left by their parents. Adults "suck" the juices from the dung extracting its micro-organisms, dehydrating it and making it more appealing to earthworms. Eggs hatch in as soon as 2-3 days and the larval-pupal stage is usually around 18 days.

In 1990, Burnie City Council paid for the release of four species of beetles in the catchment area of the Pet River to aid the reduction N and P run off associated with animal waste. It is best to release a number of different species of beetles at once. 120,000 beetles were bred in captivity and released in different sites around Tasmania. A population of *Geotrupes spiniger* will expand at about 1km/year whereas *Onthophagus fulvus* with expand at 6km/year. A single *spiniger* adult can travel up to 50kms. It is important to release high numbers of beetles at once: successful colonisation of an introduced beetle needs a community effort, as successfully adopted in Tasmania, with neighbours encouraged to get involved and kits provided to over 40 schools. Beetles need a good supply of fresh dung and it is best to avoid areas where worm drenches are used. Land and release sites should not be ploughed. Chain harrowing grassland can also be damaging. Beetles don't perform well on faeces containing high levels of grain as this alters the pH and the bacteria make-up. Beetles carry phoretic mites, these mites have been proven to eat fly eggs, but it is thought that these mites may also eat parasite eggs.

Case Study - Andrew Doube. Horticulturalist and Child Activity Worker, Hobart, Tasmania.

The purpose of the visit to Mr Doube was to explore options for engagement with the public to increase awareness of dung beetles, their value to the environment and the importance of agriculture, to learn how a breeding system can be simple enough that children can be involved, and to engage children with agriculture to help maintain its social licence.

Andrew showed the author his allotment plot where he is breeding his own *Onthaphagus vacca* beetles as part of his school programme. He also grows his own vegetables in this plot, in a soil looking exceptionally fertile. On our way to Clarendon Vale Primary School, Andrew explained how he came about bringing dung beetles to school kids. Andrew initially was commissioned to grow vegetables in Clarendon Vale Primary School with the pupils. Andrew came up with the idea to use dung beetles to further involve children with learning difficulties with the soil and agriculture.

In the initial project, Andrew was running the workshop with the children and breeding the dung beetles in tents on the school grounds. These beetles are special as they are a new species being introduced to Tasmania to extend dung beetle presence throughout the year. During the workshops, the children were able to appreciate the soil, environment, and the values of agriculture. While the project was a success, it would be far more beneficial if the teachers were able to take control of the workshops, under Andrew's guidance – which is what is being proposed for the coming school year.

Andrew introduced me to Ellen Breganti, year head at the school. Ellen's role is to formulate a customised curriculum for children who fall outside the standard learning capabilities. Ellen found Andrew's programme very useful in creating a place where children with learning difficulties could safely express their skills and interests. The children involved in the "Alternative Learning Group" were successful in sequencing, following procedural texts, and investigating the beetles. As a result, the programme helped achieve the Maths and Science curriculum. Ellen found that the children were more willing to learn in a class that was more applied and were better behaved. She was very clear that the class was a learning opportunity, not a reward.

Figure 16 – Andrew Doube floating dung beetles out of faeces at a school garden in Tasmania

