6. Discussion

The chapter is in three sections. First the results of the situational analysis are discussed (farming system, animal health delivery and epidemiological findings). We next consider the results of the evaluation of three strategies for trypanosomosis control (vector control, keeping trypanotolerant cattle and rational use of trypanocides (informing farmers, establishing paravets and training existing service providers). Finally the results of the mathematical modelling are discussed.

6.1 Situational analysis of epidemiology and management of AAT

Understanding the context is a pre-requisite to problem identification and to development and testing of solutions, and a first objective of this study was to describe the epidemiology and control of trypanosomosis in villages under risk of trypanocide resistance in West Africa. The resulting situational analysis included demography, farming system, knowledge and practice of trypanosomosis, animal health delivery, knowledge and management of resistance as well as epidemiology of trypanosomosis and other relevant cattle diseases.

High poverty and illiteracy levels, but the next generation will be better educated

The ethnic diversity we found was consistent with the literature; farmers in sub-humid west Africa, belong to small, fragmented ethnic groups, distinct from the large clusters of state-building peoples to the north and south; an exception is the Malinké in Guinea (ILCA, 1979). Pastoralism is not traditionally practised in sub-humid areas; our finding of small numbers of recently or long-term settled Fulani (the largest pastoral group in Africa and the world) reflects increasing sedentarisation, with some Fulani now found as far south as the forest zone (Blench, 1994).

The areas studied showed demographies typical of traditional west African farming societies, with the family (extended, patrilineal, partrilocal and polygynous) the central unit of production. There was some evidence of smaller, nuclear families emerging in Burkina Faso, perhaps reflecting the disaggregation of the farm household linked to more specialised, high-input farming, young men seeking autonomy from patriarchal control and socio-economic differentiation as the result of greater integration with the market economy (Toulmin and Guèye, 2003).

Literacy levels in this survey were low and 7-19% lower than those reported in national surveys (UNDP, 2005); possibly because our study sites were rural, and respondents older than the average citizen. But, younger farmers were better educated, and many children attended school.

Using the straightforward classification system used by the Demographic and Health Studies (Kamuzora, 2001), half the farmers in our survey (49%) were classified as ‘very poor’ and half (51%) as ‘poor’. This was also expected: in terms of GDP per capita, Guinea, Burkina Faso and Mali rank 156, 174 and 175 in the listing of 177 countries (UNDP, 2005).

Lack of traditional pastoral expertise, illiteracy and poverty are serious constraints to animal health management. However, the next generation will be better educated and more market-integrated than the current, suggesting that some of the problems with disease management, linked to isolation and lack of information may improve.

An agro-pastoral farming system undergoing rapid intensification

The study area lies within the "cereal-root crop mixed system" of west Africa which extends from Guinea to southern Chad (Dixon *et al.,* 2001) and our findings on farming system, crops grown and integration of cattle with crops were consistent with this. The very positive effect of cattle-keeping on the household economy is well-established; use of draft cattle in west Africa has been shown to increase total production, crop yields and farm income (Starkey, 1990).

A recent review of studies on herd size and structure in sub-humid sub-Saharan Africa, found an average herd size of 38 (range 7–77) cattle , with cows making up the largest group (Otte and Chilonda, 2002). Our study showed a smaller herd size and higher proportion of bulls/oxen indicating a system oriented towards draft, further evidence of evolving farming systems.

The cotton parastatal in Mali has been carrying out socio-economic studies in Sikasso since the 1990s (CMDT, 1995; CMDT, 2002). These show household sizes of 12 to 20, with 6 to 21 cattle per household among which are two to four draft cattle. From 18% to 28% of farmers grow fodder and 65% to 98% of cattle receive treatments each year. Our findings are comparable to these, (but towards the upper range of values reported) supporting the validity of our methodology and analysis. The larger herd size in our study is partly explained by increasing herd size with time (CMDT reports a doubling in herd size from 1994 to 2001) and partly because only cotton producers are included in the CMDT sample, excluding some farmers. Also, obtaining accurate data on herd size is notoriously difficult in developing countries. The CMDT data show the increasing intensification of the farming system over time noted in our survey.

6.1.1 Knowledge, attitude and practice of trypanosomosis management

AAT is the most important disease, and farmer knowledge of it is high

The dramatic importance of trypanosomosis, even in the trypanotolerant heartlands, was interesting and lends support to the argument that trypanosomosis is a special case, different from other African animal diseases (Jordan, 1993). Farmers had reasonable knowledge of AAT aetiology and management, comparable to that found in one study in a agro-pastoral communities in Kenya and higher than that reported in studies in Nigeria (Njoku *et al.,* 2003) and Kenya (Machila *et al.,* 2002). This is probably due to the higher priority of the disease in the study area, and, in Guinea and Kénédougou, to extension activities. Veterinary knowledge in agro-pastoral communities is typically lower than in pastoral communities (Catley *et al.,* 2002), and this was markedly the case in our study. The major knowledge deficits of farmers were ignorance of the more specific signs of trypanosomosis, belief that there were many different causes of trypanosomosis, and belief that other modern, non-trypanocidal drugs could be used to treat trypanosomosis (although they rarely used these drugs first-choices for treatment).

Multiple strategies used to manage AAT; screens and pour-ons eschewed

Farmers integrated a variety of strategies for preventing AAT, and practice generally following knowledge as predicted by psycho-social health behaviour models which posit knowledge of treatment options is a predisposing factor for health care use (Andersen and Neuman, 1975;

Ajzen and Fishbein, 1980; Prochascha *et al.,* 1992). However, an exceptionally wide gap between knowledge and practice was seen in the case of the strategy of participatory control. This was also reported by Magona *et al.* (2004b) in Uganda, and suggests failure of uptake of participatory vector control is due not to lack of knowledge but to other barriers. Farmer knowledge of trypanocidal treatments and dosages was reasonably good in this study; this was the finding of studies in Zambia (Delespaux *et al.,* 2002) and Kenya (Mugunieri, 2003). However, other studies in Kenya (Machila *et al.,* 2002) and Ethiopia (Tikue, 2001) found evidence of extensive under-dosage. Under-dosage of trypanocides was detected in this study only in a minority of cases.

The community is the most important source of treatment for AAT

The role of farmers and other untrained community members in animal health care provision has been largely ignored; we found it was central, with 72% of treatments given in the community by untrained people. This is logical given that very common diseases in very poor countries are likely to be home-managed because of lack of alternatives. A recent review of over 30 studies on malaria found that 67% of cases are managed at home with modern drugs (Winstanley *et al.,* 2004). Given that most treatments are made in the community, engaging this sector is necessary if management of trypanosomosis is to be improved.

6.1.2 Animal health services for trypanosomosis control

Formal animal health systems fail to deliver clinical services, drugs and advice

The three countries have informative differences in animal health delivery. Guinea has largely retained the statist pre-reform system that dominated post-colonial Africa, with veterinary agents in the field and a network of paravets. Disease is low, yet farmers are well-informed on AAT causes and treatment. But, while Guinea is a model of how advice and clinical services can be delivered at village level, the drug supply system is dysfunctional; prices are around twice that in neighbouring Mali and the single private vet in this huge district has a minimal role, not only in delivery of clinical services (standard for sub-Saharan Africa), but even in the supply of drugs.

