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HELICOPTER APPLICATION OF INSECTICIDES TO CONTROL RIVERINE TSETSE FLIES IN THE WEST AFRICAN SAVANNA

by

A. Challier,[a] C. Laveissiere,[a] M. Eyraud,[b]
H. Kulzer,[c] O. Pawlick[d] and M. Krupke[d]

I. INTRODUCTION

In West Africa human trypanosomiasis caused by Trypanosoma gambiense Dutton no longer occurs except in residual foci. However, there is still a risk of recrudescence of the disease, particularly in areas of new settlement.

During the last decade it has been noticed that immigrant populations are highly sensitive to local strains of trypanosomes. Under the Onchocerciasis Control Programme in the Volta River Basin area (WHO, 1973) it is planned to resume cultivation of the fertile land in the valleys abandoned by the farming populations on account of the high prevalence of onchocerciasis.

To obviate the danger of the reappearance of sleeping sickness among the resettled populations it is becoming urgent to find a technique for controlling tsetse flies that can be applied rapidly over large areas. The application of insecticides by aircraft seems to meet these requirements.

In East Africa, the aeroplane has been used since 1948 for the control of savanna tsetse flies (review of work from 1948-1970; Lee, 1969; Tarimo, 1971). The helicopter, which came into use much more recently (Spielberger, 1971; Spielberger & Abdurrahim, 1971; Spielberger et al., 1971) seems better suited than the aeroplane to the ecological conditions prevailing in the West African savanna. In this part of Africa the tsetse species involved in human trypanosomiasis are riverine species (G. palpalis gambiensis Vanderplank and G. tachinoides Westw.). Their habitat is limited to the gallery forest, "sacred woods", and the vegetation growing around permanent water-holes. Generally the watercourses are characterized by tight bends that an aeroplane cannot follow closely. The helicopter is able to fly very low over the canopy of the gallery forest at a low speed. Moreover, in a large-scale programme the logistic base of a helicopter can be moved as the work proceeds, whereas an aeroplane must have landing strips.

Under the auspices of WHO and with the aid of the Government of the Federal Republic of Germany and of USAID, trials were carried out during the 1972-1973 dry season in the area of Koutiala in the Republic of Mali.

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[a] Medical entomologist, ORSTOM.

[b] Medical entomology technician, ORSTOM.

[c] Helicopter pilot.

[d] Helicopter mechanic.

II. GENERAL ASPECTS OF THE TRIALS

1. Aim of the trials

The aim of the trials was to study the effectiveness of several insecticides applied in ultra-low volume (ULV) or in powder form with a residual action.

Since the insecticide is sprayed above the gallery forest and the resting places of the tsetse flies are situated in the lower layer of vegetation, the problem is to find out whether the droplets sprayed above the canopy[1] can penetrate the foliage and reach the micro-environment of the flies in sufficient quantity.

2. Trial areas

Trial areas were selected in the Koutiala region (Mali) within the rectangle between 12° and 13°N and between 5° and 6°W (Map 1).

The Koutiala region is situated in zone 20 of the "Vegetation map of Africa south of the Tropic of Cancer" published with the assistance of UNESCO, and consists of "undifferentiated and relatively dry type savannas" or "wooded Sudanian savannas". The climate is dry for seven to eight-and-a-half months, and the rainfall is 500-1000 mm.

The permanent habitat of G. palpalis gambiensis and G. tachinoides is the gallery forests fringing the watercourses, sacred woods near to villages and ponds, lakes and water-holes that remain comparatively humid during the dry season owing to the presence of running, stagnant or underground water.

To obtain an adequate length of gallery forest for each trial, the experiments were conducted in several zones divided into sections. Each of these sections is briefly described (Map 1).

Experiments I and II: Koutiala zone

The geographical distribution of the sections of gallery forest used in the experiments is shown in detail in Map 2.

Section 1: fairly high gallery forest with many palm trees covering dense undergrowth, interrupted by openings in the canopy;

Section 2: gallery forest with spaced palm trees and undergrowth;

Section 3: clumps of palm trees separated by spaces free from vegetation;

Section 4: dense mango forest close to a village;

Section 5: mixture of palms and other fruit trees, alternating with a gallery forest of normal appearance, sometimes 15 m wide;

Section 6: mixture of palms and other fruit trees;

Sections 7, 8, and 15: thick undergrowth 3-4 m high;

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[1] Canopy: crown of dense vegetation at the top of the gallery forest.

Sections 9 and 10: gallery forest 10 m wide, with large trees and undergrowth;

Sections 11, 12, 13 and 14: gallery forest about 15 m wide, with large trees and undergrowth.

Experiment III: Konséguéla zone

There are 10 successive sections, 4-5 km in length, along the same watercourse, the Koba (Map 3). Level with the village of Fissankoro is the start of a gallery forest consisting at first of large palm trees covering dense vegetation (Section 10). After that the stream, which is fairly straight, is completely enclosed by a vault of vegetation that is rarely interrupted. The river-bank vegetation is about 15 m wide; it consists of shrubs 5 m high with remarkably dense foliage, and several metres thick. At some points this layer of vegetation is sheltered by large trees, sometimes about 12 m high. The intertwined branches of the bushes at the forest edge form an inextricable tangle that gives the resting site perfect protection.

Experiment IV

(a) Koni zone

The Koni (Map 4) is a fairly large river; 30 km of its middle reaches were divided into six experimental sections, separated from each other by a 1 km barrier treated with DDT.

The watercourse is characterized by wide bends and is fringed by an open gallery forest, but the vegetation covers both banks without interruption for a fairly constant width of 10-15 m. The large trees shelter smaller trees, shrubs and bushes. In Sections 5 and 6, the high vegetation is fringed by a strip of bushes several dozen metres wide.

(b) N'Tiesso gallery forest

This gallery, about 6 km long, consists of large palm trees covering dense undergrowth, but interrupted at places.

(c) Sacred wood of Niessoumana

Near the village of Niessoumana, at the head of a flood plain with no gallery forest, is a small sacred wood, roughly circular in form and one hectare in area. Half the wood is made up of large trees, while the other half is covered by shrubs and bushes 4-5 m high forming an impenetrable mass of vegetation.

Supplementary experiment: Nasso gallery forest

To speed up the preliminary trials with Gardona, a supplementary experiment was carried out near Nasso, 17 km from Bobo-Dioulasso. The gallery forest is about 10 m wide and consists of large trees; beneath the canopy are free spaces with a few palm trees and bushes.

