Trypanosomosis in Goats in Zambia

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The Regional Tsetse and Trypanosomosis Control Programme (RTTCP) is a project of the Southern African Development Community (SADC). In 1986 the European Commission provided funding to the Programme to help it develop and apply new methods of tsetse and trypanosomosis monitoring and control in Malawi, Mozambique, Zambia and Zimbabwe. Funding was extended in 1992 and the Programme was evaluated in 1995.

The Programme's goal is the control of tsetse to help achieve sustainable rural development in southern Africa. The RTTCP assists national programmes in strategic planning, research and development, training, information, and technical coordination of tsetse and trypanosomosis control operations.

Since 1988 the RTTCP has provided funds to Kakumbi Tsetse Research Station in eastern Zambia, where the research described in this report was done.

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The series of experiments provided a demanding daily workload which had to be completed under difficult conditions; only during the second year's work was a reliable water supply reinstated at the station and a mains electricity supply connected. The successful completion of the research is due to the sustained efforts of Mr A. Chilenga, Mr H.K. Chisanga, Mr J. Silutongwe and their assistants. We warmly acknowledge their contributions.

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Contents

Summary

Over a four-year period, a series of experiments was performed at Kakumbi Tsetse Research Station in eastern Zambia to study the effects of trypanosomosis on the health and productivity of local goats.

Thirty-nine female weaner goats were purchased from tsetse-free areas in May 1988 and used in the first experiment in 1989. The goats were randomly allocated into groups. A 'protected' group received prophylactic treatment with isometamidium chloride at a dose rate of 0.5 mg/kg body weight at 12-week intervals. An 'unprotected' group received individual, curative treatments with diminazene aceturate at a dose rate of 7.0 mg/kg body weight when goats became parasitaemic and packed cell volume (PCV) fell to 20% or below. Another group in this year received no trypanocidal treatment. In the following years, surviving goats and their offspring were again randomly placed into similar 'protected' and 'unprotected' groups with 'unprotected' goats receiving curative treatments as described above. Every year, a weekly protocol was followed: goats were weighed, rectal temperatures were taken and blood samples were collected to determine PCV and detect parasitaemia. Tsetse were trapped in the grazing area used by the goats and flies were dissected. Apparent densities of tsetse populations and tsetse challenges were calculated and matched with weekly prevalences of trypanosomal parasitaemias. The goats were housed at night in a lion-proof house with a raised, slatted floor to separate them from their droppings. A male goat was introduced in a different month each year to ensure that the breeding cycle coincided with different seasonal changes in the prevalence of trypanosomal infections in goats.

The practice of herding goats and allowing them to browse extensively, coupled with the use of raised flooring in the goat house, was effective in preventing the build-up of helminth infection. Therefore, trypanosomosis was not complicated by helminthosis. The prevalence of trypanosomal infections peaked seasonally, generally between July and October, following seasonal increases in tsetse challenge. However, the timing and intensity of tsetse challenge varied each year. In 1989, mortality (42%) was alarmingly high in untreated goats: sick goats had significantly reduced PCV and body weight, and their rectal temperatures were generally elevated.

When 'protected' and 'unprotected' goats were compared in 1989, 1990 and 1991, small differences in PCV, body weight and rectal temperature occurred when prevalences of trypanosomal infections were high. However, trypanosomosis had a major impact on fertility. In 1990 and 1991, increases in prevalences of trypanosomal infections in late pregnancy were associated with a 28% parentage reduction in fertility of 'unprotected' goats. In 1990, trypanosomal parasitaemias in late pregnancy were individually associated with abortions and stillbirths. Chemoprophylaxis maintained high levels of fertility: 91% of 'protected' goats kidded successfully in 1989, 1990 and 1991. The degree of protection conferred by isometamidium, in terms of reduced trypanosomal parasitaemia, was estimated to be 70%.

In 1992, goats were placed randomly into 'protected' and 'unprotected' groups at the time of mating, which was chosen to coincide with the time of peak prevalence of

trypanosomal infections. Only 57% of the 'unprotected' goats kidded compared with 79% of the 'protected' group.

There was strong evidence that older goats were more susceptible to the effects of trypanosomosis than younger goats. In addition, the goats brought to Kakumbi from tsetse-free areas had significantly lower PCVs than their offspring throughout periods of high incidence of infection in 1990, 1991 and 1992. This indicated that goats born under tsetse challenge may have developed a degree of protective immunity against the effects of trypanosomosis.

Despite clear evidence that chemoprophylaxis significantly reduced the effects of trypanosomosis in goats, it is difficult to make practical recommendations for control under village conditions. The seasonal peak of tsetse challenge varied from year to year, a breeding season is not used in traditional systems and the administration of isometamidium requires skilful administration. We concluded that before recommending control measures, farmers must first be made aware of the losses that trypanosomosis can cause.

Chapter 1. Introduction

For many years, it was widely believed that goats and sheep were little affected by trypanosomosis (Stephen 1970). These small ruminants survive light to medium tsetse challenge without any specific intervention to reduce or remove tsetse flies or the infections that they transmit. The apparent ability of goats to thrive under these conditions has been variously attributed to their agility, fecundity and tolerance of trypanosomal infections (Anon 1931; Hornby 1952; MacLennan 1970). Nevertheless, there is evidence that goats and sheep naturally acquire trypanosomal infections (Griffin 1978; Hecker et al 1993, Hecker 1994). Hecker (1994) found that nutritional supplementation delayed but did not prevent the establishment of trypanosomal infections in sheep exposed to high trypanosomosis risk in northern Côte d'Ivoire. Many of these infected sheep died, although trypanosomosis was diagnosed as the cause of death only in some of the animals. Experimental infections produce serious pathology which is associated with a range of severe clinical signs, such as raised rectal temparature, increased metabolic rate and reduced feed intake (Zwart et al 1991). Field studies have been done to examine the impact of naturally acquired trypanosomosis on productivity (Griffin and Allonby 1979a) and it is now recognised that trypanosomosis probably constitutes a major, widespread constraint on small ruminant production (Luckins 1992).

Trypanosomal infections in goats and sheep are sometimes difficult to detect because of the low parasitaemias that occur. This results in a serious underestimation of the extent of the problem (MacLennan 1970) and, so, control measures have not commonly been applied. Chemoprophylactic treatment of goats in a tsetse-infested area of southern Tanzania improved productivity significantly (Hendy 1988). However, four prophylactic treatments per year were used in this study, even though the disease was not routinely diagnosed. It is doubtful if such a control regimen would be adopted by subsistence livestock owners.

The results of research have seldom benefited primary producers in Africa who face immediate, practical problems in their daily lives. In the case of small ruminant production, research was judged to have failed (Gatenby 1982) partly because the wrong questions were being asked. Goats and sheep are important in sub-Saharan Africa (Winrock International 1992) where tsetse-transmitted trypanosomosis is one of the largest disease constraints on domestic ruminant production. In overall terms, the prime need in sub-Saharan Africa is to feed the burgeoning human population; increasing the efficiency of small ruminant production is one means of improving food security.

Appropriate research is needed to help the farmer to improve production. The opportunity for a long-term study of trypanosomosis in goats arose when a tsetse research station in the Luangwa Valley of eastern Zambia was being rehabilitated. An underlying aim of the work was to produce simple recommendations to improve goat productivity in the area around the station where there was heavy tsetse challenge. The work reported here also created the opportunity for the station's technical staff assigned to field research to receive on-the-job training and gain valuable experience.

Over a four-year period from July 1988 to February 1993, a series of experiments set out to answer a number of questions:

- are goats of the local breed affected by trypanosomosis?
- what clinical syndromes occur?
- what is the mortality rate?
- what is the impact of trypanosomosis on growth rate?
- what is the impact of trypanosomosis on fertility in the female goat?
- what advice can be given to farmers to improve production?

The use of trypanocidal drugs in these experiments was not simply to demonstrate that they improved health but to examine, under heavy tsetse challenge, the severity of the constraint that trypanosomosis imposed on health and productivity when trypanocidal drugs were not applied.

This report presents data on the incidence of trypanosomal infections in goats in Chapter 3 and those on tsetse in Chapter 4. The results of individual experiments are presented separately in Chapters 5 to 9. These are discussed fully in the final two chapters.

Chapter 2. Materials and methods

2.1 Location of the studies

The studies were carried out at the Kakumbi Tsetse Research Station (Figure 2.1) in the Luangwa Valley, eastern Zambia (13°06′S 31°48′E), which is an area of sparse but increasing human settlement on the edge of the South Luangwa National Park. Heavy tsetse infestation precludes livestock production and traditionally the local inhabitants have relied on the abundant wildlife for meat. Milk is very scarce since cattle are not kept.

The predominant vegetation of the South Luangwa National Park is mopane woodland *(Colophospermum mopane)* but the pasture areas of the goats were near the Luangwa River where trees of *Acacia* and *Combretum* species are common. Across the Luangwa River, opposite the study area, there are abundant mammalian hosts of tsetse flies in the South Luangwa National Park. They include warthog *(Phacochoerus aethiopicus),* bushbuck *(Tragelaphus scriptus),* kudu *(T. strepsiceros),* puku *(Kobus vardoni),* buffalo *(Syncerus caffer),* hippopotamus *(Hippopotamus amphibius)* and elephant *(Loxodonta africana).* Some hosts, e.g. bushbuck, puku and hippopotamus, occurred in or near the study area all the year-round but others visited only seasonally, e.g. elephants in October and November.

There are, generally, three distinct seasons. The hot, rainy season starts late in October and ends in April. During this season there are 900 to 1000 mm of rain and mean monthly temperatures in the shade vary between 26 and 28°C. The cool, dry season follows from May to August with temperatures between 19 and 25°C. In the hot dry season of September and October, mean temperatures are between 26 and 28°C.

2.2 Goat management

Goats were housed at night in a lion-proof house built with mopane poles and a thatched roof (Figure 2.2). A raised floor, made of slatted bamboo, separated the goats from their droppings to reduce infection with helminths. Each day, goats were herded in grazing areas from 0630, or from 0800 after samples had been collected, until 1530. Goats were returned to the house for a rest period of two hours at midday. No supplementary feed was provided and goats were watered at the river every day.

2.3 Parasitological methods

Blood samples were collected and measurements made in a pen adjacent to the goat house between 0630 and 0800. Blood samples were collected from each goat once or twice each week, according to the experimental protocol used in each experiment. Blood from a punctured ear vein was drawn into a heparinised, microhaematocrit, capillary tube; the tube was sealed and centrifuged for five minutes. Packed red blood cell volumes (PCVs) were measured with a microhaematocrit reader before the tube was cut about 1 mm below the buffy coat. Fresh preparations of the buffy coat were examined microscopically under phase

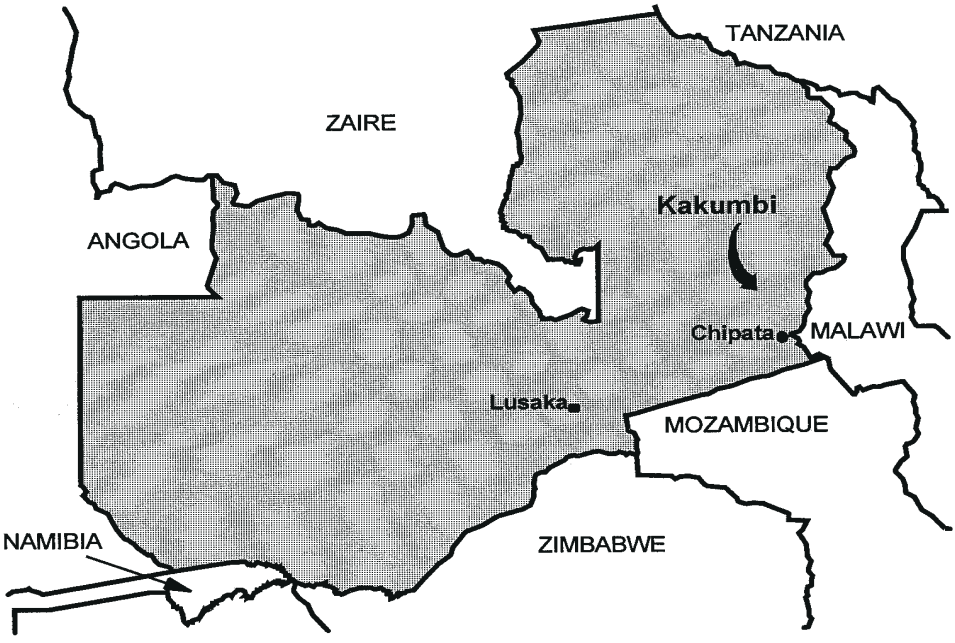


Figure 2.1 *Map of Zambia showing location of Kakumbi Tsetse Research Centre.*

contrast illumination for the presence of live trypanosomes (Murray et al 1977). Giemsa-stained thick and thin blood smears were also prepared and examined microscopically for the presence of haemoparasites. Faecal samples were collected and Trichostrongyle egg counts were made by a modified McMaster method (after Hansen and Perry 1994).

2.4 Treatments

Systematic prophylactic treatments with isometamidium chloride (Samorin®, Rhône Mérieux, France) at a dose of 0.5 mg/kg body weight, and curative treatments with diminazene aceturate (Berenil®, Hoechst, Germany) at a dose of 7 mg/kg body weight were used throughout the studies. Criteria for treatment are described in subsequent chapters for each experiment. Occasionally, injectable oxytetracycline at a dose of 7 mg/kg body weight was used to treat cases of anaplasmosis detected during routine blood smear examination.

2.5 Other measurements

Rectal temperatures were measured with a clinical thermometer once or twice a week, according to the particular experimental protocol. All goats were weighed once a week

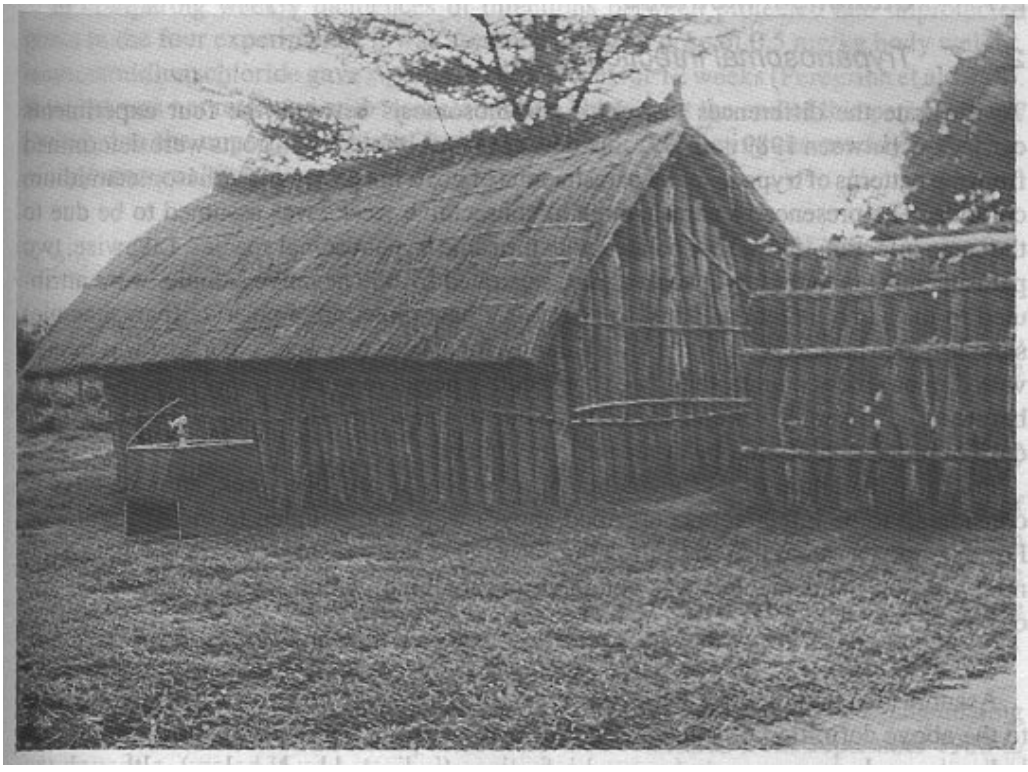


Figure 2.2 *The lion-proof house where the goats stayed (constructed entirely of locally available materials).*

in a sling attached to a spring balance. Daily rain and humidity were recorded at the meteorological station at Mfuwe Airport, 20 km from Kakumbi.

2.6 Sampling tsetse

Tsetse were caught using 10 blue F3-traps (Flint 1985) sited in the areas where goats grazed and browsed. The traps were baited with acetone and a mixture of 1-octen-3-ol, 3-*n*-propyl-phenol and 4-methyl-phenol (FAO 1992).

Each week, from Monday to Friday, the traps were set between 1330 and 1400 and trapped tsetse were collected between 1730 and 1800. The catches were stored overnight at 5°C. The number of tsetse of each sex and species caught in each trap was recorded. Live flies were dissected within 24 hours of being collected. Wings were removed and the degree of wing fray was scored on a scale of 1–6 (after Jackson 1946). The mouthparts were dissected and examined microscopically at 240× magnification for the presence of trypanosomes. The salivary glands and midguts of those flies with infected mouthparts were also examined for infection. Types of trypanosomes were identified following the method of Lloyd and Johnson (1924). From April 1991 the ovaries of all live female flies were dissected; they were scored on a scale of 0–7 (Saunders 1962) to estimate age.

2.7 Statistical methods

2.7.1 Trypanosomal infections

To illustrate the differences in risk of trypanosomosis between the four experiments carried out between 1989 and 1992, incidences of new infections in goats were determined from the patterns of trypanosomal parasitaemia of goats not protected with isometamidium chloride. The presence of parasitaemia in consecutive weeks was assumed to be due to the same infection if it was associated with the same trypanosomal species. Likewise, two parasitaemias recorded two weeks apart, separated by one negative sample, were attributed to the same infection. Thus, to count as a new infection, a positive (parasitaemic) sample had to be preceded by negative samples for at least two weeks. If a goat was treated with diminazene aceturate, then three consecutive negative weekly samples were required before a parasitaemia was considered to be due to a new infection. This allowed for 7–10 days of protection offered by diminazene treatment.

For the calculation of the 'incidence of infection' in any one week, animals already considered to be infected (as described above) were not included in the denominator. For example, assume that the following series of weekly results (where + = parasitaemic; – = non-parasitaemic) was obtained for an animal which was not treated on any occasion.

+ – + + – – + – – –

Assume also that the first + was preceded by at least two negatives. Then, according to the above definition of a new infection, this pattern of parasitaemia is interpreted as indicating only two separate (or new) infections (indicated by N below), although the animal was parasitaemic on four occasions.

N – – – – – N – – –

Individual values are included in (✓) or excluded from (x) the denominator for calculating the incidence of new infections, as follows:

✓ x x x x x ✓ x x ✓

Following a new infection (N), values are omitted as long as positive samples occur, or until the third in a series of consecutive negative samples is reached. In this example, the first two ticks (✓) correspond to parasitaemias defined as new infections and the third tick (✓) to the third negative sample recorded following a parasitaemic sample. In any one week the incidence of new infections in a group of animals is calculated as the sum of Ns divided by the sum of ticks (✓s).

Thus,

$$\text{weekly incidence} = \frac{\sum \text{ new infections}}{\sum \text{ new infections} + \sum \text{ presumed non-infected samples}}$$

In 1989, the species of trypanosomal infections were not all identified in the data available for statistical analysis. To allow direct comparisons between years, the species of trypanosome was ignored in the calculation of infection incidence in the other three years. When more than one trypanosomal species occurred, the infection was classified as a mixed one. The proportions of new infections occurring for each species were calculated for each age group of goats.

In comparing weekly incidences of infections between protected and unprotected goats in the four experiments, it was assumed that, at a dose of 0.5 mg/kg body weight, isometamidium chloride gave significant protection for 12 weeks (Peregrine et al 1988). If a goat was not retreated with isometamidium chloride at the end of this period, it was included in the unprotected group for the purpose of calculating the weekly incidence of trypanosomal infections.

2.7.2 Tsetse data

The monthly 'apparent' densities of tsetse between September 1988 and February 1993, calculated as the number of tsetse caught per trap per day, were correlated with the rainfall and relative humidity in the concurrent and preceding months.

Tsetse 'challenge' was derived, separately for each of two of the species caught, *Glossina morsitans morsitans* and *G. pallidipes*, as the product of tsetse 'apparent' density, which gives an index of tsetse apparent density relative to the availability of tsetse or the efficiency of the trapping method used, and trypanosomal infection rate in tsetse. Fewer than 50 *G. m. morsitans* were dissected per month during each of five months in 1991 and throughout 1992. The infection rates used to calculate tsetse challenge for *G. m. morsitans* in these months were the mean values calculated in 1991 and 1992, respectively.

Monthly incidences of trypanosomal infections in goats were derived by amalgamating the weekly incidences of infection; these were then correlated from September 1988 to June 1992 with the sum of the monthly 'apparent challenges' of the two species of tsetse. Data from July 1992 onwards were not included in this analysis since goats were for most of the time under chemoprophylaxis. Incidences of infection were derived from all goats that were considered not to be under prophylaxis at the time of sampling, i.e. either untreated, treated with diminazene aceturate more than three weeks earlier, or treated with isometamidium chloride more than 12 weeks before.

Mean ovarian age and wing fray categories were calculated separately for *G. pallidipes* and *G. m. morsitans* each month. A regression analysis of mean monthly wing fray category on mean monthly ovarian age category was done, weighted by the number of flies dissected each month, fitting separate regression lines for each species.

Regression analyses were conducted for trypanosomal infection rates in tsetse on both wing fray and ovarian age categories. This was done for each species of tsetse and each species of trypanosome, and a log-linear model using the GENSTAT 5 statistical program (Payne et al 1992) was fitted to the logarithms of the proportions of infected flies with linear and quadratic terms for wing fray and ovarian age category, respectively. The effect of sex was included in the model for wing fray.

Chapter 3.
The incidence of trypanosomal infections

3.1 Results

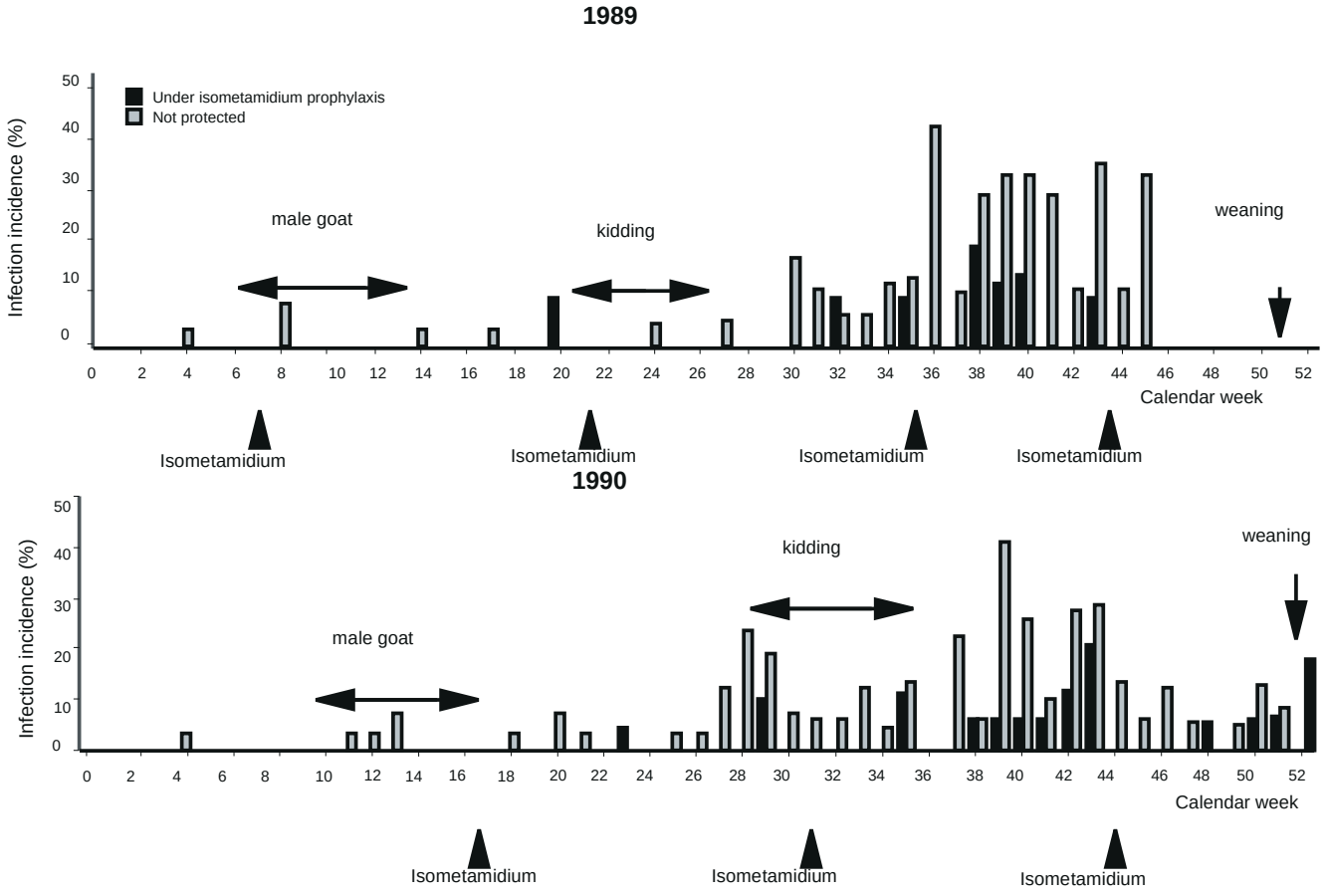
All data on the incidence of trypanosomal infections were analysed as described previously to determine seasonal trends and the relative incidence of infections due to different species of trypanosomes.