Mali has a more free market approach with the most extensive network of private sector, veterinary pharmacies. Our findings, agreeing with Fassi–Fehri (1998), were that this system delivers drugs at affordable prices but is not effective at providing advice or clinical services; Mali has the cheapest prices and the highest proportion of low quality drugs. “Copy-cat” drugs, produced in countries with low standards of quality regulation and with no effective quality control by exporting or importing countries, may foster drug resistance. Three recent studies on the quality of DIM drugs found from 10-50% of samples had less than 90% of the active ingredients stated on the packet (Karambe, 2001; Tetty *et al.,* 2002; Teko-Agbo, 2003). In Mali, economies of scale allow wholesalers/importers to deliver large quantities of drugs to division if not village level, but at the same time they compete-out independent veterinarians who are further disadvantaged because a veterinary degree is not required to treat or dispense drugs. Mali is bringing veterinary services in line with OIE recommendations, and technicians will not be allowed to treat or dispense drugs. This will certainly improve the employment prospects of veterinarians, but is unlikely to have a positive effect on drug availability and price.

In Burkina Faso the veterinary market is more regulated, with only a few high quality brands of trypanocides for sale, highest professional qualifications among veterinary pharmacists, a system of price-fixing which prevents wholesalers from under-cutting retailers, and the highest number of independent veterinarians. The corollaries are fewer legal outlets, selling a narrower range of more expensive drugs, a very large informal sector (with lower prices and higher retail margins than the formal sector) and mass buying of drugs in neighbouring Mali.

All systems have some strengths but yet all are far from meeting the needs of farmers and ensuring rational drug use, while incoherence among countries creates distortions in supply and demand. A common feature is wide divergence between policy and practice and a common challenge is complying with international regulations of unproven value to African farmers.

Important role for the informal sector explained by institutional factors

Black market economies are not easy to investigate, and little is known about the informal veterinary sector in Africa. We found it to be a major source of trypanocidal drugs, in some countries the major source. Given farmers' natural reluctance to admit to obtaining drugs from sources they know to be illegal, the importance of the sector was probably underestimated. In west Africa the informal sector accounts for more than 50% of trading GDP and employs more than 90% of trades-people (Xaba *et al.,* 2002) so its importance in animal health drug supply is not unusual. Drugs are both credence and experience goods; the existence of a large informal sector suggests that for some farmers experience is more important: these farmers use information conveyed by drug branding to reduce uncertainty, buying drugs they have found to work, irrespective of the source. For other farmers trust of the drug seller is the most important criterion (credence). However, drug sellers can be expected to know more about their products than farmers do, and this gives rise to asymmetries of information providing incentives for over-treatment (supplier-induced demand) and overcharging (McGuire, 2000; Dulleck and Kerschbamer, 2001). In developed countries institutions have evolved to resolve informational asymmetry (such as professional ethics, reputation, legal reclaim and government regulation); in developing countries these are dysfunctional (Leonard, 2004). This insitutional failure is illustrated by farmers stated preference (they trust other farmers more than they do professionals) and revealed behaviour (they buy most drugs in the informal sector).

There was (inconclusive) evidence of a relation between use of the informal sector and more treatment failures and higher drug resistance, and education and competence in this sector was clearly lower than in the formal sector. In human medicine, practices in the informal sector in developing countries are seen as major factors in the development of drug resistance (WHO, 2001c) and initiatives have been developed to eliminate or, much more rarely improve, the informal sector (Marsh *et al.,* 1999). Regulating away the informal work has rarely worked and increasing the competitiveness of the formal sector may be a more feasible option (WHO, 1999).

An important finding of our study was that in Mali where entry barriers to the veterinary pharmacy is lower (non-veterinarians with tertiary level training in livestock can sell drugs) and regulation more liberal (wholesalers sell direct to the public) there are more veterinary pharmacies, greater penetration into rural areas, a wider range of cheaper drugs, and a much less important role for the informal sector compared to more strictly regulated countries. There is a risk that recent moves to harmonise-upwards veterinary standards (Brückner, 2004) may create perverse incentives, pushing farmers to the informal sector. De Haan and Bekure (1991) point out that restricting the supply of veterinary products can stimulate illegal trade.

Practices and policies that foster trypanocide resistance

There were some suggestive findings on links between drug-use practices and resistance:

- Farmers prefer small pack sizes of trypanocides and nearly all follow the rule of "one small sachet treats one animal". Where cross-breeds and draft animals predominate (as in Kénédougou and Sikasso), this results in systematic under-dosage; a small ISMM sachet is inadequate for 75% of adult male cattle, that of DIM for 44% of adult males. Under-dosage is a key factor in the development of resistance, as well as resulting in less effective treatments, and ensuring heavy cattle are correctly dosed a priority. This could be done by changing pack size or passing information on dosage by weight.
- The common practice of giving repeated treatments with DIM for AAT prevention, increases the selection pressure for resistance to DIM and is not advisable.
- The use of DIM at standard dose in Guinea, where most infections are caused by *T. brucei*, will result in less effective treatments and may foster resistance.
- Areas with most trypanocide resistance had most reliance on fewest drugs. There is theoretical evidence to suggest that treatment heterogeneity (i.e. the policy of treating different subjects afflicted with the same disease with antibiotics that have unrelated modes of action) decreases selection pressure for resistance (Laxminarayan and Brown, 2001). This runs counter to the conventional veterinary drugs policy of designating first line drugs and reserving others.
- Farmer reliance on less-specific diagnostic signs (such as anorexia, staring coat and weight loss) means they may over-diagnose trypanosomosis and hence over-use trypanocides, fostering drug resistance. We found four diagnostic signs useful in distinguishing parasitologically positive animals from negative animals in a population consisting of animals which farmers believed were ill. None of these signs (anaemia, fever, lacrimation and enlarged lymph nodes) were widely known by farmers, and information on AAT diagnosis should be diffused.
- The RDU study also gave insights into practice and policy, which for convenience are mentioned here. The high levels of inflammatory reactions (from 5-25%) after treatments; suggest training and information should be disseminated on injection technique. (Inflammation may hinder drug absorption, resulting in effective under-dosage so fostering resistance.) The highly significant relation between more treatment failure and severity of clinical signs suggests prompt treatment of sick animals before disease is advanced is highly desirable, while the

relation between lower dosage and treatment failure supports a fundamental assumption of the training-based strategies, that is, under-dosage leads to treatment failure and fosters resistance.