III. METHODS AND TECHNIQUES

1. Insecticides and formulations

(a) Pyrethroid:

the ULV formulation of NRDC 119 (OMS-1800) has a concentration of 2.5% active ingredient;

(b) Organophosphorus compounds:

Nexion is a ULV formulation with 35% bromophos (OMS-658);

fenitrothion (OMS-43), a ULV formulation, contains 100% active ingredient,

Gardona (OMS-595) or tetrachlorvinphos is an emulsifiable concentrate with 24% active ingredient;

Nuvanol is a ULV formulation with 20% jodfenphos (OMS-1211);

(c) Organochlorine compound:

methoxychlor (OMS-466) is an emulsifiable concentrate with 20% active ingredient.

Laboratory trials showed that the ULV formulations of NRDC 119 and jodfenphos can be mixed with water, while all products except fenitrothion can be mixed with diesel oil.

Gardona is a fast-acting insecticide, while bromophos and jodfenphos are slow-acting.

2. Techniques for insecticide application

The helicopter used was a Bell 47 G-4A, 305 hp, whose operating speed is governed by the output of the nozzles and atomizers and by the amount of substance to be sprayed per hectare. The speed range is from 32 to 80 km/hour (20-50 mph).

For the application of ULV insecticides, two rotary atomizers (spinners) are fitted 6-8 m apart. Two types are used: during experiment I one type produced droplets between 20 and 30 µ in diameter at a rate of 0.6 litres per minute; the other type, which has large apertures, produced droplets 80-100 µ in diameter at a rate of 1.2 litres per minute.

For the application of substances in powder form, the number of nozzles varies according to the amount of mixture to be sprayed per hectare. Trials were conducted with nozzles of type D3-25, which produce droplets 200-300 µ in diameter; for fenitrothion the D2-23 model was used (droplets 50-200 µ in diameter).

The nozzles are fitted on a 16 m boom. The width of the swath treated is 20 m, so that the length of gallery forest equivalent to one hectare is 500 m. In very wide sections the helicopter has to make two or even three journeys.

The helicopter flies at a constant height, about 2 m above the canopy; it makes tight turns to follow the bends in the watercourse. The powerful air current propelled downwards and backwards by the rotor carries with it the insecticide droplets, which in this way are able to penetrate the vegetation and reach the ground.

In order to avoid the convection currents that develop above the ground after sunrise, the ULV applications are conducted from 6 a.m. to 8.30 a.m. Powder spraying by nozzle can continue until about 9.30 a.m. The operations can be resumed in the evening from about 4.45 p.m. when the air is calm.

3. Study of droplet size and distribution

Strips of sensitized paper are placed at random in the gallery forests, from ground level up to a height of 80 cm. When captured tsetse flies are used, a strip 10 cm in length is placed inside empty cages and another strip near to those cages. The droplets deposited on the paper dissolve it to form a circular crater with fairly distinct edges and a black bottom. Since we have no suitable equipment for measuring the diameter of the impacts we use a camera lucida (one camera lucida unit = 6 µ).

4. Evaluation of the effectiveness of the application techniques and the insecticides

(a) On batches of tsetse flies kept in cages

The tsetse flies collected in the testing sections were distributed in cages of the modified Roubaud type (15 x 8 x 5 cm), with wire netting. These cages were placed in the gallery forests before the helicopter flew over, at variable heights above the ground up to 1 m; they were removed a quarter or half-an-hour after spraying and placed in a cooled isothermic container. Control batches were placed either in an untreated gallery forest or outside the treated gallery forest but shaded by vegetation.

The mortality of the exposed batches was recorded where the mortality of the control batches was not excessive. When it exceeded 5% the mortality was corrected by Abbott's formula.

(b) On wild populations

When time permitted, tsetse flies were collected prior to treatment in the experimental sections. Teams of two to four collectors went through the gallery forest catching tsetse flies in nets. On the day of treatment and/or on the following days the same teams were sent out to the same sections to take samples of the residual population.

Insofar as time was available the captured batches were dissected to determine their age. For males six age-groups were defined by Jackson (1946) according to the extent of wear of the rear edge of the wings. For females we used the physiological age method based on the number of follicular relicts (Saunders, 1960), as improved by one of the present authors (Challier, 1965).

In Table VIII the results are given in simplified form. For both sexes the "teneral" specimens (T, nt or Nt) are those that have not yet taken their first blood meal; they emerged recently and their tegument is still soft. The males are subdivided into "teneral" specimens (T or t), young flies (Y) belonging to the first three age-groups defined by Jackson, and old flies (O) belonging to the last three age-groups. Among the females we distinguish the teneral nulliparous (Nt), non-teneral nulliparous (Ntn) aged two to eight days, young parous specimens (Py) belonging to the physiological age-groups I, II and III, and finally the old parous specimens (Po) aged more than one month.

Age determination with females is more precise than with males, and it is possible to deduce the date when an individual emerged. It is thus possible to find out whether a female captured after treatment emerged before or after that treatment. This information is essential for treatments with immediate effect: since the insecticide has only a very short period of action, the tsetse flies emerging from the stock of pupae buried in the ground form a population that should consist only of very young individuals which should be killed by a further treatment before they can reproduce.

IV. DESCRIPTION OF THE EXPERIMENTS

Experiment I, from 17-23 October in the Koutiala zone

In order to obtain results rapidly that would indicate the effective dose, the trials were conducted on batches of captive tsetse flies.

NRDC 119, bromophos, fenitrothion and Gardona were applied in small doses, using atomizers with small apertures and nozzles.

Experiment II, from 1-6 November in the Koutiala zone

Because the atomizers with small apertures broke down, this series of experiments included only trials using nozzles. The testing sections were divided off by buffer zones treated with DDT.

NRDC 119, bromophos, fenitrothion and Gardona were applied in doses twice as high as those used in experiment I. Jodfenphos was sprayed in a low dose.

Since none of the results so far was satisfactory a trial was conducted on batches of captive tsetse flies placed in open country, and a helicopter equipped with nozzles flew over them at a height of four metres. This experiment showed that the insecticide doses need to be increased.

Experiment III, from 16-21 November in the Konséguéla zone

The 10 sections marked off on the Koba were treated with doses twice as strong as those used in experiment II. The effect on captive and wild tsetse populations was assessed.

Experiment IV, from 28 November - 4 December on the Koni

For this last series of trials, six sections 4-5 km in length, including a 1 km buffer zone treated with DDT, received doses equal to or higher than those used in experiment III.

The trials with NRDC 119 were not continued since it was found that two atomizers were not enough to provide uniform distribution of droplets over the entire width of the gallery forest.

The trials with fenitrothion were discontinued because the stock was exhausted.

Bromophos and jodfenphos were applied in ULV, while Gardona and methoxychlor were sprayed with nozzles as a residual treatment.

Supplementary experiment in the Nasso gallery forest

Since the doses administered in experiment II did not provide satisfactory results, a supplementary trial was carried out between experiments II and III. Gardona was applied with nozzles and atomizers in an amount of 1.440 kg/ha. One day and 11 days after spraying, leaf samples were taken for laboratory examination of the effect of the insecticide deposit, using Kernaghan and Johnston's method (1962). Tsetse flies placed in tubes were brought into contact with the surface of the leaves for one minute.

