Aspects of Applied Biology 75, 2005
Pathways Out Of Poverty

Cheap and safe tsetse control for livestock production and mixed farming in Africa

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Summary

Trypanosomosis remains a widespread constraint on animal production, human health and agricultural livelihoods in rural Africa. Methods of tsetse control are reviewed and recent developments in bait technology are highlighted as a cost-effective and environmentally benign means of increasing agricultural production and improving food security. It is concluded that the restricted application of insecticide to cattle to suppress and eliminate local tsetse populations should be promoted as one of the key, farmer-based, disease control measures to complement, or as an alternative to, the prevailing widespread use of trypanocides.

Key words: Africa, tsetse, trypanosomosis, vector control, insecticide-treated cattle, bait technology, environmental assessment, comparative costs

Introduction

Widespread disease endemic to much of tropical Africa

Tsetse (*Glossina* spp.) are widespread in sub-Saharan Africa and are the primary vectors of animal and human trypanosomosis in the semi-arid, sub-humid and humid lowlands of 37 countries across the continent, with a potential distributional range of some 8.7 million km^2 (Rogers & Robinson, 2004). Whilst much is known about the biology and ecology of the vector and transmission of the disease, and a variety of control measures have been developed and demonstrated (Mulligan, 1970; Ford, 1971; Jordan, 1986; Leak, 1999; Budd, 1999–2002; Bourn *et al.*, 2001; Maudlin *et al.*, 2004) trypanosomosis is still a major constraint on animal production, human health and agricultural livelihoods in many parts of Africa (PATTEC, 2001; DFID-AHP, 2002; FAO, 2005; WHO, 2005).

Economic importance of trypanosomosis

The economic impacts of trypanosomosis in Africa are diverse and complex, with direct effects on animal production and human health, as well as indirect effects on settlement patterns, land use, draught power use, animal husbandry and farming. Quantifying these wide-ranging effects has proven to be difficult, but a considerable body of evidence has been gathered through numerous studies of specific situations (Swallow, 2000; Shaw, 2004). Aggregating from these results to a continental level is problematic because of general uncertainties about cattle numbers, infection rates and the extent of actual, as opposed to potential, tsetse infestation. However, direct aggregate losses due to animal trypanosomosis in the estimated 47 million cattle living in tsetse regions probably exceed the US$1.3 billion annually calculated by Kristjanson *et al*. (1999), which excluded losses from the reduced efficiency of draught oxen that can be substantial. To these estimates of direct losses need to be added expenditure on trypanocides, estimated at around US$30 million per annum for some 35 million doses (Holmes *et al.*, 2004).

With regard to human trypanosomosis, the World Health Organisation estimates that some 50,000 deaths occur annually from sleeping sickness, with some 300 000–500 000 people currently infected. The annual disease burden is put at 1.6 million disability-adjusted life years (WHO, 2005).

Pan-African Tsetse and Trypanosomosis Eradication Campaign

Funding of some US$80 million has recently been approved by the African Development Bank for the first phase of a Pan-African Tsetse and Trypanosomosis Eradication Campaign (PATTEC), as part of the African Union's New Partnership for Africa's Development (NEPAD) initiative. The first, six-year phase of the project aims to free some 13 million hectares from tsetse and trypanosomosis in two regions of West and East Africa, including parts of: Burkina Faso, Ghana and Mali; and Kenya, Ethiopia and Uganda (ADB, 2005). Whether or not tsetse and trypanosomosis will ever be eradicated from Africa, however, has been the subject of much discussion (DFID-AHP, 2002; Hargrove, 2003; DFID-AHP, 2004) and remains to be seen,

Tsetse control

Tsetse have been controlled or eliminated from extensive areas of Africa by widespread application of insecticide from the ground or the air (Allsopp & Hursey, 2004). These methods require careful environmental monitoring, to guard against adverse impacts, and implementation by government-funded agencies, since the cost, technical complexity and scale of operations are beyond the means of livestock keepers. However, with the reduction in government veterinary services over the past 20 years across Africa, together with privatisation and the introduction of cost-recovery for these services, few countries have been willing or able to implement large-scale tsetse control operations. Consequently, the use of trypanocides to cure or prevent the disease has become the mainstay of farmer-based trypanosomosis control across much of Africa today, although the sustainability of this method is threatened by drug resistance in some areas, particularly with prolonged, intensive use (Holmes *et al.*, 2004).