- Comparing drug use to prevalence suggests current usage of trypanocides is inappropriately low, and the results of strategy testing showed little evidence that levels are inappropriately high after training. An economic study on trypanocide productivity carried out by the project in Mali and Burkina Faso independently arrived at the same conclusion (Affognon, *pers. com*). We conclude the main problem is not excessive but improper drug use.
- Farmers restrict ISMM treatments to valuable animals they consider at risk and use ISMM mainly for prohphylaxis, and as this practice is less likely to foster resistance it should be encouraged (ICPTV, 1999). The higher retail margin on DIM drugs is, therefore, beneficial. The current policy to give block treatments with ISMM should be reviewed. Policies also advise sanative pair treatments; however these are rarely carried out because of the high cost. Sanative treatments are institutionally unlikely to be paid for by farmers, as they are intended to reduce the externality of resistance, the farmer paying for the treatment does not see or pay the price of resistance and has no direct incentive to give extra treatments at his own expense to reduce it.

6.1.3 Epidemiology of trypanosomosis and related diseases

Tsetse triad predominates, savannah species disappearing

The three species of tsetse we found (*G. morsitans morsitans*, *G. palpalis palpalis* and *G. tachinoides*) are known to co-exist as a 'triad' in the moist savannah (Randolph and Rogers, 1984). The first is predominantly a savannah species; at its northern ecological limit in the study area, the removal of habitat by human settlement and agriculture is generally enough to bring about eradication. Previously dominant in Kénédougou (Bauer *et al.,* 1995), *G. morsitans morsitans* was absent in our study, confirming the results of Woitag (2003) and adding that the same process of extinction, noted since 1989 (Diall, 2001), is now advanced in southern Mali. *G. tachinoides* is more mobile than *G. palpalis*, the latter rarely moving far from standing water; previous surveys had indicated that in this region *G. tachinoides* was responsible for transmitting at least three-quarters of trypanosomosis infections and current recommendations are that *G. tachinoides* should be the major target for any eradication programme (PATTEC, 2001b). Our finding that *G. palpalis* was present in higher numbers and with equal infection rates suggest that it may also be important. Further studies incorporating blood-meal analysis would elucidate this.

Tsetse density in Kénédougou was higher than previously reported and in Sikasso it was lower: specifically, an AD of 22.8 flies/trap/day in Burkina Faso versus the 3.4 reported by Woitag (2003) and of 3.3 versus 8.0 reported by Djiteye (1989) in Mali. There were no previous studies in Mandiana (AD of 0.8 in this study). However, AD and tsetse infection rates in all study areas were within the range reported for the region: 0.1 to 35 for AD and 0 to 14% for AAT prevalence, respectively (Leak *et al.,* 1978). The trapping protocol followed in this study (ten traps for six hours) is not precise; if more accurate information is needed, traps can be left for 48 hours or permanently *in situ*. The finding that female flies were on average seven days older than male flies follows from the greater longevity of female tsetse (Leak, 1999).

AAT a major problem, increasing in importance from west to east

Many surveys on trypanosomosis prevalence have been carried out, but few have used a sampling methodology that allows generalisation beyond the animals sampled, and a disproportionate number have been in response to local crises, and thus, atypical and upwardly biased. An interesting finding from this study was that judgement samples and small samples over-estimate trypanosomosis prevalence compared to true random samples and large samples. This underlines the importance of a credible and transparent survey methodology. In our study constructing a sampling frame for villages, using a pre-specified sampling strategy, and random sampling of cattle within villages, allowed precise and credible estimation of prevalence over an area larger than that covered by any previous reported survey. However, the AAT prevalences in our study (14% in Burkina Faso, 6% in Mali and 3% in Guinea) are broadly in accordance with previous studies. Summarising only recent, large-scale surveys from the region: in Togo AAT prevalence was 9.8% (unreported sampling strategy, 18 364 cattle) (Napala *et al.,* 1993); in south Burkina Faso prevalences varied from 8% to 12%) (unreported sampling strategy, 1 796 cattle) (Bengaly *et al*., 1997); in north Ghana prevalences ranged from 8% to 16% (1,019 cattle from randomly selected villages) (Mahama *et al.,* 2004). Among trypanotolerant cattle in Senegal, prevalence was 2.4% (Fall *et al.,*1999) and in Lower Guinea prevalence was 3.7% (3 467 samples) (CIRDES, 2000). Our survey, and others based on the BCT method of detecting infections, under-estimate prevalence: AAT detection using PCR may be three to four times higher (Gall *et al.,* 2004). Another caveat is that prevalence was measured in a context of frequent treatments by farmers. In the absence of this, prevalence would undoubtedly be much higher.

T. congolense more pathogenic, dominates where morbidity and mortality highest

T. vivax is regarded as the most important species in west Africa (Stephen, 1986) and in our study it predominated in the south and west. However, *T. congolense* was most common in the east where AAT had highest morbidity and mortality, and was associated with more severe anaemia. Several authors reported that female animals are more at risk, and attributed this to the stress of pregnancy and lactation (Chicoteau *et al.,* 1990; Rowlands *et al.,* 1995; Okech *et al.,* 1996). We found that male animals were more at risk, and suggest this may be due to the stress of work; this was also the conclusion from studies in western Kenya (Karanja, 2005). The positive correlation between infection and age has been noted previously (Wellde *et al.,* 1981).

Most cattle infected with worms, heavy infections low in adults and N'Dama

Other authors in Mali (Tembely, 1986) and Burkina Faso (Ouedrago *et al.,* 1992; Ganaba *et al.,* 2001) have also reported that the majority of cattle are infected with internal parasites. Our findings of nematode, trematode and cestode eggs and coccidian oocysts are typical. A possible exception is that *Nematodirus* (0.2% of our sample) is said to be rarely reported (Ndao *et al.,* 1995). The seasonal pattern of infection in west Africa (peaking in the rains) and age distribution (young most at risk) has been noted by others (Kaufamann and Pfister, 1990; Ouattara *et al.,* 1992). We found a significant difference in infection prevalence between Zebu and N'Dama but not between Zebu and Baoulé. Mattioli *et al.* (1992) report significant breed differences in faecal egg counts between N'Dama and Zebu cattle in the Gambia, and postulate a natural resistance to strongyle infection in N'Dama cattle. The positive relation between heavy worm burden and trypanosomosis infection is plausible given the pathological synergism demonstrated experimentally between trypanosome and strongyle infections (Kaufmann *et al.,* 1992).

High prevalence, low pathogenicity suggests haemoparasites endemically stable

Babesia are transmitted by several ticks of the genus *Boophilus*. *Babesia bigemina* is more widespread than the smaller but more pathogenic *B. bovis*. *Anaplasma spp.* are also transmitted primarily by *Boophilus* ticks, although *Rhipicephalus spp*. are also implicated and mechanical transmission by biting flies is thought to be important. *A. marginalis* is more pathogenic than *A. centrale*. As for *Babesia*, infections tend to be sub-clinical in calves, and immunity to infection is a feature favouring the development of enzootic stability – the epidemiological state in which clinical disease is scarce despite a high rate of infection in the population. These diseases are common in traditionally-kept cattle, and our finding of haemoparasite prevalences of 1-26% on blood smears was broadly consistent with those from elsewhere in the region. Although Mattioli *et al.* (1997) reported low prevalences 0.1-3% on blood smears and Knopf *et al.* (2002) similarily reported prevalences less than 1% using blood smears, a more recent study in Ghana found prevalences of 1-31% using blood smears (Bell-Sakyi *et al.,* 2004), and in Benin prevalences of 14-31% were detected using smears (Pangui and Salifou, 1992). The only published study on haemoparasite prevalence in Mali (Miller, 1984) reported prevalences of 12-98% using IFAD for diagnosing infection. Although we did not undertake sero-diagnosis, the high microscopic prevalence combined with low apparent pathogenicity of *Anaplasma* and *Babesia spp.* is consistent with the presence of endemic stability. This is of significance for integrated control measures, as disease control which disrupts endemic stability may have the side-effect of catastrophic losses from tick-borne disease (Torr *et al.,* 2002).