Study of the residual effect of Gardona and methoxychlor

Collections took place 20 days after treatment with Gardona in the N'tiesso gallery forest and after treatment with methoxychlor in the sacred wood of Niessoumana. From 8-13 January 1973 a final evaluation of the residual population was carried out in the two above breeding places and in sections 5 and 6 along the Koni.

V. RESULTS

1. Quantitative aspects of the effect of insecticides on tsetse flies

The results obtained for each insecticide are assembled in a table showing the effect of treatments on captive and wild tsetse flies under different experimental conditions.

NRDC 119 Table I

A. Atomizers

Mortality among the captive flies is rapid; there is a substantial "knock-down" effect in a quarter-of-an-hour, but some individuals recover during the hours following the treatment.

When low doses (10 and 20 g/ha) are administered to open gallery forests, the mortality among captive flies approaches 90%, whereas at a dose of 40 g/ha mortality among the wild population of a closed gallery is negligible or non-existent.

B. Nozzles

At low doses, mortality among the captive flies is lower than that found during the trials with atomizers. In experiment II (Kouniana-12) mortality may be regarded as total if the results for one cage in which none of the tsetse flies died are disregarded; this cage was placed at the edge of the gallery forest, and was sheltered by a bush.

The wild populations are scarcely affected; the specimens captured after treatment are mainly non-teneral flies.

NRDC 119 mixed with water has some effect on batches kept in cages (64% mortality).

bromophos Table II

A. Atomizers

A dose of 800 g active ingredient per hectare is needed to achieve a satisfactory reduction in the population. In experiment III (Konséguéla-5) no flies were captured three days after treatment, but in the other experiments the reduction was 96% for G. palpalis gambiensis and 94% for G. tachinoides. A higher dose, applied to a dense gallery forest (IV-Koni-3) achieved a reduction of only 83%. The presence of non-teneral specimens in the samples captured after treatment shows that the effective dose must be higher than 1 kg active ingredient per hectare.

B. Nozzles

Low doses applied to open galleries have a by no means negligible effect; the reduction was as high as 93% at a dose of 400 g active ingredient per hectare in experiment II (Niessasso-9), whereas it was only 84% for the dose of 800 g applied to a closed gallery (III-Konséguéla-8). The specimens captured two-and-a-half days after treatment were mainly non-teneral flies (13/20).

iodofenphos Table III

A. Atomizers

The two treatments at 600 g active ingredient per hectare produced fairly similar reductions (74% and 79.5%). At 800 g the effect was almost total (96.4%), but there were still a few non-teneral flies after treatment.

B. Nozzles

Doubling the doses leads to a clear increase in the effect on wild populations: the reduction progressed from 39% at 160 g active ingredient per hectare to 95.5% at 600 g. An unexpected result was obtained with a dose of 600 g mixed with 12 litres of water: a single teneral female was captured two days after treatment.

fenitrothion | Table IV

A. Atomizers

While low doses had a not inconsiderable effect on the population of open galleries, the maximum dose administered to a closed gallery was comparatively ineffective. Roughly similar reductions were noted for doses varying in a ratio of 1:10.

B. Nozzles

At a dose of 800 g active ingredient per hectare the mortality of captive tsetse flies was low (30%), whereas the reduction of the wild population was 87.5%.

Gardona | Table V

A. Atomizers

The trials with low doses produced no results; at a dose of 720 g active ingredient per hectare, mortality among the captive flies was only 45%.

B. Nozzles

During the initial trials, low doses had a fairly strong action and caused a reduction of 93.7% (I-Dougoumasso-5).

The latest trials on gallery forests with dense vegetation (Koni and N'tiesso) produced somewhat contradictory results; the stronger the dose, the lower the reduction in the G. p. gambiensis populations: the rates for 1.440 kg, 2 kg and 3 kg were 97%, 81.5% and 62% respectively.

C. Residual effect

In the N'tiesso gallery forest the proportion of non-teneral tsetse flies captured was still high (12/13 nt) 20 days after treatment, and 40 days afterwards it was 21/22; after the same period on the Koni, 12 non-teneral specimens were captured in the section treated with 1.440 kg and nine in the section treated with 2 kg (Table VIII).

Mortality among captive flies exposed in the Nasso gallery forest was 42.4%, a value that is fully comparable with the 43% obtained by bringing the flies into contact with leaves removed 24 hours after treatment (Table VI). Their mortality was no more than 12.5% after exposure to leaves removed 11 days later.

methoxychlor

The single treatment with a dose of 3.2 kg active ingredient per hectare, applied in the sacred wood of Niessoumana, produced no residual effect; the proportion of non-teneral specimens was 4/10, 7/15 and 15/17 after two, 20 and 40 days respectively.

Experiment in open country   Table VII

This experiment shows that Gardona and fenitrothion, which did not produce satisfactory results in the gallery forests, are nevertheless comparatively effective insecticides. Doubling the dose of jodfenphos causes a clear increase in mortality.

2. Qualitative aspects of the effect of insecticides

During experiments III and IV, population samples taken prior to treatment (controls) and after treatment were examined to determine the age of the individuals.

On examining Table VIII it is noted that the average age of the control populations is rather high; about 50% of the individuals are older than one month.

In experiment III (Konséguéla) the proportion of old females remained fairly high after treatment in most cases. Only jodfenphos applied by nozzle and bromophos applied by atomizer had any clear effect; in the former trial one teneral female was captured, whereas no tsetse flies at all were seen in the latter.

In experiment IV (Koni), despite a reduction in the number of flies after the treatment, old specimens were still observed.

In the N'tiesso gallery forest and in the sacred wood of Niessoumana the situation was the same as that found on the Koni or at Konséguéla.

3. Study of the size, density and effect of Gardona droplets on caged tsetse flies

Sensitized strips of paper were placed in several experimental sections of the watercourses. The results were very variable, so we shall only consider those obtained during the trials at Nasso (see Table V). Gardona was sprayed with 24 D3-25 nozzles (1.44 kg active ingredient per hectare at 40 km/hour) and two atomizers with large apertures (720 g active ingredient per hectare, non-diluted, at 40 km/hour).

(a) Interception of droplets by the cage netting

Comparison of the droplet density inside and outside the cages in four series of cages shows that the netting intercepts about 50% of the droplets reaching the ground (17%, 47%, 52% and 55%).

(b) Diameter and density of the droplets sprayed by nozzle

The droplet diameter was measured in 10 samples (Table IX).

