Towards the implementation of the “basket of options” approach to helminth parasite control of livestock: Emphasis on the tropics/subtropics

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Abstract

The virtual reliance on anthelmintic drugs alone to control internal parasites of livestock is inappropriate and ultimately unsustainable. In the tropics and subtropics, widespread and high levels of anthelmintic resistance, particularly in nematode parasites of small ruminants, is rife. But more to the point, many farmers in these regions of the world are resource poor and cannot afford, or are reluctant to purchase drugs that may also be of dubious quality. As it is with any intervention, the benefits must outweigh the costs. This is not only in terms of conventional parameters such as reduced mortality and increasing productivity (meat, milk, fibre and traction power) of livestock, but also within the broad framework of helminths of veterinary/human importance, the aim should be a positive impact on reducing the threat of helminth zoonoses. However, understanding the issues involved and education of the end-users (farmers) is of fundamental importance, before any internal parasite control program should be promoted.

Within the above context, we provide examples of how the “basket of options” approach could be adopted for the control of three quite disparate helminth problems in the tropics and subtropics, viz.: strongyle nematode infections of donkeys, the *Taenia solium* cysticercosis/taeniosis problem of pig and man and *Haemonchus contortus* infections in small ruminants. The “best practice” approaches can be defined as those “basket of options” that are practical, affordable, available and appropriate, whether to the commercial producer, or to the resource-poor farmer. Constraints that may restrict applying such options are accessibility to, and affordability of, suitable remedies and above all, the availability of information needed to make informed decisions in this regard.

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1. Introduction

The tropical/subtropical regions encompass a large proportion of the world that is accorded “developing nation” status by the United Nations, thus requiring special assistance (Anon., 1992). Within these regions, more than 20% of the world population (1.2 billion of 6 billion) live on less than US$ 1 per day (Thornton et al., 2002). This figure has grown to 46% in Sub-Saharan Africa and is higher than elsewhere in the world. Two-thirds (454) of the 678 million rural poor keep livestock. Whilst equids (donkeys and horses) are principally kept for draught purposes, approximately 200 million of the rural poor depend on goats, sheep and pigs as assets, as sources of income, and for family nutrition. These animals are found throughout the tropics and subtropics in both humid and arid zones, and in production systems that vary from the transhumant in the mountainous and semi-arid regions of South Asia, the pastoral systems of Africa and Asia and the humid mixed crop-livestock systems of the Caribbean, Africa and Asia.

Recently, an exhaustive review commissioned by the UK Department for International Development (DFID), endorsed by major international donors of livestock research [World Health Organization (WHO), Office International des Epizooties (OIE), Food and Agriculture Organization (FAO)], and conducted by the International Livestock Research Institute (ILRI), concluded that helminth parasitism had the highest global index as an animal health constraint to the poor keepers of livestock throughout the world (Perry et al., 2002). One should bear in mind that these evaluations were done against a backdrop of the rapidly changing patterns of demand for livestock and livestock products in the developing world, which runs counter to the changing demographics of livestock in the developed countries. For example, between 1975 and 1999, cattle and sheep numbers substantially declined (~20% for each species) and pig numbers remained constant in the developed countries, whereas there was a 27%, 22%, 56% and 56% increase in cattle, sheep, goat and pig numbers, respectively, in the developing countries of the world (Schillhorn van Veen, 1999). Inevitably, the problems of parasites in livestock will become ever more pressing, particularly when increasing livestock numbers are linked with failure of anthelmintics (whether due to drug adulteration, development of resistance in parasites) that are overwhelmingly relied upon for their control, especially in small ruminants.

In relation to developing effective parasite control messages, and particularly paying heed to the concept of ‘sustainability’, we wish to consider three examples of parasite problems of livestock and how they impact on resource-poor communities of the world. We have chosen: firstly, equid parasites, particularly in relation to donkeys, because it is one aspect of veterinary parasitology that is neglected in the developing world; secondly, cysticercosis because of its zoonotic implications in these regions and; thirdly, Haemonchus contortus, as it is the most important nematode parasite of small ruminants in the tropics/sub-tropics.