Problems with this study, its interpretation and analysis

The absence of resistance data for all villages (due to the high cost of resistance studies) limited investigation of the epidemiology of resistance. Choice of epidemiological methods (e.g. BCT without PCR for AAT diagnosis, blood smears without serology for TBDs, semi-quantitative instead of McMaster coprology, short-duration vs. permanent tsetse trapping) was constrained by logistics and budget; the use of the more precise and sensitive tests would improve the quality of data. No epidemiological investigations were made on some diseases considered important in the area (e.g. heartwater, dermatophilosis and ticks). Calculation of AAT mortality based on farmer reports, and assumes that their diagnosis is correct.

Summary and implications of situational analysis

To summarize the situational analysis, we conclude that the cotton zone of west Africa presents not a mosaic but a cline, spatial and temporal, socio-economic and epidemiologic. Towards the west, households are large, farming systems traditional, N'Dama cattle predominate, animal traction is less important, cultural roles of cattle are important, trypanosomosis prevalence is low, savannah species of tsetse are important, veterinary drugs are less available, veterinary treatments are fewer, use of traditional medicines is higher, morbidity and mortality is low and resistance to trypanocides is not found. Moving east all these parameters change until in Burkina Faso we find small, more market-oriented farms, most with only draft cattle and no cows, with high proportions of Zebus, very high animal treatment levels, high AAT morbidity, high AAT mortality, predominance of *T. congolense* and widespread trypanocide resistance. The situation is rapidly evolving, 20 years ago the east had a largely traditional system of cattle-keeping. In the absence of intervention it seems inevitable that the problems of AAT management and resistance faced by the east today will be facing the west tomorrow.

6.2 Evaluating strategies for trypanosomosis control under risk of resistance

The situational analysis showed: widespread drug use by untrained people; ignorance of drug dosage among sellers; illiteracy constraining information access by users; lack of knowledge on AAT diagnosis and trypanocide administration; a large informal sector lacking capacity to provide high quality goods and advice; and a formal sector that mainly restricts itself to drug-selling. All these factors lead to sub-optimal control of trypanosomosis. Economic imperatives make it impossible for veterinarians to treat all sick animals; institutional factors predicate that, though the state and private veterinary sectors are important sources of drugs, they are minor providers of clinical services, information or vector control. The immediate impact of these supply failures is unnecessary losses from AAT through morbidity and mortality; the indirect effect is likely to be the fostering of resistance to trypanocides, jeopardising the future management of animal and perhaps human trypanosomosis.

To address the joint problems of sub-optimal trypanosomosis control and developing resistance we evaluated three strategies: participatory vector control; keeping trypanotolerant cattle; and promoting rational drug use through a) providing information to farmers, b) training service providers and c) training paravets in integrated trypanosomosis control.

6.2.1 Participatory vector control

Targeted participatory vector control is very effective

The finding that participatory vector control using screens and insecticide-treated cattle is effective and improves cattle production and health, was anticipated and in line with other studies in the study region and elsewhere (Kamuanga, 2003). In general, use of targets/traps and insecticide-treated cattle controls tsetse within a year, unless the kill rate is too low or re-invasion pressure too high (Hargrove *et al.,* 2000). This can occur when cattle are few, game hosts many and where extensive areas of inaccessible bush persist; none of which were present in the study site. At the participatory planning, farmers selected a targeted and minimalist approach, using small numbers of screens placed only in areas of cattle vector contact; an approach successfully used previously in Burkina Faso (De la Rocque *et al.,* 2003). Costs and effort of vector control were reduced, but overall decline in tsetse densities (not just in areas of cattle-tsetse contact) was less than in previous projects using higher densities of targets (Bauer *et al.,* 1999), and re-invasion may be quicker.

Vector control decreased mortality and drug cost and increased production

Although several impact studies on trypanosomosis control have been carried out, most have not used concurrent controls (Fox *et al.,* 1993; Camus, 1995; Rowlands *et al.,* 1999) and many have lacked baseline information (Jemel and Hugh-Jones, 1995) or relied on farmer-recall of the pre-control situation to construct retrospective baselines (Kamuanga *et al.,* 1999; Kamuanga *et al.,* 2001). The impact evaluation methodology we used (with both before and after and with and without vector control comparisons) is more rigorous and would be expected to give more credible results. Another methodological innovation to vector control assessment was triangulation of epidemiological cohort data, household questionnaires and participatory appraisals. The agreement of these different methods strengthens the strong findings on major positive impact of participatory vector control.

It is known that control of tsetse brings important benefits; Swallow (2000) summarises a number of studies on AAT impact from east and west Africa and reports decreases in cattle mortality from 54-86% (71% in this study), decrease in abortion of 50-90% (66% in this study), increase in traction of 38-239% (95% in this study), increase in milk from 0-190% (10% in this study) and changes in expenditure on trypanocides from 75% decrease to 122% increase (50% decrease in this study). It can be seen that the benefits reported in our study from trypanosomosis are within the range of findings from other studies.

High level participatory approach more successful than low-level participatory

The project followed a high-level participatory approach and had higher farmer involvement in activities, fewer lost screens, higher contributions from farmers, greater short term sustainability and was evaluated more highly by farmers than previous low-level participatory projects in the study area. Participatory evaluation was cheaper, quicker and more available to farmers, and produced results similar to formal data collection and epidemiological cohort studies. There is concern that participatory data is not reliable, but the accuracy of well-conducted PRAs shown in this study has been demonstrated in other studies (Gill, 1991). PRA also allowed evaluation of the livelihood impacts of vector control by moving beyond the direct benefits to what changes these would make to farmers' lives, and empowered farmers to better manage AAT.

Participatory vector control is not sustainable because of high transaction costs

A major research focus for the participatory vector control project was investigation of the sustainability of participatory control. While it is reasonably clear that community tsetse control works, and it is also clear that it does not continue without external support, but there is no consensus in the literature as to the reasons for this.

One school of thought holds that failure of vector control to continue is due to the low-level of participation (Barrett and Okali, 1998; Catley and Leyland, 2001). We found no evidence for this; the quantity and quality of participation was high but community control was not very attractive to farmers and there was a high drop-out of villages continuing with control even in the short term.