The weekly incidence of infection in unprotected goats showed a seasonal pattern; it rose from about calendar week 30 onwards in 1989, approximately week 27 onwards in 1990 and approximately week 35 onwards in 1991 (Figure 3.1). The mean weekly incidence of infection over subsequent weeks was higher in 1989 (approximately 18%) than in 1991 (approximately 7%). The mean weekly incidence of infection in 1990 was intermediate in value between 1989 and 1991. In 1992, goats were maintained under prophylaxis most of the time. Nevertheless, the occurrence of trypanosomal infections between weeks 31 and 39 was consistent with seasonal patterns detected in the previous three years. Sporadic, and sometimes frequent, incidences of infections also occurred during the earlier months of each year (Figure 3.1). In 1992, for example, there was a relatively high incidence of trypanosomal infections between weeks 13 and 25, at which time all goats were treated with diminazene aceturate. In contrast, there were few detected cases of infections over the corresponding periods in 1989 and 1990. Direct comparisons between the different years are difficult, however, because the experimental protocols differed, mean ages of goats varied each year and the stressful events of kidding and lactation occurred at a different time each year.

Infections were characterised for *Trypanosoma brucei, T. congolense* and *T. vivax* in 1990, 1991 and 1992. The ratio of *T. congolense:T. vivax* infections was approximately 1:1. The ratio did not apparently change with age. *Trypanosoma brucei* infections were half as frequent as *T. congolense* and *T. vivax* infections (Table 3.1) and occurred mostly as mixed infections. In 1990, 35% of all infections were classed as ‘mixed infections’ (Table 3.1). This may be an overestimate since new infections with one species may sometimes have been superimposed on an existing infection with another species. Such cases have been defined as mixed infections. There were fewer ‘mixed infections’ in 1991 when the overall infection rate was lower.

3.2 Discussion

The definition of a new infection in an environment where animals acquired infections naturally and continually is somewhat arbitrary. Rowlands et al (1993) developed a similar approach for dealing with the situation of monthly sampling of trypanosusceptible cattle exposed to drug-resistant trypanosomes. The prepatent period of about 12–15 days for a trypanosomal infection, and the relative insensitivity of the diagnostic method used, could support an argument that the criterion used to define a new infection (which required only a minimum of two consecutive, negative weekly samples between


1989
Under isometamidium prophylaxis
Not protected
Infection incidence (%)
male goat
kidding
weaning
Calendar week
Isometamidium
Isometamidium
Isometamidium
Isometamidium
1990
Infection incidence (%)
male goat
kidding
weaning
Calendar week
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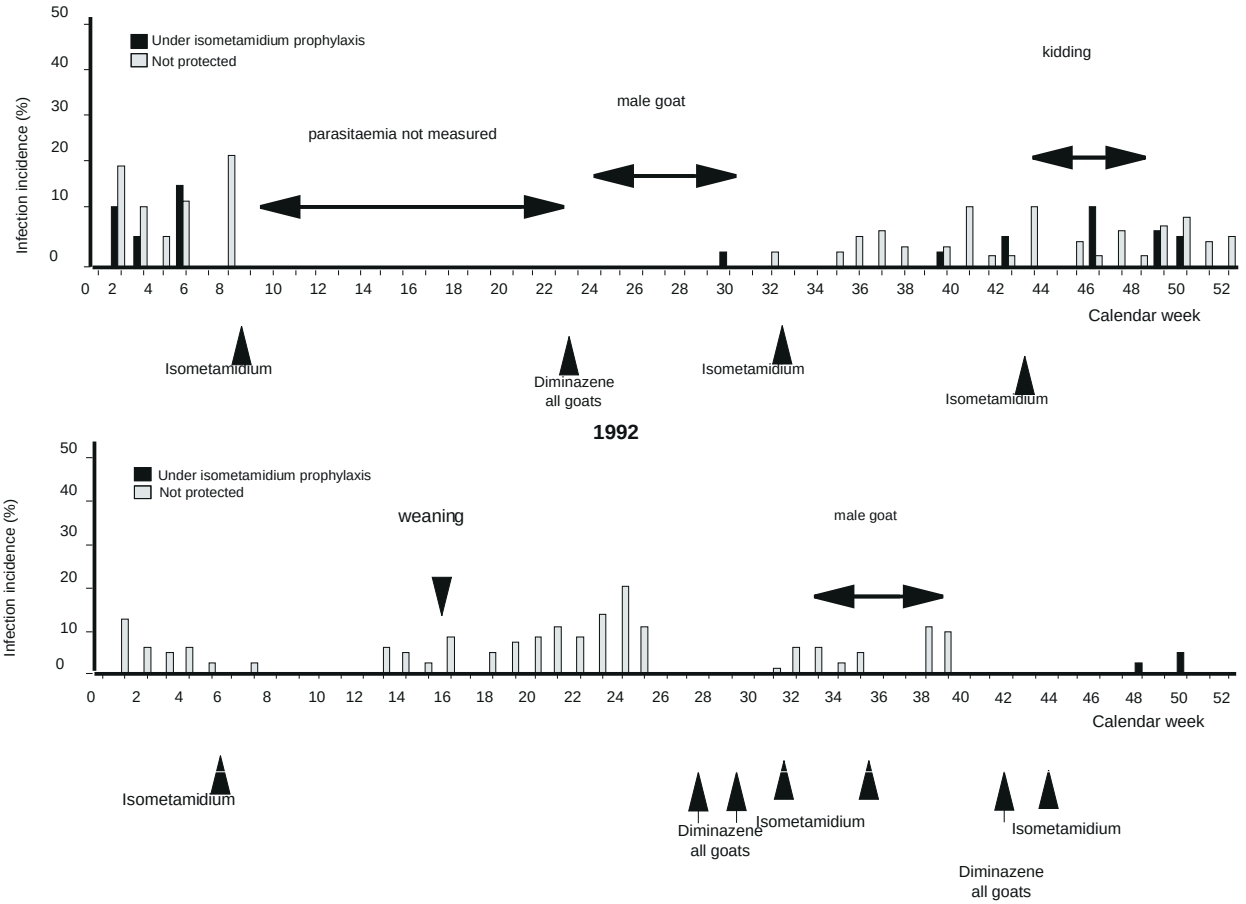

Figure 3.1 *Variations in weekly incidence of trypanosomal infections in female goats. To count as a new infection, a parasitaemic sample was required to be preceded by negative samples for at least two weeks (at least three weeks if previously treated with diminazene aceturate), as described in section 2.7.1.*

Table 3.1 *Percentages of infections in female goats attributable to* Trypanosoma congolense, T. vivax *and* T. brucei.

Year	Parity	No.[†]	Single infections			Mixed infections	Single and mixed infections[‡]		
			T. congolense	*T. vivax*	*T. brucei*		*T. congolense*	*T. vivax*	*T. brucei*
1990	1	65	38	18	6	38	45	35	20
	2	32	28	31	9	32	33	41	26
	Total	97	35	23	7	35	42	36	22
1991	1	30	23	47	20	10	27	52	21
	2	21	48	19	24	9	48	22	30
	3	11	18	64	18	0	18	64	18
	Total	62	31	40	21	8	33	43	24

[†]Number of single and mixed infections.
[‡]Counting each infection in a mixed infection separately

detected parasitaemias) would lead to an erroneous estimation of true incidence. However, of the 97 new infections identified in 1990, only four occurred three weeks after the previous diagnosis of an infection with the same species. In 1991, only two of the 62 infections were in this category. Since the species of trypanosomes were not always recorded in 1989 we decided to consider these six cases as reinfections.

Despite various biases that may have occurred in the calculation of these incidences of reinfection, the approach used allows comparison of 'levels of reinfection' in the different treatment groups and different years on the same basis. Furthermore, the comparison is made without repeatedly counting recurrent infections when deriving weekly prevalences of trypanosomal parasitaemia.

It is important to distinguish between the terms 'incidence' and 'prevalence' used in this report. 'Weekly incidence' describes the rate of acquisition of new infections observed in any one week. 'Prevalence' refers to the proportion of animals detected as being infected in any one week, regardless of when an animal first became infected. To be considered 'infected' an animal needed to be found to be parasitaemic. Thus, because of the relative insensitivity of the diagnostic method, the estimated prevalence of trypanosomal infections was less than the true prevalence. Generally, incidence of infection was less than prevalence of infection; the more persistent, or chronic, the infection, the greater the prevalence.

3.3 Summary of the findings

The period of highest trypanosomosis risk was between July and October (calendar weeks 31 to 44); however, infections also occurred at other times of the year, particularly in 1991 and 1992.

Chapter 4.
Tsetse population dynamics and challenge

4.1 Results

4.1.1 Apparent density

Three species of tsetse were trapped during the study: *Glossina pallidipes, G. m. morsitans* and *G. brevipalpis*. The mean 'apparent' density of tsetse, as defined in section 2.7.2, increased during the dry season from May to September and decreased during the rainy season (Figure 4.1). The highest apparent densities occurred in 1989. Seasonal variation was least in 1992 when apparent densities during the first half of the year were higher than in corresponding months of previous years (Figure 4.1). The mean number of tsetse caught over the entire study was 5.12 tsetse/trap per day for *G. pallidipes* and 0.78 tsetse/trap per day for *G. m. morsitans* (a ratio of 6.6:1). Few *G. m. morsitans* were caught during 1992. *Glossina brevipalpis* were trapped in very small numbers throughout the study.

When apparent density of tsetse was regressed against rainfall, correlation coefficients of –0.15, –0.30 and –0.45 were obtained respectively, with rain in the concurrent month, rain in the previous month and rain two months previously. Mean annual rainfall was lower in 1990/1991 (667 mm) and in 1991/1992 (751 mm), when the month of February was dry, than in 1988/1989 and 1989/1990 (894 and 975 mm, respectively). Mean apparent densities of tsetse were 7.36, 6.57, 4.49 and 5.32 tsetse/trap per day in 1989, 1990, 1991 and 1992, respectively. The seasonal changes in relative humidity were similar in each year (Figure 4.1). The highest correlation coefficient between apparent density of tsetse and relative humidity was –0.52 when tsetse density was compared with relative humidity in the previous month. When both rainfall and relative humidity in the previous month were included together as independent variables in a two-variable regression model, the partial correlation between tsetse apparent density and relative humidity remained significant ($P < 0.001$) but that between tsetse apparent density and rainfall was not.

4.1.2 Trypanosomal infection rates

4.1.2.1 Types of infection

Table 4.1 summarises monthly rates of *Nannomonas (T. congolense*-type) and *Duttonella (T. vivax*-type) infections (referred to hereinafter as *'T. congolense'* and *'T. vivax'* infections) in tsetse in 1991 and 1992. (The type of trypanosomal species was not recorded for all the data available for analysis in 1989 and 1990.) For *G. pallidipes*, the rate of *'T. vivax'* infections was approximately twice that of *'T. congolense'* infections (Table 4.1). *Glossina morsitans morsitans* also had a higher rate of *'T. vivax'* compared with *'T. congolense'* infections.

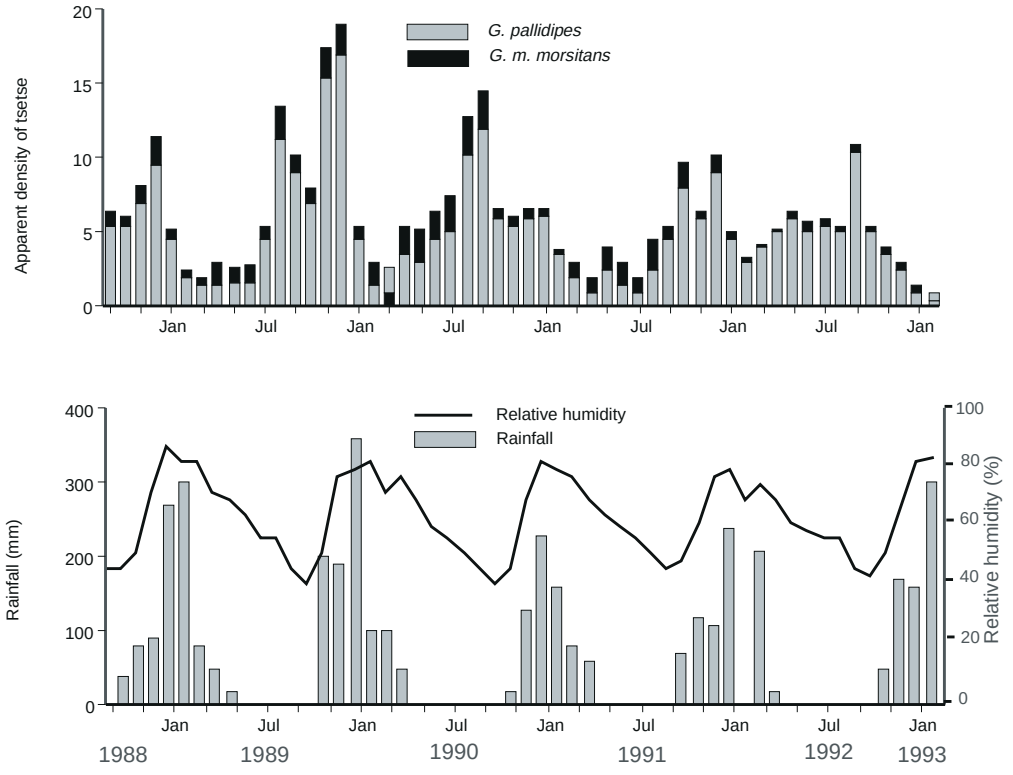

Figure 4.1 *Variations in apparent density of tsetse (flies/trap per day) at Kakumbi and variations in rainfall and relative humidity measured at a nearby meteorological station at Mfuwe Airport. Seasons are: hot, rainy (October to April), cool, dry (May to August), and hot, dry (September to October).*

4.1.2.2 Annual and seasonal variations

Mean monthly infection rates in 1991 (summed over both species of trypanosome) were 3.5 and 6.3% in *G. pallidipes* and *G. m. morsitans*, respectively. Thus, in this year, the overall infection rate in *G. m. morsitans* was double that in *G. pallidipes.* In 1992 too few *G. m. morsitans* were caught and dissected to enable comparison. In 1989 and 1990, when trypanosomal types of infections were not recorded, overall monthly infection rates were 5.9 and 5.1%, respectively, for *G. pallidipes* and 6.8 and 5.6%, respectively, for *G. m. morsitans.* Thus, during these years, infection rates were similar for the two species of tsetse. Mean infection rates, averaged over the four years, were 4.2 and 5.0% for *G. pallidipes* and *G. m. morsitans*, respectively. Monthly infection rates in both *G. pallidipes* and *G. m. morsitans* varied within years increasing to a maximum in the cool, dry season (Figure 4.2).

Table 4.1 *Trypanosomal infection rates in tsetse dissected between January 1991 and December 1992, indicating species of fly and type of trypanosomal infection.*

		Trypanosomal infection rate (%)					
		G. pallidipes			*G. m. morsitans*		
		No. dissected	Type of infection		No. dissected	Type of infection	
Year	Sex		*T. vivax*	*T. congolense*		*T. vivax*	*T. congolense*
1991	Male	1283	1.1	1.2	127	4.7	3.9
	Female	4292	2.4	1.3	731	3.4	2.5
	Total	5575	2.2	1.3	858	3.6	2.7
1992	Male	1279	1.7	0.3	65	1.5	0.0
	Female	4521	1.5	0.8	122	0.8	0.0
	Total	5800	1.5	0.7	187	1.1	0.0

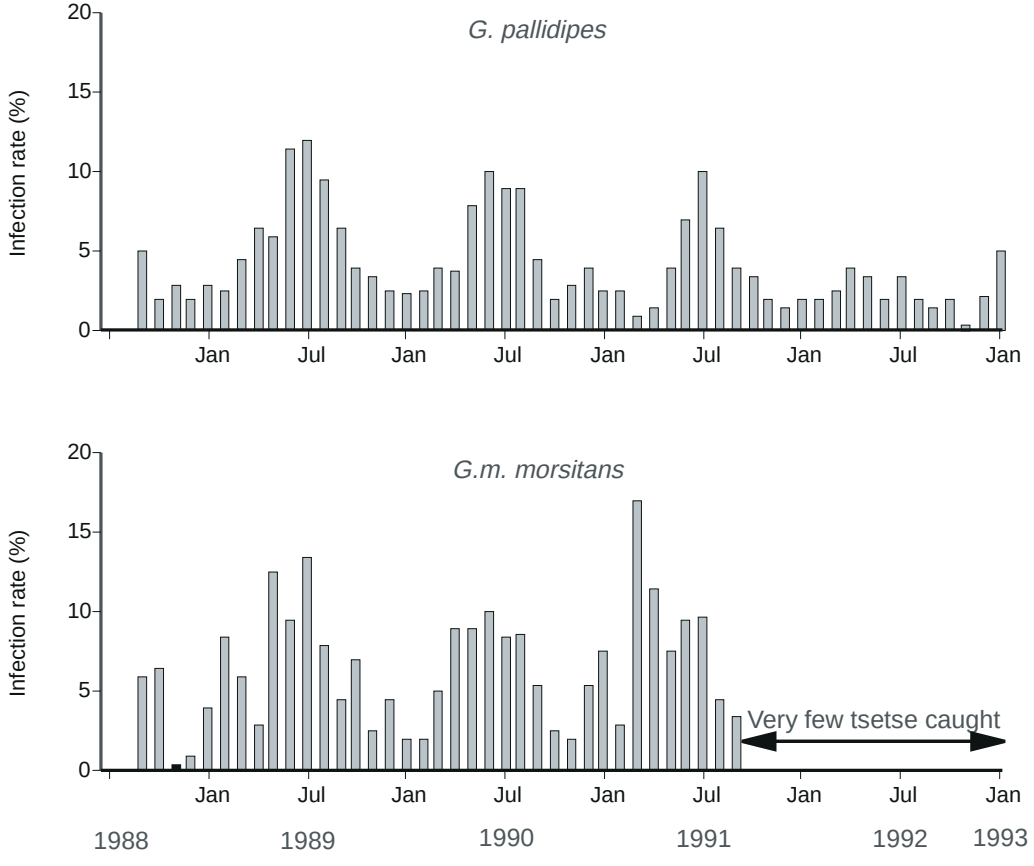

Figure 4.2 *Variations in infection rates in* G. pallidipes *and* G. m. morsitans.

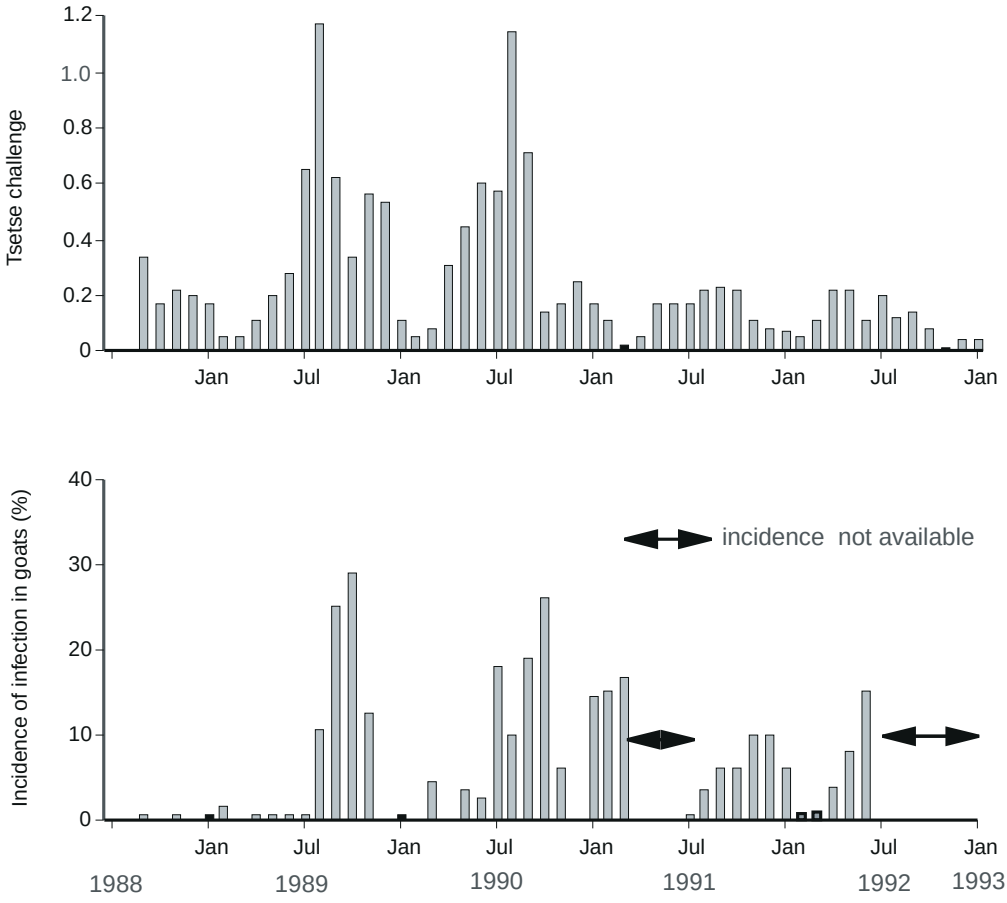

Figure 4.3 *Comparison of monthly variations in tsetse challenge and in incidence of trypanosomal infections in goats (infection incidence is defined in section 2.7.1).*

4.1.3 Tsetse challenge and incidence of trypanosomal infections in goats

Correlation coefficients between incidence of trypanosomal infections in goats and monthly tsetse challenge, as defined in section 2.7.2, were 0.27 (P = 0.07) in the concurrent month and 0.65 (P = 0.001) when the tsetse challenge of the previous month was used. When tsetse challenges in each of the previous two months were used together as independent variables in a two-variable regression analysis, the correlation coefficient increased to 0.74. Tsetse challenges in 1991 and 1992 were lower on average than in 1989 and 1990; the lower tsetse challenge in 1991 corresponded with a lower mean incidence of trypanosomal infections in goats in 1991 (Figure 4.3). Data on the incidence of infection in goats were only available for the first six months of 1992 (Figure 4.3) which restricts the comparison that can be made with tsetse challenge in that year.

4.1.4 Ovarian age and wing fray

The distributions of ovarian age and wing fray categories, measured between April 1991 and February 1993, are shown in Figure 4.4. Although comparatively few *G. m. morsitans* were caught over this period, the figure illustrates the relatively higher percentages of low categories of ovarian age (1 and 2) and wing fray (2) for *G. m. morsitans* compared with *G. pallidipes.* This tendency for lower category values in *G. m. morsitans* was further demonstrated by the distributions of mean monthly ovarian age category plotted against corresponding means of monthly wing fray category for the two species (Figure 4.5). The mean ovarian age category for *G. m. morsitans* was lower (2.75 ± 0.37; SD among months) than for *G. pallidipes* (3.34 ± 0.25; $P < 0.001$). A similar difference between the two species was apparent for wing fray category.

The following regression equation, weighted by the number of tsetse measured per month, was derived, averaged over species:

ovarian age category = 0.69 (± 0.82) + 0.75 (± 0.24) wing fray category

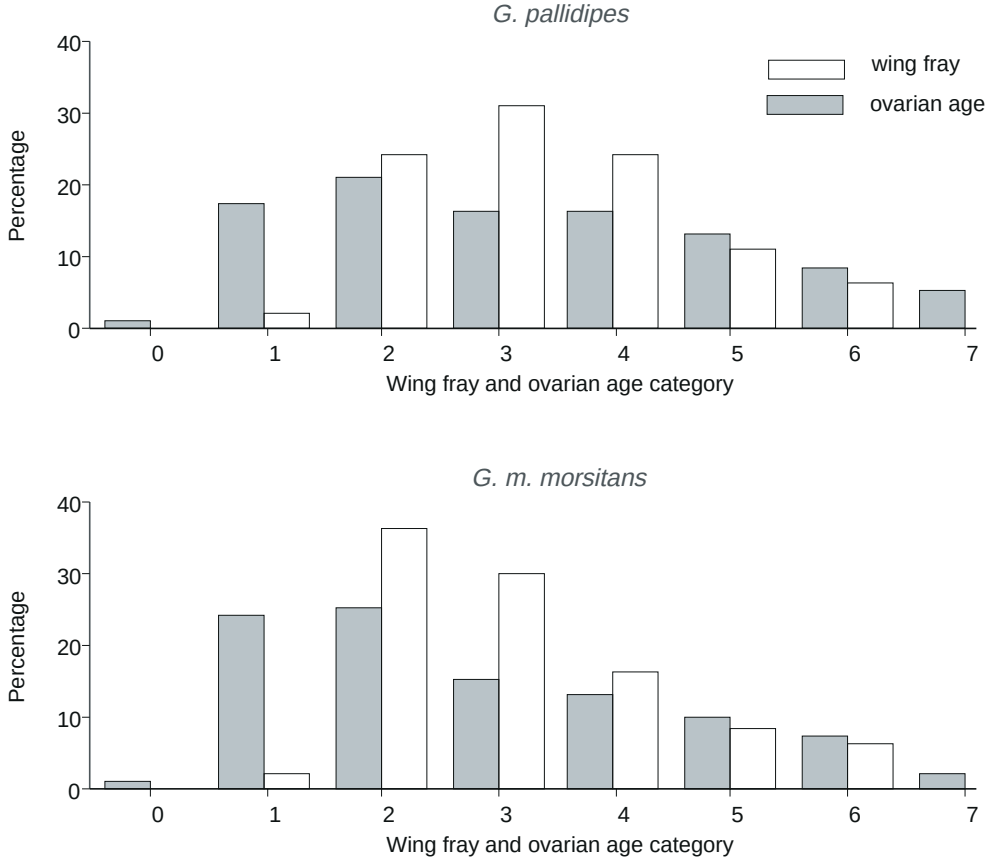

Figure 4.4 *Distributions of 7645 individual measurements of ovarian age and wing fray category for* G. pallidipes *and 618 individual measurements for* G. m. morsitans *between April 1991 and February 1993.*

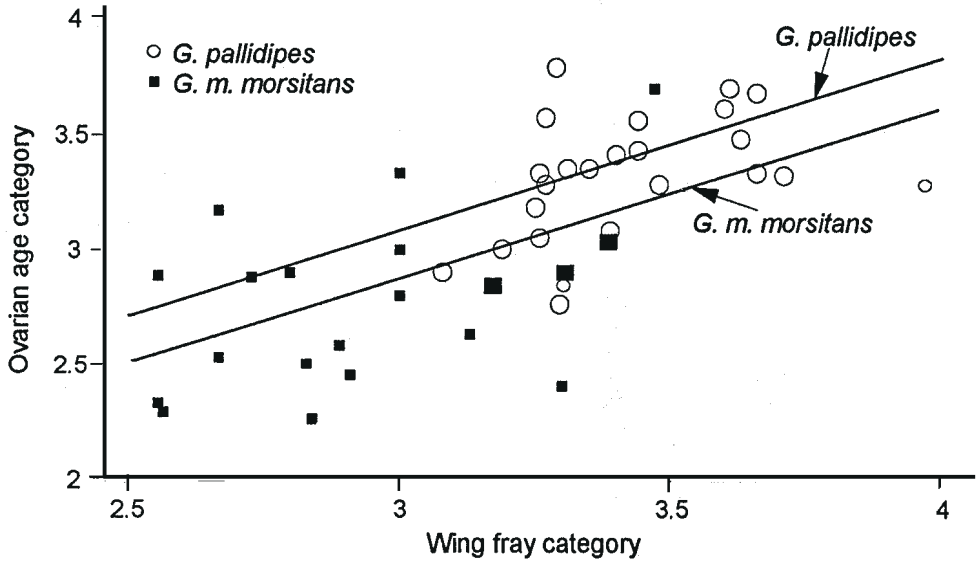

Figure 4.5 *Associations between mean monthly ovarian age and mean monthly wing fray categories between April 1991 and February 1993. Large symbols represent values based on a mean of 357 flies (range 109–611) for* G. pallidipes *and 109 (range 90–119) for* G. m. morsitans; *small symbols represent values based on a mean of 17 flies (range 5–50).*

The correlation coefficient was 0.62 ($P < 0.01$). There were no differences in the slopes of the regression lines when they were estimated for each species separately but there were differences in intercepts ($P = 0.07$) (See Figure 4.5). Thus, the mean ovarian age category corresponding to the mean wing fray category of 3.37 was higher for *G. pallidipes* (3.23 ± 0.03 SE) than for *G. m. morsitans* (2.93 ± 0.16). There was no apparent seasonal variation in ovarian age or wing fray category (data not shown).