The past 20 years have also seen the development of baits (Vale & Torr, 2004), which livestock keepers can use to attract and kill tsetse with limited environmental impact. The most cost-effective method is for farmers to treat all their cattle with a pyrethroid, applied over the animal's whole body at about monthly intervals. To be effective, the technique must be applied over an area of at least several hundred square kilometres, necessitating participation by all livestock keepers over relatively large areas. This technique is, however, not without its problems. In particular, it is too costly for general adoption by poor farmers and there are concerns about its environmental impact. Widespread use of pyrethroids can have an adverse impact on the invertebrate dung fauna (Wardhaugh *et al.*, 1998; Vale *et al.*, 1999; Vale & Grant, 2002), which play an important role in maintaining soil fertility in mixed crop–livestock farming systems, and exacerbate tick-borne diseases (Eisler *et al.*, 2003).

A solution to this dilemma was suggested by the observation that tsetse feed preferentially on the legs and belly of larger/older cattle. By restricting the application of insecticides to these locations and to larger animals, the amount of insecticide required might be reduced with benefits not only to the farmer, but also for the environment.

This paper provides a synthesis of recent studies to improve the cost-effectiveness and assess the environmental impacts of insecticide-treated cattle (ITC) to control tsetse. The potential for its adoption by livestock keepers to complement, or as an alternative to, the use of trypanocides is emphasised.

Materials and Methods

Studies related to insecticide-treated cattle

Research to develop a more cost-effective regime for treating cattle was undertaken in Zimbabwe, Tanzania and South Africa.

Attractive hosts. To assess which cattle were particularly attractive to tsetse, the numbers of flies approaching (Torr *et al.*, 2005) and feeding on (Torr & Mangwiro, 2000) different types of cattle were compared. DNA markers were used to analyse the bloodmeals of tsetse attracted to groups of cattle (Torr *et al.*, 2001) and identify which individuals within a group were bitten most.

Feeding sites. To analyse feeding patterns on a host, the distribution and duration of tsetse feeds on various types of cattle were observed (Torr & Mangwiro, 2000; Schofield & Torr, 2002). Studies were made of *Glossina pallidipes*, *G. morsitans morsitans*, *G. brevipalpis* and *G. austeni*, these being the major vectors of animal trypanosomosis in East and southern Africa.

Restricted application of insecticides. The efficacy of treating only those regions of the body where most tsetse fed was assessed following the methods of Vale *et al.* (1999). Test animals were treated with commercial formulations of deltamethrin, supplied by Ecomark Zimbabwe Limited as either a 1% pour-on formulation (Spot-on), or a 5% suspension concentrate (Decatix) diluted to a concentration of 0.05 g L^{-1}. Applications were applied to: i) belly and legs only; ii) legs only; iii) front legs only; iv) lower (cannon+pastern) front legs only; and v) front pasterns only, representing respectively 20%, 10%, 5%, 2% and 1% of a standard whole body treatment of 1.8 L of diluted Decatix. Each treatment was replicated in the hot-wet and cool-dry seasons.

Environmental assessment

Treatment of cattle. Commercial formulations of SpotOn and Decatix were provided by EcoMark (Zimbabwe) Limited and applied as recommended: Decatix a 50 g L^{-1} suspension concentrate of deltamethrin, diluted with water to a concentration of 0.05 g L^{-1} as a cattle spray, or 0.0375 g L^{-1} as a dip. SpotOn a 10 g L^{-1} solution of deltamethrin in oil, as a pour-on applicable at 0.1 ml of formulation per 1 kg of body weight. SpotOn was applied along the line of the back, or on the flanks. Decatix, normally administered in a dip, was sprayed on the whole animal, or to the legs only.