It is argued that after control is successful, it becomes of low priority to farmers, who think the disease is gone (Laveissiere *et al.,* 1990; WHO, 1999). In this study AAT was of high priority to farmers, vector control was handed over to farmers after a short period (six months), and farmers visited both areas where previous vector control had stopped and tsetse returned and neighbouring non-intervention villages where disease continued at high prevalence throughout the study. In short, farmers prioritised AAT, believed vector control was successful, and knew disease would return if it stopped; but this did not lead to sustainability.

Other authors posit that by reducing the cost and complexity of community control, sustainability can be achieved (Okoth and Nanyeenya, 2005). Again we found no evidence for this; the cost of screens at $2 per household is affordable by even poor farmers and farmers considered themselves to be fully competent to carry out control, yet control did not continue.

Our conclusion was that the high transaction costs of setting up and maintaining the institutions to deliver control, were the major threat to sustainability. The weakness of institutions to deliver control is seen by the high level of free-riding: no less than 81% of farmers. Reviews of previous participatory projects also found farmers pledged less than was needed to maintain vector control, and contributed less than they pledged (Kamuanga, 2003). Vector control with baits is a local public good, the benefits which can be entirely captured by a community choosing to implement it. But because excludability is low, rational individuals have incentives to under-contribute resulting in failure to provide vector control. In theory the high benefits (payoff) achievable from co-operation can be an incentive for group management, but for this to occur certain institutional factors are required. Among these are the ability to exclude from benefits and/or impose sanctions for non-compliance and a high dependency on the managed resource (Rasmussen and Meinzen-Dick, 1995). These features are absent from community vector control resulting in failure to generate the contributions needed to maintain control.

A further sustainability barrier for control with cattle-baits was that while treating screens with insecticide is a pure public good, non-rival and non-excludable, spraying cattle is a mixed good with private as well as public good benefits. Generally seen as an advantage, this has the disadvantage of moving the activity into the private arena. We found that no sanctions were applied if farmers chose not to spray their cattle and it was harder to observe compliance; as a result participation in group cattle-spraying was lower even than that in screen-placing.

Thirdly, poor farmers are more willing to pay for cure than prevention; not paying for preventative goods entails risk of loss, while not paying for curative goods certainty of loss. A case in point is the global market for human drugs that treat disease is $300 billion, while the global market for vaccines (preventative drugs) is $5 billion (Kremer and Snyder, 2000).

Participatory control needs external support, high benefit- cost ratio justifies this

The conclusion is that failure of community vector control to continue (and to be spontaneously adopted) is due to intrinsic characteristics rather than approach failures. This implies that community vector control will need continued support. This is especially important for small-scale control as there is a high risk of tsetse re-invasion into cleared areas. At present, community vector control programmes do not incorporate the need for continued support in program design, and many mistakenly believe that community vector control will continue after the project comes to an end (Maiga and Diabate, 2001). The need for continued support is not an argument for abandoning community vector control; indeed the high benefit-cost ratio often makes this an attractive strategy for rural development. In some cases (e.g. extremely high AAT prevalences, high levels of drug resistance) vector control is likely to be the single most appropriate control strategy and participative control compares favourable to other vector control methods in terms of cost while providing additonal social benefits such as community empowerment.

Problems with the study, its analysis and interpretation

This study was carried out in villages of high AAT prevalence and the benefits realised are situation specific. Testing two evaluations in the same villages (vector control and training farmers) raises attribution of effect issues. These were accounted for statistically, but it might have been preferable to include additional control villages where vector control took place without training. This was not possible because under the high-level participatory approach used for the vector-control project farmers were responsible for choosing interventions and all elected for training. Villages were not randomly allocated and we compensated for this by comparing baseline measures to judge comparability. An experimental design would have been stronger but was not possible because of the small number of villages available.

6.2.2 Control with trypanotolerant cattle

The second strategy evaluated for trypanosomosis control under risk or in the presence of trypanocide resistance was keeping trypanotolerant cattle. In the study areas, Baoulés were kept in the east and N'Dama in the west.

AAT much less in trypanotolerant cattle, but only in traditional systems

The much lower AAT prevalence in N'Dama cattle documented here has been frequently reported. However, AAT disease was not negligible and losses from morbidity and mortality were of major concern to farmers. It is know that that trypanotolerance is relative rather than absolute and that trypanotolerant breeds can be severely affected if the level of challenge is high enough (Murray *et al.,* 1979; Trail *et al.,* 1991). Nonetheless, in those cases where N'Dama were parasitologically positive for AAT, they had significantly higher PCV than positive Métis or Zebus. Ability to control anaemia is a feature of trypanotolerant cattle (Trail *et al.,* 1991).

Our finding that infections with gastro-intestinal parasites were significantly lower in N'Dama cattle, and that farmers reported N'Dama cattle were more tolerant of heat stress and less nutritionally demanding than Zebus, are consistent with other reports (Agyemang, 2005).

An important and concerning finding was that while prevalence of *T. vivax* was significantly lower in Baoulé, prevalence of *T. congolense* was not. This could be partially explained by the location of Baoulé in areas of higher risk, but even when comparing cattle in the same village there was no significant improved resistance to *T. congolense* infections in Baoulés versus Zebus and Métis. Murray *et al.* (1981) also report that under natural field conditions, N'Dama are significantly more resistant than Zebu to tsetse transmission of *T. vivax*, but there was not significant difference in the case of *T. congolense*. Under artificial challenge, Mattioli *et al.* (1999) found that trypanotolerant N'Dama cattle were adversely affected by *T. congolense* and mixed *T. congolense/T. vivax* infections, (while pure *T. vivax* infection did not produce appreciable negative effects on their health and productivity). Studies in Burkina Faso report a substantial minority of Baoulés were as susceptible as Zebu (Roelants *et al.,* 1987). The implication is that in the eastern zones, where the problem of AAT and trypanocide resistance is most severe, AAT mortality and morbidity is highest, and *T. congolense* predominates, the strategy of keeping trypanotolerant cattle may be less effective, at least in terms of reducing prevalence. However, even in this area keeping trypanotolerant cattle can be regarded as a potentially useful coping strategy given the higher PCV, more days worked and better reproductive performance of Baoulé; the favourable performance of trypanotolerant cattle compared to other breeds, especially when productivity is measured per kg or per kg metabolic weight, and when exposed to trypanosomosis is abundantly documented (Feron *et al.,* 1988; Agyemang *et al.,* 1994).

Advocates of trypanotolerant cattle often claim that their lack of popularity among farmers stems from mistaken beliefs about poor productivity (Holmes, 1997; Agyemang, 2005). We found no support for the hypothesis that farmers have false beliefs about the productivity of trypanotolerant cattle that are leading them to discard the breed. In fact, we found that farmers regard the productivity (and disease resistance) of trypanotolerant cattle highly. Undesirable features of N'Dama are: temperament (not docile, poor herd instinct, stubborn and difficult to train); slowness while working; short legs which make them liable damage the crop while weeding; slow growth; slow weight gain; smaller overall size; low sale price and slower sale. The higher sale price of Zebu cattle and the fact that only Zebus are regarded as "beautiful" by farmers indicates that they have greater utility than other breeds as financial instruments and status objects. This was also the finding of Kamuanga *et al,* (2001) who showed that lower sale price of trypanotolerant cattle is not entirely due to smaller size and body weight.