Statistical analysis of the results (A. Lafaye, In: Doc. Tech. OCCGE, No. 5 261/86/DOC-STAT.09 and Doc. Tech. OCCGE, No. 5 651/102/DOC-STAT.40) shows that the distribution of the diameters is bimodal (first mode around 96 μ; second mode around 336 μ); two sub-distributions (small and large droplets) are therefore distinguished, with the dividing line around 221-230 μ.

The means were compared by variance analysis after converting the data ($x' = \log x$). For both the large and the small droplets the means differed very significantly (P = 1/1000).

By applying the test to means arranged in decreasing order of sizes the means can be divided into homogeneous groups:

small droplets:

samples: 10 (?) <u>7 4 5 3 8 1</u> <u>2 9 6</u>

large droplets:

samples: <u>5 9 3 6 2(?) 4</u> <u>10 8 7 1</u>

The classification of the means in decreasing order for the small and large droplets together is as follows:

samples: 10, 7, 4, 2, 9, 5, 3, 8, 6, 1.

The sequence of samples in the gallery forest, from south to north, was: No. 1, 2, 3, 10, 4, 8, 7, 5, 6, 9; sample No. 10 was taken from the fringe of the gallery forest.

The variation in droplet diameters along the gallery forest appears to be time-linked.

(c) <u>Density of droplets applied in ULV</u>

The droplet density decreases in the direction of the flight (Table X).

(d) <u>Mortality of tsetse flies exposed in cages</u>

The relationship between the mortality of the captive tsetse flies and droplet density was studied on the basis of the data from the Nasso experiments (Lafaye, <u>loc. cit.</u>). The results obtained after spraying Gardona from nozzles (Table IX) were analysed after making the conversion $\log x' = \log x + 0.060$ and probit adjustment. The regression equation is as follows: $Y = 20.7\,x' - 2.9$ (confidence interval of the regression curve for probability P = 5%: 20.7 ± 12.15, i.e. 8.5 to 32.9). This equation is used to calculate the effective densities (ED) of droplets causing 50%, 90% and 99% mortality in the cages:

ED 50 : 2.10 droplets/cm^2 (5% confidence interval : 1.99-2.23)

ED 90 : 2.41 droplets/cm^2 (5% confidence interval : 2.18-2.67)

ED 99 : 2.71 droplets/cm^2 (5% confidence interval : 2.31-3.18)

ED 99, extrapolated with all the usual reservations, shows that a density of three droplets per cm^2 is enough to kill all the tsetse flies exposed in cages. In the trials with ULV (Table X) there was total mortality in three out of five cages where the density was higher than three, whereas mortality was low in the cages penetrated by less than three droplets per cm^2.

V. DISCUSSION

To facilitate comparison between the various types of treatment and between insecticides, the results are summarized in Table XI.

1. Methods of evaluating the effect of insecticides

When the effect of treatments was evaluated both by the method using captured tsetse flies and by the method of surveys of wild populations before and after treatment, the former method consistently gave lower results than the latter, with one exception.

We were not able to convert the impact diameters into actual droplet diameters, but the comparisons remained valid.

The variations in droplet density and diameter are no doubt due to differences in foliage density. It is therefore possible that in sections of gallery forest with very dense vegetation, the droplet density is not sufficient to kill 100% of the tsetse flies.

It does seem that the density of the droplets produced in ULV application is higher on average than that of the droplets sprayed from nozzles. The small droplets are more likely to reach the ground than the large ones.

The mortality of tsetse flies in cages is 100% when the droplet density is higher than three. An area of 1 cm^2 may therefore contain three droplets; this density can therefore be taken as the lower limit of the effective density.

It is possible to evaluate the effect on wild populations, even with limited sampling by studying the composition by age-groups of the samples taken from residual populations.

2. Effectiveness of the insecticides and the application techniques

Some of the results obtained with low doses are not negligible (NRDC 119, bromophos and Gardona) and show that the effectiveness of treatments can be satisfactory in gallery forests without dense vegetation, such as those treated in experiments I and II. The gallery forests in experiments III and IV represent the worst conditions that can be encountered in savanna areas; since the resting sites in the Koutiala region are close to the northern limit of distribution of the species involved in the transmission of sleeping sickness, it is reasonable to suppose that these vegetation conditions are even more prevalent in the southern districts of the savanna. In order to assess the value of the control techniques it is essential to experiment under such conditions.

The insecticides used in the trial were selected for their effectiveness as demonstrated by laboratory tests or in the field (for Gardona, Challier, 1972); the trials on open terrain (Table V) show that for a given technique it is still necessary to arrive at a characteristic dose for each insecticide.

The basic problem, therefore, is the penetration of the droplets through the vegetation. Where the vegetation is very dense it is important to distribute the insecticide as well as possible throughout the entire space occupied by the gallery forest. Here it seems that the small aperture atomizers used in experiment I are preferable to the atomizers with large apertures. According to Irving et al. (1969) synergized pyrethrins are most effective with equipment producing droplets between 30 and 40 µ in diameter.

Observation (II-Kouniana-12) of a cage in which not a single tsetse fly died, whereas in all the other cages all the tsetse flies died, shows clearly that insecticide applied in ULV must be well distributed. There must be enough atomizers to produce a homogeneous mist across the entire width of the gallery forest.

A rather unexpected result was obtained with jodfenphos mixed with water.

Under the trial conditions Gardona and methoxychlor showed no appreciable residual effect, whereas the same products have proved effective in powder form on the ground. The short duration of their effect must be due to the small amount of insecticide reaching the tsetse fly resting places. The doses will no doubt have to be increased fairly strongly.

3. Behaviour of tsetse flies as an impeding factor

During experiment IV (Koni-3) a team of insect collectors installed on the site at 6.30 a.m. before the helicopter flew over revealed the presence of about 10 tsetse flies at rest among the tall grasses fringing the gallery forest. These flies were dispersed up to about 10 metres from the eastern fringe of a section of the Koni flowing north and south.

G. palpalis gambiensis, attracted by the rays of the rising sun from below the horizon, moves eastward and leaves the gallery forest. The number of flies observed, comparatively high for an area as small as that in which the collection team was posted, leads to the assumption that a not inconsiderable proportion of the population leaves the resting place and thus escapes any immediate effect treatment.

This behaviour on the part of the tsetse flies might constitute an impeding factor. However, it is possible that the insecticides applied in ULV have a residual effect that is very short, but still long enough for the tsetse flies to undergo the action of the treatment on their return to the gallery forest when the sun has risen sufficiently high above the horizon.

VI. CONCLUSION

The insecticides applied in ULV by helicopter are effective on the tsetse fly populations of gallery forests with very dense vegetation, provided that they are uniformly distributed over the entire width of the resting places.

The doses providing droplet density that is adequate in the lower stratum of vegetation are in the order of 1 kg activer ingredient per hectare for bromophos and jodfenphos and over 1 kg for fenitrothion.