Residue chemistry. Pyrethroid residues in cattle dung and soil were analysed by accredited laboratories in the UK and Zimbabwe. Both labs followed the same extraction and analytical procedures, with a g.l.c. detection limit of 0.005 parts per million (ppm). Residue concentrations in dung are reported as ppm (µg deltamethrin g fresh wet wt^{-1}) and in soil on a dry weight basis.

Acute toxicity of dung residues by bioassay. Laboratory and field bioassays of cattle dung toxicity employed dung beetles and muscoid larvae collected from dung beetle traps. Dung spiked with concentration ranges of various pyrethroid formulations was used to produce a 24-hour 50% lethal dose index for a range of abundant dung fauna, the most useful histerids and scarabs being: *Hister spp.; Copris amyntor* Harold; *Digitonthphagus gazella* Fabricius*; Onitis westermanni* Lansberg; *Sisyphus goryi* Harold; and the dipterous muscid larvae of *Musca lusoria* (Wiedemann). Full details of the bioassay technique and species are given in Vale *et al.* (1999).

Dung Dispersal. A gravimetric method for assessing the dispersal of dung pats into soil during wet and dry seasons was complemented by a second technique for elucidating the role of subterranean termites (*Microtermes* spp., Isoptera: Termitidae). Losses of uncontaminated dung were compared with those from dung pats spiked with SpotOn and Decatix *(loc.cit.)*.

Residue Pathways. Transport of bound deltamethrin residues from dung to soil was investigated by analysing soils for residues that were sampled below spiked dung. Dung was watered periodically to emulate wet season conditions where leaching of residues is a possible mechanism of dissipation (DFID-AHP-LPP, 2003).

Economic assessment

The multiplicity of approaches for dealing with trypanosomosis on a variety of scales with a range of technologies controlling either the vector or the disease itself, pose particular challenges to any attempt to analyse their comparative effectiveness in reducing disease incidence, as highlighted by McDermott & Coleman (2001). Comparing control costs is also difficult. Most estimates include the direct field costs, but the majority tend to exclude planning and organisational overheads, which vary from strategy to strategy (Shaw, 2003). The picture is further complicated when the control strategies being compared involve some that are applied on an ongoing annual basis and others that aim to eliminate the fly from defined areas, with or without barriers to prevent reinvasion. The economic methodology for dealing with these comparisons, however, is clear, simple and widely used. It involves projecting all costs for a given area over an extended period (generally 20 years), assigning a progressively lower weighting to future incomes and expenditures, relative to current incomes and expenditures, using a process known as "discounting" and then comparing the cost-effectiveness of the different approaches.

Results

Insecticide-treated cattle

Attractive hosts. Studies of the numbers of tsetse attracted to and feeding on individual cattle showed that in general larger cattle attracted more tsetse than smaller ones (Vale & Torr, 2005) and that a greater proportion of tsetse fed on older cattle (Torr & Mangwiro, 2000). The net effect being that a large ox is bitten ~10 times more by tsetse than a calf. Within herds, these differences are even more marked (Torr *et al.*, 2001), with ~75% of tsetse feeding from ~25% of the herd (Fig. 1).

