Are faecal egg counts approaching their "sell-by" date?

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Abstract

Historically, the primary determinant for the state of parasitism has been the concentration of nematode eggs in the faeces (FEC). This descriptor has a number of limitations that have implications for the development of drug resistance and hamper the identification of resilient livestock. A major fallacy is that FEC can reliably assess the worm burden, the need for anthelmintic and the efficacy of that treatment. FEC is a ratio, eggs per gram of faeces, not a quantity. Not only is the denominator ignored but interpretation of the numerator requires knowledge of nematode species present and female fecundity which can be affected by infra-population dynamics. By definition, a parasite exists at the expense of its host. As such, the consistent ability of resilient animals to maintain performance, despite a high FEC, strongly suggests that FEC does not provide a reliable indicator of the cost of parasitism. This manuscript reviews the factors that affect FEC and argues for a step change in our approach to the control of nematode parasitism in pastoral systems to one focused on individual treatments based on animal performance utilising radio-frequency electronic identification and automated weighing and drafting systems.

Keywords: faecal egg counts; parasitism; sheep; regulation of egg production; targeted selective treatments

Introduction

Control of gastrointestinal nematode parasitism is vital to the sustainability of pastoral systems. Faecal egg counts (FEC) have been a well used tool in diagnosis of helminthoses and the need for anthelmintic treatment. But what have they really contributed to the management of animal performance? Could reliance on them have contributed to the development of resistance to many classes of anthelmintic? Arguably, FEC had their greatest relevance in developing our understanding of nematode epidemiology and the accumulated data on levels of FEC in many situations lead to strategic suppressive drenching regimes designed to limit future contamination (Brunsdon & Vlassoff 1982). However, once these regimes were established, often little consideration was then given to FEC until relatively recently when the availability of on-farm diagnostic kits led to anthelmintic programmes that were tailored to individual properties. Even then this still involved whole flock treatment based on mean FEC. The recognition of the importance of refugia in slowing the development of anthelmintic resistance in combination with the desire for the responsible use of chemicals in food producing animals, has led the move away from these whole flock treatments to ones based on individual need for treatment (van Wyk & Bath 2002). There are many reasons why the use of FEC in these situations has significant limitations.

It must be clear what FEC is a proxy for. FEC is often perceived to provide an indication of the worm burden within the host, either to assist with limiting the production costs associated with nematode infections, or to determine the efficacy of anthelmintic treatment through a FEC reduction test (FECRT) in which the % reduction in FEC post treatment is calculated. For a number of reasons which relate not only to the technique but also the probability that the mature egg laying population of nematodes may not be the major or only cause of pathology (Coop et al. 1982), it is likely in many situations that FEC is not suitable for these tasks. Further, as knowledge of the host by nematode relationship expands, it has become clear that for some nematode species of temperate environments, the impact of infection on the host is more heavily influenced by the animal's own response to the infection than the actual infection *per se*, as observed in animals which are resilient to nematode infection (Bisset et al. 2001).

From time to time technological advances provide an opportunity to rejuvenate our approach to what is considered 'normal' farming practice. It is incumbent upon us as scientists to investigate these options. Such an opportunity has arisen in recent years with the widespread availability of electronic recording of livestock and automated weighing and drafting systems. Here we highlight some of the known, but often overlooked, complexities and technical limitations that can severely impact on the interpretation of a FEC result and make the case for abandonment of FEC in favour of targeted selective treatments based on individual animal performance using modern electronic identification and recording technology.

The denominator

FEC is not an absolute number; it is a ratio, the number of eggs per gram of fresh faeces. Any factors that change the volume of fresh faeces, such as differences in dry matter (DM) intake, feed quality or

Table 1 Simulation of the impact of faecal output, shown in bold, on the interpretation of faecal egg counts (FEC) based on the feed consumption required to meet the energetic requirement of a 25 kg lamb growing at either 100 or 330 g per day (AFRC 1993) with faecal moisture of either 15% or 30%. Herbage quality is assumed at 11 megajoules of metabolisable energy (MJME) per kg dry matter (DM) with a DM digestibility of 75%. Scenario A: Expected FEC when total egg production is constant at 1,000,000 eggs per day. Scenario B: Expected total egg production when FEC is constant at 500 eggs per g.