The very variable results obtained with NRDC 119 permit no definite conclusion. The trials need to be resumed with an adequate number of atomizers.

Residual treatments with Gardona and methoxychlor provided only a time-limited effect. To achieve total and long-lasting effectiveness a dose of more than 3 kg active ingredient per hectare would be required. The problem therefore is to find out whether the increase in dose would be ruled out by the cost of treatment and by the harmful effects on the environment and especially on non-target fauna.

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TABLE I. EFFECT ON G. PALPALIS GAMBIENSIS OF NRDC 119 (ULV, 2.5% ACTIVE INGREDIENT) APPLIED TO GALLERY FORESTS

Equipment B = nozzles (type) At = atomizers	Insecticide dose applied per ha		Helicopter		Experiment no. place, section of gallery forest	Mortality in cages (%)		Effect on wild tsetse flies		
	Active ingredient (g/ha)	Mixture (litres)	Speed (km/h)	Time		Corrected %age (total no. after n hrs of observation)	Controls (deaths/ total)	No. captured before treatment	No. captured after treatment (n days after)	Reduction (%)
2 At, small holes	10 20	0.4 unmixed 0.8 unmixed	80 40	07.25 06.30	I - Tiri 2 I - Koutiala 1	89% (48-9h) 86.5% (48-9h)	3/43 3/43	9 5	0 (3 d) 0 (3 d)	100 100
2 At, large holes	40	1.5+1.5 diesel	40	06.20	III - Konséguéla 10	11/30[a] (13h)	7/32	62♂, 30♀	♂13t (42 nt)[b] ♀38 (20 nt)[c]	0
2 B/D3-25	10 20	0.4 unmixed 0.8 unmixed	80 40	08.15 08.05	I - Nietabougouro 4 I - Kaniko 3	25% (40-9h) 5/49 (7h)	3/43 3/43	40 -	43 (3 d) 5 (3 d)	0 ?
6 B/D3-25	5 5 10 10	0.2+1 diesel " " " 0.4+2 diesel " " "	80 80 40 40	07.05 16.45 07.45 16.40	I - Kouniana 14 I - Niessasso 10 I - Kouniana 13 I - Niessasso 9	57% (30-4h) 12.5% (40-4h) 27% (30-8h) 25% (40-4h)	1/20 0/24 1/20 0/24	32 15 32 15	13 (1 d) 11 (1 d) 19 (1 d) 2 (1 d)	59 27 40 87
10 B/D3-25	5 10	0.2+ diesel 0.4+ diesel	80 40	17.30 16.35	I - Niessasso 10 I - Niessasso 9	3/15 (13h) 1/15 (4h)	0/40 0/43	15 15	11 (3 d) 2 (3 d)	27 87
12 B/D3-25	40	1.6+3.7 diesel	40	06.45	II - Kouniana 12	100% (54-8h)	3/60	18♂, 2♀	8♂ nt (1 d)	60
15 B/D3-25	37.5	1.5+7.5 diesel	40	07.00	III - Konséguéla 1	97% (39-24h)	1/32	-	4t, 5nt ♂ (2 d) 1t, 7nt ♀	?
24 B/D3-25	37.5	1.5+13.5 water	40	08.15	III - Konséguéla 4	64% (39-24h)	1/32	-	6t, 24 ♂ (2 d) 2nt ♀	?

[a] Number of dead tsetse flies/total number in batch.

[b] t = teneral tsetse flies; nt = non-teneral tsetse flies.

[c] 20 ♀ dissected out of 38 captured.

TABLE II. EFFECT ON G. P. GAMBIENSIS AND G. TACHINOIDES OF BROMOPHOS (ULV, 35% ACTIVE INGREDIENT) APPLIED TO GALLERY FORESTS

Equipment B = nozzles (type) At = atomizers	Insecticide dose applied per ha		Helicopter		*Experiment no.* place, section of gallery forest	Mortality in cages (%)		Effect on wild tsetse flies		
	Active ingredient (g/ha)	Mixture (litres)	Speed (km/h)	Time		Corrected %age (total no. after n hrs of observation)	Controls (deaths/ total)	No. captured before treatment	No. captured after treatment (n days after)	Reduction (%)
2 At, small holes	100	0.3 unmixed	96	07.25	I - Karangasso 5	48% (23-14h)	2/24	P[a] : 80	29 (1 d)	64
	200	0.6 unmixed	48	07.20	I - Lele 6	29% (23-14h)	2/24	P : 3	2 (1 d)	-
2 At, large holes	800	2.3+0.7 diesel	40	07.00	III - Konséguéla 5	14/16[b] (8h)	5/32	P : 167	0 (3 d)	100
	"	" " "	"	07.20	" "	20/32 (12h)	7/32	-	0 (3 d)	-
	"	" " "	"	07.00	IV - Koni 4	- -	-	P:67♂, 76♀	P:1t♂, 2t, 3nt♀[c]	96
								T:10♂, 7♀	T:1t♀ (3 d)	94
	1050	3 unmixed	40	07.00	IV - Koni 3	- -	-	P:23♂, 30♀	P:1t, 2nt♂, 6nt♀	83
								T: 0♂, 2♀	T:0 (3 d)	100
6 B/D3-25	100	0.3+0.9 diesel	80	09.35	I - Famessasso 7	5/12 (12h)	0/24	P : 26	4 (1 d)	84.5
	200	0.6+1.8 diesel	40	09.35	I - Sourbasso 8	14% (22-12h)	0/24	-	-	-
12 B/D3-25	400	1.2+4.1 diesel	40	07.30	II - Niessasso 9	66% (79-13h)	3/79	P:18♂, 12♀	1nt, 1t♀ (1 d)	93
15 B/D3-25	800	2.3+6.7 diesel	40	07.30	III - Konséguéla 9	3/32 (8h)	7/32	P : 127	5t, 6nt♂ 2t, 7nt♀ (2.5 d)	84

[a] P = G. palpalis; T = G. tachinoides.

[b] Number of dead tsetse flies/total number in batch.

[c] t = teneral tsetse flies; nt = non-teneral tsetse flies.