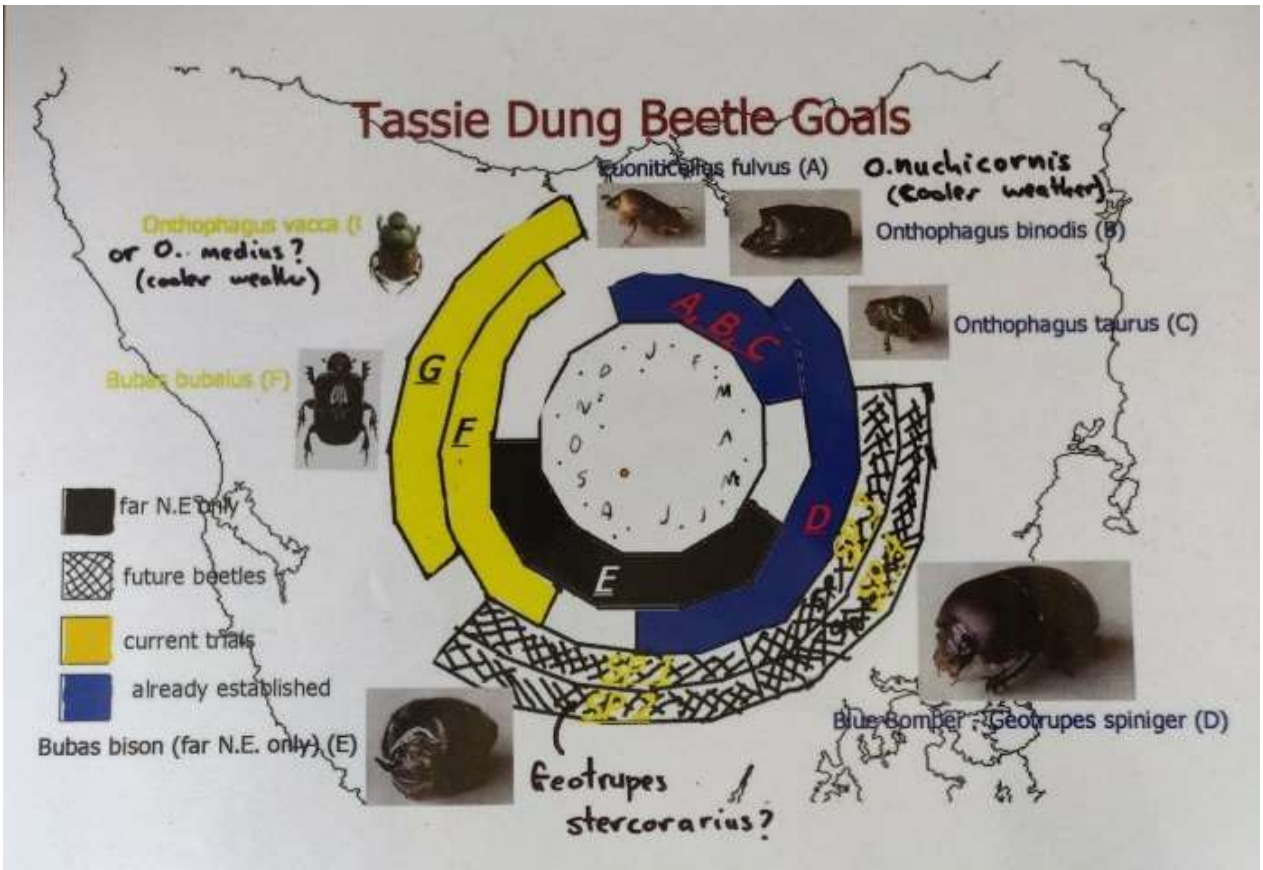

Figure 17 – A chart prepared by young adolescents with learning difficulties.

Key points arising from this chapter:

- Dung beetles are an excellent gateway to educate children in the wider ecological benefits of agriculture while incorporating components of their school curriculum.
- The burial of dung with beetles increases the nutrients available to plants leading to increased herbage growth.
- Different grazing practices have an effect on beetle diversity and abundance, therefore an effect on ecology.
- Dung beetles can be an effective tool for reducing the prevalence of algal bloom.
- Animal waste can now be seen as a multi-beneficial resource to both agriculture and ecology showing the importance of an integrated and circular agricultural system.
- The most successful beetle in Tasmania *Geotrupes spiniger* is native to Ireland.