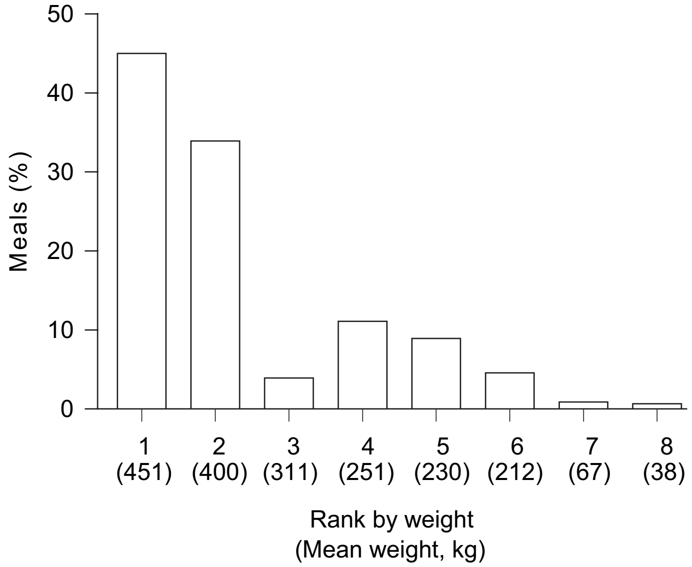

Fig. 1**.** Proportion of meals taken from cattle ranked by their weight. Data derived from pooled analyses of the feeding patterns of tsetse (*n*=460) attracted to five different herds of eight Mashona cattle. Mean weight of each rank is shown in brackets. (Data source: S Torr, unpublished).

Feeding sites. For all species and countries, >75% of tsetse fed on the legs or belly and >48% fed on the legs (Fig. 2).

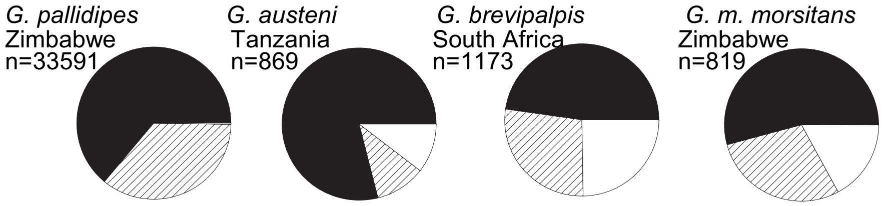

Fig. 2. Proportion of *Glossina* spp. observed landing or feeding on: the legs (black), belly (cross hatched), or other region (white) of cattle. (Data sources: G Vale & S Torr, Zimbabwe; V Kovacic & S Torr, Tanzania; J Esterhuizen, South Africa).

Restricted application of insecticides.

Limiting the area of an ox treated with insecticide reduced the effective life of the insecticide significantly. During the dry season, for instance, the belly+legs or legs-only treatments were effective for 15-20 and 10-15 days, respectively, compared to 20-25 days for the whole-body treatment (Fig. 3). More restricted applications (front legs, lower front legs, front pasterns) were effective for <6 days. The most cost-effective regime seemed to be treatment of the belly and legs of cattle at 2-3 week intervals, rather than the monthly interval recommended for whole body treatment. This restricted application regime halves the amount of insecticide used, while improving overall efficacy and is appropriate for all four species of tsetse.

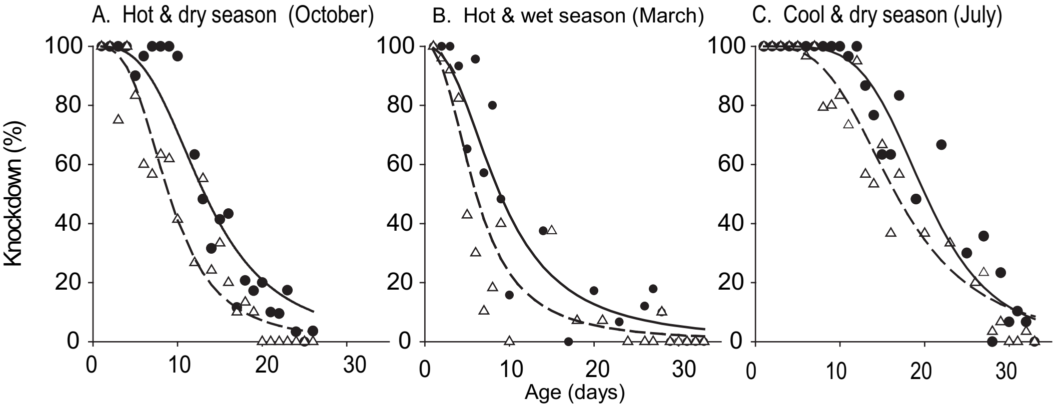

Fig. 3. Knock-down of wild, female *G. pallidipes* exposed to cattle treated with deltamethrin (0.005% Decatix spray) applied either to the whole body (solid circles), or with 20% of the standard dose applied to the legs and belly only (triangles). Knock-down was assessed for up to 35 days post-treatment, with each percentage knock-down being based on the observation of 30 tsetse. Curves fitted by logistic regression. Knock-down of tsetse exposed to untreated (control) cattle was < 1% (data not shown). (Data source: G Vale & S Torr, unpublished).