2. Nematodes of equids

Whereas helminths in equids include nematodes, cestodes and trematodes, the widest diversity is the nematode species and the levels which inhabit the equine host are enormous. Most of the helminth species are nematodes, with 70 species of large and small strongyles (cyathostomins). Burdens of millions of nematodes are not uncommon in zebras (Krecek et al., 1987). The investigation by Perry et al. (2002) concluded that two of the top three pathogens in donkeys owned by the poor were helminths and trypanosomes, and the third was wounds/injuries. The challenge is to combat and to manage these parasites with sustainable and appropriate recommendations to the owners.

Donkeys and a few horses are extensively used for work, including transporting people, goods and water in Africa (Krecek et al., 1995; Starkey, 1997). Parasitic nematodes directly affect the health and production of hard-working, stressed equids, which, in turn, results in a reduction in their work output and ultimately in the income of the owner and the community. The socio-economic impact, multiparasitism, production and economics in domestic animals, particularly on production and draught (traction) animals in Africa, has received attention (Krecek et al., 1995; Zinsstag et al., 1998).

Worldwide, there are an estimated 44 million donkeys (Anon., 1997a). More than 96% of these are in the developing countries, where the number of
donkeys continues to increase. In contrast, in developed countries, the number of donkeys has fallen steadily by two-thirds in the last 50 years (Starkey, 1997). For every two or three people actively engaged in agriculture, often at subsistence level, one donkey is depended upon for work (Fielding, 1991). In contrast, the total number of horses in Africa is estimated to be 500,000, compared to 50,000,000 worldwide. Most horses in Africa are used for recreation rather than work.

The challenge now facing research and extension personnel working with owners of equids in Africa, is to develop a series of “best practice, basket of options” that combine a variety of management approaches to restore and maintain good health of these animals (Krecek, 2004). This necessitates that these researchers work in the developing communities to assist the resource-poor farmer with his/her work both in agricultural practices and transport of persons and goods.

2.1. Pasture hygiene

The pasture hygiene approach was designed for horses kept under intensive conditions in USA and UK, where constant re-infection problems occur (Herd, 1993). Twice weekly removal of excessive faeces provided superior nematode strongyle cyathostomin and ascarid control, as well as a 100% increase in grazing area, and freedom from drug-related problems. The cost of pasture sweeping or vacuuming may thus be offset by improved worm control, slower selection for anthelmintic resistance, and by the increased grazing area due to the elimination of ungrazed roughs around faecal deposits. This approach was of particular value in controlling the unique problems of weanling and yearling horses under intensive grazing conditions in the USA (Herd, 1986; Herd and Gabel, 1990).

Krecek and Guthrie (1999) report that on stud farms in South Africa, thoroughbreds are bred for the recreational and racing industry. The routine management systems on these farms include removal of faeces once, or twice, every 2 months. This practice results in the reduction of nematode egg counts to less than 300 eggs per gram (epg). Additionally, these counts are augmented by faecal cultures to test for the presence of large strongyle larvae. Treatments are not recommended for faecal egg counts that are below 300 epg (Krecek et al., 1994). Another example in Africa where faecal removal can potentially affect nematode levels is on farms that maintain valuable antelope (sable valued at US$ 6000 each), and where H. contortus poses a continual threat to young animals. An evaluation of the efficacy of lowering worm levels by manual removal of faeces, compared to that of a mechanical broom, is presently under investigation on such farms (R. Els, R.C. Krecek and R. Burroughs, unpublished observations). The question of economics and productivity increases should also be considered in this management system when determining the most cost effective and practical method of breaking the life cycle of helminths.

The life cycle of parasites is interrupted when faeces is removed, or collected to use for fuel, building material and for composting (Krecek and Guthrie, 1999). Faeces from donkeys in Ethiopia, Zimbabwe, South Africa and many other countries are often collected and sold for fuel, bartered for vegetables and destined for compost. In Ethiopia the poorest of the poor sell a bag of donkey faeces for approximately US$ 1, which is burned for fuel (R.C. Krecek, unpublished results). Such income is considerable for these donkey owners.

2.2. Changes in management

Various management systems of working donkeys, which affect the intensity of parasitic helminth infections, were studied in a long-term project in several resource-poor communities of the North-West Province in South Africa (Wells et al., 1998b). These systems included zero grazing, free-ranging on communal grazing, communal grazing with winter supplementary feeding and grazing on the owner’s land. In some of these husbandry systems, the animals were kraaled (or corralled) at night or for short periods before harnessing for work, which allowed faeces to accumulate in a small area, which facilitated collection. In summary, the donkeys which do have access to better food resources have lower strongyle egg counts than donkeys on limited grazing (Wells et al., 1998b).