4.1.5 Variation in infection rates with age and sex

4.1.5.1 Wing fray

There were significant increases in infection rates with increasing wing fray category on the logarithmic scale *(G. pallidipes:* $P < 0.001$ for both types of trypanosomal species; *G. m. morsitans:* $P < 0.001$ for *'T. vivax';* and $P < 0.05$ for *'T. congolense').* None of the quadratic terms in the equations fitted was significant, implying that linear and quadratic curves provided equally good statistical fits to the data. Nevertheless, the quadratic relationships were retained since, from a biological point of view (Welburn and Maudlin 1992), a convex relationship signifying a declining increase in infection rates in older flies might be expected. Because of the few data for wing fray categories 5 and 6 recorded for *G. m. morsitans* (Figure 4.6), these categories were combined for this species and equated to 5.5. The fitted 'quadratic' curves are shown in Figure 4.6 when transformed back to the non-logarithmic scale. The figure shows how infection rates increased with increasing wing fray category.

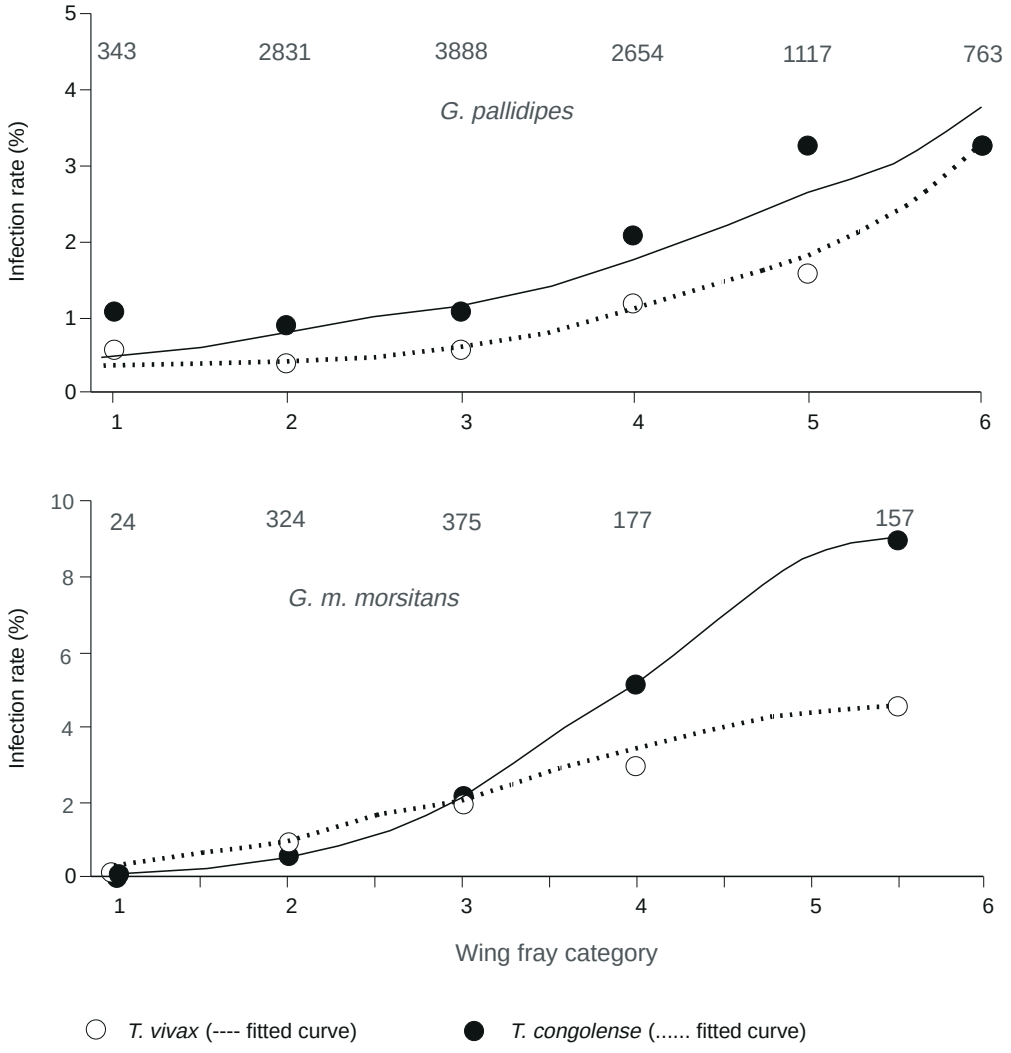

Figure 4.6 *Relationships between infection rate and wing fray category for* T. congolense *and* T. vivax *types of infections in* G. pallidipes *and* G. m. morsitans, *when adjusted for sex. The number of dissected flies are* given at the top of each graph. Wing fray categories of 5 and 6 for G. m. morsitans *have been equated to 5.5.*

4.1.5.2 Ovarian age

The log-linear regression analyses were repeated for females using ovarian age category instead of wing fray. Fitted curves for *G. pallidipes* are shown in Figure 4.7. A similar relationship ($P < 0.001$) to that shown previously for wing fray was apparent between *T. vivax* type of infection and ovarian age category. However, *'T. congolense'* infection rates decreased from ovarian age category 5 to 6 (Figure 4.7) and the quadratic term in the regression equation was significant ($P < 0.05$). Multiple log-linear regression analyses were also undertaken fitting terms for ovarian age and wing fray categories

Table 4.2 *Regression coefficients ± SE for trypanosomal infection rates in female tsetse in a log-linear regression analysis of infection rate (y) on wing fray category (x) (x = 1, ..., 6) and ovarian age category (z) (z = 0, ..., 7), respectively.*

	'T. vivax' infections	*'T. congolense'* infections
G. pallidipes (7645)†		
Wing fray category‡	$0.395 \pm 0.061^{***}$	$0.399 \pm 0.086^{***}$
Ovarian age category‡	$0.272 \pm 0.044^{***}$	$0.225 \pm 0.061^{***}$
Wing fray/ovarian age§	$0.245 \pm 0.084^{**}$	$0.334 \pm 0.118^{**}$
Ovarian age/wing fray§	$0.157 \pm 0.060^{**}$	0.067 ± 0.084¶
G. m. morsitans (618)†		
Wing fray category‡	$0.654 \pm 0.174^{***}$	$0.406 \pm 0.189^{*}$
Ovarian age category‡	$0.451 \pm 0.135^{***}$	0.169 ± 0.148

†Number of tsetse.
‡Regression coefficient in the equations: $1n(y) = a_1 + b_1 x$ or $ln(y) = a_2 + b_2 z$.
§Regression coefficients adjusted for each other in the equation: $1n(y) = a' + b'_1 x + b'_2 z$.
¶The quadratic term in the regression of infection rate on ovarian age category was significant ($P < 0.05$) when adjusted for wing fray.
*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

simultaneously. Both terms were equally significant for *'T. vivax'* infections, when corrected for each other ($P < 0.01$), but wing fray category was more significant than ovarian age category for *'T. congolense'* infections ($P < 0.01$) (Table 4.2).

'Trypanosoma vivax' infections in *G. m. morsitans* increased with ovarian age ($P < 0.001$) (data not shown), but the association with ovarian age was not significant for *'T. congolense'* infections. The number of dissected female flies, however, was low (618).

Table 4.2 shows linear regression coefficients for female tsetse in log-linear regression analyses (without quadratic terms) of infection rates on ovarian age and wing fray. The increase in *'T. vivax'* infections with age was greater for *G. m. morsitans* than for *G. pallidipes*, as illustrated in Figure 4.6.

4.1.5.3 Sex

There were no significant differences in mean infection rates between male and female tsetse for either type of trypanosomal infection when the model with both sex and wing fray category was fitted.

4.2 Discussion

4.2.1 Apparent densities of G. pallidipes *and* G. m. morsitans

The apparent density of *G. pallidipes* as determined from the trap catches was over six times that of *G. m. morsitans*. Average monthly infection rates in *G. m. morsitans* and *G. pallidipes* were similar, although *G. m. morsitans* had higher infection rates in 1991. However, *G. m. morsitans* are known to be less readily caught in traps compared with *G. pallidipes*, and, therefore, they will have been present in higher numbers than

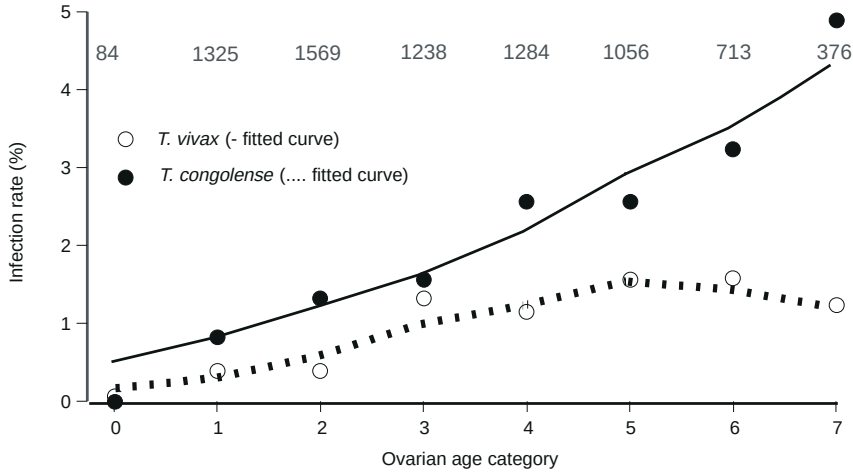

Figure 4.7 *Relationships between infection rate and ovarian age category for* T. congolense *and* T. vivax *types of infections in* G. pallidipes. *The number of dissected flies is given at the top of the graph.*

indicated from the apparent density index (Vale 1993). Thus it is not possible to conclude that one species was a more important vector of trypanosomes than the other. The correlation between overall tsetse challenge, heavily weighted towards *G. pallidipes*, and infection incidence in goats nevertheless implies that *G. pallidipes* was a significant vector. Recent research at Kakumbi studying catches of tsetse in refuges will contribute to a future RTTCP paper on the relative availabilities of different species of tsetse to traps.

4.2.1.1 Association between apparent density of tsetse and weather

The highest correlation between tsetse apparent density and relative humidity or rainfall, bearing in mind the relative availabilities of the species, was a negative correlation with relative humidity in the month previous to trapping the flies. Tsetse apparent density was also negatively correlated with previous rainfall. Both these associations conformed to the observation that the apparent density of tsetse recorded in the areas where the goats grazed started to increase during the cool, dry season and to decrease as the rains progressed. This increase is likely to have been due to tsetse moving to the Luangwa River during the dry season, and not to an increase in reproduction of the tsetse *per se* that would normally be expected to occur during the rainy season as found by Griffin and Allonby (1979b) in a study of trypanosomosis in goats in Kenya. Similar effects of *G. pallidipes* moving closer to a river during the dry season have been shown in Ethiopia (Leak et al 1993). After the start of the rainy season the tsetse likely dispersed with a corresponding reduction in the apparent density of tsetse recorded at the site. The apparent density of tsetse was on average lower in 1991 and 1992 than in 1989 and 1990. These lower annual densities followed periods of lower annual rainfall in 1990/1991 and 1991/1992. The lower tsetse apparent densities (and the lower tsetse

challenges) may also be associated with increased human settlement which took place near the trapping sites during the period of the study, resulting in the removal of natural vegetation and disturbance of the wild animals on which the tsetse normally fed.

4.2.2 Trypanosomal infection rates

4.2.2.1 Types of infection

Mean monthly trypanosomal infection rates were almost twice as high for *'T. vivax'* as for *'T. congolense'*, averaging 1.9 and 1.0%, respectively, for *G. pallidipes* and 2.4 and 1.4%, respectively, for *G. m. morsitans* in 1991 and 1992. Woolhouse et al (1994) found a similar difference in infection rates between species for *G. pallidipes* at a site neighbouring Kakumbi, where the average infection rate was slightly higher than that recorded at Kakumbi. *'Trypanosoma vivax'* infections were also found to be more frequent in *G. pallidipes* in Zimbabwe (Woolhouse et al 1993), but not in Ethiopia *(G. pallidipes* and *G. m. submorsitans)* or in Kenya *(G. pallidipes)*, where the infection rate for *'T. congolense'* infections was higher (Leak and Rowlands 1996). Such differences may result from the feeding habits of tsetse at each site. Suidae, for example, are refractory to infections with *'T. vivax'* (Jordan 1986) and, when they are the major host, rates of infection with *'T. vivax'* tend to be lower than those with *'T. congolense'*. This was not the case in Ethiopia, however, where cattle and people were the major hosts (Leak et al 1993). In contrast, rates of *'T. vivax'* infections often tend to be higher than those of *'T. congolense'* infections for reasons such as the developmental cycle being shorter and simpler (Desowitz and Fairbairn 1955; Jordan 1974) and the trypanosomes not being exposed to trypanocidal factors in the gut (Stiles et al 1990).

4.2.2.2 Seasonal variations

The monthly infection rates in both *G. pallidipes* and *G. m. morsitans* in 1991 reached a peak in the cool, dry season prior to a seasonal increase in tsetse apparent density. This peak is unlikely to have been due to a change in age structure as no seasonal variation was apparent in mean values of ovarian age or wing fray. At the site neighbouring Kakumbi, Woolhouse et al (1994) also found seasonal variations in infection rate to be independent of changes in infection rate with age. They suggested that the variation may be associated with differential availability of infective hosts. Increases in infection rate can also occur with increases in temperature (Ford and Leggate 1961; Desowitz and Fairbairn 1955). However, this was not the situation in the present study, since the highest infection rates occurred when the weather was coolest.

4.2.3 Tsetse challenge and incidence of infection in goats

The monthly variation in tsetse challenge, which encompasses tsetse apparent density and infection rate, was correlated with the incidence of trypanosomal infections in goats occurring in the following month. A lagged correlation by one month has been found

by other workers (Leak et al 1993; Rawlings et al 1993) and allows for the pre-patent period following the bite of an infected tsetse. Fifty-five per cent of the variation in monthly infection incidence was accounted for by a regression on tsetse challenge over the previous two months. In general, rates of trypanosomal infection in goats were higher during the second six months of each year, and the series of experiments from 1989 to 1992 was designed with this in mind. The mean incidence of trypanosomal infections in 1991 was, however, lower than in the previous two years. This corresponded with a lower mean tsetse challenge, which followed a period of slightly lower annual rainfall in 1990/1991.

4.2.4 Ovarian age and wing fray

Both techniques give estimates of age. However, the correlation of 0.62, when compared with higher correlations recorded in Ethiopia (Leak and Rowlands 1996), might indicate some possible errors in measurement. Ovarian ageing is theoretically more accurate but is technically a more difficult and possibly a more error-prone method for determining the age of a female fly than that using wing fray, which itself can only provide an indication of relative age, unless calibrated for a particular species (Potts 1970). The limitations of wing fray category determinations were discussed by Allsopp (1985) with respect to *G. m. morsitans.*

Differences found between mean wing fray for *G. pallidipes* and *G. m. morsitans* may have resulted from differences in activity. *Glossina morsitans morsitans* tends to inhabit the more open savanna, and *G. pallidipes* the thickets. The data show that for a given ovarian age, wing fray was higher in *G. m. morsitans* than *G. pallidipes* (Figure 4.5). Seasonal variation in wing fray category can also occur since an increase in tsetse apparent density is often associated with an increase in the number of younger flies in the population. There may also be differences in the rate of fraying of wings between the sexes, since female flies are generally less active than males. In this study wing fray category provided a closer fit than ovarian age category for rates of *T. congolense* types of infections in *G. pallidipes*. However, for *'T. vivax'* infections the most significant association between infection rate and age was found when measurements of wing fray and ovarian age categories were used together. Presumably, inclusion of each variable compensated for errors in measurement of the other. There were changes in technical staff during the study which may have contributed to some of the variation.

4.2.5 Variations in infection rate with age and sex

4.2.5.1 Age

The data summarised in this chapter formed part of a wider analysis of the associations between trypanosomal infection rates and age in six species of tsetse at sites in six countries in western, central and eastern Africa (Leak and Rowlands 1996). The results of the wider analysis suggest that all six species of tsetse studied continually acquired mature trypanosomal infections with increasing age in relation to *'T. congolense'*, and

at least three in relation to *'T. vivax'* infections. The present observations confirm those of Woolhouse et al (1994) who observed, at a site near Kakumbi, that, with increasing age, the prevalence of both *'T. vivax'* and *'T. congolense'* infections increased in *G. pallidipes* between June 1991 and September 1992. In Zimbabwe, Woolhouse et al (1993) showed the same relationship between increasing age and prevalence of *'T. vivax'* infections in *G. pallidipes*. However, for *'T. congolense'*, the curve tended to be convex with a decreasing prevalence at older ovarian ages as in the present study. The differences in apparent shapes of the curves, expressing relationships between *'T. congolense'* infection rate and ovarian age category, and those between infection rate and wing fray category, in the present study, are difficult to understand. Mistakes can arise in assessing ovarian age, particularly in older flies; possibly age was underestimated or overestimated in some flies. Nevertheless, when corresponding curves were compared for *'T. vivax'* infections, very similar relationships occurred when either wing fray or ovarian age was used. Pooling data from Kakumbi and from one site in Ethiopia, Leak and Rowlands (1996) found similar patterns of increases in both *T. congolense* and *T. vivax* types of infections in two subspecies of *G. morsitans*.

In conclusion, these field observations suggest that tsetse continue to acquire infections following the teneral feed, which contradicts the laboratory findings of Welburn and Maudlin (1992). These contradictions are further discussed by Leak and Rowlands (1996).

4.2.5.2 Sex

No differences in mean infection rates in males and females were found for either *G. pallidipes* or *G. m. morsitans*. This accords with the findings of Woolhouse et al (1993, 1994). When using a larger data set from four sites, Leak and Rowlands (1996) found that infections of the *T. vivax* type were slightly higher in male than female *G. pallidipes*.

4.3 Summary of the findings

4.3.1 Infection rates, age and sex

Relationships between infection rate and age and sex of tsetse may be somewhat academic in relation to the acquisition of infections by goats in this study. However, the results indicate that tsetse continue to be infected even after the teneral feed. The results contribute to the current debate on the subject.

4.3.2 Seasonal variations in apparent density and tsetse challenge

Increases in apparent density of tsetse occurred during the middle of the cool, dry season and in the early wet season. An increase in tsetse challenge preceded by one month an increase in the incidence of trypanosomal infections in goats. The periods from July to October appeared to be the time of highest trypanosomosis risk. The design of the four

experiments from 1989 to 1992 attempted to ensure that periods of pregnancy and lactation coincided with this period of high trypanosomosis risk. In 1991 and 1992 apparent tsetse challenge was lower than in the two previous years.

4.3.3 Transmission of trypanosomes

Glossina pallidipes was an important vector of trypanosomosis in the study area. *Glossina morsitans morsitans* may have been as important but because of their lesser availability fewer tsetse were caught.

Chapter 5. 1989 experiment

5.1 Aim

(i) To determine the effects of prophylactic and curative trypanocidal regimens on the health and productivity of goats exposed to naturally acquired trypanosomosis.
(ii) To examine the effect of strategic anthelmintic treatments on the course of trypanosomal infections.

5.2 Materials and methods

5.2.1 Experimental design

Thirty-nine female weaner goats, aged four to six months, were purchased from tsetse-free areas of Eastern Province, Zambia and brought to Kakumbi in May 1988. Two days after arrival they were dosed with anthelmintic (Panacur®, Hoechst, Germany) and drenched for treatment of ticks. The goats were ranked into sets of four on the basis of body weight and assigned at random on 24 June 1988 (calendar week 25) to four treatment groups. Goats in group 1 received prophylactic treatment with isometamidium chloride at a dose rate of 0.5 mg/kg body weight (b.w.) on the following dates:

Date	Calendar week
8 July 1988	27
15 November 1988	46
17 February 1989	7
29 May 1989	22
1 September 1989	35
4 November 1989	44

Individual goats in group 2 were treated with diminazene aceturate at a dose rate of 7 mg/kg b.w. when they were detected parasitaemic and their packed cell volume (PCV) had fallen to 20% or below. Goats in groups 3 and 4 were not given trypanocidal treatments. Groups 1, 2 and 3 were treated with anthelmintics in November 1988 and April 1989, before and after the rainy season. Group 4 received no anthelmintic treatment.

The experiment started in calendar week 2 of 1989 when an adult male goat, obtained locally and protected with isometamidium chloride, was introduced to the females and remained with them for six weeks (see Figure 5.1). A different male goat was introduced in week 11 for a further six weeks (not indicated in Figure 5.1). Kidding commenced in week 21. Male kids were sold in week 48 and female kids weaned between week 51 and week 54 (week 2 of 1990). Female goats were weighed weekly. Blood samples were collected twice a week from week 2 to week 40, and weekly thereafter, to measure PCV and detect trypanosomal parasitaemia. Rectal temperatures were taken at the same intervals. All kids were weighed at birth and female kids were also weighed from week 42 until weaning at week 51. Female kids were also sampled twice weekly from calendar week 42 until calendar week 9 of 1990, when they were approximately nine months old, to measure PCV and detect parasitaemia.

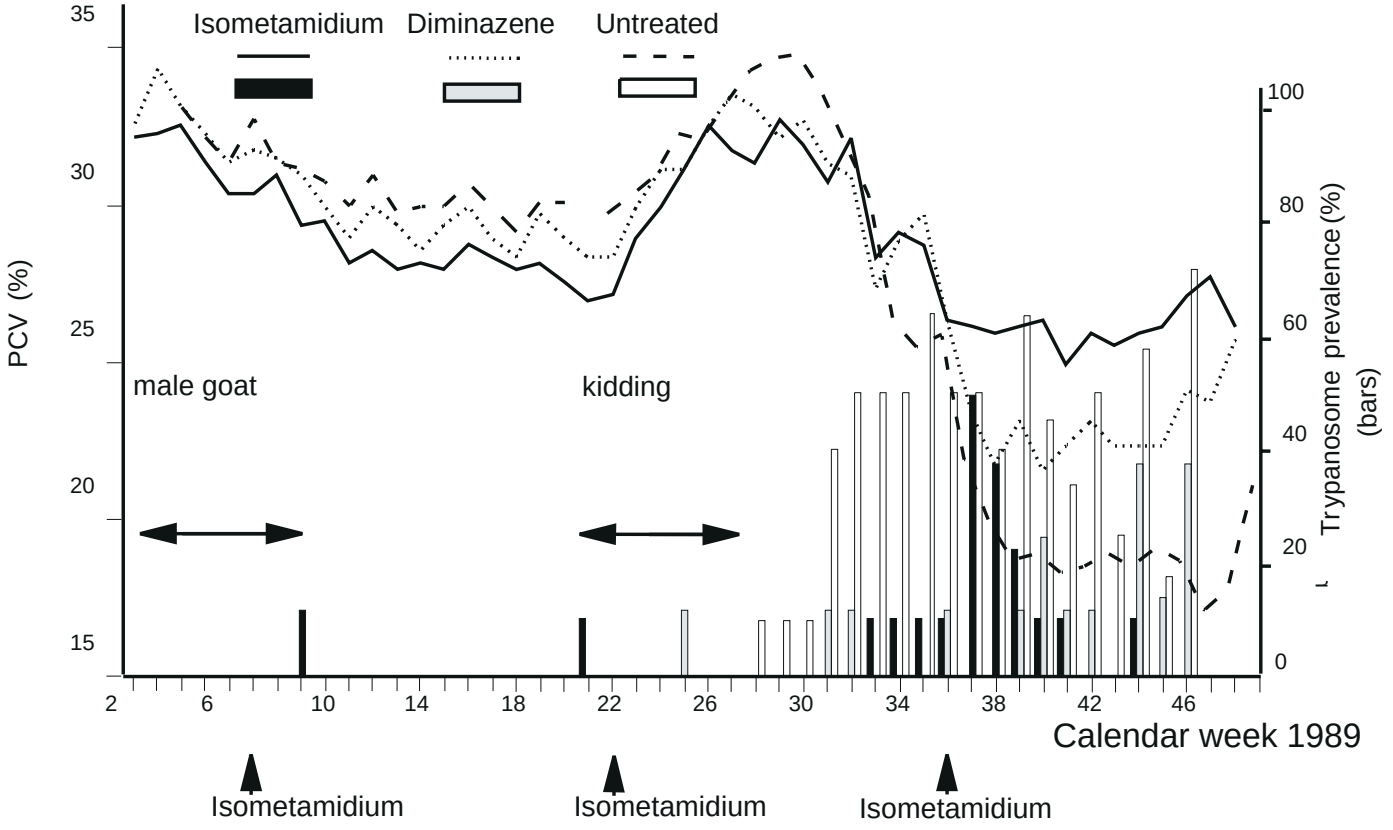

Figure 5.1 *Changes in mean PCV of adult (one-year-old) female goats that raised a live kid. [9 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., 8 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%, and 10 untreated, 4 of which died between weeks 40 and 45.]*

5.2.2 Statistical analysis

The fertility of a female goat was defined to be impaired if
(i) no kid was born (4 goats)
(ii) kids were conceived to the second, not the first, male (2 goats) or
(iii) kids were born prematurely and were stillborn or died within four days of birth (1 goat). (Twins needed to be both dead for the dam to be included in this category.)