Conclusions

- Parasites associated with agriculture have evolved a very intricate life cycle. Domestication of livestock and the introduction of anti-parasitic medicines cover a very short period of this evolution and parasites are already adapting.
- Parasites are costing the livestock industry in Ireland a considerable amount of money. Adding to this, anthelmintic resistance is reducing the effectiveness of anti-parasitic drugs and thus adding even further costs to the sector. This is not going to improve.
- Anthelmintic resistance is a change in genetic coding that persists indefinitely in a parasite population. Once it is there, it is there for good.
- We have a very limited arsenal of anti-parasitic medicines. These are crucial to maintain the highest standard of animal welfare. There are very few resources being put into the development of new products.
- Diagnostics are going to play a very important role going forward.
- The free-living stages of parasites' lifecycles do not get enough attention by farmers. Removing the word "control" and replacing it with "management" when referring to parasites is a positive step.
- Anthelmintics pose a threat to biodiversity and have likely contributed significantly to the reduction in species numbers, particularly coprophagous (faeces-eating) creatures and their prey.
- Anthelmintics are potentially a groundwater pollutant.
- Dung beetles significantly reduce parasite burdens on pasture and have been very successful in Australia when artificially mass reared to increase abundance.
- Dung beetles provide other benefits such as reducing the threat of nutrient leaching and run-off, reducing pasture fouling, increasing herbage mass, providing food for creatures of prey, improving soil structure and reducing pest insects that breed in the dung.
- Allowing some areas to become refugia is a simple tool that can be used on the majority of farms.
- Educating children about the nutrient cycle really raises their attention and awareness in a fun way, lending to a better understanding of the intricacies of the role of animal agriculture in the wider ecological landscape.

Recommendations

1. A significant reduction in anthelmintic usage is not just needed, but also possible and will save farmers money. I recommend the **development of a programme** to be funded by DAFM, aligning with the EU's Biodiversity Strategy goals to reduce pesticide use and restore biodiversity. This programme needs to upskill veterinary practitioners, consultants and advisors in the area of free-living stages of parasite management, diagnostics and the sustainable usage of anthelmintics.
2. We have access to extensive relevant information sources in this country: regional laboratories, milk processors, meat factories/abattoirs, veterinary practitioners, the PastureBase Programme, farm management software, DAFM, ICBF, private diagnostic laboratories, FEC counting machines, AHI, Met Eireann and Teagasc. By **creating an information processing network**, possibly facilitated by AHI, to collate the information coming from these sources into a database, we could regionalise outbreaks of parasites in real time to feedback information to at-risk farmers, predict outbreaks of parasites based on trends and weather forecast, learn what particular fields are at highest risk to avoid grazing them with vulnerable stock, gain advances in genetically predisposed blood lines suitable for reduced anthelmintic usage, gain advice on what products to use as the season unfolds.
3. I further recommend **labelling of products by HPRA** to clearly state their environmental risks in order to fully inform the user.
4. A **mass-rearing programme of native dung burying beetles** should be undertaken, in part at least through the ASSAP programme. This would allow to restore their populations, helping farmers reduce their cost of parasite management while also reducing the level of nutrients leaching into our waterways.
5. **Practical aspects of the nutrient cycle should be added to the school curriculum** in subjects such as Agricultural Science or Biology. These areas should teach about the sustainable use of important medicines and the importance of animal agriculture in ecology.

Glossary

Anthelmintics: A group of drugs used to expel parasites from their host.

Anthelmintic Resistance: The genetic ability of parasites to survive a dose of anthelmintic.

Bottle jaw: a pendulous oedematous condition of the tissues under the lower jaw in cattle and sheep resulting from infestation with bloodsucking gastrointestinal parasites (as of the genus Haemonchus).

Brood Balls: A nest and food source made by dung beetles from faeces in which the females lay their eggs.

Cercaria: (Plural, cercariae) a free-swimming larval stage in which a parasitic fluke passes from an intermediate host (typically a snail) to another intermediate host or to the final vertebrate host.

Coprophagous: Faeces eating.

Gastrin: a hormone which stimulates secretion of gastric juice and is secreted into the bloodstream by the stomach wall in response to the presence of food.

Geotrupes: A species of beetle.

Hypobiosis: An arrested stage of development in some larvae.

Macrocyclic lactones: A group of anti-parasitic colloquially known as “clear” wormers e.g., Ivermectin.

Mass Rearing: A process used to breed many beetles in an enclosure.