Environmental assessment

The presence of pyrethroid residues in dung from a range of cattle treatments and products was confirmed. Within days of cattle treatment, between 0.01 and 0.1 ppm (wet wt) of pyrethroids were present in dung. Dung produced for up to two weeks after treatment contained residues in this concentration range. At these concentrations, deltamethrin residues were toxic to many species of dung fauna. Dung beetles and muscid fly larvae were susceptible to a range of pyrethroids, including formulations of deltamethrin, alphacypermethrin, cyfluthrin, cypermethrin and flumethrin (Vale *et al.*, 2004). Deltamethrin was most toxic to beetles and fly larvae (Table 1). Adult muscoids and earthworms were less susceptible.

When SpotOn was applied along the backs of oxen, the beetles used to assay residue toxicity suffered high mortality (65-84%) when exposed to the droppings just one day after treatment,

Table 1. *LD50s of various beetles and muscid larvae and adults exposed for 24 hours to dung spiked with deltamethrin formulations*

Insect	24 h LD_{50} SpotOn (ppm0	24 h LD_{50} Decatix (ppm)
Copris amyntor	0.04	0.17
Digitonthphagus gazella	0.01	0.27
Hister spp.	0.01	0.12
Onitis westermanni	0.14	0.45
Sisyphus goryi	0.13	1.82
Miscellaneous beetles*	0.02	0.04
Muscid larvae	0.11	0.37
Geometric mean	0.042	0.252
Relative toxicity	1.00	0.17

* Scarabidae, including: *Euoniticellus intermedius* and *Kheper* spp.

declining to zero on droppings produced two weeks after treatment. Application of SpotOn to the flanks reduced beetle mortality on the first day to 12–39%, but it rose to 58–88% by day 2 or 3 (Fig. 4).

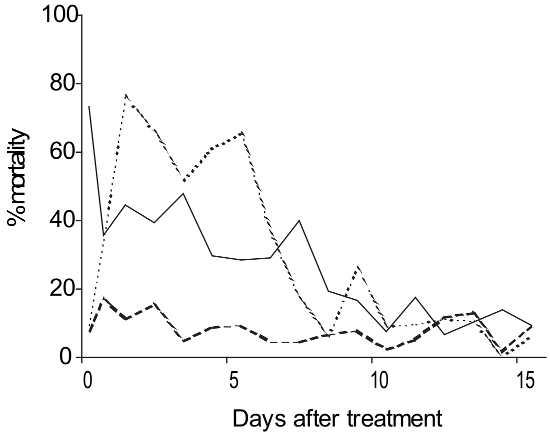

Fig. 4. Percent mortality of beetles at pats dropped at various days after applying Spot-On to the back or flank, or whole-body spraying with Decatix. Soild line, SpotOn back; Dotted line, SpotOn, flank; Dashed line, Decatix.

Mortalities were mostly below 20% for the whole body Decatix treatment. Chemical residue data on dung from the treated oxen show good correlation with the results of the bioassay (Fig. 5). Applications of Decatix to the legs of oxen at intervals of 1, 5 or 25 days showed that dung contamination would only be slight with 5 and 25-day treatments, but high after a few weeks of 1-day treatments (Fig. 6). There were no mortalities from the dung of untreated animals.

No marked effects of deltamethrin on dispersal rates of dung pats were evident, unless dung residues were > 0.01 ppm, i.e. 10–100 times the 24-hour LD_{50} of beetles. Dispersal of pats by *Microtermes* spp., which were responsible for a significant proportion of long-term disposal, was affected when pyrethroid residues reached 1 ppm, but not at 0.1 ppm *(loc. cit.)*

Negligible residues of deltamethrin were found in blood and milk samples of oxen (at or below detection limit), but only one opportunity to sample each was presented.