The results from these seven goats were omitted in analysing the effect of treatment regimen on body weight, PCV and rectal temperature. Similarly, the results from five additional goats which died before or during pregnancy were also omitted. The 27 remaining goats kidded between calendar weeks 21 and 26. The proportion of goats kidding in the four groups were compared by a χ^2 test (Snedecor and Cochran 1980).

Two-way analyses of variance (see, for example, Snedecor and Cochran 1980) involving set and treatment group were carried out on body weights at 17 weeks and 1 week before kidding and at 2 and 17 weeks after kidding. The mean of three weighings (the current, previous and following weeks) was used for each calculation. Similar analyses of variance were undertaken on average daily weight gain between 17 weeks and 1 week before kidding and on average daily weight change from 2 to 17 weeks of lactation. Mean PCVs and rectal temperatures before kidding (weeks –17 to –1) and after kidding (weeks 2 to 17) were calculated and analysed similarly. Analyses of variance were done using a general least-squares computer program (Harvey 1990). When two measurements were made in a week (calendar weeks 2–40) the first measurement was used. Incidence of new infections was calculated as previously described (section 2.7.1).

Analyses of variance were also done on mean birth weight and mean body weight of female kids at 20 weeks of age, with terms for treatment group and number of kids born and reared. The mother was used as the observational unit in this analysis and mean body weights were calculated for the progeny of each dam.

Trypanosomal parasitaemia was most prevalent in the untreated groups between calendar weeks 31 and 46, which was about 9 to 24 weeks after kidding (Figure 5.1). The period from calendar week 36 to week 46 was chosen to compare mean PCVs and rectal temperatures, since isometamidium chloride was given to group 1 in week 35 and goats in this group should have been protected over this period. Thirty-four goats alive for at least part of this period were compared. Five goats in groups 3 and 4 died between weeks 40 and 44.

5.3 Results

5.3.1 Faecal egg counts

The degree of helminth infection observed from weekly faecal egg counts in the non-anthelmintic-treated group 4 was extremely light throughout the experiment. Although 61% of samples were positive, most of these contained only 50 or 100 eggs per gram (epg) and the maximum count was 300 epg. The geometric mean of all samples was 13 epg. Because of the insignificant worm burden, groups 3 and 4, neither of which

Table 5.1 *Mortality among adult (one-year-old) female goats.*

Treatment group†	Number of goats	Number of deaths	
		Before kidding	After kidding
1 (isometamidium chloride)	10	0	1 (crocodile)
2 (diminazene aceturate)	9‡	0	0
3 (untreated)	19	4 (3 trypanosome +ve, 1 crocodile)	5 (all trypanosome +ve)

†Group 1 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., group 2 treated on an individual basis with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%, group 3 not treated.

‡One goat was killed by a crocodile before the male goat was introduced to the females.

received trypanocidal drugs, were combined in subsequent analyses. The combined group is referred to from now on as group 3.

Female kids were sampled for two months after weaning. The geometric mean faecal egg count was 70 epg between calendar weeks 3 and 9 of 1990.

5.3.2 Mortality

Eight of 19 untreated goats (42%) died as a result of being infected with trypanosomes (Table 5.1). The effect of infection on body weight, PCV and rectal temperature of one of the goats that died because of trypanosomosis is shown in Figure 5.2. There were no deaths due to trypanosomosis in the other two groups, but three goats were caught by crocodiles, one from each of the three groups. Data on the goats that died were excluded from subsequent analyses.

5.3.3 Fertility

Nine of 10 goats in group 1 (treated with isometamidium chloride) conceived to the first male and gave birth to live kids. This compared to 8/9 goats in group 2 (treated with diminazene aceturate) and 10/15 goats in the untreated group (Table 5.2). The lower proportion of goats kidding in the untreated group, however, was not significantly different from the proportions kidding in the other two groups. The median period of 'gestation' from the date of entry of the first male was 155 days (range 144–174 days) for these 27 goats. There were no significant differences between groups. Mean litter size for group 1 was 1.56 compared with 1.33 for the other two groups; this difference was not significant.

5.3.4 Prevalence of trypanosomal infections

Trypanosomal infections were most prevalent from week 31 onwards and the level remained higher throughout this period in the diminazene-treated and untreated groups (groups 2 and 3) than in the isometamidium-treated group (Figure 5.1). Mean weekly prevalences of trypanosomal infections ranged from 5% in group 1 to 32.5% in group

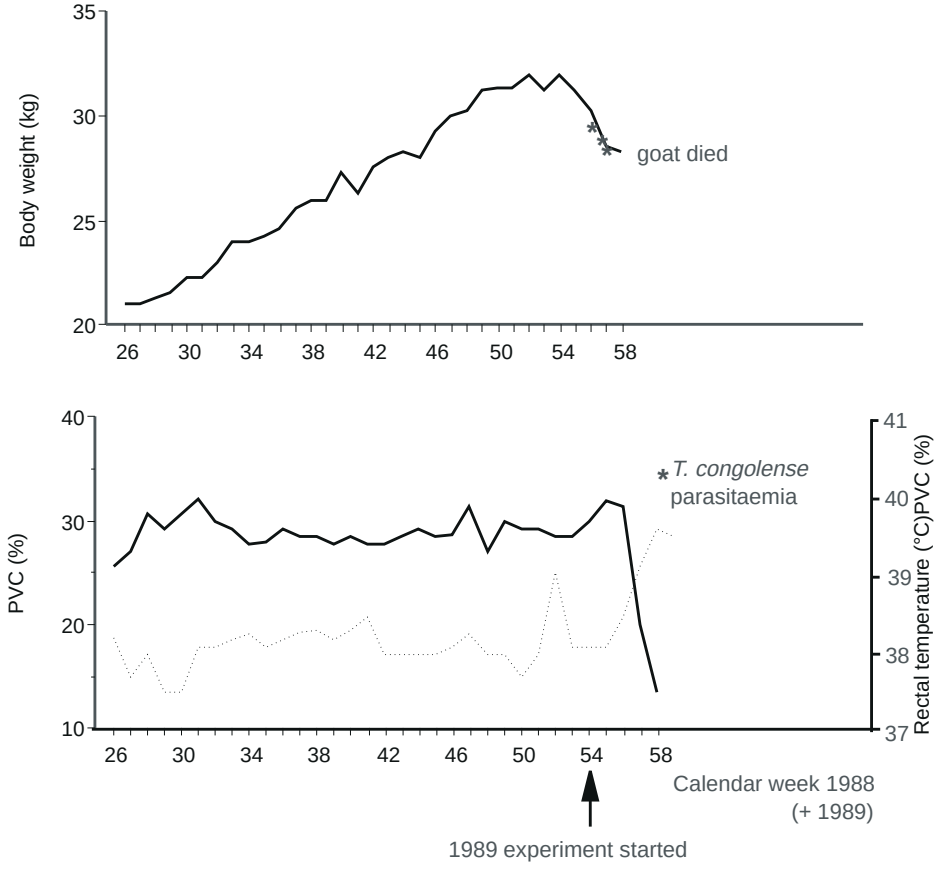

Figure 5.2 *Example of changes in body weight, PCV and rectal temperature associated with the onset of naturally acquired acute trypanosomosis in goat number 12 from group 3 (no trypanocidal treatment).*

3 over the 17-week period following kidding (Table 5.3). Only isolated parasitaemias were detected during pregnancy. The species of trypanosomes were not routinely recorded during the year.

One kid was detected parasitaemic with *Trypanosoma vivax* in calendar week 50 (25 weeks old), and it remained parasitaemic over the following nine weeks. No other kid was parasitaemic. One isolated trypanosomal infection was found in adults over this same period (Figure 3.1).

5.3.5 Treatment with diminazene aceturate

During the period of peak prevalence of trypanosomal infections from calendar week 31 to week 46, seven of the nine goats in group 2 were treated with diminazene aceturate when their PCV fell to 20% or below; of these, three were treated twice and four once. The average weekly incidence of treatments was 7.4% between weeks 31 and 46.

Table 5.2 *Fertility of adult (one-year-old) female goats.*

Treatment group[†]	Number mated	Number[‡] kidding successfully	Mean[§] litter size	Mean[§] birth weight of kids (kg)
1 (isometamidium)	10	9	1.56	1.94
2 (diminazene)	9	8	1.38	1.85
3 (untreated)	15	10	1.30	1.89
Average SE of difference between two means			0.24	0.12

[†]See footnote to Table 5.1.
[‡]Excluding two goats which conceived to second male and one goat which gave birth prematurely to kids that died within four days.
[§]Including only live births.
[¶]Ignoring four goats which died during pregnancy.

Table 5.3 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume and rectal temperature over periods of 17 weeks before and after kidding in adult (one-year-old) female goats that raised a kid.*

	Treatment group[†]			
	1 (isometamidium)	2 (diminazene)	3 (untreated)	Average SED[‡]
Number of goats	9	8	10	
Prevalence of trypanosomal infections (%)				
Before kidding	0.5	0.7	0.4	—
After kidding	5.0	10.4	32.5	—
Incidence of infection (%)[§]				
Before kidding	0.5	0.7	0.4	—
After kidding	4.1	7.8	12.0	—
Packed cell volume (%)				
Before kidding	28.8	29.8	30.5	0.74
After kidding	29.2	28.5	26.6	0.91
Rectal temperature (°C)				
Before kidding	38.18	38.09	38.20	0.07
After kidding	38.14	38.24	38.50	0.13

[†]See footnote to Table 5.1.
[‡]Average standard error of difference between two means.
[§]Cases of parasitaemia preceded by at least two samples without parasitaemia being detected (see section 2.7.1 for complete definition).
(—) Not calculated.

5.3.6 Packed cell volume and rectal temperature

During pregnancy there were no significant differences in PCV but during lactation the untreated goats (group 3) had lower mean PCVs compared with the other two groups ($P < 0.05$) (Table 5.3). During the period between weeks 36 and 47, when trypanosomosis risk was at its highest (Figure 5.1), mean PCV fell to 25.6, 23.7 and 19.3% in

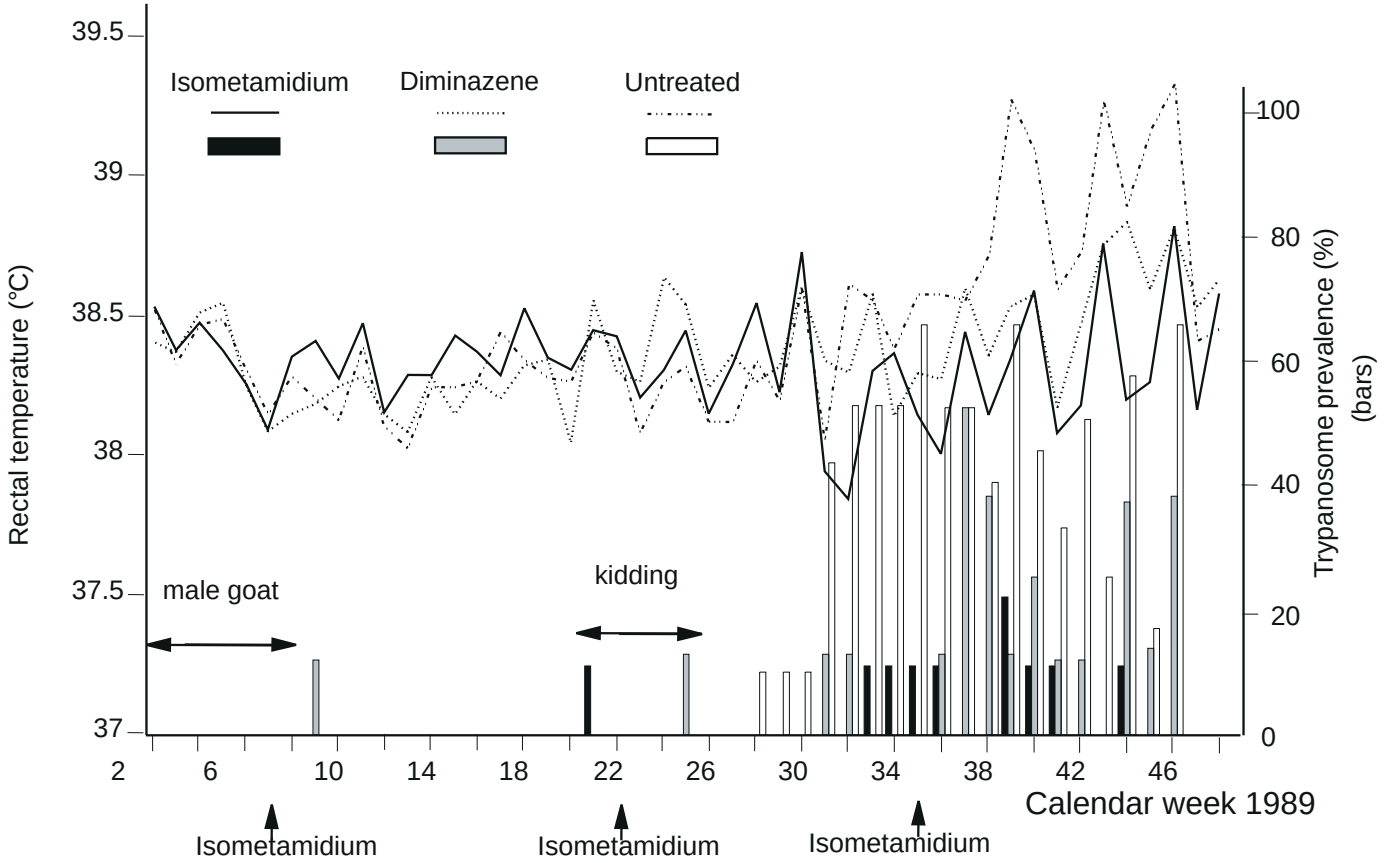

Figure 5.3. *Changes in mean rectal temperature of adult (one-year-old) female goats that raised a live kid. [9 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., 8 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%, and 10 untreated, 4 of which died between weeks 40 and 45.]*

Table 5.4 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume and rectal temperature between calendar weeks 36 and 47 in adult (one-year-old) female goats.*[†]

	Treatment group[‡]			
	1 (isometamidium)	2 (diminazene)	3 (untreated)	Average SED[§]
Number of goats	10	9	15	
Prevalence of trypanosomal infections (%)	5.1	19.6	39.7	—
Incidence of infection (%)[¶]	5.6	18.2	30.4	—
Packed cell volume (%)	25.6	23.7	19.3	1.22
Rectal temperature (°C)	38.20	38.42	38.82	0.15

[†]Including 27 goats that raised a kid (see Table 5.3) and 7 which did not.
[‡]See footnote to Table 5.1.
[§]Average standard error of difference between two means.
[¶]See footnote in Table 5.3.
(—) not calculated.

groups 1, 2 and 3, respectively ($P < 0.001$) (Table 5.4). Mean rectal temperature also showed a significant increase in the untreated group compared to the two treated groups ($P < 0.001$) (Figure 5.3; Table 5.4).

5.3.7 Body weight changes

During pregnancy, body weight increased from a mean of 26.7 kg 17 weeks before kidding to 34.9 kg one week before kidding (see Table 5.5); there were no significant differences between treatment groups. Changes in body weights of dams differed between groups during lactation; unlike group 1, body weights of goats in groups 2 and 3 did not increase during the period of peak prevalence of trypanosomal infections (Figure 5.4). Between weeks 2 and 17 after kidding the isometamidium-protected goats that raised a kid showed a mean weight gain of 15 g/d, whereas untreated goats lost 25.5 g/d ($P < 0.01$) (Table 5.5). The diminazene-treated group lost an average of 2.5 g/d, although this was not significantly lower than group 1. These changes in body weight were inversely associated with the prevalence of trypanosomal infections in the three groups (Table 5.3).

Female kids of untreated dams (group 3) were lighter than those of treated dams (groups 1 and 2) at 20 weeks of age, but not significantly so (Table 5.5). No kids died because of trypanosomosis.

5.3.8 Herd growth

At the beginning of the study there were 19 goats in the untreated group and 10 each in groups 1 and 2. Twenty weeks after kidding, when male kids had been removed, there were 19 adults and kids in the untreated group, 16 in the isometamidium-protected group and 13 in the diminazene-treated group.

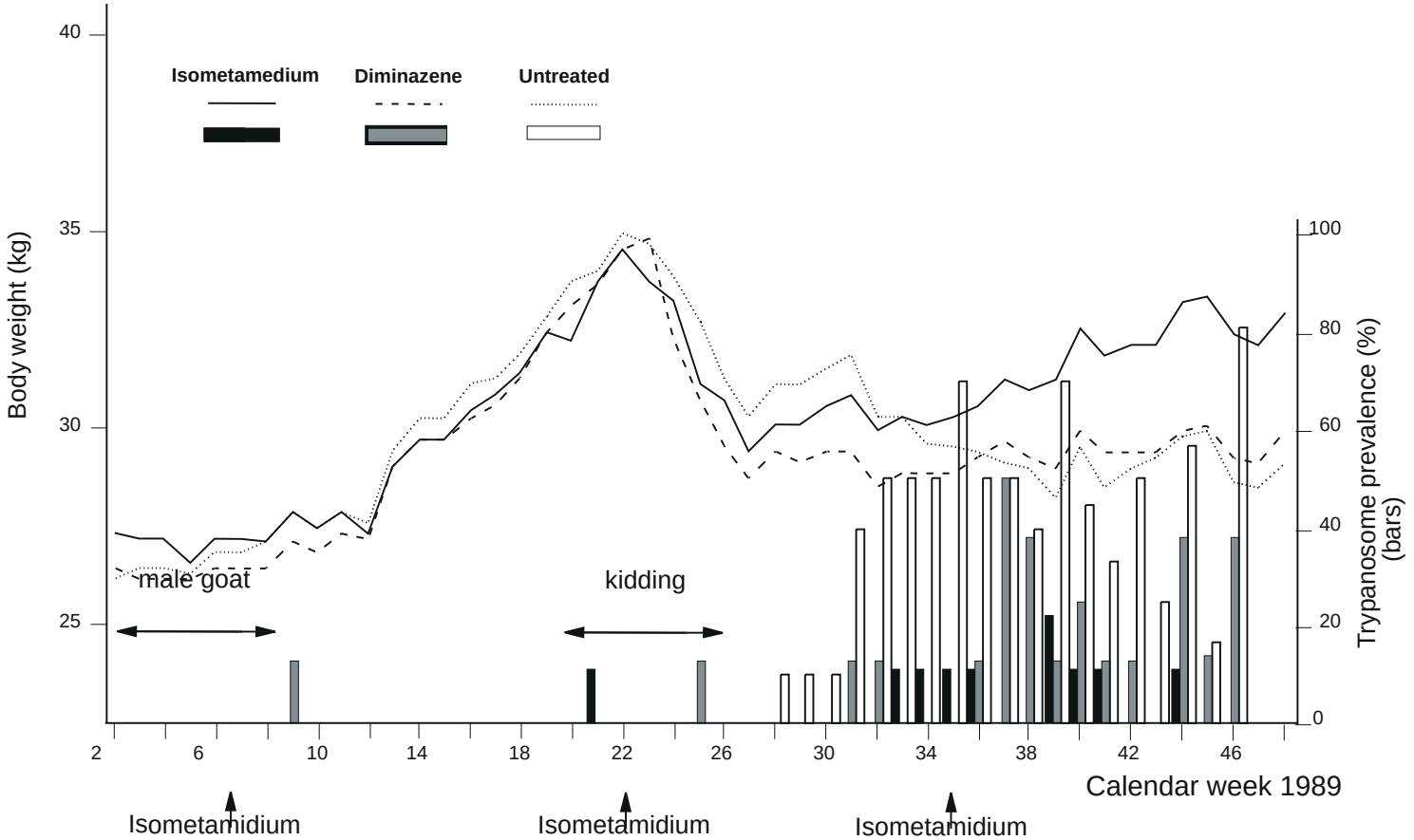

Figure 5.4 *Changes in mean body weight of adult (one-year-old) female goats that raised a live kid. [9 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., 8 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic with PCV ≤ 20%, and 10 untreated, 4 of which died between weeks 40 and 45.]*

Table 5.5 *Mean body weight changes in adult (one-year-old) female goats that raised a kid, and mean body weight of their female kids at 20 weeks of age, corrected for litter size.*

	Treatment group[†]			Average SED[‡]
	1 (isometamidium)	2 (diminazene)	3 (untreated)	
Number of goats	9	8	10	
Body weights				
Before kidding				
–17 weeks (kg)	27.1	26.2	26.7	1.2
–1 week (kg)	34.8	34.6	35.3	1.2
Weight change (g/d)	69.1	74.4	77.3	14.4
After kidding				
2 weeks (kg)	30.5	29.9	31.2	1.1
17 weeks (kg)	32.1	29.6	28.5	1.4
Weight change (g/d)	15.0	–2.5	–25.5	12.6
Body weight of kids at 20 weeks of age (kg)[§]	15.3 (6)	15.2 (4)	14.1 (7)	0.8

[†]See footnote to Table 5.1.
[‡]Average standard error of difference between two means.
[§]Female kids only (males not weighed), number of dams in parentheses.

5.4 Summary of the findings

5.4.1 Faecal egg counts

Helminth infections did occur but the level of infection was not clinically significant (Hansen and Perry 1994). The practice of herding goats and allowing them to browse extensively, coupled with the use of raised, slatted flooring used in the goat house, prevented the build-up of helminth infection.

5.4.2 Mortality and herd growth

Trypanosomosis caused the death of 42% of untreated goats. Death followed a relatively short illness of only a few weeks which was characterised by a rapidly developing anaemia, fever and weight loss. Trypanosome-infected goats responded well to treatment with diminazene at a dose rate of 7 mg/kg. This regimen of diagnosis and treatment effectively prevented deaths from trypanosomosis and reduced the severity of the losses.

The zero growth in the herd size of the untreated group well demonstrates the impact of trypanosomosis, contradicting the common observation that ‘goats apparently thrive under tsetse challenge’. In contrast, the other two groups grew on average by 45% when surviving dams and their female kids were counted at weaning.

5.4.3 Fertility

Untreated goats had the lowest fertility, but the proportion kidding successfully was not significantly lower than that of the other two groups.

5.4.4 Prevalence of trypanosomal infections

The prevalence of trypanosomal infections in unprotected goats rose after tsetse challenge increased. This occurred two to three months after kidding. The sporadic occurrence of infections during pregnancy was associated with a lower tsetse challenge. Prophylaxis with isometamidium effectively controlled the incidence of trypanosomal infections, although a few cases occurred when incidence was high in unprotected goats.

5.4.5 Packed cell volume, rectal temperature and body weight

Untreated trypanosomal infections caused serious anaemia and weight loss and consistently elevated mean rectal temperatures. During lactation, at the time of peak prevalence of trypanosomal infections, protected goats maintained higher PCV and body weight and lower rectal temperature than untreated goats.

Chapter 6. 1990 experiment

6.1 Aim

(i) To determine the effects of prophylactic and curative trypanocidal regimens on the course of naturally acquired trypanosomosis in goats of different ages.
(ii) To determine the severity of the constraints imposed by trypanosomosis at the time of peak tsetse challenge on the fertility of goats and their productivity during lactation.

6.2 Materials and methods

6.2.1 Experimental design

For this experiment, mating was delayed by two months so that kidding commenced during the predicted seasonal rise in tsetse challenge.

Seven female goats which received protection with isometamidium chloride during 1989 continued to be protected during 1990 (group 1). These goats were treated at a dose rate of 0.5 mg/kg b.w. in calendar week 44 (1989) and calendar weeks 17, 30 and 43 (1990) (Figure 6.1) and also in calendar week 4 (1991). Fifteen goats which had belonged to the diminazene-treated and untreated groups in 1989 formed a new, single group 2. Individual goats in this group with trypanosomal parasitaemia and a packed cell volume (PCV) of 20% or less were treated with diminazene aceturate at a dose rate of 7 mg/kg b.w. Five goats that completed the previous experiment were not included; one died in between experiments and four accidentally became pregnant to a male kid. Twenty female goats born during 1989 were allocated randomly and equally to the two groups. It was found necessary to treat one goat in group 1 with diminazene aceturate shortly after kidding; it was transferred to group 2 for the remainder of the experiment.

An adult male goat (obtained locally, dewormed and treated with isometamidium chloride in week 1 of 1990) was introduced in week 10 and remained with the females for six weeks (Figure 6.1). The same goat was reintroduced for a further three weeks from week 22 (not indicated in Figure 6.1). In week 28 a premature kid was born. The first birth of normal, live kids was one week later. Kids were weaned in week 52.