2.3. A place for anthelmintics?

In Africa, working domestic equids are most often used in rural and resource-limited communities. These
communities embrace a wide range of farming and management systems in which the control of disease agents, such as cyathostomins, has not yet been well tested. For example, for many of these owners the use of anthelmintics is constrained by both the cost and their availability. The price of a donkey is about US$ 30, and the wholesale cost of a single dose of a de-wormer effective against the histotrophic stages of helminths in South Africa is US$ 15. In addition, the agricultural co-operatives, or other sources from where de-worming products are available, are often long distances (i.e. 40 km) away from the owners and therefore difficult to access. Such a situation calls for alternative interventions for helminth control that are cost effective, appropriate and acceptable to owners.

Krecek et al. (1994) compared the effects of conventional and selective antiparasitic treatments on nematode parasites of horses from two management systems in South Africa. The study showed that selective treatment resulted in considerable savings and the advantage of the avoidance of further anthelmintic resistance development. Duncan and Love (1991) were the first to report on this alternative strategy of controlling strongyles in horses in the UK. Both the large size of the horse (e.g. 400 kg) and relatively high cost of the anthelmintic encourages this approach among horse owners. Although the donkeys are smaller (averaging 150 kg) and therefore anthelmintics would be less costly, limited facilities are available to the large majority of these owners, and therefore the needed laboratory tests for their animals before deciding on the selective chemotherapy option are not available (Krecek and Guthrie, 1999).

To verify the effect of management systems on nematode parasite levels on working donkeys, studies were undertaken in Gauteng Province, located in the summer rainfall region of South Africa (Wells et al., 1998b). A single strategically scheduled pre-winter moxidectin treatment with monthly removal of faeces resulted in the lowest faecal egg count in these donkeys, compared with other treatment groups and untreated animals (Matthee et al., 2002a,b).

However, the inescapable fact is that even when anthelmintics are available, owners in these resource-limited communities can often not afford de-wormers, or do not consider their use a priority, when compared to other herd management issues, such as stock theft or visible disease agents such as ticks (Wells et al., 1998a,b). Owners could be taught to use body condition scoring as an indicator of the health, or the nutrition status of their animals. It is expected that the use of body condition scores together with appropriate management interventions (i.e. removal of faeces) will result in more effective nematode control.

There is a need to understand the owners’ perceptions concerning the role of their equids and the relevant priorities of their animal health issues if we are to make appropriate recommendations and expect them to be adopted by resource-poor communities. Our knowledge of the impact of worms and disease agents on working equids should allow us to develop effective, sustainable control strategies for these situations.

3. Taenia solium cysticercosis/taeniosis

problem of pig and man

_T. solium_ is a zoonotic disease afflicting the poor of developing countries, caused by the tapeworm being transmitted among humans, and between humans and pigs. Humans acquire taeniosis when eating raw, or undercooked, pork contaminated with cysticerci, the larval form of _T. solium_. When ingested, the cysticerci establish as adult tapeworms in human intestines and produce eggs that are passed with faeces. Eggs can infect humans and pigs when ingested following direct contact with infected faecal matter, or by indirect contamination of water or food. Ingestion of eggs results in larvae migrating throughout pig and human tissues and eventually forming cysts. Human neurocysticercosis (NCC) occurs when the cysts develop in the brain (Mafojane et al., 2003). This leads to blindness, epilepsy, madness and death. NCC is a common, but preventable cause of epilepsy especially in developing countries. The social consequences of NCC include stigmatization, incapacitation and decreased work productivity (Phiri et al., 2003). NCC can also occur in individuals that do not raise pigs or consume pork.

3.1. Is eradication of _T. solium_ cysticercosis/taeniosis realistic?

This disease is potentially eradicable, however, there are few documented examples in which...
eradication has been achieved through active intervention (Schantz, 1999). Theoretically, there are several characteristics of the parasite which appear to make it vulnerable to eradication:

(1) The life cycle requires humans as definitive hosts.
(2) Tapeworm infections in humans are the only source of infection for pigs, the natural intermediate hosts.
(3) Swine herds can be managed. This must include a combination of confinement of pigs, and of humans defecating where the excrement is not available to pigs, to successfully break the life cycle. If humans use pit toilets, which are not available to pigs, this would also be a significant step towards eradication.
(4) No reservoirs for infection exist in wildlife.
(5) Practical methods of surveillance now exist for cysticercosis in pigs (visual inspection of tongues) and humans (antibody assay) and taeniosis in humans (coproantigen assay).
(6) Technology for intervention is available in the form of safe and effective drugs for mass chemotherapy of taeniosis in humans and cysticercosis in swine (Schantz, 1999).