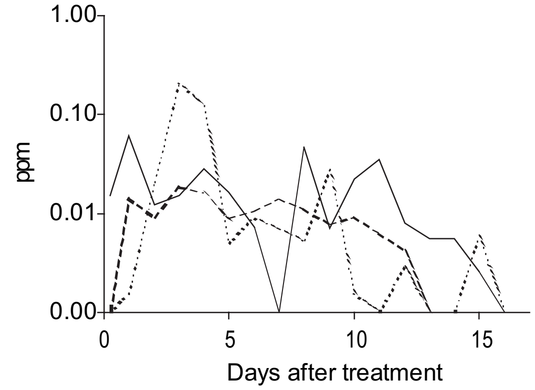

Fig. 5. Average ppm of deltamethrin in the wet weight of dung dropped at various days after applying SpotOn to the back or flank, or whole-body spraying with Decatix. Each plot is the mean of 3-5 assays. Soild line, SpotOn back; Dotted line, SpotOn, flank; Dashed line, Decatix

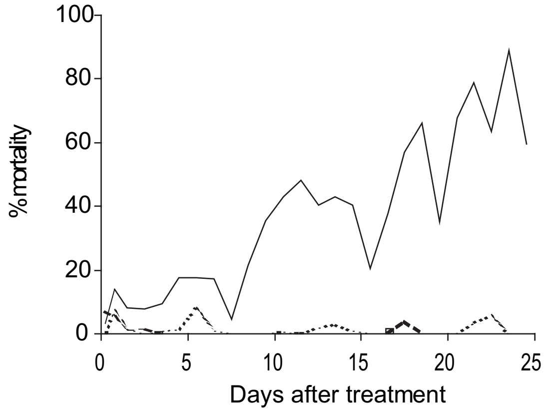

Fig. 6. Percent mortality of beetles at pats dropped at various days after application of Decatix to the legs of cattle, at intervals of one, five or 25 days. Solid line, 1 day; Dotted line, 5 days; Dashed line, 25 days.

Comparative costs

Only a limited comparison of the cost-effectiveness of different disease control approaches can be attempted here. Broad brush comparisons of historical and current field level costs have been summarised by Allsopp & Hursey (2004) and Shaw (2004). Manipulating the figures in the latter and comparing approaches for local elimination, excluding the cost of barriers to prevent reinvasion, gives indicative field costs of US\$300–400 km^{-2} for fixed wing aerial spraying and US\$700–1100 km^{-2} for use of the Sterile Insect Technique (SIT), including initial suppression using aerial spraying and US\$300–400 km^{-2} for ground spraying. In all probability, however, all these costs need to be at least doubled to include planning and overheads, giving an indicative range of US\$600–2200 km^{-2} for tsetse elimination.

Use of trypanocides is the main strategy of livestock keepers throughout tsetse-infested Africa to control trypanosomosis. Trypanocide costs vary both from country to country and, more significantly, according to the quantity bought, sales outlet and availability. Normally prices for a curative dose sufficient for a 250 kg bovine range from US\$0.50–1.30 for diminazene aceturate and US\$0.60–1.30 for isometamidium chloride. After adding a cost of US\$0.20–0.50 for administering the drug and adjusting for the lower average weight of herd cattle treated, the costs, at standard curative doses applied to an average liveweight of 200 kg would be US\$0.60–1.50 for diminazene and US\$0.70–1.50 for isometamidium. This means that the commonly-cited figure of US\$1 is still appropriate, increasing to US\$2 for diminazene used curatively at double the normal dose and isometamidium used prophylactically. Trypanocide costs at a stocking density of 10 cattle km^{-2}, each receiving 1 standard curative dose (costed at US$1) and 0.5 prophylactic doses (costed at US$2) appropriate to a 200kg animal per year, would amount to US$3 per animal per year, or US$30 km^{-2} per year. The present value of this amount applied annually over 20 years at a 10% discount rate, for comparison with the cost of elimination, would be US$255. If it is assumed that trypanocides are half as effective in preventing losses as tsetse elimination, the proper figure for comparison would be 255/0.5 or US$510, still less than the US$600–2200 range for tsetse elimination.