Female goats were weighed and their rectal temperatures taken weekly. Blood samples were also collected weekly to measure PCV and detect trypanosomal parasitaemia. Kids were weighed at birth and weekly thereafter until weaning.

6.2.2 Statistical analysis

As in the first experiment, the fertility of the female goats was defined to be impaired if:
(i) no kid was born (3 goats);
(ii) kids were conceived during the second introduction of the male (2 goats); or
(iii) kids were born prematurely and were stillborn, or died naturally within four days (5 goats).

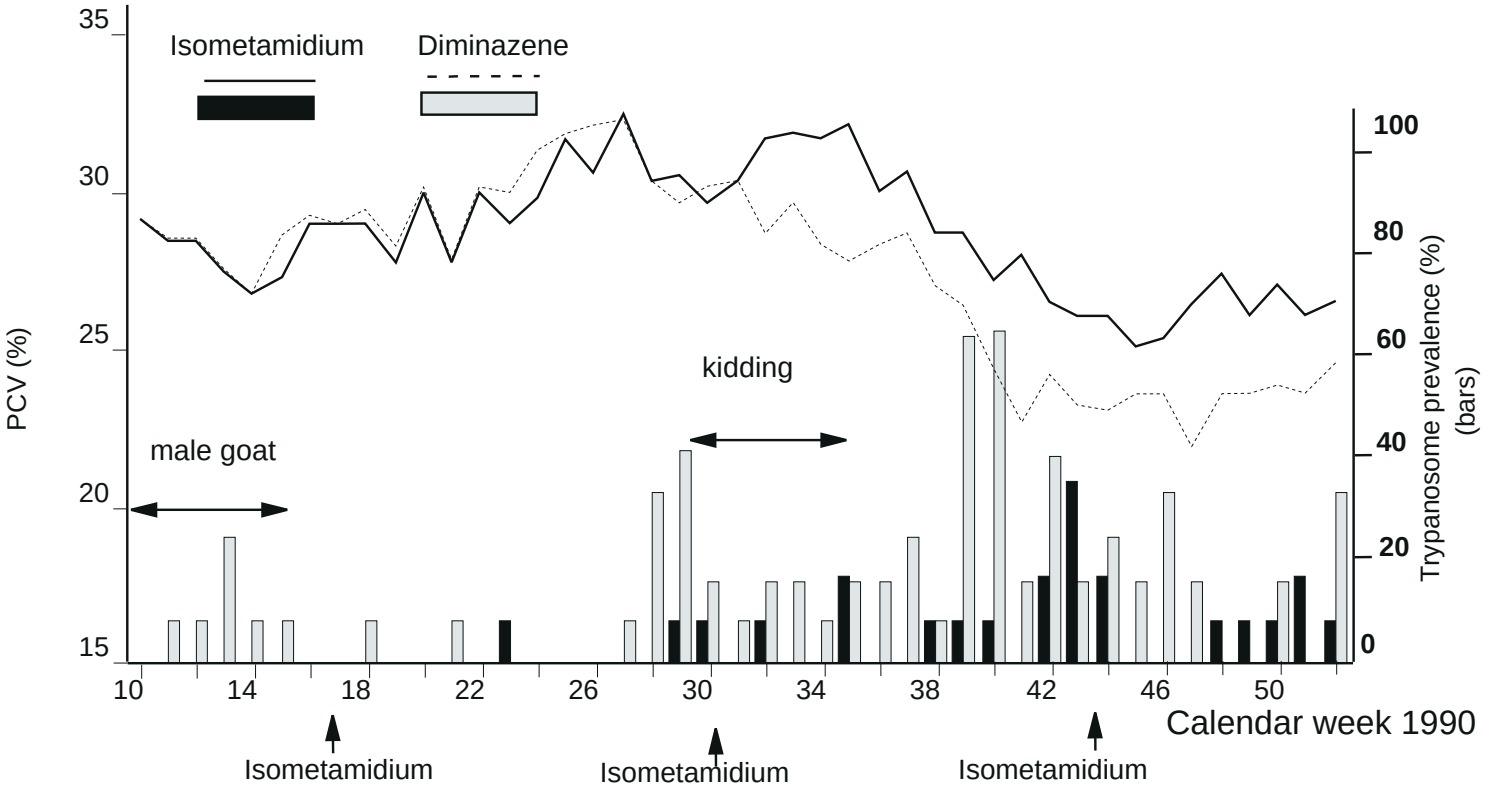

Figure 6.1 *Changes in mean PCV of one- and two-year-old female goats that raised a live kid. [14 goats treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. and 15 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.]*

Results obtained from these 10 goats were omitted from analyses of the effects of treatment regimen on body weight, PCV and rectal temperature. Results from three other goats were also omitted: one which was killed by a lion during pregnancy, one whose kid was crushed and died at 1 week of age, and one which was treated when parasitaemic just after kidding and was switched from the isometamidium-treated to the diminazene-treated group. The 29 remaining goats kidded between weeks 29 and 35. Analyses of variance with terms for treatment group, parity and their interaction were carried out for body weight, weight change, PCV and rectal temperature over the same 17-week periods relative to kidding as in the first experiment.

Isometamidium chloride was given twice to goats in group 1 during the period of highest prevalences of trypanosomal parasitaemia in weeks 30 and 43. Mean PCVs and rectal temperatures were calculated and compared over the period between weeks 31 and 56 which coincided with the period over which goats in group 1 were protected with isometamidium chloride.

Analyses of variance were also carried out on mean birth weights and body weights of kids at 20 weeks of age, with terms for treatment group, sex and numbers of kids born or raised. Dam was used as the observational unit as before.

6.3 Results

6.3.1 Mortality

One female goat was killed by a lion in week 27.

6.3.2 Fertility

Fifteen of 17 isometamidium-protected goats successfully gave birth to live kids compared to only 16 of 24 diminazene-treated goats (Table 6.1). This difference, however, was not significant ($\chi^2 = 2.52$ with 1 degree of freedom). The median period of 'gestation' from the first entry of the male goat was 152 days (range 137–182 days). There was no significant difference between the groups. Six of the eight diminazene-treated goats in the low fertility category were parity 2 goats. There was an association between foetal death and the occurrence of parasitaemia in the last weeks of pregnancy of parity 2 goats (Table 6.2). Four goats (numbers 1, 3, 20 and 38) which were not parasitaemic during the last six weeks of pregnancy gave birth to live kids, whereas four goats (numbers 5, 27, 28 and 31) that aborted or gave birth to premature kids were each parasitaemic at least twice in the latter part of pregnancy. Only one of the younger goats gave birth to a dead, premature kid (data not shown); the mother was parasitaemic the day after parturition. Another one-year-old goat detected parasitaemic during the last three weeks of pregnancy had a normal birth.

There was no significant difference in litter size or kid birth weight between the two treatment groups (see Table 6.1). However, parity 2 goats had a significantly higher mean litter size of 1.71 ± 0.16 (SE) kids than parity 1 goats (1.17 ± 0.10; $P < 0.01$).

Table 6.1 *Fertility of adult female goats by parity and treatment group.*

	Parity						
	1		2		Total		
	Proportion kidding successfully†	Mean‡ litter size	Proportion kidding successfully†	Mean‡ litter size	Proportion kidding successfully	Mean litter size	Mean birth weight of kids (kg)
Treatment group§							
1 (isometamidium)	9/10	1.22	6/7	1.50	15/17	1.33	1.97
2 (diminazene)	8/10	1.12	8/14	1.88	16/24	1.50	1.71
Total and mean	17/20	1.17	14/21	1.71	31/41	1.42	1.84

†Ignoring two goats which conceived to second male and five goats which gave birth prematurely to kids that were stillborn or died within four days.
‡Including only live births.
§Group 1 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. at 13 week intervals; group 2 treated on an individual basis with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.

Table 6.2 *Occurrence of trypanosomal infections during the last six weeks of pregnancy in 12 two-year-old goats that produced live or dead offspring and that did not receive prophylactic treatment.*†

Dam number	Weeks before kidding						Number of cases of parasitaemia
	6	5	4	3	2	1	
Live kids							
1	—	—	—	—	—	—	0
3	—	—	—	—	—	—	0
10	—	*	—	—	—	—	1
11	—	*	*	*	—	—	3
16	—	—	—	—	—	*	1
20	—	—	—	—	—	—	0
23	—	—	—	—	*	*	2
38	—	—	—	—	—	—	0
Stillbirths or abortions							
5	—	—	—	—	*	*	2
27	—	—	—	*	*	*	3
28	—	—	—	—	*	*	2
31	*	—	*	—	—	*	3

†Two goats not included in this table (see Table 6.1) did not give birth.
*Parasitaemia detected.
(—) Parasitaemia not detected.

6.3.3 Prevalence of trypanosomal infections

In contrast to the first experiment, the onset of peak incidence of parasitaemia occurred just before the first goat kidded in week 29 (Figure 6.1). However, in 1990, as in 1989, this onset coincided approximately with the peak of tsetse challenge. Trypanosomal infections continued to occur throughout the period when the goats raised their kids. Average weekly prevalences of trypanosomal infections during this period were 6.3%

Table 6.3 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume and rectal temperature by treatment group over 17-week periods before and after kidding in 29 one- and two-year-old female goats that raised a kid.*

	Treatment group[†]		
	1 (isometamidium)	2 (diminazene)	SED[‡]
Number of goats	14	15	
Prevalence of trypanosomal infections (%)			
Before kidding	0.8	5.3	—
After kidding	6.3	19.0	—
Incidence of infection (%)[§]			
Before kidding	0.8	4.9	—
After kidding	3.1	13.9	—
Packed cell volume (%)[¶]			
Before kidding	29.1	29.6	0.62
After kidding	28.2	25.6	0.94
Rectal temperature (°C)[¶]			
Before kidding	38.00	38.02	0.050
After kidding	38.11	38.51	0.093

[†]See footnote to Table 6.1.
[‡]Standard error of difference between means.
[§]Cases of parasitaemia preceded by at least two samples without parasitaemia being detected (see section 2.7.1 for complete definition).
[¶]Corrected for parity by analysis of variance.
(—) Not calculated.

in the isometamidium-protected group and 19% in the diminazene-treated group (Table 6.3). Over the period between weeks 31 and 56, and considering all 41 goats, mean prevalences of trypanosomal infections were 7.1 and 18.2% for groups 1 and 2, respectively. Averaged over treatment groups, the mean prevalence of trypanosomal infections after kidding was higher in parity 2 than in parity 1 goats (Table 6.4).

Trypanosoma congolense accounted for 35% of the infections, *T. vivax* 23% and *T. brucei* 7%. The remaining 35% were mixed infections, with approximately equal proportions for the three species.

6.3.4 Treatment with diminazene aceturate

During the period of peak prevalence of trypanosomal infections (from week 28 to week 52) 11 of the 14 parity 2 goats in group 2 were treated with diminazene aceturate when their PCV fell to 20% or below. Of these two were treated on three occasions, four twice and five once. Four of the 10 parity 1 goats were treated once. The average weekly incidence of treatment over the period was 5.4% for parity 2 goats and 1.6% for parity 1 goats.

6.3.5 Packed cell volume and rectal temperature

There were no significant differences in PCV during pregnancy, but mean PCV after kidding was significantly higher in the isometamidium-protected group than the

Table 6.4 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume, rectal temperature and body weight change over 17-week periods before and after kidding in parity 1 and 2 goats that raised a kid.*

	Parity		
	1	2	SED[†]
Number of goats	16	13	
Prevalence of trypanosomal infections (%)			
Before kidding	2.6	3.6	—
After kidding	9.0	17.0	—
Incidence of infection (%)[‡]			
Before kidding	1.5	2.6	—
After kidding	6.9	13.5	—
Packed cell volume (%)[§]			
Before kidding	31.0	27.3	0.63
After kidding	29.1	24.1	0.94
Rectal temperature (°C)[§]			
Before kidding	38.00	38.01	0.05
After kidding	38.33	38.30	0.09
Body weight change (g/d)[§]			
Before kidding	71.6	70.1	4.1
After kidding	3.6	–21.3	5.7

[†]Standard error of difference between means.
[‡]See footnote to Table 6.3.
[§]Corrected for treatment group by analysis of variance.
(—) Not calculated.

diminazene-treated group ($P < 0.01$) (Figure 6.1; Table 6.3). When the results from all goats, including those that did not kid, were analysed over the period 31–56 weeks, mean PCVs were 28.1 and 25.2% for the protected and unprotected groups, respectively.

During pregnancy the mean PCV in the older goats was 27.3% (Table 6.4). Despite the low levels of detected parasitaemia this mean PCV was significantly lower than the mean of 31.0% in the younger goats ($P < 0.001$). Mean PCV decreased after kidding in both age groups and remained significantly lower in parity 2 goats than in parity 1 goats ($P < 0.01$).

The higher prevalence of trypanosomal infections after kidding resulted in higher rectal temperatures in unprotected goats (mean 38.51°C) than in protected goats (mean 38.11°C; $P < 0.01$) (Table 6.3). This difference was, however, more pronounced in parity 2 goats (38.60 and 37.97°C in unprotected and protected goats, respectively) than in parity 1 goats (38.44 and 38.21°C in unprotected and protected goats, respectively). This treatment group × parity interaction was significant ($P < 0.05$).

6.3.6 Body weight changes

From 17 weeks to 1 week before kidding, mean body weight increased from 21.7 to 29.7 kg and from 37.1 to 44.9 kg in the younger and older goats, respectively. Over this period there were no significant differences in body weight between the two treatment groups (Table 6.5). However, from about week 34, shortly after parturition, body weights in the

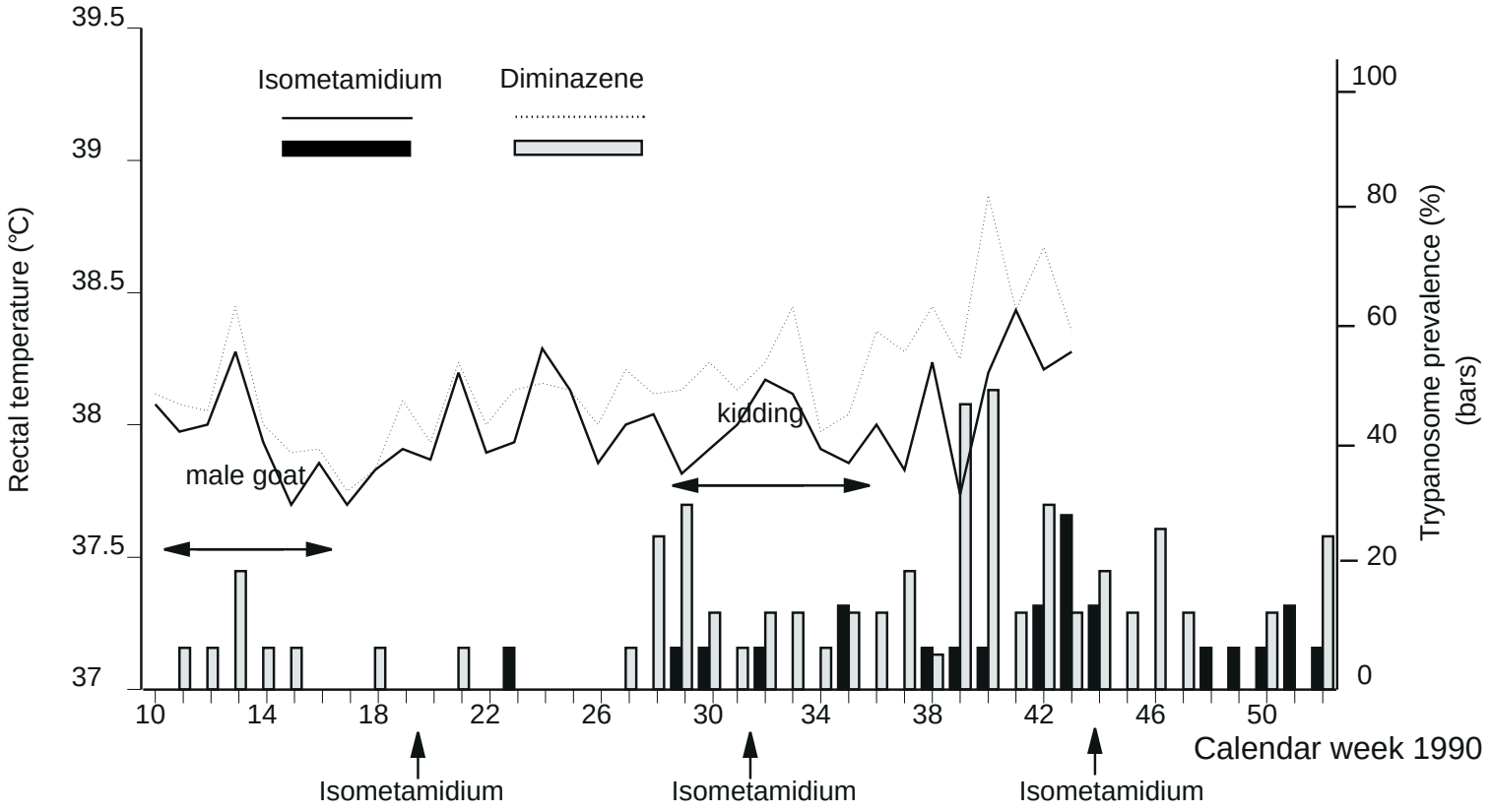

Figure 6.2 *Changes in mean rectal temperature of one- and two-year-old female goats that raised a live kid. [14 goats treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. and 15 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%]*

Table 6.5 *Mean body weight changes by treatment group, corrected for parity, in one- and two-year-old female goats that raised a kid, and mean body weights of their kids at 20 weeks of age, corrected for sex and litter size.*

	Treatment group[†]		
	1 (isometamidium)	2 (diminazene)	SED[‡]
Number of adult goats	14	15	
Body weights of adult goats			
Before kidding			
–17 weeks (kg)	28.8	28.4	1.2
–1 week (kg)	36.5	36.6	1.2
Weight change (g/d)	68.2	73.4	4.1
After kidding			
2 weeks (kg)	32.5	32.1	1.0
17 weeks (kg)	32.4	30.6	1.0
Weight change (g/d)	–0.5	–14.2	5.7
Body weight of kids at 20 weeks of age (kg)	15.8	15.1	1.0

[†]See footnote to Table 6.1.
[‡]Standard error of difference between means.

diminazene-treated group decreased faster than those in the isometamidium-protected group (Figure 6.3). From 2 to 17 weeks after kidding, the average reductions in body weights in the two groups were respectively 0.5 g/d and 14.2 g/d ($P < 0.05$) (Table 6.5), and there was no significant treatment group × parity interaction. The difference in body weight change after kidding was associated with a corresponding difference in prevalence of infection between the two treatment groups (Table 6.3). The mean difference in body weight between the two groups 17 weeks after kidding was 1.8 kg ($P = 0.08$) (Table 6.5). Parity 2 goats lost weight during lactation, whereas parity 1 goats maintained weight. Body weights 17 weeks before and 17 weeks after kidding were, respectively, 21.7 and 27.3 kg for parity 1 goats and 37.1 and 36.6 kg for parity 2 goats.

At 20 weeks of age, body weights of kids born to unprotected dams were not significantly lower than those of kids born to protected dams (Table 6.5). Mean body weights of twins were 13.3 kg compared with 17.7 kg for singletons ($P < 0.001$). Parity 2 goats produced heavier 20-week-old kids (17.4 kg) than did parity 1 goats (13.6 kg) ($P < 0.001$) despite the higher prevalence of trypanosomal infections in the older goats during lactation (Table 6.4).

6.3.7 Herd growth

At the beginning of the experiment there were 25 goats in the unprotected group and 17 in the protected group. At weaning, the numbers of goats, including female kids, had increased to 32 in the unprotected group (a 28% increase) and 23 in the protected group (a 35% increase). There were, however, by chance, many more male (31) than female kids (14) born to the male goat used in 1990, which reduced potential growth of the female herd.

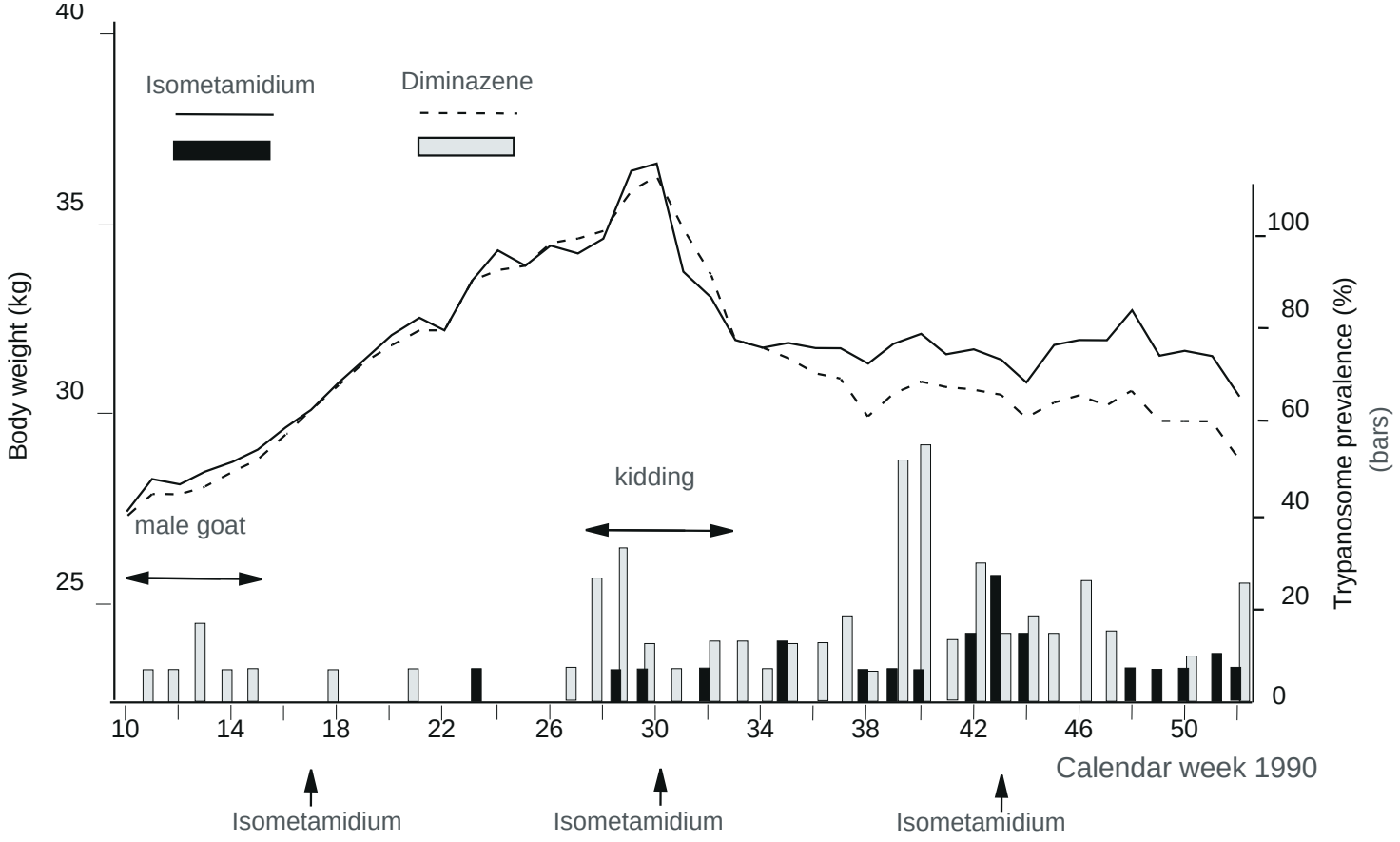

Figure 6.3 *Changes in mean body weight of one- and two-year-old female goats that raised a live kid. [14 goats treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. and 15 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.]*

6.4 Summary of the findings

6.4.1 Mortality and herd growth

As in the 1989 experiment, trypanocidal treatment and prophylaxis effectively prevented deaths from trypanosomosis. For instance, two goats that were treated three times when their PCV fell to 20% or below would probably otherwise have died. Similar increases in female herd growth were achieved in the two treatment groups.

6.4.2 Fertility

Although not statistically significant, diminazene-treated goats had poorer fertility in 1990 than 1989 (16/24 gave birth to live kids in 1990 compared with 8/9 in 1989). This was presumably due to the higher prevalence of trypanosomal infections in pregnant goats in 1990. The proportions of isometamidium-protected goats giving birth to live kids were similar in the two years (9/10 in 1989, 15/17 in 1990). Despite the lower fertility in the diminazene-treated group, both groups showed similar herd growth when female kids were counted at weaning.

Stillbirths and abortions were associated with parasitaemias in late pregnancy.

6.4.3 Prevalence of trypanosomal infections

As in 1989, trypanosomal infections rose following the seasonal increase in tsetse challenge. This was just before kidding.

6.4.4 Packed cell volume, rectal temperature and body weight

During the lactational period, when trypanosomal infections were most prevalent, the PCVs and body weights of the unprotected goats were significantly lower, and rectal temperatures significantly higher, than those of isometamidium-protected goats. The differences were similar to those in 1989 during the corresponding period of peak tsetse challenge.

6.4.5 Age

A number of effects of age (or parity) were observed. At the time of peak tsetse challenge during late pregnancy and lactation, parity 2 goats had higher prevalences of trypanosomal parasitaemias, and higher rectal temperatures, than parity 1 goats. The older goats also had significantly lower PCVs, both before and after kidding. Despite these differences the older goats that kidded successfully had significantly higher fecundity.

Chapter 7. 1991 experiment

7.1 Aim

To compare the fertility of goats given chemoprophylaxis during pregnancy with that of unprotected goats, and to compare the efficacy of a single prophylactic treatment given early in pregnancy with that of two treatments, one given early and one given later in pregnancy.

7.2 Materials and methods

7.2.1 Experimental design

Compared with 1990, the mating was delayed a further three months to ensure that the whole period of pregnancy coincided with the period of peak tsetse challenge.