Further evidence for farmer preference can be seen in population trends for different breeds. A recent review found that, while trypanotolerant cattle populations in west and central Africa were increasing over the period 1985-98, populations of cross-breeds were growing at a faster rate; in effect, the proportion of trypanotolerant cattle is in decline (Agyemang and Rege, 2004).

Furthermore, in the areas of introduction (Benin, Burkina Faso, Cameroon, Central African Republic, Gabon, Ghana, Nigeria, Togo and Zaire) populations of trypanotolerant cattle (N'Dama, savannah Shorthorns and dwarf Shorthorns) are disappearing, as are populations in inland forest and sahelian countries.

Farmers are aware of the disease resistance of N'Dama cattle, but our finding was that disease resistance is currently not their main criterion in choosing breeds. Furthermore, the importance of disease resistance is becoming less important due to the widespread availability and use of drugs, and the decline of tsetse populations through changes in land-use and climate.

We include there are constraints to widespread use of trypanotolerant cattle as a strategy for AAT management in west Africa. However, if drug resistance removes the option of drug use, keeping trypanotolerant cattle becomes more attractive. Farmers are unaware of the phenomenon of drug resistance and it is possible that better knowledge of this would result in greater preference for trypanotolerant breeds. This is especially the case if drug resistance is, as some fear, an irreversible phenomenon. The precautionary principle would justify support for safeguarding the genetic resource of trypanotolerance *in situ* or *in labo*, as a fall-back option for the worst-case scenario of total resistance to existing trypanocides, combined with failure to develop new drugs.

Problems with the study, its analysis and interpretation

This was a descriptive study and as such questions of causality cannot be answered. The suggestive finding of relatively poor AAT resistance of Baoulé cattle in Burkina Faso compared to good AAT resistance of N'Dama in Mali and Guinea requires further investigation. Breed allocation was by phenotype supplemented with information from farmers; this was imprecise and some animals may have been misclassified. Mortality data was based on farmer reports and assumes accuracy of diagnosis.

6.2.3 Provision of rational drug use information

The third strategy for the management of trypanosomosis under risk or in presence of resistance was the provision of rational drug use information. This strategy posits trypanosomosis control through drugs but use of drugs exerts selection pressure for the development of resistance, and a balance must be made between sufficient treatments to avoid loss while minimising the development of resistance. The problem is essentially one of optimal use, trading off the benefits of therapy and prophylaxis against the externality of resistance.

Target groups for RDU information

Most RDU initiatives have targeted prescribers and clinicians. Legal service providers are accessible and training is uncontroversial. We carried out one trial among service providers in Guinea. However, in sub-Saharan Africa where there are many cattle, few veterinarians, much disease and wide availability of veterinary drugs, then farmers and non-professionals have necessarily an important role in veterinary drug administration. Community members have been found to be the most important providers of treatment in South Africa (Gehring, 2005), Ethiopia (Tikue, 2001), Kenya (Mugunieri and Murilla, 2003; Roderick *et al.,* 2000) and Zambia (Van den

Bossche *et al.,* 2000). Although legislation does not recognise the role of farmers in treating their sick cattle, we targeted farmers in another RDU trial. The remaining trial involved the establishment of primary animal health services (paravets). This concept, taken from primary human health (WHO, 1978), is gradually gaining acceptance.

Simple strategies of information provision can be effective

Information strategies employing multiple iterated modalities of communication have been found to be most effective in improving drug use (Ross-Degnan *et al.,* 1997). This method was followed in the training of paravets, and to a lesser extent, the workshops for service providers. The trial targeting farmers, however, consisted simply of giving farmers a leaflet, short enough to be included as a pack insert, as our objective was testing practical interventions that could be applied at wide-scale and low-cost using existing channels. Though more intensive training gives better results, simple interventions can be worthwhile. For example, distributing a colour booklet containing information on malaria without any other interventions, resulted in a marked and significant improvement in knowledge in families receiving the booklet (Blair and Shiels, 2002).

Strategy 1: RDU information given to farmers

We measured three outcomes: changes in knowledge, changes in practice and changes in clinical outcomes. The theoretical basis for this was Health Care Behaviour Models, which predict that change in knowledge precedes and exceeds change in behaviour, and change in behaviour leads to, but many not result in, better clinical outcomes (Andersen and Neuman, 1975).

Improvement in farmer knowledge was measured in three areas: diagnosis, choice of drugs and drug administration. Giving information resulted in significant and substantial improvements in knowledge in all three areas. There was also improvement in the control group, probably due to participation in the survey, in which animals were tested for AAT, and positive animals treated. (This underlines the importance of having a control group and not relying on pre and post measures.) Knowledge at five months was less than at two weeks; this is expected as learning follows a decay curve if not re-enforced, and implies information on drugs should be continuously available, one possibility is through pack inserts, another is posters and/or leaflets at the point of sale. Although some studies have found that correcting wrong knowledge is more difficult than transferring correct knowledge, this was not the case in our study. Possibly because the knowledge imparted was technical and not in conflict with any belief system.

RDU information improves farmer practice and decreases drug under-dosage

Improvements in practice were also assessed. The improvement in dosage was particularly encouraging, given the highly significant relation between under-dosage and treatment failure. Farmers may under-dose animals in order to treat more for a given outlay, but our finding that farmer concern about dosage (of those experiencing treatment failure 47.2% said it could be due to wrong dosage), is an incentive for farmers to give correct dosages and suggests informing farmers on dosages would be valuable. In the medium term, farmers receiving information had significantly greater use of preventative drugs and diagnosed more sick animals than farmers who did not receive information. There was a 35% increase in farmers giving the correct dosage and a 8% increase in use of ISMM in the test group versus the control. This improvement is high: Snyder *et al.* (2000) performed a meta analysis of the degree of behavioural impact of 48 media health campaigns (170 000 participants), typically comparing treatment communities with control communities or exposed vs non-exposed audiences. On average, behaviour change occurs among approximately 7% to 10% more of the people in the campaign sites than those in control communities.

Better clinical outcomes and fewer treatment complications with RDU information

Improvements in clinical parameters were significant only for decrease in temperature. The follow-up period of two weeks was probably too short to find differences in haematocrit improvement, given cattle had been ill for some time before treatment. The wide (more than physiological) variation in weight suggests that the method chosen for estimating weight (girth measure) was not sufficiently precise; however, more accurate measures were not logistically feasible. Nonetheless, the significantly greater decrease in temperature in the animals treated by farmers in the test group suggests better treatment quality in this group. A significant and substantial difference was detected in the level of side-effects in the two groups. Incorrect injection technique can result in trauma, inflammation and infection in the patient and needle stick injury to the provider, as well as decreasing the effectiveness of the drug (Hutin *et al.,* 2003). Use of dirty injection equipment, contaminated water, and lack of hygiene in administration are commonplace and lead to infections and treatment failure (Hauri *et al.,* 2003). High levels of complications are associated with unhygienic administration, a survey in Uganda found 43% of people has experienced complications after injections, the most common being abscesses (van Staa and Harden,1996) and the simple hygiene information we gave resulted in an important decrease in side-effects.