Turning to the use of ITC, in recent years the cost of pyrethroids has declined dramatically, largely because they are no longer under patent and the annual cost of insecticide plus a generous allowance for field level overheads for the whole body treatment is just under US$7 per adult animal treated per year (Vale & Torr, 2005). The economies made possible by the restricted application of insecticide, means that the annual cost is under US$1.50 per adult animal treated per year.

Treating 4 adult cattle km^{-2} annually would normally be sufficient to achieve control or eliminate a population of tsetse. At a rounded up cost of US$7 per animal, the annual cost would be US$28, equivalent to a total present value of US$238 over 20 years, if repeated annually to control tsetse. Farmer's time and other field overheads have already been allowed for in this figure and costs for planning and organisation are far lower than for other tsetse control options. Thus, adding 50% to the insecticide costs would be a generous allowance for additional overheads, bringing the annual cost to US$42 and the present value to US$357 over 20 years, or roughly two-thirds of the cost of using trypanocides to obtain an equivalent effect. Furthermore, if the economies involved in restricted application are taken into account and the cost reduced to approximately US$6km^{-2} year-1 for treating 4 cattle, achieving 93% of the tsetse kill of the whole body treatment, then over 20 years, the total cost for comparison would be a mere US$55, or just over 10% of the cost of using trypanocides.

Discussion

Cost-effective tsetse control

Present findings will improve the cost-effectiveness of using ITC to control tsetse-borne-trypanosomosis. Treating, for example, only the belly and legs of cattle will reduce insecticide costs by 80% with only a slight reduction in efficacy.

The effective life of insecticides applied to cattle is between 1–4 weeks, in marked contrast to the widespread misconception that far longer re-treatment intervals are adequate. For instance, livestock keepers in Konso District of southern Ethiopia retreat their animals at ~12 week intervals and similar periods are being used for tsetse control elsewhere in Ethiopia and Tanzania.

If the restricted application regime were used in Konso and the treatment interval were reduced from three months to three weeks, overall cost would be reduced and the average "kill" of tsetse would be increased threefold. It is only necessary to increase female mortality by some 4% a day for a population to decline, and if that rate is maintained over an entire, closed population, it will eventually be eliminated (Hargrove, 2003). Thus, the restricted application regime will not only allow farmers to reduce costs, but will also enable them to achieve far better control.

To take this argument further, all tsetse control methods can be used either to suppress or eliminate tsetse populations, with the exception of SIT, which is exclusively used with prior suppression methods to achieve elimination. Thus, if non-restrictively treated cattle were used for 3 years to eliminate a tsetse population, at a cost of US$42 km^{-2} discounted at 10%, the total cost of elimination would be US$104 km^{-2}, which is less than 20% of any of the other elimination options. However, where cattle populations are present all year round and reasonably evenly spread, the evidence indicates that one year of ITC might be sufficient for elimination, so that the cost might only be US$42 km^{-2}, or even just US$6km^{-2}, if restrictive application were used. These figures need further verification and the conditions under which they apply need to be further defined.

For example, usually cattle population densities would need to be at least 10 km^{-2} for four large individuals suitable for ITC to be present

Environmental impacts

Extensive modelling has shown that toxicity of contaminated dung could reduce markedly the abundance of dung fauna, especially the slower breeding species (Wardhaugh *et al.*, 1998; Vale & Grant, 2002). The implications of impaired dung faunal activity on nutrient cycling and soil fertility led to the search for a cattle treatment that minimised contamination without compromising control efficacy and costs. The bioassay techniques provided a fast, reliable and inexpensive alternative to chemical analysis and showed that the likely pathways of dung contamination were: a) from pour-on contact with dung near the anus; and b) from grooming i.e., licking the treated areas that may be irritated by pyrethroids, and/or in the case of SpotOn tasty, as coconut oil is one formulating agent. Around 5–10% of the topically applied deltamethrin is licked away. By whichever route, about 1.6% of the applied deltamethrin migrated into the dung. A veterinary collar that stopped the animal licking its flanks reduced by about two-thirds the degree of dung contamination over a 1–7 day period, thus suggesting that licking could account for about half of all insecticide entering dung after normal flank treatment. If the area capable of being licked is reduced, then so should be the subsequent faecal contamination.