Parameter	Slowing growing lamb		Fast growing lamb	
	Low faecal DM	High faecal DM	Low faecal DM	High faecal DM
Live weight (kg)	25		25	
Liveweight gain (g/d)	100		330	
Energy requirement (MJME/d)	7.62		15.1	
Feed intake (g DM/d)	692		1,376	
Faeces produced (g DM/d)	173		344	
Faecal DM (%)	15	30	15	30
Fresh faeces produced (g)	1154	577	2,293	1,146
Scenario A (Constant egg production)				
Total egg production (eggs/d)	1,000,000	1,000,000	1,000,000	1,000,000
Faecal egg count (eggs/g)	867	1,733	436	872
Scenario B (Constant faecal egg count)				
Total egg production (eggs/d)	576,934	288,467	1,146,292	573,146
Faecal egg count (eggs/g)	500	500	500	500

in faecal moisture, such as through scouring due to inflammatory components of the immune response (Colditz 2008), can affect FEC with no change in the total number of eggs excreted. This is a simple concept, but one that is not commonly considered when FEC results are evaluated, either in commercial situations or even, disappointingly, in research articles by experts in the field. These effects on either the resultant FEC or the interpretation of a FEC result, can be considerable as indicated by the calculations given in Table 1. The ubiquitous reduction in voluntary feed intake as a result of infection can vary even in subclinical infections between 10% and 90% (Van Houtert & Sykes 1996) and will concentrate numbers of eggs per gram of faeces. FEC may provide a useful indicator of presence of infection, but begs the question – is the high FEC of a poor performing individual the cause or consequence of reduced performance? Other clinical observations are needed. Examples of the influence of faecal dilution on the interpretation of FEC are present in several scientific studies. Alvarez et al. (2008) observed beneficial effects on FEC of feeding sainfoin hay rather than grass but a 30% lower DM consumption of grass than of sainfoin allowed them to conclude that total egg output was not different. In a similar vein, Niezen et al. (1998) reported an approximate halving of FEC in lambs grazing lotus compared with ryegrass of approximately 1,600epg compared with 3,000 epg; a difference which can be almost completely explained by respective DM intakes required to enable growth rates of 193 g/d on lotus and 35.5 g/d on ryegrass. In both these examples reliance on FEC alone may provide a false indication of any anti-parasitic properties of the plant sources consumed.

Regulation of egg production

In the absence of any other information, even a count of total nematode egg output in faeces calculated as FEC x faecal DM, may provide little indication of numbers or mass of nematode population in the host. This is particularly the case in mixed field infections in temperate and subtropical environments as female fecundity varies considerably between nematode species. *Haemonchus contortus* consistently produces between 4,000 and 10,000 eggs per female per day (Gordon 1967; Coyne 1991; Mupeyo et al. 2011) whereas *Trichostrongylus* spp produce just a few hundred (Gordon 1967; Coyne 1991). In a mixed infection, Mupeyo et al. (2011) reported mean *T. colubriformis* egg production of 904 and 930 eggs per female per day while mean egg production for *Teladorsagia circumcincta* was 254 and 267 eggs per female per day for lambs consuming lucerne and willow, respectively. In monospecific infections the low egg production of *T. circumcincta* females has been confirmed to be consistently below 350 eggs per female per day (Stear & Bishop 1999; Valderrabano et al. 2002; Kidane et al. 2009). These differences in fecundity mean that interpretation of nematode egg counts is heavily reliant on knowledge of species composition. Given the cost and specialist skills required for species differentiation, this is rarely attempted.

Even with knowledge of the composition of the nematode species present there are further

complexities that impair the ability to accurately gauge the number of worms within the host using FEC. Although there are instances in which FEC has been shown to be largely indicative of worm burden (Douch et al. 1984), there are infra-population mechanisms that regulate female worm fecundity and are dependent on the nematode species. These seem to be limited for *H. contortus* as both FEC and total egg output increase linearly with both the number and mass of worms (LeJambre et al. 1971; Coadwell & Ward 1982). For *T. colubriformis* things are less clear as FEC is often poorly correlated with adult worm burden (Steel et al. 1980; Sykes et al. 1988; Gruner et al. 2004). The situation with *T. circumcincta* appears to be more extreme since strong nematode density-dependent effects on female worm length and fecundity occur. A convex relationship between worm number and FEC has been shown with a peak FEC of 277 epg predicted to occur at a burden of just 2,167 adult worms and FEC thereafter declining as the worm burden increases (Bishop & Stear 2000). Support for this phenomenon is commonly observed in studies where graded levels of *T. circumcincta* infections have been given to lambs. In a study by Symons et al. (1981) FECs between 4 to 8 weeks of infection were consistently four to five fold greater in animals receiving only 1,200 or 12,000 larvae per week compared with their counterparts challenged with 120,000 larvae per week despite harbouring one fifth of the number of adult worms eight-weeks post-infection. Similarly, Sykes et al. (1988) reported a consistently greater FEC in lambs challenged with 2,000 L3 *T. circumcincta* larvae per day than their contemporaries receiving either 1,000 or 4,000 larvae per day despite the greater dose rate resulting in the greatest worm burden after 12 weeks of infection, while Kidane et al. (2009) reported greater egg excretion in animals receiving a challenge of 1,000 L3 *T. circumcincta* larvae per day compared with their contemporaries receiving 10,000 L3 per day. Although the exact mechanisms that drive this phenomenon are still unknown, the infra-population regulation of worm length and fecundity that is commonly observed for *T. circumcincta* results in the number of eggs produced providing no reliable indication of the number of worms present in the host. This is pertinent in a New Zealand context as *T. circumcincta* is reported to constitute up to 56% of the nematode population on South Island farms (Herve et al. 2003).