The factors that Schantz (1999) considers to be most promising in the elimination of T. solium, are improvements such as general sanitation and economic status, the introduction of indoor pig husbandry and rigorous meat inspection. In Mexico, the approach to eradicating this disease has progressed through three steps (Sarti, 2002). The first step was to estimate the disease prevalence, which was conducted during the 1970s. The next step took place in the 1980s when the risk factors were determined. Finally, in the 1990s interventions of control were developed.

3.2. Progress towards control, based on integration

Two strategies for the control of T. solium in the last decade included mass praziquantel treatment and health education (Sarti et al., 1997; Sarti, 2002). Both measures were applied to three rural communities of Mexico with similar social, economic and cultural characteristics. Community ‘A’ received mass praziquantel treatment, community ‘B’ received health education and community ‘C’ received both mass praziquantel treatment and health education. Demographic, epidemiological, clinical, sanitary and sociological data from 98% of the inhabitants were obtained. Evaluations were performed 6 and 42 months after intervention. Prevalence and incidence rates of human taeniosis were measured by the frequency of Taenia coproantigens and Taenia eggs in faeces. Swine cysticercosis was measured by lingual examination and the presence of serum antibodies. Changes in knowledge, attitudes and practices in the communities were evaluated by questionnaires and interviews. Praziquantel treatment reduced rates of taeniosis by 66%. Treatment alone had no impact on swine cysticercosis. A 66–77% decrease in swine cysticercosis was observed in communities where health education was provided. Evaluation of long-term outcome revealed a reduction of 48% of taeniosis in community ‘B’. Health education had a two-fold effect. Improved sanitary practices and curtailing free-ranging pigs led to a decrease in the frequency of porcine cysticercosis and ultimately human taeniosis. Results of these studies suggested that health educational programmes are effective for T. solium control.

Mexico leads Africa in combating problems associated with T. solium, in so far as workers in Africa are now only establishing the disease prevalence and associated risk factors. Mafojane et al. (2003) highlighted the need for studies to be undertaken, including those that are community based, to establish the levels of human and porcine cysticercosis in Africa. In response to this need, the first community based study on the epidemiology of porcine cysticercosis in South Africa was carried out in the Eastern Cape, in the former homelands of the Transkei and Ciskei (Krecek et al., 2004). This study was funded by the United States Agency for International Development (USAID) in South Africa and was carried out in endemic areas where the highest levels of juvenile NCC have been reported. The objectives were: firstly to compare lingual examination in pigs with three biotechnological diagnostic tests (both for the detection of antibody and antigen), to determine the presence of T. solium cysticerci and therefore the prevalence of disease; and secondly, with a questionnaire to gain a better understanding of practices of pig husbandry, pork consumption, sanitation and
people’s knowledge of this parasite. The study included 21 villages in the endemic areas and the results provide essential information to propose potential interventions for prevention and management relevant to these communities (Krecek et al., 2004). Prevalence of porcine cysticercosis for this study ranged from 41 to 55% based on the serodiagnostic tests, and an interview survey showed a positive correlation between the prevalence of disease and the number of individuals seeking information about the disease, in these villages (R.C. Krecek, unpublished data).

In September 2004, a meeting was held in Bellagio, Italy, to establish a “Global Program for Combating Cysticercosis”. An action plan was outlined which focused on: advocacy, surveillance, prevention and control, research, training, resource mobilization and organisation/networking. Two actions which have been delivered since the workshop: the assessment of the disease burden in several developing countries and the production of an educational CD based on the first training and an awareness workshop on the human disease held in South Africa in June 2004.

Some of the “basket of options” applicable to the control of this disease include deworming pigs, deworming humans, economic development, health education campaigns, swine husbandry, meat inspection, pig vaccination and hygiene.