TABLE III. EFFECT ON G. P. GAMBIENSIS OF JODFENPHOS (ULV, 20% ACTIVE INGREDIENT) APPLIED TO GALLERY FORESTS

Equipment B = nozzles (type) At = atomizers	Insecticide dose applied per ha		Helicopter		Experiment no. place, section of gallery forest	Mortality in cages (%)		Effect on wild tsetse flies		
	Active ingredient (g/ha)	Mixture (litres)	Speed (km/h)	Time		Corrected %age (total no. after n hrs of observation)	Controls (deaths/ total)	No. captured before treatment	No. captured after treatment (n days after)	Reduction (%)
2 At, large holes	600	3 unmixed	40	06.50	III - Konséguéla 9	48% (31- 8h)	6/32[a]	52♂, 20♀	4t, 6nt♂[b] 4t, 4nt♀ (2 d)	75
	"	" "	"	06.20	IV - Koni 1	- -	-	37♂, 16♀	55♂, 23♀ (0 d) 2t, 8nt♂ (2 d) 1t, 5nt♀ (2 d)	- 79.5
	800	4 unmixed	32	06.30	IV - Koni 2	- -	-	48♂, 91♀	42♂, 71♀ (0 d) 1t♂, 4nt♀ (2 d)	 96.4
12 B/D3-25	160 320	0.8+4.5 diesel 1.6+3.7 diesel	40 40	07.00 07.20	II - Kouniana 13 II - Kouniana 14	5% (40-11h) 19% (37-11h)	0/30 0/30	38♂, 3♀ 24♂, 6♀	25♂ (0 d) 9♂ (0 d)	39 70
15 B/D3-25	600	3+6 diesel	40	07.10	III - Konséguéla 7	21/29 (11h)	7/32	66	2nt♂, 1nt♀ (2 d)	95.5
24 B/D3-25	600	3+12 water	40	17.15	III - Konséguéla 3	37% (31-25h)	4/32	-	1t♀ (2 d)	100

[a] Number of dead tsetse flies/total number in batch.

[b] t = teneral tsetse flies; nt = non-teneral tsetse flies.

TABLE IV. EFFECT ON G. P. GAMBIENSIS OF FENITROTHION (ULV, 100% ACTIVE INGREDIENT) APPLIED TO GALLERY FORESTS

Equipment B = nozzles (type) At = atomizers	Insecticide dose applied per ha		Helicopter		Experiment no. place, section of gallery forest	Mortality in cages (%)		Effect on wild tsetse flies		
	Active ingredient (g/ha)	Mixture (litres)	Speed (km/h)	Time		Corrected %age (total no. after n hrs of observation)	Controls (deaths/ total)	No. captured before treatment	No. captured after treatment (n days after)	Reduction (%)
2 At, small holes	100 200	0.1 unmixed 0.2 unmixed	80 80	08.20 07.35	I - Kouniana 12 I - Kouniana 11	17.5% (40-9h) 18% (38-11h)	1/20[a] 1/20	32 -	13 (1 d) 19 (1 d)	60 -
2 At, large holes	1000	1 unmixed	40	06.50	III - Konséguéla 6	74% (32-11h)	5/32	167	15t,[b] 37nt♂ 9nt♀ (2 d)	63
4 B/D2-23	800	0.8 unmixed	72	06.55	II - Kouniana 11	30% (78-11h)	4/60	51♂, 6♀	5nt♂, 2nt♀ (1 d)	87.5

[a] Number of dead tsetse flies/total number in batch.

[b] t = teneral tsetse flies; nt = non-teneral tsetse flies.

TABLE V. EFFECT ON G. P. GAMBIENSIS AND G. TACHINOIDES OF GARDONA (EMULSIFIABLE CONCENTRATE, 24% ACTIVE INGREDIENT) APPLIED TO GALLERY FORESTS

Equipment B = nozzles (type) At = atomizers	Insecticide dose applied per ha		Helicopter		Experiment no. place, section of gallery forest	Mortality in cages (%)		Effect on wild tsetse flies		
	Active ingredient (g/ha)	Mixture (litres)	Speed (km/h)	Time		Corrected %age (total no. after n hrs of observation)	Controls (deaths/ total)	No. captured before treatment	No. captured after treatment (n days after)	Reduction (%)
2 At, small holes	100 200	0.4 unmixed 0.8 unmixed	80 40	08.10 08.20	I - Sourbasso 8 I - Zougoumasso 7	7/56[a] (8h) 10/60 (9h)	8/57 8/57	P : 26 -	56 (1 d) 3 (1 d)	0 -
2 At, large holes	720	3 unmixed	40	07.15	Nasso 2	45% (61-27h)	5/36	-	-	-
6 B/D3-25	100 200	0.4+0.8 diesel 0.8+1.6 diesel	80 40	06.45 07.05	I - Zougoumasso 5 I - Famessasso 15	8/56 (8h) 6/56 (8h)	7/57 7/57	P : 80 -	5 (1 d) 6 (1 d)	93.7 -
12 B/D3-25	400	1.6+3.7 diesel	40	06.45	II - Niessasso 10	16% (79-13h)	3/79	P:5♂, 1♀	2 seen (1 d)	-
15 B/D3-25	1440	6+3 diesel	40	07.30	III - Konséguéla 2	79% (28-11h)	0/32	P: -	2t,[b] 1nt♂ (2 d) 2t, 2nt♀	-
24 B/D3-25	1440 1440	6+9 water 6+9 water	40 40	08.00 06.30	Nasso 1 IV - Koni 5	42% (36-24h) -	0/36 -	- P:[c] 58♂, 112♀ T: 20♂, 13♀	- P:7♂, 9♀ (0 d) T:2♂, 3♀ P:2nt♂, 3t♀ (2 d) T:0♂, 0♀	- - 97 100
	2000	8.3+6.7 water	40	06.30	IV - Koni 6	-	-	P:28♂, 37♀ T:14♂, 4♀	P:1t♂, 7nt♂ 4nt♀ T:2t, 5nt♂ (2 d) 3t, 4nt♀	81.5 22
	3000	11.5+3.5 water	40	06.45	IV - N'tiesso	-	-	P:31♂, 8♀	P:11nt♂, 3t, 14nt♀ (2 d) P:1t, 12nt♂	62

[a] Number of dead tsetse flies/total number in batch.

[b] t = teneral tsetse flies; nt = non-teneral tsetse flies.

[c] P = G. palpalis; T = G. tachinoides.

TABLE VI. MORTALITY OBSERVED IN THE LABORATORY AMONG BATCHES OF MALE TSETSE FLIES (G. PALPALIS GAMBIENSIS) BROUGHT INTO CONTACT FOR ONE MINUTE WITH THE SURFACE OF LEAVES TAKEN FROM THE NASSO GALLERY FOREST AFTER TREATMENT WITH GARDONA - KERNAGHAN & JOHNSTON'S METHOD

Active ingredient per ha, mixture	Leaves removed after	Mortality (controls)	Mortality after n hrs of observation	Corrected mortality (%)
1440 g (6 l + 9 l water) - 24 nozzles	24 hours 11 days	2/25 0/40	10/25 (21 h) 0/40 (26 h)	43% 12.5%
720 g (unmixed, 2 atomizers)	24 hours	2/25	4/25 (21 h)	8.7%

TABLE VII. MORTALITY AMONG G. PALPALIS GAMBIENSIS IN CAGES ON OPEN TERRAIN WHEN EXPOSED TO INSECTICIDES APPLIED BY HELICOPTER FLYING 4m ABOVE THE GROUND