The 41 female goats which survived the previous experiment were reallocated randomly within each age and treatment group. For this purpose the three-year-old goats were also subdivided into those that had reared and those that had not reared kids during 1990. Goats were assigned at random from each of these categories to form three new groups of 11, 11 and 19 goats. To these groups were assigned, respectively, 3, 3 and 8 female kids that were born in 1990. Goats in group 1 were given isometamidium chloride at a dose rate of 0.5 mg/kg once during pregnancy and goats in group 2 were protected twice during pregnancy. Goats in group 3 were not protected but were treated with diminazene aceturate at a dose rate of 7 mg/kg body weight when trypanosomal parasitaemia was detected and packed cell volume (PCV) was 20% or below.

All 55 goats were treated with diminazene aceturate at a dose rate of 7 mg/kg body weight in calendar weeks 19 and 22. A male goat, obtained locally and protected with isometamidium chloride, was introduced in calendar week 23 and remained with the females for six weeks. Kidding commenced in week 43, although one premature birth occurred one month earlier. Kids were weaned in week 68 (calendar week 16 of 1992). Isometamidium chloride was given to groups 1 and 2 in week 29 at a dose rate of 0.5 mg/kg body weight, two days after the male goat was removed, and again to group 2 in week 40.

Female goats were weighed and rectal temperatures taken weekly. Blood samples were collected weekly to measure PCV and detect trypanosomal parasitaemia. Kids were weighed at birth and weekly thereafter until weaning. Blood samples were also collected from kids from week 58 (calendar week 6 of 1992) onwards when the kids were on average 12 weeks old.

7.2.2 Statistical analysis

Three goats were removed from the data set (one in group 2 and two in group 3): one died early in pregnancy and two were removed from the experiment in week 43 because of ruptures, probably caused by fighting. The results from the remaining 52 goats were analysed.

As in previous experiments fertility of the female goats was defined to be impaired if:

(i) no kid was born (5 goats); or

(ii) kids were born prematurely and were either stillborn or died within four days (4 goats).

In addition, two goats that died late in pregnancy with signs of trypanosomosis were included in this low fertility category. The 11 goats with impaired fertility were omitted from analyses of the effects of treatment regimens on body weight, PCV and rectal temperature. The remaining 41 goats kidded between weeks 43 and 49. Analyses of variance with terms for treatment, parity and their interaction were carried out on body weight, body weight change, mean PCV and mean rectal temperature over the same time periods relative to kidding as in the first two experiments. The results from four of the 41 goats were omitted in this analysis—two whose kids died and two that were injured during lactation and were removed from the experiment.

The highest prevalences of trypanosomal parasitaemia occurred between week 35 (eight weeks before the commencement of kidding) and week 55. Isometamidium chloride was given to group 2 goats in week 40. Mean PCVs and rectal temperatures were thus calculated and compared over the period between weeks 41 and 52, when isometamidium chloride was expected to protect group 2 goats. The results from 47 goats, which were alive at the end of this period, were used in an analysis of variance, which included terms for treatment group, parity and treatment group × parity.

Analyses of variance were also carried out on mean birth weight and mean body weight of kids at 20 weeks of age with terms for treatment group, sex and number of kids reared. Dam was used as the observational unit as before.

7.3 Results

7.3.1 Mortality

Ten of the 55 goats died or were removed during the course of the experiment (three in group 1, one in group 2 and six in group 3). Five of these deaths, as already mentioned, occurred during pregnancy; the remainder occurred during lactation. Six goats were removed due to ruptures, probably caused by fighting. Only two of the deaths (one in each of groups 1 and 3, both of parity 3, and unprotected at the time) appeared to be associated with trypanosomosis. Trypanosomal parasitaemias were detected in both of these goats before their death in late pregnancy. The other two goats had very low PCVs when they died, but the causes of death were not diagnosed.

7.3.2 Fertility

Twenty-five of the 27 isometamidium-protected goats successfully gave birth to live kids, compared with only 16 of 25 diminazene-treated goats. This difference was significant ($\chi^2 = 6.32$ with 1 degree of freedom, $P < 0.05$) (Table 7.1). There was no significant difference between groups 1 and 2. The median period of 'gestation' from the first day that the male goat was introduced was 156 days (range 142–186 days). Only three of the nine diminazene-

Table 7.1 *Fertility of adult female goats by parity and treatment group.*

Treatment group[§]	Parity 1	Parity 2	Parity 3	Total and mean	Mean litter size[‡]	Mean birth weight of kids (kg)
	Proportions kidding successfully[†]					
1 (isometamidium given once)	3/3	4/5	5/6	12/14	1.58	1.56
2 (isometamidium given twice)	3/3	5/5	5/5	13/13	1.46	1.79
3 (diminazene)	5/8	6/9	5/8	16/25	1.50	1.56
Total and mean	11/14	15/19	15/19	41/52	1.51	1.64
Mean litter size	1.27	1.53	1.60	1.49		
Mean birth weight of kids (kg)	1.65	1.63	1.63	1.64		

[†]Ignoring four goats that gave birth prematurely to kids that were stillborn or died within four days.
[‡]Including only live births.
[§]Group 1 treated with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. two days after male goat was removed; group 2 treated at the same time with the same dose of isometamidium chloride and again 11 weeks later, three weeks before the first kid was born.

treated goats in the low fertility category gave birth to stillborn kids. Compared with the previous year, prevalence of trypanosomal infections was not as high during the last six weeks of pregnancy and there were no individual associations between the occurrence of infection and stillbirth or abortion, as was found in the previous experiment (Table 6.2).

The mean litter size in parity 2 and 3 goats was 1.57 ± 0.09 (SE). This was higher than for parity 1 goats (1.27 ± 0.14) but not significantly. There were no significant differences in mean litter size or mean birth weights of kids between protected and unprotected goats.

7.3.3 Prevalence of trypanosomal infections

During pregnancy, average weekly prevalences of trypanosomal infections were 1.0% in the two isometamidium-protected groups and 7.3% in the diminazene-treated group (Table 7.2). The onset of parasitaemia in week 35 was about two months before the end of pregnancy (Figure 7.1). This coincided with the increase in tsetse challenge which was, however, of lower intensity and occurred later than in the previous two years. Thus, the intention to compare treatments when goats were exposed to high tsetse challenge over the whole period of pregnancy was, unfortunately, not realised.

During lactation, similar weekly prevalences of trypanosomal infections occurred in groups 1 and 3 (average 10%), neither of which was protected at this time; there was a lower prevalence of 4.2% in group 2 (Table 7.2). However, the average weekly infection rate in unprotected goats after kidding was approximately half that in the previous experiment (see Table 6.3). Group 2 goats received their second treatment with isometamidium chloride in week 40. Between weeks 41 and 52 the weekly prevalence of trypanosomal infections in these goats was 3.6% compared with 7.7% in group 1 and 11.2% in group 3 goats (Table 7.3).

During pregnancy, parity 3 goats were on average more frequently parasitaemic than parity 1 and 2 goats, but infection rates were similar among the three ages of goats after kidding (Table 7.4).

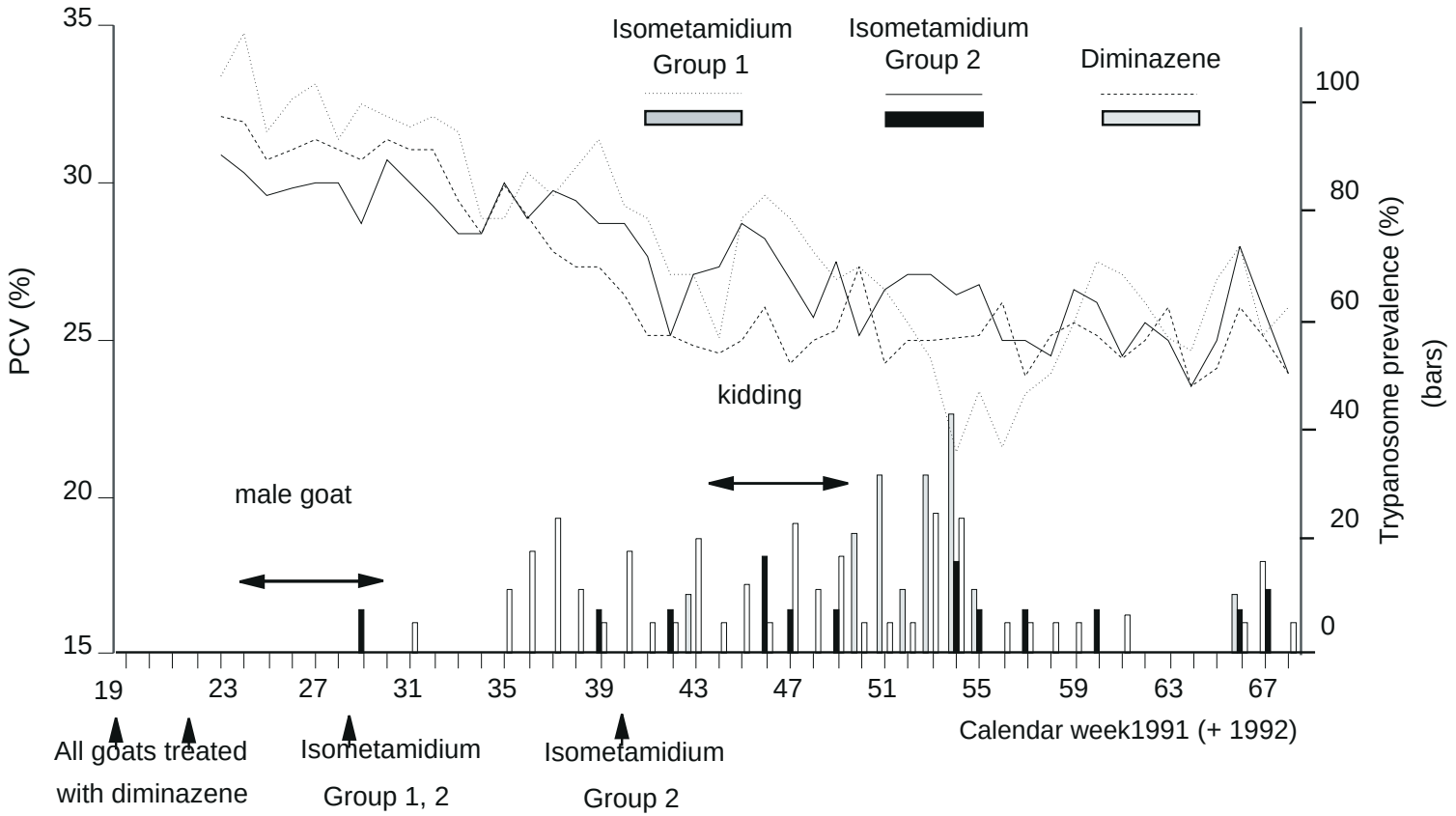

Figure 7.1 *Changes in mean PCV of one-, two- and three-year-old female goats that raised a live kid. [21 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. (9 once, 12 twice) and 16 treated with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.]*

Table 7.2 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume and rectal temperature by treatment group over periods of 17 weeks before and after kidding in 37 one-, two- and three-year-old female goats that raised a kid.*

	Treatment group[†]			
	1 (isometamidium given once)	2 (isometamidium given twice)	3 (diminazene)	SED[‡]
Number of goats	9	12	16	
Prevalence of trypanosomal infections (%)				
Before kidding	0.6	1.3	7.3	—
After kidding	10.3	4.2	9.6	—
Incidence of infection (%)[§]				
Before kidding	0.6	1.3	5.0	—
After kidding	6.8	4.2	7.9	—
Packed cell volume (%)[¶]				
Before kidding	30.0	28.7	28.3	0.80
After kidding	25.6	26.2	24.9	1.06
Rectal temperature (°C)[¶]				
Before kidding	37.9	37.9	37.9	0.074
After kidding	38.6	38.7	38.7	0.097

[†]See footnote to Table 7.1.
[‡]Average standard error of difference between two means.
[§]Cases of parasitaemia preceded by at least two samples without parasitaemia being detected (see section 2.7.1 for complete definition).
[¶]Corrected for parity by analysis of variance.
(—) Not calculated.

Trypanosoma congolense accounted for 31% of the infections, *T. vivax 40%* and *T. brucei 21%*. The remaining 8% were mixed infections. There was no apparent change in pattern of infection with age.

Trypanosomal infections began to occur again in adult goats from week 66 (calendar week 14 of 1992) (Figure 7.1). Two kids were detected parasitaemic with *T. vivax*, one at week 61 and the other at week 63. Following weaning, another kid was found to have a *T. congolense* infection in week 71. All three kids were from group 1 dams.

7.3.4 Treatment with diminazene aceturate

During the period of peak prevalence of trypanosomal infections, between weeks 35 and 55, four of the 25 goats in the diminazene-treated group were treated twice and eight were treated once. The average weekly incidence of treatment was 3.2%. The first diminazene treatment given to a goat in group 1 was in calendar week 43, 14 weeks after treatment with isometamidium. The average weekly incidence of diminazene treatment in this group was 5.4%, from week 43 to 55. Three goats in group 2 were treated on the basis of low PCV; individual treatments were given 6, 10 and 14 weeks after the second group treatment with isometamidium chloride.

Table 7.3 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume and rectal temperature between weeks 41 and 52 in 13 protected (group 2) and 34 unprotected one-, two- and three-year-old female goats (groups 1 and 3).*

	Treatment group[†]			
	1 (isometamidium given once)	2 (isometamidium given twice)	3 (diminazene)	SED[‡]
Number of goats	12	13	22	
Prevalence of trypanosomal infections (%)	7.7	3.6	11.2	—
Incidence of infection (%)[§]	4.9	3.3	8.0	—
Packed cell volume (%)[¶]	27.7	27.0	24.7	0.92
Rectal temperature (°C)[¶]	38.6	38.7	38.7	0.09

[†]See footnote to Table 7.1.
[‡]Average standard error of difference between two means.
[§]See footnote of Table 7.2.
[¶]Corrected for parity by analysis of variance.
(—) Not calculated.

7.3.5 Packed cell volume and rectal temperature

There was a gradual reduction in PCV during the course of the experiment (Figure 7.1). There were no significant differences between treatment groups during pregnancy or during the first 17 weeks of lactation (Table 7.2). However, between weeks 41 and 52, the period of peak parasitaemia, the mean PCV of the group 3 goats that were unprotected throughout pregnancy was significantly lower than the mean PCV of group 2 protected goats ($P < 0.01$) (Table 7.3). There was, however, no difference in mean PCV between group 1 and group 2 goats, even though those in the former group were no longer protected over the period. Packed cell volumes in group 1 goats did, however, decrease later, between weeks 54 and 56 (Figure 7.1).

During pregnancy, the mean PCV of parity 3 goats was lower (26.4%) than the mean PCV of parity 1 goats (30.1%) and parity 2 goats (30.2%; $P < 0.001$) (Table 7.4). During lactation, mean PCV also decreased with increasing parity: 27.0 and 25.9% in parity 1 and 2 goats, respectively, compared with 23.8% in parity 3 goats ($P < 0.01$).

There were no significant differences in rectal temperatures between treatment groups, although there was a general rise in average rectal temperatures in all three groups during the period of peak prevalence of trypanosomal infections (Figure 7.2).

7.3.6 Body weight changes

Despite random allocation of goats to treatment groups, body weights of goats were, by chance, on average higher in group 2 than in groups 1 and 3 at the start of the experiment (Figure 7.3). There were, nevertheless, no significant differences in average weight gain during pregnancy in the three groups (Table 7.5). Over the early part of the lactational period, during the period of peak parasitaemia (Figure 7.3), goats in group 1 lost weight more rapidly than those of the other two groups. Over the whole period from kidding

Table 7.4 *Mean weekly prevalence of trypanosomal infections, weekly incidence of infection, packed cell volume, rectal temperatures and body weight change over periods of 17 weeks before and after kidding, by parity, in 37 female goats that raised a kid.*

	Parity			
	1	2	3	SED[†]
Number of goats	10	14	13	
Prevalence of trypanosomal infections (%)				
Before kidding	1.7	0.9	7.4	—
After kidding	5.7	11.2	7.1	—
Incidence of infection (%)[‡]				
Before kidding	1.0	0.6	5.4	—
After kidding	4.5	9.1	5.3	—
Packed cell volume (%)[§]				
Before kidding	30.1	30.2	26.4	0.79
After kidding	27.0	25.9	23.8	1.04
Rectal temperature (°C)[§]				
Before kidding	38.0	37.9	37.8	0.07
After kidding	38.7	38.6	38.6	0.10
Body weight change (g/d)[§]				
Before kidding	52.1	62.1	58.1	5.1
After kidding	25.2	0.0	–21.5	9.4

[†]Average standard error of difference between two means.
[‡]See footnote to Table 7.2.
[§]Corrected for treatment group by analysis of variance.
(—) Not calculated.

to weaning in week 68, however, there were no significant differences between treatment groups.

Goats of parities 1, 2 and 3 showed similar average weight gains during pregnancy. After kidding, however, parity 1 goats continued to grow (25.2 g/d), whereas parity 2 goats maintained their body weight and parity 3 goats lost weight (21.5 g/d; $P < 0.001$) (Table 7.4). Mean body weights measured 17 weeks before kidding were 19.4, 31.4 and 39.6 kg for parity 1, 2 and 3 goats, respectively. Seventeen weeks after kidding the weights were 26.1, 34.1 and 38.1 kg, respectively.

There were no differences in mean growth rates of kids between protected and unprotected dams, and their body weights at 20 weeks of age were similar (Table 7.5). In contrast to the results of the 1990 experiment, parity had no significant effect on body weights of kids at 20 weeks of age (11.3 kg, parity 1; 12.4 kg, parities 2 and 3). Average body weights of twins (12.4 kg) and singletons (11.6 kg) were also similar at this age.

7.3.7 Herd growth

The total number of female goats in the two protected groups increased from a total of 28 to 45 head at weaning (a 61% increase). The unprotected group increased from 27 to 34 females (a 26% increase). There was thus positive herd growth in all groups, but

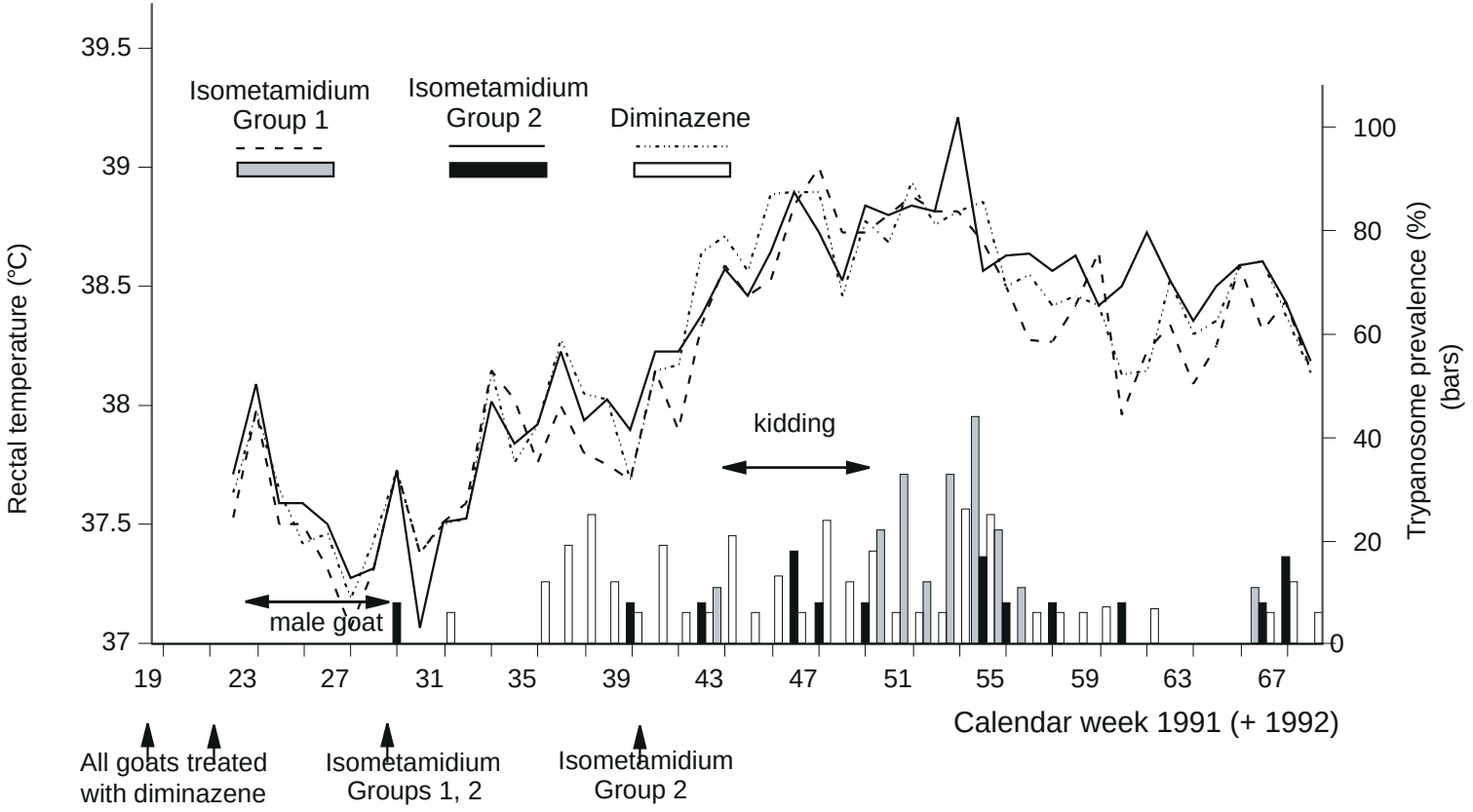

Figure 7.2 *Changes in mean rectal temperature of one-, two- and three-year-old female goats that raised a live kid. [21 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. (9 once, 12 twice) and 16 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.]*

Table 7.5 *Mean body weight changes by treatment group, corrected for parity, in 37 one-, two- and three-year-old female goats that raised a kid, and mean body weight of their kids at 20 weeks of age, corrected for sex and litter size.*

	Treatment group[†]			
	1 (isometamidium given once)	2 (isometamidium given twice)	3 (diminazene)	SED[‡]
Number of goats	9	12	16	
Body weights of adult goats				
Before kidding				
–17 weeks (kg)	30.7	32.9	29.9	1.3
–1 week (kg)	37.7	39.6	35.8	1.3
Weight change (g/d)	62.8	60.1	52.6	5.2
After kidding				
2 weeks (kg)	33.3	36.2	32.0	1.1
17 weeks (kg)	32.1	35.8	32.2	1.6
Weight change (g/d)	–11.0	–4.3	2.2	9.6
Body weight of kids at 20 weeks of age (kg)	12.4	12.2	11.6	0.8

[†]See footnote to Table 7.1.
[‡]Average standard error of difference between two means.

growth in the diminazene-treated group was lower than that in the two isometamidium-protected groups.

7.4 Summary of the findings

7.4.1 Mortality

Two deaths were associated with trypanosomal infections in late pregnancy. Neither goat was under isometamidium prophylaxis at the time.

The increase in the size of the female herd from conception to weaning was twice as high in the protected groups than the unprotected group.

7.4.2 Fertility

Isometamidium prophylaxis during pregnancy resulted in a fertility rate similar to that in 1989 and 1990; 25 of 27 goats kidded normally. Despite the lower prevalence of trypanosomal infections in 1991, the fertility rate in the diminazene-treated group was also similar to that in 1990; 16 of 25 goats kidded normally.

Protected goats were more fertile than unprotected goats but a second prophylactic treatment in pregnancy conferred no significant benefit.

7.4.3 Prevalence of trypanosomal infections

As in 1989 and 1990, the prevalence of trypanosomal infections increased following the seasonal increase in tsetse challenge. Both increases, however, occurred six weeks later

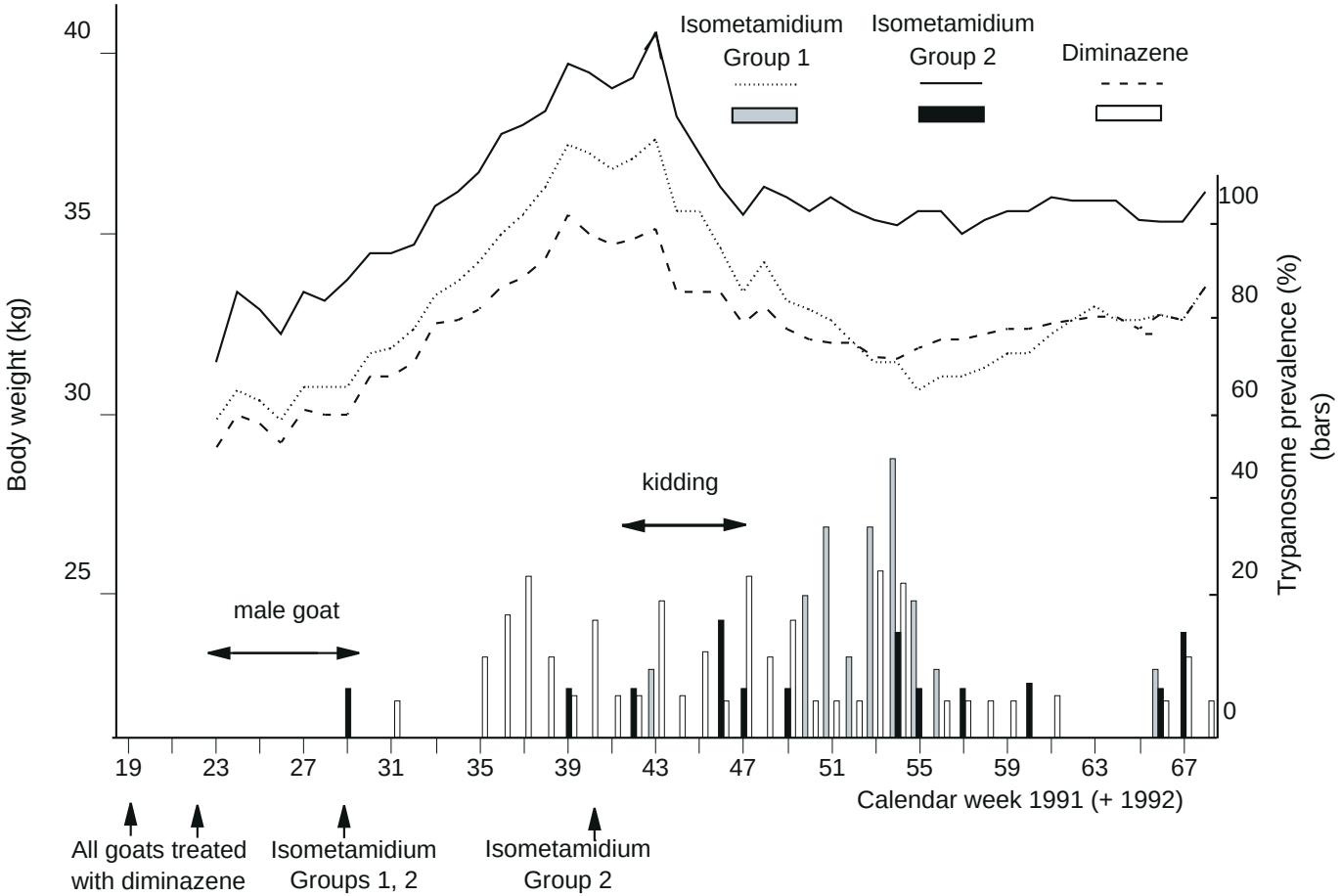

Figure 7.3 *Changes in mean body weight of one-, two- and three-year-old female goat that raised a live kid. [21 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. (9 once, 12 twice) and 16 with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.]*

than in 1989 and 1990. The tsetse challenge and the mean prevalence of trypanosomal infections during lactation were lower in 1991 than in the previous two years.