Control Efficacy As the reported belly plus legs and legs-only treatments are effective for 15-20 and 10-15 days, Fig. 6 indicates that any residues and subsequent impacts on dung fauna are likely to be insignificant. If partially filled dip tanks were used to treat cattle in this fashion, then proper disposal of insecticide containers and dip tank washings would be the only caution.

The dispersal of pats, including the significant role of subterranean termites, is unlikely to be impeded by the observed range of residues found in the dung of treated cattle. Deltamethrin residues were bound strongly to dung and were not readily transported to underlying soil by physical factors, such as leaching. Pyrethroid residues will be incorporated eventually into the soil by some biotic/abiotic agency, but their persistence at such low concentrations is likely to be short-lived, especially when microbial populations are activated in the wet season.

The presence of insecticides in the alimentary canal might raise questions of consumer safety, if high residue levels accrued in milk and meat products, but residues in blood and milk samples from SpotOn treated animals were only found at the very limits of detection.

The limited environmental impacts of targeted and restricted application of deltamethrin to cattle, compared with aerial and ground spraying (Grant, 2001), clearly demonstrate the cost-effectiveness and environmentally benign nature of this means of tsetse control.

Integrated control of vector-borne diseases

Indigenous cattle breeds in Africa, which are in the great majority, have the important advantage of being resistant to several important tick-borne diseases and some are also trypanotolerant. The resistance depends on young cattle being bitten by infected ticks; the young cattle become infected, experience only mild and transitory disease and are immune thereafter. This condition, termed enzootic stability, can be undermined by widespread and frequent treatment of cattle with pyrethroids for tsetse control. However, the attachment sites of ticks and the feeding sites of tsetse differ (Torr *et al.*, 2002), while > 95% tsetse feed on adult cattle (Torr *et al.*, 2001). Thus, by treating only the legs and bellies of older cattle, effective tsetse control can be achieved without threatening enzootic stability.

Conclusion

It seems clear from the above that the restricted application of insecticide to cattle for tsetse suppression and local elimination needs to be more widely demonstrated and promoted as a highly cost-effective and environmentally benign, farmer-based disease control component of the African Union's Pan African Tsetse and Trypanosomosis Eradication Campaign to complement, or as an alternative to, the prevailing widespread use of trypanocides, especially in areas of emerging drug resistance.

Whilst the use of ITC is not a panacea for dealing with all aspects of animal trypanosomosis in Africa and obviously cannot be applied where there are very few or no cattle, the technique is considered appropriate for agro-pastoral/mixed farming communities and cattle producer groups willing to co-operate in collective action to improve the health and productivity of their stock. Healthier animals are also stronger and better able to pull carts and ploughs. More land can be cultivated and more crops can be produced and transported to market. Thus, the wider use of ITC has the potential not only for increasing overall crop and livestock production and enhancing rural livelihoods, but also for improving food security through mixed farming.

Acknowledgements

We wish to thank Professor Ian Maudlin and Dr Wyn Richards, managers of DFID's Animal Health and Livestock Production Programmes, for their support and encouragement in preparing this paper, and Dr Glyn Vale for many helpful discussions and allowing the use of unpublished data. We are also most grateful to all those who participated in field and laboratory studies in Ethiopia, South Africa, Tanzania and Zimbabwe.

Disclaimer

This paper was funded by the United Kingdom Government's Department for International Development (DFID). However, DFID can accept no responsibility for the information provided, or for any of interpretations or views expressed, which are the responsibilities of the authors alone.

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