Metacercaria: a tailless encysted late larva of a digenetic trematode that is usually the form which is infective for the definitive host.

Miracidium: (Plural, miracidia) a free-swimming ciliated larval stage in which a parasitic fluke passes from the egg to its first host, typically a snail.

Oocyst: a cyst containing a zygote formed by a parasitic protozoan such as the malaria parasite.

Pepsin: the chief digestive enzyme in the stomach, which breaks down proteins into polypeptides.

Pepsinogen: a substance which is secreted by the stomach wall and converted into the enzyme pepsin by gastric acid.

Refugium: (Plural: *refugia*) is a location which supports an isolated population of a once more widespread species. In the case of parasites, it involves creating a refuge harbouring parasites that are susceptible to anthelmintics to use as a genetic stock.

Sporozoite: a motile spore-like stage in the life cycle of some parasitic sporozoans (e.g. the malaria organism), that is typically the infective agent introduced into a host.

Sporulate: produce or form a spore or spores.

References

The Animal Health Market in Ireland, APHA **https://www.apha.ie/AboutUs/Markets.aspx**.

J Charlier et al (2020) *Initial assessment of the economic burden of major parasitic helminth infections to the ruminant livestock industry in Europe* **https://sci-hub.se/https://doi.org/10.1016/j.prevetmed.2020.105103**.

JP Lumaret et al (2012) *A Review on the Toxicity and Non-Target Effects of Macrocyclic Lactones in Terrestrial and Aquatic Environments* **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3409360/** .

Forbes, A. B. (2021). *Parasites of Cattle and Sheep: A practical Guide to their Biology and Control.*

Dorris, M., De Ley, P., & Blaxter, M. (1999). Molecular analysis of nematode diversity and the evolution of parasitism. *Parasitology Today*.

Raberg, L., Graham, A., & Read, A. (2009). Decomposing Health: tolerance and resistance to parasites in animals. *Philosophical Transactions of the Royal Society of London*.

Halleron, R. (2015, July 11th). *Some Sheep Breeds Have Higher Resistance to Parasites Than Others.* Retrieved from Agriland: https://www.agriland.ie/farming-news/some-sheep-breeds-have-a-higher-resistance-to-parasites-than-others/

Pania, F. (2020). *Deer Parasite Management.*

Ritchie, J., Anderson, N., Armour, J., Jarrett, W., Jennings, F., & GM, U. (1966). Experimental *Ostertagia ostertagi* infections in calves: parasitology and pathogenesis of a single infection. *American Journal Of Veterinary Research*.

Osbourne, J., Batte, E., & RR, B. (1960). The Pathology following single infections of *Ostertagia ostertagi* in calves. *The Cornell Veterinarian*.

Rinaldi, M., Dreesen, L., Hoorens, P., Li, R., & Clarebout, E. (2011). Infection with the gastro-intestinal nematode *Ostertagia ostertagi* infections in cattle affects mucus biosynthesis in the abomasum. *Veterinary Research 27*

Martin, W., Thomas, B., & Urquhart, G. (1957). Chronic diarrhea in housed cattle due to atypical parasitic gastritis. *Veterinary Record 69*.

Bisset, S., & Marshall, E. (1987). Dynamics of *Ostertagia spp*. and *Cooperia oncophora* in field grazed cattle from weaning to 2 years old in New Zealand. *Veterinary Parasitology 24*.

Familton, A. S., & McAnulty R. W. Life cycles and development of nematode parasites of ruminants. *Sustainable Control of Internal Parasites in Ruminants, Animal Industries Workshop, Lincoln University*

Forbes, A., Huckle, C., Gibb, M., Rook, A., & Nuthall, R. (2000). Evaluation of the effects of nematode parasitism on grazing behaviour, herbage intake and growth in young grazing cattle. *Veterinary Parasitology*.

Carl Fredrik Ihler (2010) *Anthelmintic resistance. An overview of the situation in the Nordic countries* **https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2994301/** .