4. H. contortus in sheep and goats

The Perry report (Perry et al., 2002) concluded that H. contortus was singly the most important of all the gastrointestinal nematodes that constrain the survival and productivity of sheep and goats owned by the rural poor in the developing world. This haematophagous parasite is infamous throughout the humid tropics/subtropics, being responsible for acute disease outbreaks with high level of mortalities, particularly in young animals. In monetary terms alone, for example, in Kenya (Anon., 1999) and South Africa (I. Horak, pers. comm.), annual losses due to this parasite are between US$ 26 million and US$ 45 million. Costs associated with control of this parasite in India have also been estimated to be US$ 103 million (McLeod, 2004). These financial losses do not estimate the effect of the uncertainty that disease imposes on livestock keepers and which contributes so much to poverty (Wood, 2003).

It is probably the only nematode parasite of sheep and goats that can be accurately diagnosed without the aid of laboratory testing. Signs of acute anaemia are obvious. Past history and discounting other less common conditions causing anaemia (e.g. fasciolosis, theileriosis, etc.), will strongly suggest clinical haemonchosis. On a worm-for-worm basis, H. contortus is considered to be the most pathogenic parasite of small ruminants. It has very high biotic potential and at times when transmission of this parasite is favoured (warm and moist), losses can occur in all classes of animals. Although it occurs in mixed infections with other nematode parasites, it invariably dominates the faecal worm egg counts and often approaches 90% of worm egg contamination on pastures in the humid tropics/subtropics. H. contortus is also prominent amongst the reports of anthelmintic resistance that has emerged in all countries of the world that produce small ruminants (Kaplan, 2004). In Africa, anthelmintic resistance has been reported in both the commercial and resource-poor farming sectors in at least 13 countries and, amongst the commercial farms in South Africa, the situation is considered the worst in the world, with high levels of resistance in H. contortus to all classes of anthelmintics (Anon., 2001). The use of anthelmintics is further limited by poorly formulated or adulterated products in markets accessed by small holder farming communities (Monteiro et al., 1998), which apparently is a particularly common problem throughout Africa. Elsewhere in the humid regions of the developing world, anthelmintic resistance in H. contortus appears to be less severe than on the African continent, although there are reports in Malaysia where total chemotherapeutic failure to control this parasite occurs on both sheep and goat government farms that are used as source of stock that are provided to small holder farmers (Chandrawathani et al., 2003a, 2004a). Also severe problems with anthelmintic resistance were reported approximately a decade ago amongst sheep farms in countries of southern Latin America (1996; Argentina: Eddi et al., 1996; Brazil: Echevarria et al., 1996; Paraguay: Maciel et al., 1996; Uruguay: Nari et al., 1996).

The apparently lower level of anthelmintic resistance in H. contortus in other developing countries of
the humid tropics/subtropics, could be due to greater degree of zero grazing and/or diversification (esp. Asia), less investigation into the prevalence of anthelmintic resistance, or simply that the rural poor do not de-worm their small stock. Although parasitologists, economists or animal scientists from the developed countries of the world may find the reasons for de-worming sheep and goats in the humid tropics to be compelling, the rural poor in these regions are not secure enough to make the investment in anthelmintic drugs, either because they have higher priorities for cash-in-hand, they are uncertain that their animals will survive, or they have little confidence in when and how their animals will be sold, and at a price which will re-coup their investment in drugs (Sani and Gray, 2004).

4.1. H. contortus control by grazing management

In theory at least, it could be argued that control of H. contortus (+ other gastrointestinal (GI) nematodes) of small ruminants in the humid tropics/subtropics should be relatively straightforward and simple. After all, studies have shown that although development of eggs to infective larvae is very rapid (3–4 days), their survival on pastures is very short (4–6 weeks) (Banks et al., 1990; Barger et al., 1994; Sani and Chandrawathani, 1996). That is, provided that humidity remains continuously high in the pasture microenvironment and infective larvae are contained in water films, where they remain active and thus rapidly exhaust their food reserves. However, in situations where drying occurs, then the infective larvae desiccate, become inactive, but remain viable for longer periods of time.