The association between worm burden and FEC can also exhibit temporal changes, which may reflect the stage of immune development of the host. This adds another level of complexity as immunoglobulin A (IgA) mediated effects on both female worm length and fecundity (Stear et al. 1995), which appear to be more pronounced in infections with *T. circumcincta* than with *T. colubriformis* (Kemper et al. 2010), mean that the stage of development of the immune response is likely to affect FEC and/or egg output. As such, an animal with an immature immune response and low nematode burden may conceivably produce as many eggs as an animal with a more mature immune response harbouring more, but shorter and less fecund female worms. As such, FEC is unlikely to provide a reliable indicator of the actual worm burden in animals that are older than four months of age and, thus, can be expected to have some degree of immune development.

Host responses

It has been accepted dogma that an animal harbouring a large nematode burden and exhibiting a high FEC must have compromised performance. There is evidence that this may not necessarily be the case. Genetic selection studies in New Zealand have consistently shown lines of animals selected for resilience that is the ability to maintain performance despite continued larval challenge or high FEC, to have greater productivity than their resistant counterparts who have the ability maintain low FEC, despite the former exhibiting greater FEC (Morris et al. 1997; Morris et al. 2000; Morris et al. 2005). In addition, animals selected for either fleece weight, liveweight gain or using a general productivity index have shown greater FEC than their randomly bred counterparts (McEwan et al. 1992). This presumably reflects an apparent trade-off between nutrients for the immune response and productive functions (Coop & Kyriazakis 1999; Greer 2008). In agreement with this concept, immune suppression studies with *T. circumcincta* and *T. colubriformis* have shown nearly all of the direct cost of infection, including loss of both appetite and performance, and increased faecal scouring, can be attributed to components of the immune response associated with the acquisition of immunity (Greer et al. 2005; Greer et al. 2008). While the same is unlikely to apply to *H. contortus* infections, these results allow the suggestion that the normal relationship of these temperate nematodes with the host tends towards commensal unless the host becomes hypersensitive, or the antigenic challenge is above a tolerance threshold.

The capacity to respond immunologically to a nematode infection appears, at least in part, to be governed by the relative maturity of the host as indicated by failure to regulate FEC in Merino lambs that were less than 23 kg in weight at the time of primary exposure to *T. colubriformis* (McClure & Emery 2007). As such, hypo-responsive animals that are not sufficiently mature or that have not received the level of antigenic stimulation required to initiate an immune response would not be expected to incur a production penalty from infection with these temperate nematode species. This is supported by a lack of effect of *T. circumcincta* infection on the performance of very young lambs between six and 12 weeks of age, despite relatively high FEC and worm burdens (Iposu et al. 2008). Moreover, the timing at which an immune response is invoked is critical to

when such impacts on animal performance are observed. This can help explain the productivity differences reported between resistant and resilient animals as the former can be expected to have a lower antigenic threshold which invokes an immune response, and its associated costs, at a younger age (Greer 2008). Ultimately, this means that a high FEC in a resilient or immunologically immature animal does not necessarily mean that the individual is currently suffering a loss in performance from infection. Similarly, animals undergoing the acquisition of immunity may exhibit a low FEC but may, in fact, have compromised performance.

Implications

The implications of the potential impact of faecal volume, infra-population dynamics and host responses on the interpretation of FEC are very much dependent on the intended use of this information. In many farm situations mob averages of FEC may be typically used to determine the need for anthelmintic intervention in order to minimise the production loss in the measured animals. However, there are many shortcomings to this approach, particularly as there is seldom any knowledge of the composition of nematode species present, or any awareness of the potential fecundity or infra-population regulation of the nematode species present. Consequently, it is difficult to justify advice to farmers to treat their animals based on an arbitrary threshold of a single FEC result. Further, given the pre-patent period of approximately three weeks and the impact of incoming larvae on animal performance, treating based on FEC risks significant loss of productivity and, in the face of continued larval challenge, is unlikely to restore other than a fraction of lost productivity (Coop et al. 1982).