Charles, W. (1997). Internal parasitesof cattle in New Zealand: Gastrointestinal nematodes and lungworm. *Sustainable control of internal parasites in ruminants*.

Lane, S. Mann, D. (2016). A review of the status of the beetles of Great Britain. *Natural England Commissioned Report NECR224*

Nilon, (March, 2020). Personal communication with the author, Launceston, Tasmania.

Doube, (March, 2020). Personal communication with the author, Adelaide, Australia.

W. G. (2018, July). Lungworm-The Facts. *AHI- Parasite control leaflet series*.

Jarrett, W., McIntyre, W., & Urquhart, G. (1957). The pathology of experimental bovine parasitic bronchitis. *Journal of pathology and Bacteriology 73*.

Michel, J., & Mackenzie, A. (1965). Duration of the acquired resistance of calves to infection with Dictyocaulus viviparus. *Research in Veterinary Science 6*.

Taylor, M., COOP, R., & Wall, R. (2007). *Veterinary Parasitology 3rd edn. Oxford*.

Ross, J., Purcell, A., Dow, C., & Todd, J. (1968). Experimental infections of calves with Trichostrongylus, observations on lethal infections. *Research in veterinary science 9*.

Gibson, T., & Parfitt, J. (1975). Egg output by *Trichostrongylus axei* in sheep given a single injection. *Journal of Comparative Pathology 85*.

SCOPS. (2020, August). *Haemonchus contortus.* Retrieved from SCOPS: **https://www.scops.org.uk/workspace/pdfs/haemonchus_1.pdf**

SCOPS. (n.d.). *Nematodirus in Lambs.* Retrieved from SCOPS: https://www.scops.org.uk/internal-parasites/worms/nematodirus-in-lambs/

Damian Mooney (2021) *Investigating veterinary antiparasitic drugs as emerging contaminants in Irish groundwater* **http://www.tara.tcd.ie/handle/2262/94825**.

John Finn et al: *Lethal and sub-lethal effects of ivermectin on north temperate dung beetles, Aphodius ater and Aphodius rufipes (Coleoptera: Scarabaeidae).* **https://repository.wit.ie/1974/2/Bioassays_final.pdf** .

Pomroy, W. (1997). Cestode parasites of ruminants in New Zealand. *Sustainable control of internal parasites in ruminants*.

Flynn, R., Mannion, C., Golden, O., Hacariz, O., & Mulcahy, G. (2007). *Fasciola hepatica* infection alters responses to tests used for diagnosis of bovine tuberculosis. *Infection and Immunity 75*.

AHI. (2021, February). Rumen Fluke-The Facts. *Parasite control leaflet series*.

AHI. (2015, October). Bovine Coccidosis-the facts. *AHI Parasite Control Leaftlet Series, V2*.

Anne C. Kelleher, Barbara Good, Theo de Waal & Orla M. Keane. (2020) Anthelmintic resistance among gastrointestinal nematodes of cattle on dairy calf to beef farms in Ireland. *Irish Veterinary Journal, article 73, 2020.*

O'Shaughnessy, J. Earley, B. Mee, J.F. M. L. Doherty, M.L. Crosson, D. Barrett. Prendiville, R. Macrelli, M. de Waal, T. (2014) Detection of anthelmintic resistance on two Irish beef research farms. BVA Veterinary Record.

Report on ABC of project by Charles Sturt University researcher Professor Leslie Weston (2018) **https://www.abc.net.au/news/rural/2018-09-12/dung-beetles-produce-economic-turnover-for-agriculture-industry/10231166**.

Dr Sarah Beynon (2015) *The application of an ecosystem services framework to estimate the economic value of dung beetles to the U.K. cattle industry.* **https://onlinelibrary.wiley.com/doi/full/10.1111/een.12240**.

Andrew Doube (2019). Landcare Tas *Dung Beetle Kids: Students Contributing to Tasmanian Environmental Health* **https://www.landcaretas.org.au/andrewdoube**.