Thus, simply ensuring that sheep and goats do not graze on the same pastures for more than a couple of days, thereby preventing auto-infection, returning after approximately 1 month, affords excellent control of H. contortus by this strategy alone. This theory has been put into practice (Barger et al., 1994; Sani and Chandrawathani, 1996), whereby short-term rotational grazing strategies that strictly follow a management regimen of 3.5 days grazing and 4–6 weeks spelling, showed excellent parasite control, compared with the need to dose set-stocked animals every 3–4 weeks. For small holder farmers who have neither the number of animals nor pasture, the same principals apply for managing individual tethered animals, roadsides used for grazing, or rice padi bunds (Anon., 2000).

Unfortunately these simple and practical grazing management systems tend to be abandoned, not because they ultimately fail, but because they require some effort, forward planning, and losses avoided are impossible to quantify if the farmer cannot see what happens if he does not manage his stock in this way. On the large, often government owned, small ruminant farms in the humid tropics there is still a depressing tendency for them to continue the practice of over-grazing, set stocking and suppressive de-worming of stock. But inevitably these operations will be abandoned, even if it is for economic reasons alone. Ultimately, total anthelmintic failure will be reached. At this stage stock losses exceeding 25% of the total flock per year, attributed primarily to H. contortus are commonplace, despite whatever de-worming treatments are given (Chandrawathani et al., 2004a).

4.2. H. contortus control by direct intervention

By this we mean treating animals—generally regarded as synonymous with anthelmintic use. The literature is replete with extensive reviews of the ways, means, mechanisms, etc. of anthelmintics/anthelmintic resistance in H. contortus that we do not wish to ‘plough over well-tilled ground’ [readers interested in these subjects should consult the Special Edition of Trends in Parasitology 2004, vol. 20, No. 10, for several reviews]. However new approaches in the use of existing anthelmintics, which are designed specifically for management of H. contortus in the face of high level of resistance, are worth mentioning in this review.

Firstly, is the FAMACHA system (Malan et al., 2001; Vatta et al., 2001, 2002), where the conjunctiva of individual sheep and goats is matched to a simple colour chart to grade the anaemia (a diagnostic feature of haemonchosis) to identify the worst affected animals for treatment. South African veterinary parasitologists have successfully used this system to
slow the development of anthelmintic resistant *H. contortus* in commercial sheep flocks and the system is being trialled in many countries in the tropics/subtropics—with commercial and small holder farmers alike. The method also serves as a tool to identify sheep that repeatedly require anthelmintic treatment so that such individuals may be culled from the flock. The system was originally developed for use in flocks where anaemia is only caused by *H. contortus*, but further work is now planned to examine the utility of FAMACHA in environments where trypanosomes and liver fluke (*Fasciola hepatica*), other important causes of anaemia in sheep and goats, are endemic. FAMACHA also allows for treatment decisions to be made for the individual animal based on the anaemia-status of the whole herd/flock. By comparing the number of anaemic to non-anaemic animals over time, treatment decisions can be made for the individual animal to prevent the risk of an impending outbreak of haemonchosis, as well as reduce the selection for anthelmintic resistance.

Secondly, in situations where effective anthelmintic treatment options have been severely compromised by the development of resistance, the use of combination drug therapy (including narrow spectrum as well as broad spectrum anthelmintics) at very restricted and very specific times to maximise effectiveness, is being promoted (Dobson et al., 2001; Leathwick et al., 2001). The objective is to achieve very high levels of efficacy (>99.9%), but at the same time ensure that unselected sub-populations of parasites exist (‘refugia’) on the farm or flock, by not treating ‘low risk’ animals.

4.3. *H. contortus* control by seeding, feeding, or breeding

Seeding the faecal environment with nematophagous fungi, specifically *Duddingtonia flagrans*, to control *H. contortus* in the tropics/subtropics has moved from experimental pen studies (Chandrawathani et al., 2002; Pena et al., 2002) to field investigations (Chandrawathani et al., 2003b, 2004b). This work concentrated on supplying the fungal spores in a daily feed ration (Chandrawathani et al., 2002; Pena et al., 2002), or incorporation of the spores into small feed blocks (Chandrawathani et al., 2003b, 2004b). Particularly promising were the results from the latter studies in Malaysia, where the combination of *D. flagrans* with short-term rotational grazing, showed that pastures were consistently less infective with *H. contortus* and young sheep grew significantly better, than those that were rotationally grazed alone (Chandrawathani et al., 2004b). However, continuous daily feeding of *D. flagrans* spores would not be economically viable, so further ‘fine tuning’ of the duration spore administration during rotation cycles needs to be investigated, and certainly *D. flagrans* administration alone (without any other measure of worm control) could not be expected to maintain satisfactory control of *H. contortus*. Although the research and development (R&D) agenda of biological control of nematode parasites of livestock is driven primarily by government and private sector activities in the industrial countries (see: http://www.wormcops.dk/), veterinary parasitologists and livestock extension specialists from Asian, Pacific Island, Central and South American countries, who attended two recent workshops (Anon., 1997b, 2002), consider that the concept of biological control of nematode parasites of livestock to be appropriate for their countries.