No evidence of harm from RDU interventions

There was no increased cattle mortality in the villages receiving RDU information and a trend to decreased mortality. The significantly higher haematocrit in test villages and more appropriate use of drugs suggest benefits to cattle health. In only one area there was some suggestion that drug use post-intervention may have been inappropriately high, implying messages need adjustment according to disease prevalence and current drug use. The fact that there was no significant difference in prevalence between the two groups was anticipated. AAT is a vector transmitted disease, with many alternative hosts, and the trypanosome population in tsetse flies and other hosts would dramatically exceed the trypanosome population in cattle. Only in situations where tsetse fed almost exclusively on cattle and all the cattle were treated, would improvements in treatment be likely to reduce prevalence.

Problems with this study, its analysis and interpretation

A weakness of this study was the short follow-up period (five months) making it difficult to estimate mortality from AAT. Animals were only checked twice so no accurate assessment of intervention impact on cattle production was possible. The study did not directly assess the effects of RDU on trypanocide resistance. Given lack of knowledge on the natural history of trypanocide resistance and absence of cheap, accurate and rapid tests for resistance, studies on a wide scale and long time would be required to investigate the relations between provision of information, change of behaviour and development of resistance.

Strategy 2:Establishing primary animal health services

The second strategy to be evaluated was establishing primary animal health services by training farmers in integrated trypanosomosis control (paravets or community animal health workers). Training covered vector control, diagnosis and treatment of AAT, diagnosis and treatment of other diseases, use of traditional medicines and cattle nutrition.

Training paravets increases ability to carry out vector control, knowledge of animal diseases and nutrition and skill in diagnosis and treating disease

We found large and significant differences in knowledge and skill both before and after training, and between trained farmers and comparable farmers who had not been trained. Ten months after training, there was no significant decrease in the level of knowledge and skill. Training paravets is an established development intervention; evaluations, though not always rigorous (Curran and MacLehose, 2005) are usually positive (Martin, 2001), our findings on the positive effects of training paravets are in line with previous studies.

Integrating vector control, trypanocidal drugs, health and nutrition successful

Integration of trypanosomosis control strategies is often advised, both because each strategy has limitations and because perverse effects are possible. For example successful vector control in the absence of training and information on drug use has resulted in paradoxical increased use of trypanocides (Kamuanga, 1999). In this study training of farmers in drug use, diagnosis of trypanosomosis, other cattle diseases and nutrition, was combined in four villages with vector control, and in another three villages was given as a single intervention. There was a clear synergistic effect between training and vector control. For example in the villages without intervention the annual expenditure on trypanocides per farm household was 22 140 FCFA, while in villages with paravets the expenditure was reduced to 14 234 FCFA. However, in villages with both vector control and paravets, expenditure on trypanocides was only 9345 FCFA.

Models useful for evaluating health service performance

Psycho-social models are useful in the evaluation of health-seeking behaviour because they can parsimoniously explain findings, ensure elements are not omitted, strengthen evidence of causality, and give conceptual coherence to evaluations (Kennedy and Abbatangelo, 2005). Several models have been used in human health seeking behaviour: the Theory of Reasoned Action (Ajzen and Fishbein, 1980), the Transtheoretical Model (Prochascha *et al*., 1997), and Social Cognitive Theory being among the most commonly used (Bandura, 1986). All of these are individual-based, but because our focus was on utilisation of paravets in this evaluation we used a supply side model, the ‘Four A’s model’, which is widely used by medical geographers, health economists and evaluators of health services. We evaluated paravets relative to other service providers, because in developing countries, where health services deviate profoundly from best practice and the ideal health care option may be infeasible and unaffordable, the most pertinent question is the relative rather than the absolute quality of health provision.

Paravet services are available, accessible, affordable and acceptable to users

We found that primary animal health services were available and accessible; this was not surprising given their location in the community. In terms of providing advice on drug dosage and weight estimation, paravets were better than professionals. This could be because paravets were well-trained in dosage estimation and gave treatments on a daily basis, whereas professionals gave treatments infrequently and generally employed counter-staff (unqualified) to give drugs and advice. Dosage for trypanocides is complex, so it is perhaps not surprising professionals were not able to remember it. Studies in human health have similarly found that qualifications did not affect competency at prescribing common drugs (Guyon, 1994). Paravets were the most affordable of trained service providers and the most trusted of all service providers. Studies in human health have reported greater trust in community providers than in qualified doctors and nurses (Tawfik *et al.,* 2002). In developing countries trust may be more linked to social relations, knowledge and common interests than to qualifications and professional membership.

Farmers using paravets get more correct treatments, and have less AAT mortality

The study also showed that, as reported by farmers, there was significantly lower mortality and a higher percentage of rational treatments when paravets were responsible for treatments rather than farmers or other untrained service providers. There is often concern that training paravets will have negative effects, but this is yet to be reported in a project evaluation or study.

Problems with the study, its analysis and interpretation

In Guinea, informal sector service providers were not willing to participate in the study, and their level of activity had to be indirectly assessed. While direct observation of service quality took place in Burkina Faso, in general quality of service provision was indirectly assessed through service provider knowledge and qualifications and farmer reports on clinical outcomes.

Strategy 3:Training service providers

Training service providers is the most used and studied RDU intervention and our results were typical, with significant improvements in diagnosis and treatment (WHO, 1987). The relatively high level of baseline performance (appropriate diagnosis, appropriate drug choice and correct dosage all >90%), made it more difficult (and less important) to show improvements in performance. Greatest improvements were seen in increasing the use of specific signs in the diagnosis of AAT (more than three-fold increase in the test group), and in decreasing the number of treatments inappropriate for the clinical signs (more than halved in the test group). However, specific diagnostic signs were reported in less than 20% of cases of AAT, whereas the study in Mali had showed that these were present in 81% of cases presented by farmers. It is possible that the cases presented in Guinea had less marked clinical presentation, as AAT is generally milder in N'Dama cattle. But also, systematic reviews have shown that educational interventions that have successfully increased clinicians' knowledge may fail to have a significant impact on clinicians' behaviour (Davis *et al.,* 1999). Behaviour depends on many other factors as well as knowledge, including client expectation (or demand) and the convenience and interest of the Service Provider. There was an improvement in the performance of both groups during the period studied that could be due to a Hawthorne effect, that is, improvement due to the service providers knowing that their behaviour was recorded (Parsons, 1974), or because recording of treatments led to reflection and self-learning (feed-back promoted learning), or because the supervisors recording treatments unconsciously gave feed-back on the treatments (e.g. by frowning or looking puzzled when incorrect treatments were mentioned).