7.4.4 Packed cell volume, rectal temperature and body weight

With the lower prevalence of trypanosomal infections in 1991, isometamidium prophylaxis had minimal effects on PCV, rectal temperature and body weight during lactation, compared with those of unprotected goats. Isometamidium prophylaxis, therefore, conferred no advantage during the year compared with the alternative regimen of treatment with diminazene aceturate given to individual goats with low PCVs.

7.4.5 Age

The oldest (parity 3) goats were more frequently parasitaemic during pregnancy and had lower PCVs throughout the experiment compared with parity 1 and 2 goats. This maintained the pattern observed in 1990.

Chapter 8.
1989, 1990 and 1991 experiments

8.1 Aim

To examine the overall impact of trypanosomosis on the fertility, health and productivity of protected and unprotected goats, by combining the individual results from the three experiments performed in 1989, 1990 and 1991.

8.2 Materials and methods

8.2.1 Statistical analysis

In the experiments performed in 1989, 1990 and 1991, mating was organised so that kidding occurred at different times relative to the onset of peak tsetse challenge.

Data from the 1989, 1990 and 1991 experiments were combined and analyses of variance were done by the method of general least squares on mean measurements for packed cell volume (PCV) and body weight changes before and after kidding (Harvey 1990). Terms fitted in the statistical models were treatment group (isometamidium-treated or 'protected' and diminazene-treated or 'unprotected'), year and parity, together with second order interactions. In 1991, the 'unprotected group' used for the purpose of this analysis after kidding was a combination of groups 1 and 3, since it was assumed that by the time of kidding no prophylactic effect of isometamidium chloride, administered 14 weeks earlier to group 1, remained. Similar models were also fitted for birth weight and body weight of kids at 20 weeks of age, including as additional parameters sex and numbers of kids born or raised.

Mean prevalences of trypanosomal parasitaemias were also calculated over the three years for each 12-week period following treatment with isometamidium chloride, or until the next isometamidium treatment if this was given earlier than 12 weeks. There were nine such periods (four in 1989, three in 1990 and two in 1991). Corresponding mean prevalences of infection were also calculated over the same periods for the groups of 'unprotected' goats (diminazene-treated goats). Regression analyses were undertaken relating the mean weekly prevalence of trypanosomal infections in 'protected' goats against the mean prevalence in corresponding 'unprotected' goats.

8.3 Results

8.3.1 Effect of trypanosomosis on fertility

The proportions of goats giving birth to live kids in 1989, 1990 and 1991 are summarised in Table 8.1. In 1990 and 1991, even when 'unprotected' goats were treated with diminazene aceturate, trypanosomosis reduced fertility by an average of 28% (24 and 31%, respectively) when compared to levels achieved under isometamidium chloride prophy-

Table 8.1 *Fertility of adult female goats from 1989 to 1991 with corresponding mean weekly prevalences of trypanosomal infections over the period of 17 weeks before kidding.*

	Proportion kidding successfully		
Treatment group[†]	1989	1990	1991
1 (isometamidium)	9/10 (0.90)	15/17 (0.88)	25/27 (0.93)
2 (diminazene)	8/9 (0.89)	16/24 (0.67)	16/25 (0.64)
3 (untreated)	10/15 (0.67)	—	—
Percentage reduction in fertility[‡]	1	24	31
Treatment group	Mean prevalence of trypanosomal infections (%)		
1 (isometamidium)	0.7	0.8	1.0
2 (diminazene)	0.5	5.3	7.3
3 (untreated)	0.4	—	—

[†]Group 1 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., group 2 treated on an individual basis with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%, group 3 not treated.

[‡]Reduction in proportion of goats kidding successfully in group 2 as a percentage of proportion of those kidding successfully in group 1.

(—) Not available.

laxis. Averaging over both years this reduction was significant ($P < 0.01$; $\chi^2 = 8.59$ with 1 degree of freedom). In 1989, when mating occurred earlier in the year and the incidence of infections was much lower (0.7%), similar levels of fertility occurred in the two groups. Compared with protected goats, the mean overall reduction in fertility over the three years was 19% in the diminazene-treated goats. Ranges of 'gestation' periods were similar in 1989, 1990 and 1991 and between 'protected' and 'unprotected' goats. The overall median period of 'gestation', resulting from six-week periods of mating, was 154 days (range 137–186 days).

8.3.2 *Effect of trypanosomosis on packed cell volume and changes in body weight*

Trypanosomosis was not observed to have a significant overall effect on mean PCV during pregnancy; the results from the two treatment groups were similar (Table 8.2). However, over the first 17 weeks after kidding, mean PCV was significantly higher in 'protected' groups (27.7%) than in 'unprotected' groups (25.7%; $P < 0.01$) (Table 8.2). The mean prevalence of trypanosomal parasitaemias in 'unprotected' goats was higher during lactation (13.1%) than during pregnancy (4.4%) (Table 8.2).

When compared to diminazene treatment, chemoprophylaxis had no significant effect on average body weight change, either before or after kidding, over the three years (Table 8.2).

8.3.3 *Effect of parity on packed cell volume and body weight changes*

During lactation, mean PCV decreased with age ($P < 0.001$) (Table 8.3). There was, however, a significant year × parity interaction ($P < 0.001$). In 1991, parity 1 and 2 goats

Table 8.2 *Mean weekly prevalence of trypanosomal infections, packed cell volume and body weight change over periods of 17 weeks before and after kidding in adult female goats adjusted for year and parity, and body weight of kids at birth and 20 weeks of age, adjusted for year, sex, litter size and parity.*

	Treatment group†		
	Protected (isometamidium)	Unprotected (diminazene)	SED‡
Number of goats			
Before kidding	44	39	—
After kidding	35	48	—
Prevalence of trypanosomal infections (%)			
Before kidding	0.8	4.4	—
After kidding	5.2	13.1	—
Packed cell volume (%)			
Before kidding	29.2	29.3	0.5
After kidding	27.7	25.7	0.7
Body weight change (g/d)			
Before kidding	66.5	66.3	3.2
After kidding	2.0	–7.3	6.0
Birth weight of kids (kg)	1.85	1.69	0.07
Body weight of kids at 20 weeks of age (kg)	13.9	13.5	0.6

†See footnote to Table 8.1.
‡Standard error of difference between means.
(—) Not calculated.

had similar mean PCVs, whereas, in 1990, PCVs of parity 2 goats were lower than those of primiparous goats (Table 8.3).

During pregnancy there were no significant differences in increases in body weight between the three age groups but, after kidding, primiparous goats gained weight whereas parity 3 goats lost weight ($P < 0.001$) (Table 8.4). There were no significant year × parity interactions in relation to body weight change.

8.3.4 Litter size, birth weight and weights of kids at 20 weeks of age

Older goats had increased fecundity. Mean litter sizes averaged for 1990 and 1991 were 1.62 ± 0.07 (SE) (parity 2 and 3 goats) and 1.21 ± 0.09 (parity 1 goats). The difference was significant ($P < 0.01$).

Treatment with isometamidium chloride had an overall significant effect on kid birth weight (1.85 kg for 'protected' goats, 1.69 kg for 'unprotected' goats ($P < 0.01$) (Table 8.2) when adjusted for year, parity, sex and litter size. There was no overall significant effect of treatment, however, on the mean body weight of kids at 20 weeks of age.

Male kids were on average heavier than female kids at birth (1.89 versus 1.64 kg; $P < 0.01$) and at 20 weeks (14.4 versus 12.3 kg; $P < 0.001$). Twins weighed less at birth (1.67 kg) than singletons (1.87 kg; $P < 0.01$) and also at 20 weeks of age (12.7 versus 14.7 kg; $P < 0.001$). Birth weights were higher in 1989 and 1990 (1.84 kg) than in 1991

Table 8.3 *Mean weekly prevalence of trypanosomal infections and mean packed cell volume of adult female goats during pregnancy and lactation (17 weeks before and after kidding) by parity adjusted for average effects of treatment group.*

		1989	1990	1991	SED[†]
During pregnancy					
Prevalence of trypanosomal infections (%)					
Parity	1	0.6 (17)[‡]	2.6 (16)	1.7 (10)	—
	2	—	3.6 (13)	0.9 (14)	
	3	—	—	7.4 (13)	
Packed cell volume (%)					
Parity	1	28.4	30.9	31.6	0.7
	2	—	27.2	31.8	
	3	—	—	27.7	
During lactation					
Prevalence of trypanosomal infections (%)					
Parity	1	7.7 (17)	9.0 (16)	5.7 (10)	—
	2	—	17.0 (13)	11.2 (14)	
	3	—	—	7.1 (13)	
Packed cell volume (%)					
Parity	1	27.0	28.7	27.6	1.0
	2	—	23.8	26.6	
	3	—	—	24.9	

[†]Average standard error of difference between two parity means within 1990 or 1991.
[‡]Number of goats in parentheses.
(—) Not calculated.

(1.63 kg; $P < 0.05$). Body weights of kids at 20 weeks of age were 16.5, 14.2 and 10.5 kg in 1989, 1990 and 1991, respectively, and were significantly lower in 1991 than in the other two years ($P < 0.001$). Parity had no average effect on birth weight but kids from parity 2 and 3 dams had higher rates of growth to weaning and were heavier at 20 weeks of age ($P < 0.01$) (Table 8.4).

8.3.5 Herd growth

When averaged over 1989, 1990 and 1991, protection of dams resulted in an annual increase in female herd size of 50%. The corresponding increase when dams were not protected was 30%.

8.3.6 Efficacy of isometamidium chloride

The relationship for mean 12-week weekly incidence of trypanosomal infections in 'protected' groups on 12-week weekly incidence of trypanosomal infections in 'unprotected' groups is shown in Figure 8.1. The regression coefficient is 0.30 ± 0.03. This means that protection with isometamidium chloride reduced the weekly incidence of trypanosomal infections on average by 70%.

Table 8.4 *Association with parity of mean body weight changes over periods of 17 weeks before and after kidding in adult female goats adjusted for year and treatment group, and of body weight of kids at birth and 20 weeks of age adjusted for year, sex, litter size and treatment group.*

	Parity			
	1	2	3	SED†
Number of kids	36	25	13	
Body weight change (g/d)				
Before kidding	66.1	67.0	58.1	3.9
After kidding	27.9	4.9	–21.5	7.3
Birth weight of kids (kg)	1.72	1.81	1.78	0.10
Body weight of kids at 20 weeks of age (kg)	12.5	14.2	14.5	0.7

†Average standard error of difference between two means.
(—) Not calculated.

8.4 Summary of the findings

8.4.1 Fertility and herd growth

The average reduction in fertility associated with trypanosomosis in diminazene-treated groups over 1989, 1990 and 1991 was 19%. Chemoprophylaxis maintained high levels of fertility with 91% of protected goats kidding successfully over the three years.

Female herd growth was greater when adult female goats were protected with isometamidium chloride than when they were not.

8.4.2 Packed cell volume and body weight

During lactation, when the average weekly prevalence of trypanosomal parasitaemia in diminazene-treated goats was 13.1%, isometamidium-protected goats maintained higher PCVs than did unprotected goats. Although chemoprophylaxis prevented loss of body weight in 1990 at a time when the prevalence of trypanosomal infections was particularly high, overall, averaged over 1989, 1990 and 1991, there was no significant effect of treatment with isometamidium chloride on change in body weight during lactation. During pregnancy, when the prevalence of trypanosomal parasitaemia was lower, chemoprophylaxis affected neither PCV nor changes in body weight of dams.

8.4.3 Birth weight and growth of kids

Kids from ‘protected’ dams had higher birth weights on average than those from ‘unprotected’ dams, but subsequent growth rate was similar for the two groups. Mean body weights at birth and 20 weeks of age were lower in 1991 by 11 and 32% than in 1989 and 1990, respectively.

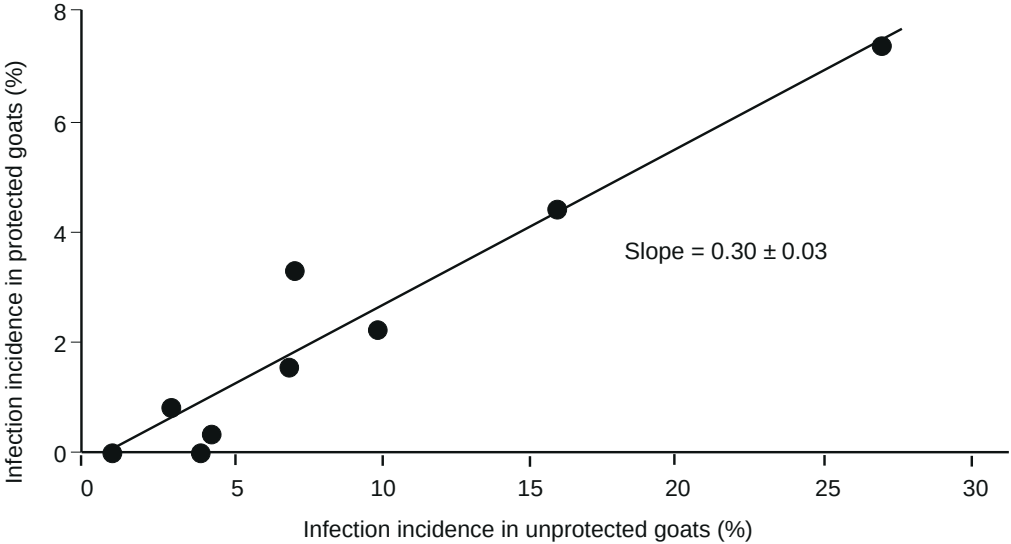

Figure 8.1 *Relationship between average weekly incidence of infection over periods of 12 weeks in 1989, 1990 and 1991 in adult female goats 'protected' and 'unprotected' with isometamidium chloride given at a dose rate of 0.5 mg/kg b.w. in week 0. 'Unprotected' goats were individually treated with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%.*

8.4.4 Effect of parity on packed cell volume

The older goats which had been brought from tsetse-free areas to Kakumbi had significantly lower PCVs than their offspring throughout the three years.

8.4.5 Efficacy of isometamidium chloride

The degree of protection given by isometamidium chloride, in terms of reduction in incidence of trypanosomal infection, was estimated to be 70%.

Chapter 9. 1992 experiment

9.1 Aim

To determine the effects of trypanosomal infections naturally acquired early in the breeding cycle on the subsequent fertility of goats.

9.2 Materials and methods

9.2.1 Experimental design

Forty-three female goats used in the 1991 experiment and alive at the end of May 1992 were assigned at random from each of three parities to two groups, namely groups 1 and 2, in a ratio of 2:3. Two three-year-old goats that had completed the previous experiment died in April and May 1992, respectively, for reasons other than trypanosomosis. Thirty young female goats born in 1991 were classed as those less than 14 kg, those between 14 kg and 16 kg and those greater than 16 kg body weight in week 22. These were then assigned at random in the same ratio from each class to the two groups.

All goats received diminazene aceturate at 7 mg/kg b.w. in week 25 and again in week 27 (Figure 9.1). The 29 goats in group 1 received isometamidium chloride at 0.5 mg/kg b.w. in week 29 and week 33; the 44 goats in group 2 were not given chemoprophylaxis.

A male goat, obtained locally, treated with anthelmintic and protected with isometamidium chloride at a dose of 1 mg/kg b.w. in weeks 26 and 35, was introduced to the females in week 36 and remained with them for three weeks (Figure 9.1). The day after removal of the male from the herd, all 73 female goats received diminazene aceturate at a dose rate of 7 mg/kg b.w. and two weeks later, in week 41, all were treated with isometamidium chloride at a dose rate of 0.5 mg/kg b.w.

Until week 39, when the male goat was removed, individual goats in group 2 were treated with diminazene aceturate at 7 mg/kg b.w. when detected with trypanosomal parasitaemia and with a packed cell volume (PCV) of 20% or below. Thereafter, all cases of trypanosomal parasitaemia were treated in either group, regardless of their haematocrit value.

Each week all goats were weighed, rectal temperatures taken and blood samples collected to measure PCV and detect trypanosomal parasitaemia. Weekly monitoring continued until all goats kidded. Kidding commenced in week 56 (calendar week 4 of 1993) and continued until week 59.

9.2.2 Statistical analysis

The proportions of goats kidding in the two groups were compared by a χ^2 test (Snedecor and Cochran 1980).

Mean body weights were calculated between weeks 25 and 27 (the start of the experiment) and between weeks 37 and 39 (the period of conception). Average daily weight increase up to the time of mating was then calculated and examined by analysis of variance with terms for treatment group, parity, body weight class within primiparous goats, and

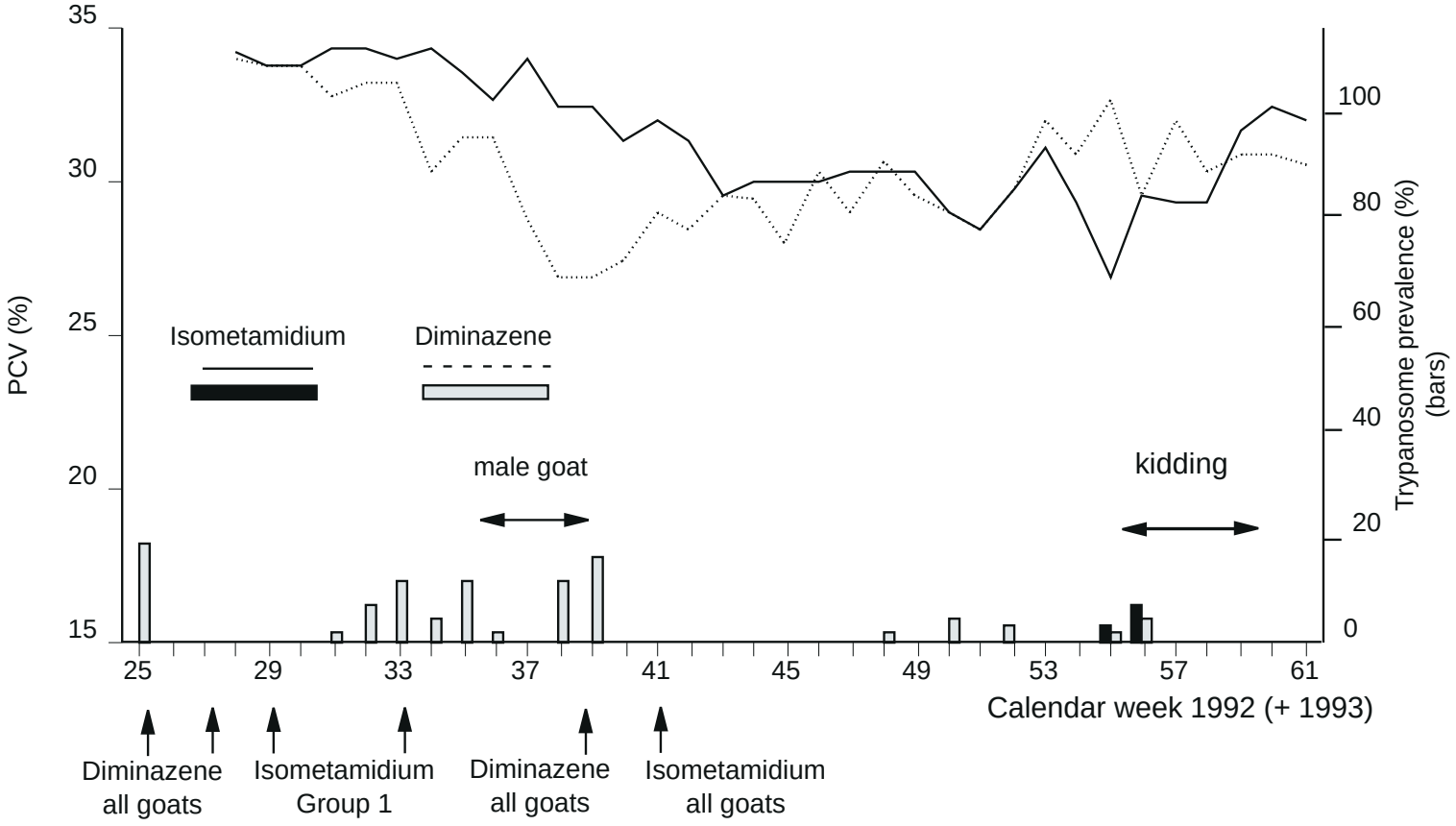

Figure 9.1 *Changes in mean PCV of one-, two-, three- and four-year-old female goats that raised a live kid. [23 goats were treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., and, until the end of mating, 23 received diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%. Both groups were protected after the male was removed.]*

treatment group × parity. As in previous experiments, analyses were conducted using a general least-squares computer program (Harvey 1990). The same model was used to analyse body weight gain during pregnancy (until weeks 53–55 for those goats that gave birth). Mean PCV was also analysed up to the time the male was removed (between weeks 31 and 39) and during the period of pregnancy (between weeks 42 and 54). The latter period followed a blanket treatment with isometamidium chloride given to all goats in week 41.

9.3 Results

9.3.1 Mortality

Two goats, one in group 1 and one in group 2, died following treatment with isometamidium chloride in week 41. Two weeks later, another goat in group 2 was found trapped in a snare and was slaughtered. Postmortem examination revealed foetuses in both group 2 goats (diminazene-treated) but not in the group 1 goat (isometamidium-protected).

9.3.2 Fertility

Including the three goats that died, 23/29 (79%) of the isometamidium-protected goats conceived compared with only 25/44 (57%) of the unprotected group (Table 9.1). This difference was significant ($P < 0.05$; $\chi^2 = 3.92$ with 1 degree of freedom) and was consistent across ages, even though no trypanosomal parasitaemias were detected in parity 1 goats and only one parity 2 goat was found to be parasitaemic. Mean litter sizes for parity 2, 3 and 4 goats were 1.60 and 1.81, and for primiparous goats 1.38 and 1.42, in groups 1 and 2, respectively. The median 'gestation' interval, from the day the male goat was first introduced to the females, was 151 days (ranging from 140 to 163 days). The youngest goats had the lowest fertility: 16/30 conceived.

Four of the 23 goats that kidded in group 2 gave birth to stillborn kids or to kids that died within four days of birth compared with one of the 23 goats in group 1. A number of early deaths was due to kids being crushed owing to the large number of goats in the house.

9.3.3 Prevalence of trypanosomal infections

The first case of parasitaemia in the diminazene-treated group was detected in week 31; cases continued to be observed in this group throughout the next eight weeks (Figure 9.1) until the male goat was withdrawn and all female goats were treated with diminazene aceturate. No cases of parasitaemia were detected in the isometamidium-protected group over this period.

Most cases of parasitaemia were detected in the two older groups of goats (Table 9.2). Fourteen of 18 parity 3 and 4 goats were detected positive at least once between weeks 31 and 39; the average weekly prevalence of trypanosomal infections in these two age groups was 17.2% (Table 9.2). Of the 14 goats detected parasitaemic at this time, only seven conceived, whereas all four goats that were not detected parasitaemic conceived.

Table 9.1 *Numbers of adult female goats (percentages in parenthesis) conceiving*[†].

	Treatment group[‡]		
Parity	1 (isometamidium)	2 (diminazene)	Total
1	8/12 (67)	8/18 (44)	16/30 (53)
2	4/5 (80)	6/8 (75)	10/13 (77)
3	6/7 (86)	6/10 (60)	12/17 (71)
4	5/5 (100)	5/8 (63)	10/13 (77)
Total	23/29 (79)	25/44 (57)	48/73 (66)

[†]Three goats have been included that died during pregnancy (one in group 1 and two in group 2). Postmortem examination indicated presence or absence of foetuses.

[‡]Group 1 treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w. at approximately 13-week intervals, group 2 treated on an individual basis with diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20% for five weeks before and three weeks during the period when the male goat was with the females. Following removal of the male goat this group was also protected as for group 1.

9.3.4 Treatment with diminazene aceturate

Nine of 14 parity 3 and 4 goats detected parasitaemic between weeks 31 and 39 were treated with diminazene aceturate when their PCV fell to 20% or below. Three were treated before and six during the period of mating. Four were infected with *T. congolense*, two with *T. vivax* and three with *T. brucei.*

During pregnancy all cases of parasitaemia that occurred (see Figure 9.1) were treated with diminazene aceturate regardless of their haematocrit value. Three goats in group 1 and six in group 2 were treated. In two goats (one in each group) PCV fell below 20%.