With regards to feeding, it is well known that animals that are better nourished are able to withstand the effects of worm infection than those on a low plane of nutrition (Coop and Kyriazakis, 1999). Smallholder farmers generally strive to provide supplement to their animals, however often it is not an option available to the resource-poor (Sani and Gray, 2004). Tree forages can be particularly beneficial as they reduce the intake of infective larvae, improve the nutritional status, and may possibly have de-worming properties. In this context, ethnoveterinary plant preparations have been used for eons in many countries of the developing world by resource-poor farmers. Various plant products have been described to be active against a range of helminth parasites in small ruminants. However, there is only anecdotal evidence on the usage and efficacy of plant preparations for helminth control in ruminants. Some plant products have been applied as a single plant extract, or as a combination of plants, on one occasion, or dosed to the animal on a several occasions. However, there have been very few instances where the anthelmintic activity of such products has been verified, particularly in naturally infected sheep under controlled field conditions (Githiori, 2004).

Copper wire particle (COWP) capsules were developed to overcome copper deficiency in ruminants
grazing on mineral deficient and marginal grazing lands. Following dissolution in the rumen, the copper particles pass to the abomasum where they lodge in the mucosal folds and release ionic copper over an extended period of time. An additional important benefit of ultra-low dose copper therapy is on reducing certain parasite infections in grazing livestock. Research has shown that 2–5 g COWP capsules administered orally to sheep resulted in a high level anthelmintic effect against H. contortus, as well as extended protection (approximately 3 months) against incoming infection of this parasite (Bang et al., 1990; Reid, 1995). This is supported by positive results in the tropical countries of Brazil (Nyman, 2000) and Mexico (Canto-Dorantes et al., 2004). Moreover, a recent study in a semi-arid region of Kenya, showed that East African goats which received 2 g COWP capsules had 75% less H. contortus eggs and worms than controls, for up to 8 weeks following treatment (Waruiru et al., 2004). COWP are merely small pieces of copper oxide wire contained within a gelatin capsule. Such a simple, generic product lends itself to local manufacture and to low capital input entrepreneurial activities in the developing world.

Breeding to obtain livestock that are genetically resistant to nematode infection is the ultimate in sustainable parasite control (Baker, 1995, 1998). In this regard, it is being increasingly recognised that the animal genetic resources of the tropics/subtropics are likely to provide the foundation to sustainable and environmentally sound solutions to the plethora of animal disease problems confronting this region of the world. Although the tropically adapted breeds lack the productivity and performance capacity of their counterparts in the more temperate climes, they possess the great advantage of being able to thrive in their environment and to tolerate, or resist, disease. Good examples of genetic resistance can be found across the wide spectrum of animal parasitic disease entities of the tropics; such as the resistance of Bos indicus cattle to the cattle tick, Boophilus microplus, trypanotolerance of the N’dama and West African Shorthorn cattle, nematode (specifically H. contortus) resistance in the East African Maasai, Florida and Louisiana Native, Barbados Blackbelly and the St. Croix breeds of sheep, and trematode resistance in Javanese thin-tailed sheep. Nevertheless, these examples merely represent those breeds that have been chosen for study in any detail. There is still a huge, untapped genetic resource awaiting investigation represented by the multiplicity of different livestock breeds found throughout the tropics/subtropics. These have evolved such characteristics based on the Darwinian principle of “survival of the fittest”, whereby the extreme selection pressure induced by the combination of environmental stress, malnutrition, more-or-less continuous and massive parasite challenge, often without any remedial treatment, has been imposed for many years.