Insecticide and dose (active ingredient/ha)	Equipment	Observation n hours after exposure	Tsetse fly mortality	
			Controls	Corrected %age and (no.)
Gardona 400 g	12 nozzles D3-25	16	3/79	68.4% (13/19)
fenitrothion 800 g	4 nozzles D2-23	11	2/20	94% (18/19)
NRDC 119 40 g	12 nozzles D3-25	3	2/20	100% (18/18)
jodfenphos 400 g 800 g	 12 nozzles D3-25 " " "	 13 "	 0/30 "	 10% (2/20) 65% (13/20)

TABLE VIII. COMPOSITION BY AGE-GROUP OF G. PALPALIS GAMBIENSIS POPULATION SAMPLES COLLECTED BEFORE (CONTROLS) OR AFTER THE APPLICATION OF INSECTICIDES (FOR AGE-GROUPS SEE TEXT)

Place and date of observation	Treatment : dose (g/ha) equipment	No. collected before treatment	Age of males and females							
			No. of days after treatment	♂			♀			
				T	Y	O	Nt	Ntn	Py	Po
Koni (13.X)	Control	-	-	0	0	-	1	3	0	7
Koni (2.XII)	"	-	-	1	6	2	0	0	2	7
Tiri (12.XII)	"	-	-	-	-	-	2	1	8	3
Konséguéla (16-21.XI)	NRDC 119									
	37.5 - 15 nozzles	-	2	4	5nt[a]		1	0	1	6
	37.5 - 24 nozzles	-	2	6	24nt		0	0	1	1
	40 - 2 atomizers	62♂, 30♀	2	13	42nt		0	2	2	16[b]
	bromophos									
	800 - 2 atomizers	167	3	0	0		0	0	0	0
	800 - 15 nozzles	127	2.5	5	6nt		2	0	2	5
	jodfenphos									
	600 - 2 atomizers	52♂, 20♀	2	4	6nt		4	0	1	3
	600 - 15 nozzles	66	2	0	2nt		0	0	0	1
	600 - 24 nozzles	-	2	0	0		1	0	0	0
	fenitrothion									
	1000 - 15 nozzles	167	2	15	37nt		0	0	2	6(+2)[c]
	Gardona									
	1440 - 15 nozzles	-	2	2	1nt		2	1	0	1
Koni (28.XI-4.XII and 1.73)	bromophos									
	800 - 2 atomizers	67♂, 20♀	3	1	0	0	2	0	1	2
	1050 - 2 atomizers	23♂, 30♀	3	1	1	2	0	1	3	2
	jodfenphos									
	600 - 2 atomizers	37♂, 16♀	2	2	6	2	1	1	1	3
	800 - 2 atomizers	48♂, 91♀	2	1	0	0	0	0	2	2
	Gardona									
	1440 - 24 nozzles	58♂, 112♀	2	0	2[d]	0	3	0	0	0
	2000 - 24 nozzles	28♂, 37♀	40	0	4	1	0	0	7	0
	2000 - 24 nozzles	28♂, 37♀	40	0	3	0	0	0	1	3(2p)[c]
N'tiesso (2.XII and 1.73)	Gardona 3000 - 24 nozzles	31♂, 8♀	2	0	10[e]	1	3	1	0	0
			20	1	12	0	0	0	0	0
			40	0	15	1	1	1	3	1
Niessoumana (2.XII and 1.73)	methoxychlor 3200 - 24 nozzles	22♂, 4♀	2	4	1	0	2	0	2	1
			20	4	3	0	4	1	3	0
			40	0	7	0	2	2	4	0

[a] nt = non-teneral specimens.

[b] 16 out of 38 dissected.

[c] plus 2 of indeterminate age; 2p = 2 parous.

[d] males with soft tegument.

[e] 10 males with the "smoke-blackened" wings of teneral specimens and with blood still red in the midgut.

TABLE IX. MEAN DIAMETER (μ) OF GARDONA DROPLETS ON SENSITIZED PAPER, DENSITY PER CM^2, AND MORTALITY OF TSETSE FLIES EXPOSED IN CAGES (NASSO TRIAL: 1440 kg ACTIVE INGREDIENT PER ha - 24 3D-25 NOZZLES - 40 km/h)

Samples		1	2	3	4	5	6	7	8	9	10
Mean droplet diameter	G[a]	413	352	344	366	319	348	413	412	334	401
	P[b]	108	115	104	98	102	125	95	106	119	86
	T[c]	269	173	221	154	192	250	144	250	192	125
No. of droplets per cm^2		0.88	2.58	1.92	2.20	1.97	6.70	2.38	3.19	3.80	1.50
Mortality of tsetse flies in cages		0/5	8/8	1/7	4/8	3/8	-	-	-	-	-

[a] G = large droplets.

[b] P = small droplets.

[c] T = total.

TABLE X. GARDONA DROPLET DENSITY PER CM^2 ON SENSITIZED PAPER AND MORTALITY OF TSETSE FLIES EXPOSED IN CAGES (NASSO TRIAL: 720 g ACTIVE INGREDIENT PER ha - 2 LARGE-APERTURE ATOMIZERS - 40 km/h)

Samples	11	12	13	14	15	16	17	18	19	20
No. of droplets per cm^2	6.2	6.6	7.4	5.3	3.5	2	2.9	1.5	2	0.6
Mortality of tsetse flies in cages	8/8	4/8	2/7	6/6	7/7	2/7	0/3	3/8	1/6	1/7

TABLE XI. SUMMARY OF RESULTS (PART 1)
PERCENTAGE REDUCTION OF WILD POPULATION AND PERCENTAGE MORTALITY AMONG BATCHES OF G. PALPALIS GAMBIENSIS IN CAGES (BETWEEN BRACKETS) AFTER THE APPLICATION OF INSECTICIDES TO GALLERY FORESTS.

Insecticide and formulation	Product + solvent (litres/ha)	% active ingredient	Dose of active ingredient (g/ha)								
			10	20	40	100	200	600	720	800	1000 1050
NRDC 119 ULV 2.5	0.4 + 0 0.8 + 0	2.5 2.5	100(89)	100(86.5)							
bromophos ULV 35	0.3 + 0 0.6 + 0	35 35				64(48)	(29)				
fenitrothion ULV 100	0.1 + 0 0.2 + 0	100 100				60(17.5)	19[a](18)				
Gardona CE 24	0.4 + 0 0.8 + 0	24 24				0(0)	3[a](0)				
NRDC 119 ULV 2.5	1.5+1.5 diesel	1.25			0(11/30)						
bromophos ULV 35	2.3+0.7 diesel " " " " " " 3 + 0	26.6 " " 35								100(14/16)[b] (20/32) 96p, 94t[b,c]	83[b]
jodfenphos ULV 20	3 + 0 " " 4 + 0	20 " "						75(48)[b] 79.5[b]		96.4[b]	
fenitrothion ULV 100	1 + 0	100									63(74)
Gardona CE 20	3 + 0	24							(45)		

[a] No. of tsetse flies collected after treatment, with no collection before treatment.