One common use of FEC on-farm is the determination of the efficacy of anthelmintic treatments with the use of a FECRT. Even if the species composition is known, given the density-dependent effects on female egg production for *T. circumcincta,* these results may be misleading if large populations of this species are present, unless a complete reduction in FEC is observed. Such concerns are not unique to livestock, with the potential impact of density dependant fecundity mechanisms highlighted as a major constraint to the use of FECRT to determine the efficacy of anthelmintic treatment in human hookworm infections (Kotze & Kopp 2008). In addition, current FECRT protocols (Coles et al. 2006) do not take into account faecal volume which can be expected to change due to the rapid restoration of feed intake of parasitized animals following anthelmintic treatment (Kyriazakis et al. 1996). The consequences are likely to be an overestimate of the true efficacy due to greater dilution of the nematode eggs in faecal material.

Unfortunately, there are relatively few alternatives to FECRT for the determination of anthelmintic resistance status. Controlled efficacy tests, in which animals are slaughtered and the worm population speciated and enumerated may be too expensive to become routine. In comparison, *in vitro* tests, such as larval migration inhibition test, are relatively inexpensive but suffer from considerable variation between laboratories (Demeler et al. 2010). As such, there are likely to be few on-farm alternatives to FECRT until the molecular diagnosis of anthelmintic resistance becomes commercially available.

Future direction

The conclusion that must be drawn is that FEC on its own can reliably provide, at best, an indicator that nematodes are present. Even then, it is not always clear if an animal is actually suffering performance loss from the infection. Ultimately, nematodiasis is a problem of animal production and, as such, the most appropriate measure of the need for treatment must be the actual performance of the infected animals, irrespective of their FEC or perceived worm burden. Are we willing to relax our reliance on FEC as a measure of parasitism and instead concentrate on delivering nematode control strategies that are sensitive to the actual impact of the infection on the host? Such examples currently exist in the form of targeted selective treatment regimes in which lambs receive anthelmintic based on the level of pathogenicity caused by the nematode infection, either in terms of anaemia in the case of *H. contortus* (Van Wyk & Bath 2002) or on the ability to reach acceptable growth targets, such as the Happy Factor® targeted selective treatment regime as described by (Greer et al. 2009).

The Happy Factor® system uses estimates of the efficiency of energy utilisation, once non-parasite factors that affect growth such as feed availability and quality and the environment are taken into account, to predict liveweight gain targets for an individual. Any animal that fails to reach its target growth rate is then treated with anthelmintic. This regime has been evaluated in a continuing field study by Scottish researchers for the past five years in which it is compared with the anthelmintic regimes of a conventional monthly whole-flock treatment and a whole flock treatment based on a combination of the appearance of clinical signs of scouring and high FEC (Kenyon et al. 2011). In this study, animals in the targeted selective treatment regime maintained the same growth rates as their monthly treated counterparts despite a 55% reduction in the number of treatments. By comparison, animals in the regime of whole flock treatments administered only when FEC were high suffered a 9% reduction in growth with anthelmintic use reduced by 65%. Interestingly, despite the reduced total anthelmintic input in the whole flock regime based on FEC, the efficacy in this group of anthelmintic treatment calculated by a

FECRT, had declined to 82% by Year 5 compared with mean efficacies of 66% and 95% in the monthly whole-flock and targeted selective treatment regimes, respectively. However, some caution must be applied to the calculated efficacies given the dominance of *T. circumcincta* in this environment. While the strategy of targeting anthelmintic to individuals based on performance in this Scottish field study was initially developed with the aim of providing greater levels of refugia. The apparent success of this regime is arguably a consequence of providing measures that complement the complex biology of the host by nematode interaction. On the one hand, it is appreciated that monitoring of animal performance requires significantly greater labour input through, for example, weighing animals at regular intervals. This may be unrealistic in some situations, but on the other hand, recent developments in radio-frequency electronic identification and automated weighing and drafting systems greatly assist the practicality of such approaches. Further, information gathered during this process can be utilised to identify breeding stock that are able to perform well with minimal anthelmintic intervention, be they resilient or both resilient and resistant, assisting with de-polarising the views of New Zealand ram breeders surrounding the merits of selecting for either resilience or resistance based on FEC. This involves a step-change in how we view the usefulness of FEC, and indeed, the host by nematode interaction overall, with the ultimate goal of improving animal production while reducing the impact of parasitism in production animals. The question is; are we willing to face up to the limitations of FEC and abandon this as the primary measure of parasitism?

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