There are numerous examples of failed livestock improvement projects in the tropics/subtropics, which were based on European breed imports. The assumption being that the introduction of high performance genotypes was the fastest route to success. This resulted in a large amount of indiscriminate cross-breeding, without any attempt to compare the exotic breeds or their crosses with indigenous breeds, although in some cases it has been extremely difficult to keep the exotic breeds alive and reproducing (Baker, 1996, 1998). Not only do the exotic breeds have reduced tolerance to disease and heat stress, greater nutrient maintenance requirements because of generally larger body frames, but in the case of sheep produce a definitely undesirable product in the wet tropics—namely wool. Unfortunately many countries in the humid tropics have their sheep industries based on the European breeds, which are not renowned for their high innate resistance to nematode parasites. Moreover, these breeds require regular shearing to dispose of the otherwise worthless fleece which predisposes the sheep to heat stress, dermatitis, fleece rot and myiasis (Ibrahim, 1996; Maciel et al., 1996; Manueli, 1997). Efforts are now being made to select sheep adapted to the humid tropics, based on the judicious infusion with British breeds but mainly on hair breeds that have evolved in the tropics, together with those capable of regularly shedding their fleece to obviate the necessity for shearing (P. Chandrawathani; P. Manueli, pers. comm.).

There is evidence that genetic variation in resistance to nematode infections within breeds (Gray et al., 1987) can be as great as that between breeds (Barger, 1989). It would seem sensible that, because of the natural evolution of breeds in the developing countries of the tropics/subtropics outlined above, breeding programs in these countries should concentrate on genetic
improvement of the local indigenous breeds. However, Baker (1995) added a note of caution in this approach as little is known of the genetic variation of these indigenous breeds, but it is likely to be greater than for those breeds of the developed countries. Whatever the outcome, it is clear that much more informed approaches to animal breeding in the tropics/subtropics needs to be implemented. Exploiting genetic resistance of livestock to disease in general, and to parasites in particular, represents the ultimate approach towards sustainable parasite control, especially for resource-poor farmers.

5. Conclusion

Regarding the control of helminth control of parasites in livestock, getting farmers to move from the simple (i.e. do nothing, or rely entirely on anthelmintics), to the complex (implementing the “basket of options” approach) has had very limited success to date—whether it has been in the developed or developing countries of the world (Waller, 1997a). The incentive must be obvious. In the more affluent countries with significant sheep and goat populations, the increasing threat of multiple high level anthelmintic resistance now looms large as the single most important issue confronting the long-term sustainability of these livestock industries (Waller, 1997b). Farmers are being encouraged to adopt integrated parasite control schemes where chemotherapy plays a much less dominant role, and by doing so accept that a degree of production loss in their flocks is preferable to the excessive exposure of worm populations to anthelmintics, with the inevitable increase in the levels of resistance (Besier and Love, 2003). Similar strong recommendations have also been made to the managers of government owned small ruminant breeding farms in the humid tropics that now have to cope with total broad spectrum anthelmintic failure (Chandrawathani et al., 2004).

For the rural poor small holder farmers in the tropics and subtropics, the incentives are different. Anthelmintic resistance is unlikely to be the problem, and the benefits of parasite control are often very difficult to quantify (Sani and Gray, 2004). However the opportunities for increasing animal production by simple, inexpensive and technologically appropriate parasite control schemes do have a place. But in the first instance it is important to identify those technology options to match the problems, capacity and resources of target communities, secondly to adapt these options (and their combinations), and thirdly to evaluate their impact on livestock keepers and their communities by measuring their effects on sheep and goat survival and production.

Nevertheless there have been recent successes in the transfer of technology to farmers and stimulating change in farming communities, in the developing world. These have been based on active participation of farmers in research and evaluation of technology options, such as the Livestock Farmer Field Schools (LFFS) for dairy cattle in Kenya (Sones et al., 2003) and for goats in South East Asia by ILRI and partners (Sani and Gray, 2004), and similar participatory initiatives by Farm Africa, Heifer International and CAPE (Catley and Mariner, 2002) in several countries of Africa. Also, there are activities currently underway in Eastern Africa which are focused on improving the well-being of resource-poor communities through simple cost-effective and appropriate technologies of parasite control in small ruminants (Anon., 2005).

These processes are complex and location specific and require long-term commitments by highly committed groups with sound contacts. The role of any research and development project focused on helminth control for the resource-poor owners of livestock in the tropics/subtropics is to engage such groups, using participatory methods and respond to their demands for technology options and information. By doing so, this will in turn train them in the technology options and methods to evaluate their effectiveness and provide complementary resources and supervision.

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