Problems with the study, its analysis and interpretation

In this study clinical outcomes were not observed. We assume that if diagnosis and dosage are better then there will be better management of disease and less encouragement of resistance as is standard in the RDU literature. Reliance on service provider recall and disclosure is a methodological limitation given the well documented discrepancies between service provider actual and reported behaviour (Harries *et al.,* 1996).

6.2.4 Benefit-cost ratios for the different interventions

A benefit-cost analysis was calculated for each intervention based on reduction in mortality in a typical village. The detailed impact assessment of vector control showed this was the single biggest benefit and equal to at least half of the total benefits. All strategies had more benefits than costs under the typical epidemiological conditions prevailing in the cotton zone, but sensitivity analysis suggested that vector control and keeping trypanotolerant cattle had higher costs than benefits when AAT prevalence was low. RDU had least benefits but costs were lowest, vector control has highest benefits and highest costs. A higher benefit-cost ratio for information/training initiatives was also the finding of an extensive review of malaria cost effectiveness studies: interventions aimed at improving drug use were ten times more cost effective than those aimed at vector control (Goodman *et al.,* 1999).

There are important considerations in the adoption of AAT control strategies beyond benefit-cost ratios, including acceptability, equity, practicability and effects on the externality of resistance. In terms of practicability, providing information to farmers is an attractive strategy as it can be adopted by individuals and its costs are lowest. For establishment of primary animal health services and vector control the minimum unit of application is the community, and for vector control there are many advantages for application over large areas. Our work suggests that substantial benefits from trypanotolerance are only realised where trypanotolerant cattle predominate in the region. In terms of acceptability to all stakeholders both provision of RDU information to farmers and paravet training are problematic, especially in areas where private veterinary practice is established. The costs of switching to trypanotolerant cattle would result in financial loss to farmers, raising equity and feasibility issues. Vector control is the only strategy which can proactively contain resistance, though keeping of trypanotolerant cattle would allow living with resistance, as to a lesser extent would paravet training (because improving nutrition and treating other diseases would enable greater tolerance of AAT infections by resistant trypanosomes). Training formal sector service providers is acceptable to all stakeholders and has large impact for low cost. Improving quality and value added services in the formal sector might also make this sector more attractive, and hence decrease use of the informal sector where quality is probably lower and regulation certainly more difficult (although prices are more affordable and accessibility better).

Implication of the strategies for trypanocide resistance management

These analyses are based on direct savings from better management of AAT and not the benefits from preventing or containing trypanocide resistance. Strategies to control antimicrobial resistance have been divided into those seeking to decrease the emergence of resistance by restricting or using antibiotics more effectively and those which seek to eliminate or reduce transmission of resistance through surveillance, decontamination or outbreak management (Smith *et al.,* 2001). Establishing paravets, training existing service providers and informing farmers fits in the first category, and vector control and keeping trypanotolerant livestock the second.

Vector control is the b strategy for resistance containment, and has the added advantage of potentially eliminating resistant strains. Management of resistance is a public good, furthermore it is international (resistance knows no frontiers) and trans-generational (drug misuse today causes resistance tomorrow) and so has a strong claim to external support. There have been no field studies on the reversibility of trypanocide resistance, but modelling and some evidence on the reduced fitness of resistant strains, suggests this may be possible.

In preventing the practices that foster resistance, training paravets and informing farmers were useful interventions. There are few scientific or socio-economic grounds for opposing these, but there are policy constraints as our workshops showed. National regulations in most sub-Saharan countries do not allow farmers to treat their own animals, and vets usually oppose automedication and paravets. International policy is also unfavourable: the OIE (draft) recommendation is that antimicrobial agents should be "*prescribed by a veterinarian*" and *"administered to animals by a veterinarian, or under the supervision of a veterinarian, or by his/her agent*" (OIE, 2000). It is argued that because misuse of antimicrobials can cause resistance, they should be restricted to veterinary prescription (Leonard *et al.,* 1999). However, there is no evidence that restricting drugs to veterinarians is possible, effective or of net benefit; indeed, the evidence points the other way. Several studies have shown that trained farmers can effectively treat their animals generating significant benefits (Holden, 1997; Hanks *et al.,* 1998; Huttner, 2000), while restricting animal drugs to vets is not possible in developing countries due to a shortage of professionals, and stringent regulations would damage livestock health and production (Lobry, 1989). Training existing formal sector service providers was also effective and less controversial. Costs are lower as service providers are already in place, and professional service providers have more clients than paravets, so potential outreach is greater.

Summary of strategy testing

Trypanosomosis is a major constraint in west Africa, and trypanocide resistance an emerging threat that undermines the most important method of AAT control (use of trypanocides). Improvement of trypanosomosis management and prevention/containment of resistance are urgently required. But given competing demands for scarce development resources there is need for both careful targeting of interventions and supporting these with favourable policy.

Where resistance to trypanocides is established the most efficient, effective and acceptable solution is likely to be vector control with external support.

Under the present socio-economic conditions, initiatives to promote trypanotolerant cattle may not be successful. However, in areas where AAT is not a major problem because of a predominantly traditional farming system, where *T. congolense* is infrequent and where the N'Dama breed predominate, initiatives to inform farmers of benefits of trypanotolerant cattle of which they are unaware (the problem of drug resistance) may be useful. In any case, the genetic resource of trypanotolerance should be preserved, as a fall-back strategy against the eventuality that no new trypanocides emerge, and that funding is not available for vector control.

Where existing policy supports establishing primary animal health care and informing farmers this should be promoted. Where policy is hostile to this, efforts should be made to engage stakeholders in analysing existing policy, its costs and benefits and equity, and developing policy that better meets the needs of stakeholders. Overcoming the hostility to paravets shown by private veterinarians and decision-makers in Mali and Burkina Faso, presents a considerable challenge. Methods such as Regulatory Impact Assessment could provide an objective framework for analysing present and alternative animal health system systems (Kirkpatrick, 1992).

Formal sector service providers should receive training in trypanosomosis and resistance management. This could be supported by drug companies and profession organisations and thus is more attractive than strategies which require public or non-profit sector funding.

Integrating strategies increases effectiveness and decreases probability of adverse impacts.

6.3 Modelling trypanosomosis and trypanocide resistance

The mathematical model gave some interesting insights into the problematic of trypanosomosis and resistance. The first was that, given the transmission characteristics of AAT, simply changing the breed profile can bring about dramatic changes in disease and resistance development. The implication is that change in cattle breed (itself driven by socio-economic factors) is driving the emergence of resistance rather than change in drug use. The second conclusion is that the situation in terms of prevalence, morbidity and mortality and resistance may deteriorate considerably from its present level. Resistance typically follows an S-shaped curved, this model suggests that we are still on the accelerating portion of this curve. The third and optimistic conclusion was that vector control, even if only resulting in small increases in tsetse mortality, can rapidly reverse the situation. This is in agreement with other models of tsetse dynamics (Hargrove, 2003b).