9.3.5 Packed cell volume

The occurrence of trypanosomal infections before and after the introduction of the male goat decreased the PCVs of the older goats in the diminazene-treated group (Figure 9.1). Mean PCVs were significantly reduced in parity 3 and 4 goats ($P < 0.001$) but not in parity 1 and 2 goats (see Table 9.2). Mean PCVs of parity 4 goats were significantly lower than those of parity 3 goats ($P < 0.001$), even though similar levels of trypanosomal infection occurred for both parities. Mean PCVs recovered after all goats received treatment with diminazene aceturate in week 39; they then remained similar for the two groups throughout pregnancy (Figure 9.1).

9.3.6 Body weight

There was no significant difference in mean overall body weight of the 29 isometamidium-treated (29.9 kg) and 44 diminazene-treated goats (28.6 kg) during the presence of the male ($P = 0.10$). Corresponding mean body weights at the start of the experiment were 27.6 and 27.2 kg, respectively. However, the body weight changes over the first 14 weeks of the experiment leading up to the period of mating were significantly different between treatment groups for parity 3 and 4 goats ($P < 0.01$).

Table 9.2 *Proportion of adult female goats detected parasitaemic, mean weekly prevalence of trypanosomal infections and mean packed cell volume up to mating (between weeks 31 and 39). [Male goat was with females in weeks 36 to 38 inclusive.]*

		Treatment group†		
		1 (isometamidium)	2 (diminazene)	SED‡
Proportion parasitaemic at least once				
Parity	1	0/12	0/18	—
	2	0/5	1/8	—
	3	0/7	7/10	—
	4	0/5	7/8	—
Prevalence of trypanosomal infections (%)				
Parity	1	0.0	0.0	—
	2	0.0	1.4	—
	3	0.0	14.4	—
	4	0.0	20.8	—
Packed cell volume (%)				
Parity	1	35.6	34.4	0.74
	2	31.6	29.7	1.13
	3	32.7	28.7	0.98
	4	31.5	25.1	1.13

†See footnote to Table 9.1.
‡Standard error of difference between means.
(—) Not determined.

These were the goats that were detected parasitaemic most frequently (Table 9.2). Whereas isometamidium-protected goats gained weight over this period, goats in the diminazene-treated group lost weight (Table 9.3). Following removal of the male goat, and treatment of all female goats with diminazene aceturate and, two weeks later, with isometamidium chloride, body weight changes remained similar in the two groups until kidding (see Figure 9.2 which shows changes in body weight for the 46 goats that kidded).

9.4 Summary of findings

9.4.1 Prevalence of trypanosomal infections

Trypanosomal infections occurred during the months of August and September when a proportion of the goats was unprotected. This corresponded to the period when seasonal increases in incidence of trypanosomal infections occurred in the previous years.

9.4.2 Mortality

There were no deaths due to trypanosomosis; curative treatment of goats in group 2 at the time of breeding is likely to have prevented a number of deaths that may have occurred. Two goats died shortly after being injected with isometamidium.

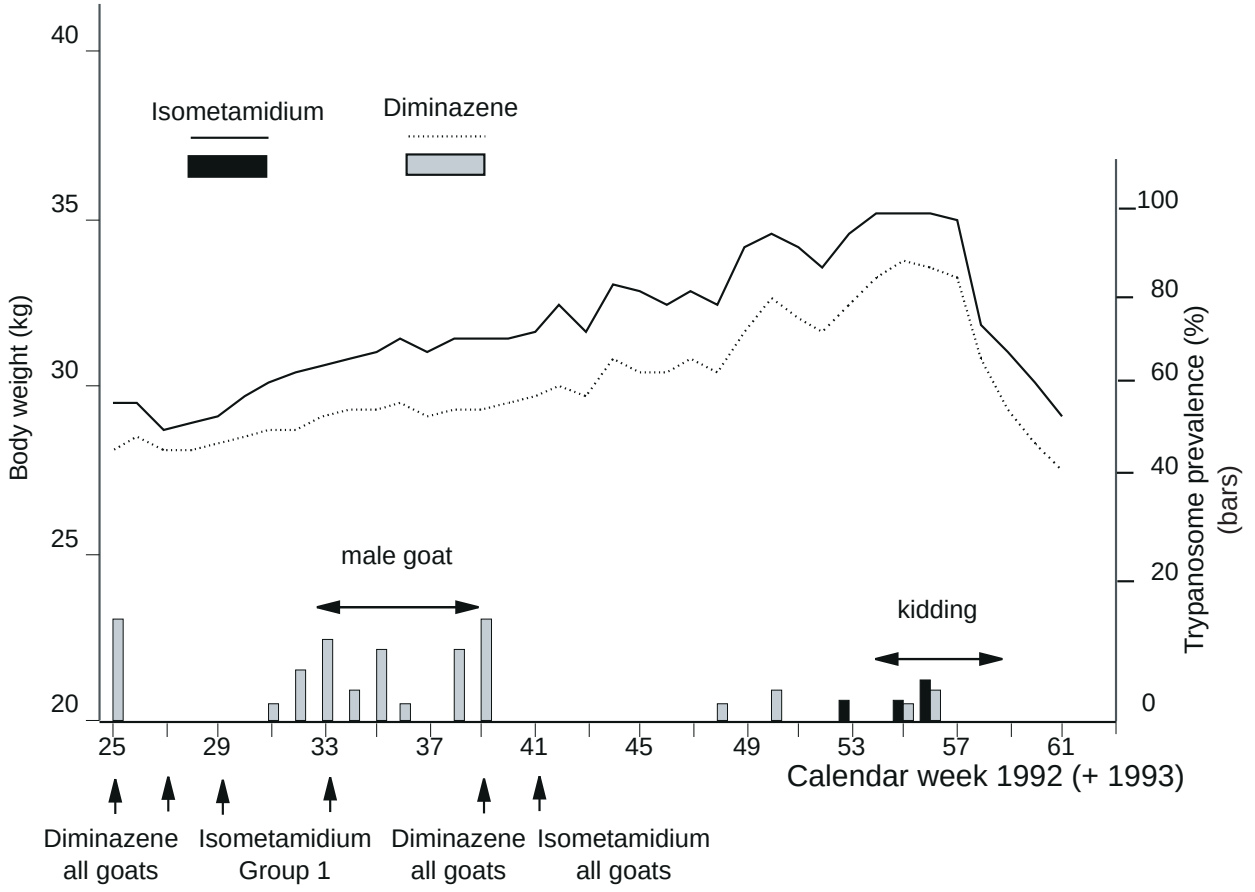

Figure 9.2 *Changes in mean body weights of one-, two-, three- and four-year-old female goats that raised a live kid. [23 goats were treated systematically with isometamidium chloride at a dose rate of 0.5 mg/kg b.w., and, until the end of mating, 23 received diminazene aceturate at a dose rate of 7 mg/kg b.w. when detected parasitaemic and with PCV ≤ 20%. Both groups were protected after the male was removed.]*

Table 9.3 *Mean body weights of adult female goats and body weight changes from week 26 to week 38. [Male goat was with females in weeks 36 to 38 inclusive.]*

	Treatment group[†]		
	1 (isometamidium)	2 (diminazene)	SED[‡]
Parity 1	(12)[§]	(18)	
Mean body weight			
Weeks 25–27 (kg)	16.2	15.8	1.3
Weeks 37–39 (kg)	19.7	19.6	1.2
Body weight change (g/d)	42	45	6
Parity 2	(5)	(8)	
Mean body weight			
Weeks 25–27 (kg)	30.0	29.4	1.9
Weeks 37–39 (kg)	31.7	30.9	1.8
Body weight change (g/d)	21	18	9
Parity 3			
Mean body weight			
Weeks 25–27 (kg)	36.5	35.7	1.7
Weeks 37–39 (kg)	38.5	34.7	1.6
Body weight change (g/d)	24	–12	8
Parity 4	(5)	(8)	
Mean body weight			
Weeks 25–27 (kg)	39.7	39.8	1.9
Weeks 37–39 (kg)	40.1	39.1	1.8
Body weight change (g/d)	5	–9	9

[†]See footnote to Table 9.1.
[‡]Standard error of difference between means.
[§]Number of goats in parenthesis.

9.4.3 Fertility

Chemoprophylaxis significantly improved conception rate.

9.4.4 Packed cell volume and body weight

Trypanosomal parasitaemia significantly reduced PCV and body weight gain in parity 3 and 4 goats before mating.

9.4.5 Age

There was strong evidence of increased susceptibility to trypanosomosis in parity 3 and 4 goats. Packed cell volumes of the parity 4 goats, which were brought to Kakumbi from tsetse-free areas, were, as in previous years, significantly lower than their immediate offspring, despite a high prevalence of trypanosomal infections in goats of both ages.

Chapter 10. General discussion

10.1 Tsetse

Because of the abundance of tsetse, cattle are not kept in the Luangwa Valley. The results of our experiments confirmed that the Kakumbi Tsetse Research Station is in a high tsetse challenge area. On the basis of the trap catches and infection rates in tsetse, the primary vectors of trypanosomes appeared to be *Glossina pallidipes* and *G. m. morsitans* and a close correlation was found between tsetse challenge and incidence of trypanosomal infections in goats one month later. However, the prevalence of trypanosomal infections in goats varied from year to year; more infections were recorded in 1989 and 1990 than in subsequent years, and the onset of the peak incidence of trypanosomal infections occurred later in 1991 than in 1990. Possible reasons for the marked year to year variation in tsetse challenge have been discussed in Chapter 4. This year-to-year variability in tsetse challenge affected the experiments since we had arranged mating so that pregnancy and lactation could occur each year under different intensities of challenge. Unfortunately, the variations that occurred among years meant that the differences were not as clear-cut as we had wished.

10.2 Trypanosomal infections

The increase in the prevalence of trypanosomal infections in goats in 1990 coincided with late pregnancy; a similar pattern occurred in 1991. In 1989, 1990 and 1991 highest prevalences of trypanosomal infections occurred during lactation each year. Lactation creates significant stress (MacLennan 1974) and the high incidence of infections that occurred may have been partly due to the stress of lactation; at this time, even the isometamidium-protected goats sometimes became parasitaemic a few weeks after treatment. By comparing the lactating goats with those that were not raising a kid an attempt was made to determine whether lactating goats were more susceptible than non-lactating goats to trypanosomosis. In 1989, 1990 and 1991 mean weekly trypanosomal prevalences were compared, within the year, between lactating and non-lactating goats over the 16 weeks following the week when the last goat kidded. In 1989, the mean weekly trypanosomal prevalence in 10 untreated goats that raised a kid was 38%; this was twice the level in five goats that did not (19%). All 15 goats were parasitaemic at least once. In 1990, mean weekly prevalences of trypanosomal infections were similar in unprotected lactating (19%) and non-lactating goats (21%). Thirteen of the 16 unprotected goats that raised a kid during this year were parasitaemic at least once compared with seven of the eight unprotected goats that did not. In 1991, the prevalence of trypanosomal infections in unprotected goats over the same 16-week period was lower than in the two previous years and averaged 7% in lactating and non-lactating goats. Although, a larger proportion of unprotected, lactating goats (7/16) were parasitaemic compared with unprotected, non-lactating goats (1/5 that completed the 16-week period), this difference was not significant. These results are somewhat inconclusive,

and would indicate that, whilst stress of lactation may have had some influence on level of trypanosomal prevalence infections in goats, it is likely to have been only a contributory factor. The only way to separate effects of lactation from other confounding seasonal factors would be to compare two groups of goats conceiving at different times of the year so that one group is kidding when the other group is being mated.

Goats became infected with *Trypanosoma brucei, T. congolense* and *T. vivax* and all three species were quite common at Kakumbi, where trypanosome transmission was continuous. It is interesting that most *T. brucei* infections occurred as mixed infections. Similar findings have been reported in cattle in Côte d'Ivoire (Rowlands et al 1996). In our studies, mixed infections were sufficiently common to make it impossible to attribute the impact of trypanosomosis at the herd level to a particular species of trypanosome. This is usually the case under field conditions.

10.3 Interaction of trypanosomal infections with helminthosis and other conditions

The severity of trypanosomosis is exacerbated by intercurrent infections, and the synergistic effects of trypanosomal and helminth infections in goats have been described in detail (Griffin et al 1981). Helminthosis is a major constraint on small ruminant production (Fabiyi 1987), and ranks high among diseases affecting small ruminant production (Ademosun 1994), but, in our experiments, the practice of herding goats to extensive pastures with plentiful year-round browse, coupled with the raised slatted flooring in the goat house, evidently prevented a build-up of contamination and infection. Helminth infections did occur but the level of infection, as indicated by faecal egg counts, was not clinically significant (Hansen and Perry 1994); thus anthelmintic treatments were discontinued at an early stage.

At the start of the study in July 1988, soon after the goats had been brought to the station, anaplasmosis was diagnosed in 18 of 39 goats during routine blood smear examination. Thereafter, anaplasmosis was infrequently diagnosed when it was associated with a fall in packed cell volume (PCV) in the absence of trypanosomal parasitaemia; in these cases the affected goat was treated individually with injectable oxytetracycline. Throughout the four years there were, however, only very occasional cases of anaplasmosis, and so trypanosomosis generally occurred as an uncomplicated disease.

10.4 The disease

10.4.1 Mortality

To establish the first year's experiment, goats were transported to the Luangwa Valley from tsetse-free areas and mortality in untreated goats was alarmingly high (42% died). The other cause of mortality in this year was predation, but, over the four years, the losses due to predation were low considering that the station is separated from the South Luangwa National Park by the crocodile-infested Luangwa River. In later experiments, losses also occurred due to trauma resulting from overcrowding, trampling and fighting

at the time of mating and kidding. Many of the deaths due to trypanosomosis in 1989 occurred after a relatively short illness although, in some cases, goats had been infected for several weeks before their health rapidly deteriorated.

10.4.2 Signs and course of illness

Trypanosomosis was a serious disease in the untreated goats. Acute, sub-acute and chronic syndromes were reported to occur in goats and sheep with naturally acquired *T. congolense* infections in Kenya (Griffin and Allonby 1979c) and we observed similar syndromes during the first experiment. Unfortunately, detailed clinical records were not kept during the experiments because there was no resident clinician at the station. However, in 1989, during frequent visits to Kakumbi, one of us (RJC) observed goats known to be infected. Some affected goats became inappetent and listless with drooping ears and tail. These signs were usually transient, disappearing after one to two days, and were intermittent.

Examination of sick goats often revealed pale, mucous membranes and a rapid, thready pulse; enlarged prescapular lymph nodes were easily palpable in many chronically affected goats. These clinical signs were associated with chronic trypanosomosis; throughout the experiments the mean PCVs of unprotected goats during periods of peak trypanosomal parasitaemias were consistently lower than those of protected goats. Acute disease was characterised by a rapidly developing anaemia, fever associated with parasitaemia and weight loss. Death was often sudden and was preceded by rapid loss of body weight, a concurrent sharp fall in PCV and terminal fever (Figure 5.2).

10.5 Efficacy of trypanocides

After stopping anthelmintic treatments, and except for the occasional use of oxytetracycline, the only drugs used routinely were trypanocides. Without the use of diminazene and isometamidium it would not have been possible to raise and maintain an increasing number of goats. Goats that received no prophylactic treatment suffered the effects of trypanosomosis; some became anaemic and were less productive overall. Nevertheless, the regimen of diagnosis and treatment minimised the mortality rate, and trypanosome-infected goats responded well to treatment with diminazene at a dose rate of 7 mg/kg body weight when their PCV fell to 20% or below.

Trypanocidal chemoprophylaxis was apparently effective for up to 12 weeks. However, the duration of prophylaxis was dependent on the incidence of trypanosomal infection at the time and may also have been reduced during lactation. In 1989 and 1990, when the prevalence of trypanosomal infections in unprotected goats was high, isometamidium-protected goats maintained higher mean body weights post-partum; they were also more fertile than unprotected goats. In 1992 the prevention of detectable parasitaemia preceding and during the mating period led to an improved conception rate, and in 1990 and 1991 protection with isometamidium during pregnancy prevented foetal death and neonatal mortality. Overall, isometamidium-treated goats maintained higher PCVs during lactation than did unprotected goats, and their kids had significantly

higher birth weights. The growth of kids up to the time of weaning, however, was not affected by the treatment given to their dams. In the 1992 experiment, two goats died immediately after treatment with isometamidium. Intravascular administration of isometamidium is known to be potentially fatal (Schillinger et al 1985) and a faulty injection technique may have caused these deaths.

By using chemoprophylaxis in these experiments we could assume that the performance of protected goats would approximate to that of goats unaffected by trypanosomosis. The performance of unprotected goats, compared with that of protected (or 'normal') goats, thus gives an indication of the impact of trypanosomosis on goat health and productivity.

10.6 Productivity

In this series of experiments we examined productivity in terms of birth weight, mortality, body weight change, herd growth and fertility.

10.6.1 Birth weight and growth rate of kids

Trypanosomosis significantly reduced birth weights of kids; kids born of unprotected dams were not as heavy as those of protected dams, a finding previously recorded by Hendy (1988). Furthermore, parasitaemia in the last weeks of pregnancy in 1990 was associated with premature stillbirths. Although not evident in these experiments, since subsequent growth of kids was independent of birth weight and no kid died before weaning, higher birth weights will generally result in stronger kids that have a better chance of survival as reported by Mtenga et al (1994). We could not determine the impact of trypanosomosis on the growth rate of kids because very few kids in our study were parasitaemic. This may have been partly due to colostral immunity (Whitelaw and Jordt 1985) and to the apparently low level of helminth challenge.

Banda et al (1993) have assembled productivity data available on the local Malawi goat. The Chipata and Chadiza areas from which the goats in this study originated adjoin western Malawi and so the goats in eastern Zambia are likely to have the same origins as the Malawi goat. The data collected by Banda et al (1993) gave birth and weaning weights that were slightly higher than those of kids born to protected dams in our study. Thus, liveweight gains in our study were not above normal for goats raised under traditional management.

10.6.2 Body weight change

Body weight gain during pregnancy was not significantly affected by trypanosomosis, but the prevalence of trypanosomal infections in goats was generally low at this time. The effects of trypanosomosis on growth of primiparous goats after kidding, however, was clearly demonstrated in untreated goats in the first experiment. Whereas, protected dams continued to grow after kidding, unprotected, trypanosome-affected goats stopped growing. Later, however, these goats compensated for this loss in weight gain, so that

there was no difference in the mean body weights of the goats in these two groups that survived to the start of the fourth experiment. In subsequent years when the prevalence of trypanosomal infections in goats was high, trypanosomal infections also caused significant loss in body weight of the older goats during lactation. As already discussed, it is not clear to what extent lactating goats may have been more susceptible to trypanosomal infection than non-lactating goats, or whether the high prevalence of infections during lactation was entirely due to increases in tsetse challenge which coincided with periods of lactation.

10.6.3 Herd growth

Herd growth is important and is determined by mortality, offtake (slaughter and sales), kidding rate and purchases. For the purpose of calculating herd growth, male kids were not considered. In any herd, these are usually the animals that are readily sold or slaughtered. Even if they are kept in the herd for any length of time, only one or two fertile males are necessary for the average herd, and so the surplus males contribute little to herd growth. By counting the number of females in a herd, however, a clearer indication of the potential for herd growth is obtained. Our studies showed that trypanosomosis reduced female herd growth significantly. In the first experiment, there was zero female herd growth of the untreated group; this contrasted with a 60% growth of the protected group. Average herd growth achieved in our experiments will be higher than that achieved under conditions of traditional management. In Tanzania, for example, Mtenga et al (1994) reported average preweaning mortalities of 40% in small East African goats raised between 1972 and 1989.

10.6.4 Fertility

Reproductive efficiency in tropical goats has been reviewed by Wilson (1989). Any condition that reduces kidding rate reduces herd growth. Kidding rate is the result of the conception rate and losses during pregnancy. In the 1992 experiment, only 57% of the unprotected goats conceived compared with 79% of the protected goats (a percentage reduction of 28%). This significant reduction in fertility was attributable to trypanosomal infections at the time of mating because subsequent foetal losses during pregnancy were controlled by chemoprophylaxis given to all goats.

When goats were not protected during pregnancy in 1991, the occurrence of trypanosomal parasitaemia in late pregnancy was associated with late abortions and stillbirths; similar observations were recorded from sheep in Rhodesia (now Zimbabwe) (Boyt 1971). Reports have been made of the impact of trypanosomosis on the reproductive performance of goats under natural tsetse challenge (Griffin and Allonby 1979a; Hendy 1988; Kanyari et al 1983). In our experiments the mean percentage reduction in the proportions of goats kidding successfully in 1990 and 1991, when an increase in the incidence of infection coincided with late pregnancy, was 28%. We examined only female reproduction, but male reproductive health is also known to be adversely affected by trypanosomal infections (discussed by Luckins 1992).

Mean gestation length in local Malawi goats was reported to be 148 days (Banda et al 1993). The mean value in our experiments of 154 days, recorded from the day that the male was introduced to the females to the day that they kidded, suggests that the median interval from entry of the male to conception was as little as six days.

10.7 Age

Haematocrit values decline from birth and reach a stable mean value early in adulthood, when erythropoietic activity also declines (Jain 1986). When trypanosomal infections are superimposed on these physiological changes it may be expected that the disease will have different effects in different age groups. The results of the experiments performed at Kakumbi indicate that young goats are more tolerant of infections than older goats, particularly when compared with those brought to Kakumbi in 1988 from tsetse-free areas outside the Luangwa Valley; young goats maintained higher PCVs and were less frequently parasitaemic than older goats. Throughout the study the original goats had PCVs that were consistently lower, when they suffered the effects of trypanosomosis, than those of their immediate offspring. In 1992, for example, although unprotected three-and four-year-old goats both had high prevalences of trypanosomal infections, PCVs were lower in the goats that had not been born at the station. The three-year-old goats born at Kakumbi may therefore have developed a degree of acquired immunity to the effects of trypanosomosis whilst they were benefiting from colostral immunity.

Apart from occasional cases of parasitaemia occurring in kids, the first major episode of trypanosomosis in young goats appears to have occurred during their first lactation. These primiparous goats continued to grow after they kidded provided they received prophylaxis or were treated before trypanosomal infections became chronic. By their third parity, however, goats lost weight during lactation. The higher potential productivity of these older goats, in terms of fecundity and milk yield (evidenced by the significantly higher birth rates and growth rates of their kids), apparently placed them at greater risk of more serious trypanosomosis. There would thus seem to be a 'trade-off' between the higher productivity of older goats, which appeared to be more susceptible to the effects of trypanosomosis, and the greater tolerance of trypanosomosis of younger goats which have lower fecundity and whose kids grow more slowly.

In 1992, the conception rate of the youngest goats was the lowest. This may have been associated with the competition for the male goat, or selection by him of the females that came into oestrus early. Body weight is unlikely to have been an important factor in the low conception rate as the mean weight of the youngest goats at the time of breeding was 18 kg (as it was for primiparous goats in 1991). The ratio of females:male was reasonable for the earlier experiments but, in the last experiment, one male was used for 73 females over a period of only 21 days.

10.8 Conclusion

This series of experiments enabled the staff at Kakumbi to gain extensive experience of the routine procedures used in basic field studies of tsetse and trypanosomosis. The

results of these experiments answered many of the questions posed in 1988. Tsetse challenge varied seasonally but there were marked year-to-year variations which interfered with the expected effects of the times of mating. This variability also makes it difficult to apply routine preventive measures based on seasonal interventions.

Trypanosomosis was a serious constraint on goat production, increasing mortality and reducing fertility. These two effects reduce herd growth and potential offtake and availability of meat, milk and skins. Under village conditions, the effects of trypanosomosis adversely affect people's health, welfare and food security and impede their socioeconomic development.

Herding goats to extensive pastures and housing them on a raised slatted floor effectively prevented helminthosis, although helminth infections did occur. Trypanocidal chemoprophylaxis effectively reduced the incidence of trypanosomal infection, reduced losses and permitted high conception rates which led to positive herd growth.

Chapter 11. Recommendations

The most difficult question to answer is: 'What advice can be given to farmers to improve goat production?' Three management adjustments could be considered:

11.1 House goats on raised, slatted floors and herd them to browse in order to reduce helminthosis

It would first have to be determined if goat owners would be prepared to invest time, labour and money in implementing this recommendation.

One persuasive factor would be the ready availability of manure which would accumulate beneath the floors. This was appreciated by the families of the staff at Kakumbi who used it in their vegetable gardens to good effect.

11.2 Introduce mating season early in year to ensure pregnancy and kidding occur at a time of low tsetse challenge

The difficulties here are:

- both the seasonal peak and intensity of challenge would probably vary from year to year;
- under traditional village conditions controlling all male goats in an area might be impractical; and
- one breeding season per year reduces the potential for goats to kid four times in three years (as reported by Banda et al 1993).

11.3 Give prophylactive treatment during pregnancy

Implementation of this recommendation would be complicated by several factors:

- two treatments would be required to cover the whole period from mating to kidding and trypanocides may not be available at village level at affordable prices;
- in the absence of a breeding season, treating individual goats during pregnancy would be impractical, especially since isometamidium is presented as a powder in 1.0 g packs, which are sufficient to treat at least 40 goats. The powder has to be dissolved in sterile water before injection and cannot be stored in solution;
- skilled staff may not be available to administer trypanocides;
- possible untoward side effects arising from faulty injection technique could lead farmers to abandon the intervention; and
- year-to-year changes in the seasonal peak of tsetse challenge may mean that goats are not protected throughout periods when tsetse challenge is highest.

Before recommendations could be considered, measures would need to be taken to enable farmers to demonstrate to themselves and their neighbours the very significant losses that can occur as a result of tsetse-transmitted trypanosomosis. This would be a necessary step in a true development process which is based on a continuous series of analysis—action—reflection exercises (Burkey 1992).

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