Angus McQueen, CSIRO (1975): *Effects of cattle dung and dung beetle activity on growth of bardless wheatgrass in British Columbia* **https://cdnsciencepub.com/doi/pdf/10.4141/cjps75-152**.

Dr Bernard Doube (2017) *Ecosystem services provided by dung beetles in Australia.* **https://www.researchgate.net/publication/319888927_Ecosystem_services_provided_by_dung_beetles_in_Australia**.

Max Anderson (2021) *Insects: a barometer for environmental health – National Insect Week* **https://www.mammal.org.uk/2021/06/insects-a-barometer-for-environmental-health-national-insect-week/**.

Natascha Meunier (AHI) (January 2021) Personal communication with the author. Teams platform.

James O'Shaughnessy (DAFM) (January 2021) Personal communication with the author. Teams platform.

Orla Keane Teagasc, Grange. (January 2020) Personal communication with the author. Grange Castle

John O'Connell, Sheep farmer, Leitrim, Ireland. (January 2021) Personal communication with the author. Zoom platform.

Grange research farm, Teagasc (ref. for trial 2017-18)

Seamus Fagan, DAFM veterinary inspector. (March 2021) Personal communication with the author. Author's farm.

Philip Skuce, Researcher, Moredun Institute. (December 2020) Personal communication with the author. Zoom platform.

Nicholas Cotter, sheep farmer and co-inventor of the Cotter Crate. (December 2020) Personal communication with the author. Zoom platform.

Eurion Thomas, European director of sales for FEKPAKG2, Techion UK. (January 2021) Personal communication with the author. Zoom platform.

Sean Smith, CEO, Micron Agritech, Ireland. (January 2021) Personal communication with the author. Zoom platform.

Treating cattle with Ivermectin: Effects on the Fauna and Decomposition of Dung Pats (M. Madsen, B Overgaard Nielsen, P Holter, OC Pedersen, J Brochner Jespersen, etc…, British Ecological Society)

Analysis of the spatio-temporal occurrence of anthelmintic veterinary drugs residues in groundwater (D Mooney, KG Richards, D Danaher, J Grant, L Gill, PE Mellander, CE Coxon, Science of the Total Environment)

Pat Farrell and TJ Maher, IFA National Animal Health Committee. (March 2021) Personal communication with the author. Teams platform.

Bryony Sands, Senior Research Associate, University of Bristol. (November 2020) Personal communication with the author. Zoom platform.

Graeme Stephenson, Landcare developer, retired Senior Research Officer with the dairy branch of Tasmania's Agriculture Department (March 2020) Personal communication with the author. Burnie, Tasmania.

Bernard Doube, Dung Beetles Solutions, Adelaide, Australia. (March 2020) Personal communication with the author. Adelaide, Australia.

Shane and Kylie Miglich, dairy farmers, South Australia. (March 2020) Personal communication with the author. Adelaide, Australia.

Cherry and David Machlin, dairy farmers, South Australia. (March 2020) Personal communication with the author. Flerieu Peninsula, Australia.

Mark and Laynette Higgins, grass based intensive beef producers, Fleurieu Peninsula, South Australia. (March 2020). Personal communication with the author. Fleurieu Peninsula, South Australia.

Michael Viney in the Irish Times, 6th June 2020: The Irish farmers peering into cow pats for precious dung beetles. **https://www.irishtimes.com/news/environment/the-irish-farmers-peering-into-cow-pats-for-precious-dung-beetles-1.4264787**

Ben Malone for the National Biodiversity Data Centre: Dung beetle volunteers from the farming community needed to assist research project. April 2020. **https://www.biodiversityireland.ie/dung-beetle-volunteers-from-the-farming-community-needed-to-assist-research-project/**

Andrew Doube, Horticulturist and Child Activity Worker, Hobart, Tasmania. (March 2020) Personal communication with the author. Hobart, Tasmania.

Melissa Rebbeck, CEO Climate and Agricultural Support, Fleurieu Peninsula, South Australia. (March 2020). Personal communication with the author. Fleurieu Peninsula.