[b] Effect on tsetse flies in gallery forests with a very dense canopy.

[c] p = G. p. gambiensis; t = G. tachinoides.

TABLE XI. SUMMARY OF RESULTS (PART 2)
PERCENTAGE REDUCTION OF WILD POPULATION AND PERCENTAGE MORTALITY AMONG BATCHES OF G. PALPALIS GAMBIENSIS IN CAGES (BETWEEN BRACKETS) AFTER THE APPLICATION OF INSECTICIDES TO GALLERY FORESTS, USING D3-25 NOZZLES (D2-23 IN THE CASE OF FENITROTHION)

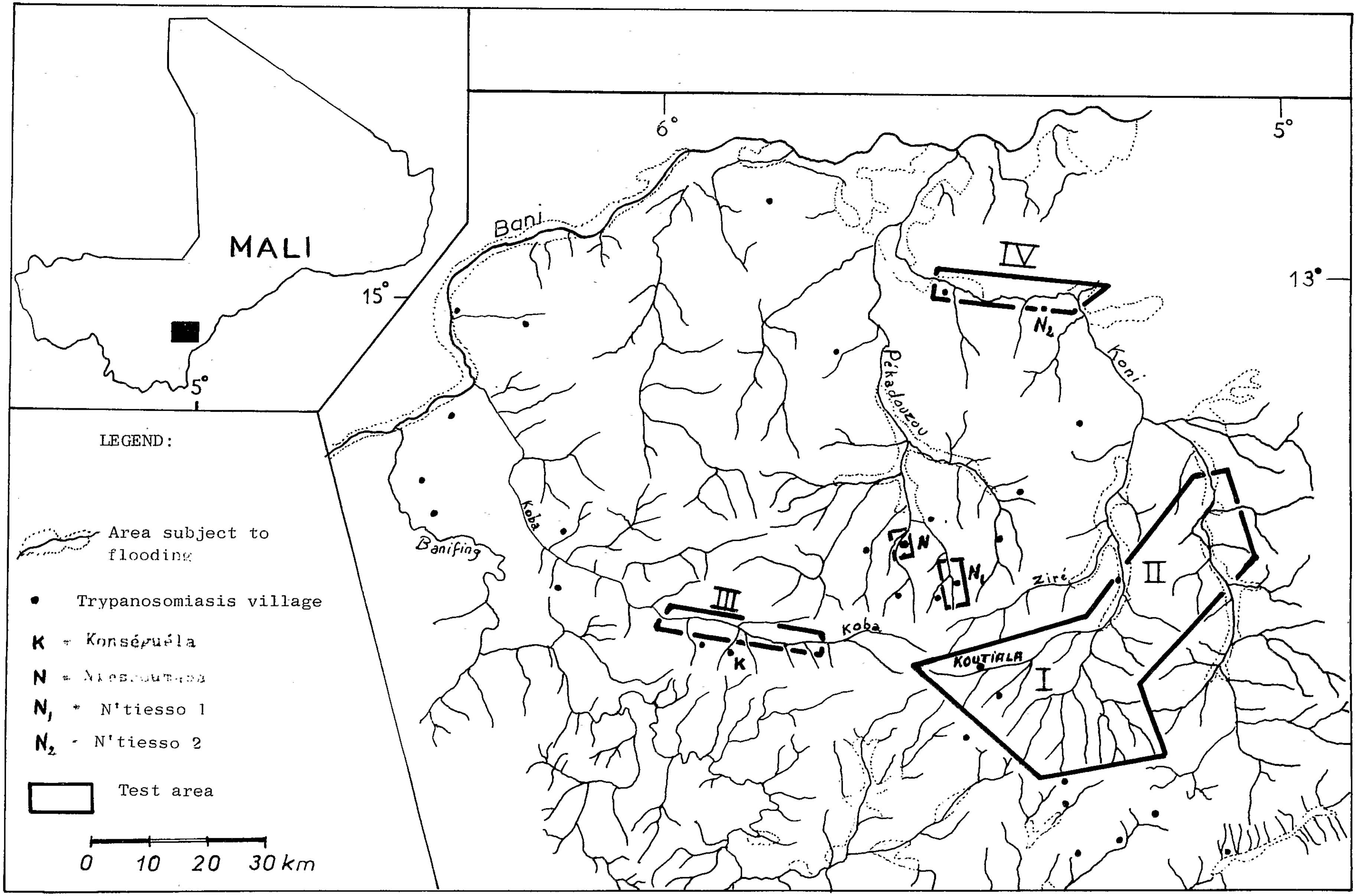
Insecticide and formulation	No. of nozzles	Product + solvent (litres/ha)	% active ingredient	Dose of active ingredient (g/ha)													
				5	10	20	40	100	160	200	320	400	600	800	1440	2000	3000
NRDC 119 (ULV 2.5)	2	0.4+0	2.5		0(25)												
		0.8+0	2.5			5[a]											
	6	0.2+1 diesel	0.4	59(57) 27(12.5)													
		0.4+2 diesel	0.4		40(27) 87(25)												
	10	0.2+1 diesel	0.4	27(3/15)													
		0.4+2 diesel	0.4		87(1/15)												
	12	1.6+3.7 diesel	0.7				60(100)										
	15	1.5+7.5 diesel	0.4				17[a](97)[b]										
	24	1.5+13.5 water	0.25				32[a](64)										
bromophos (ULV 35)	6	0.3+0.9 diesel	8.7					84.5(5/12)									
		0.6+1.8 diesel	8.7							(14)							
	12	1.2+4.1 diesel	8.0									93(66)					
	15	2.3+3.6 diesel	8.8											84(3/32)			
jodfenphos (ULV 20)	12	0.8+4.5 diesel	3.2					39(5)									
		1.6+3.7 diesel	6.4							70(19)							
	15	3+6 diesel	6.6										95.5(21/29)				
	24	3+12 diesel	4.8										100(37)				
fenitrothion (ULV 100)	4/D2-23	0.8+0	100											87.5(30)			
	6	0.4+0.8 diesel	8					93.7									
		0.8+1.6 diesel	8							6[a]							
	12	1.3+7 diesel	7.2									(16)					
	15	6+3 diesel	16											7[a](79)			
	24	6+9 water	9.6											(42)			
		" " "	"											97p 100t[b,c]			
		8.3+6.7 water	13.3													(81.5 (22t[b]	
		11.5+3.5 water	20														62

[a] No. of tsetse flies collected after treatment, with no collection before treatment.

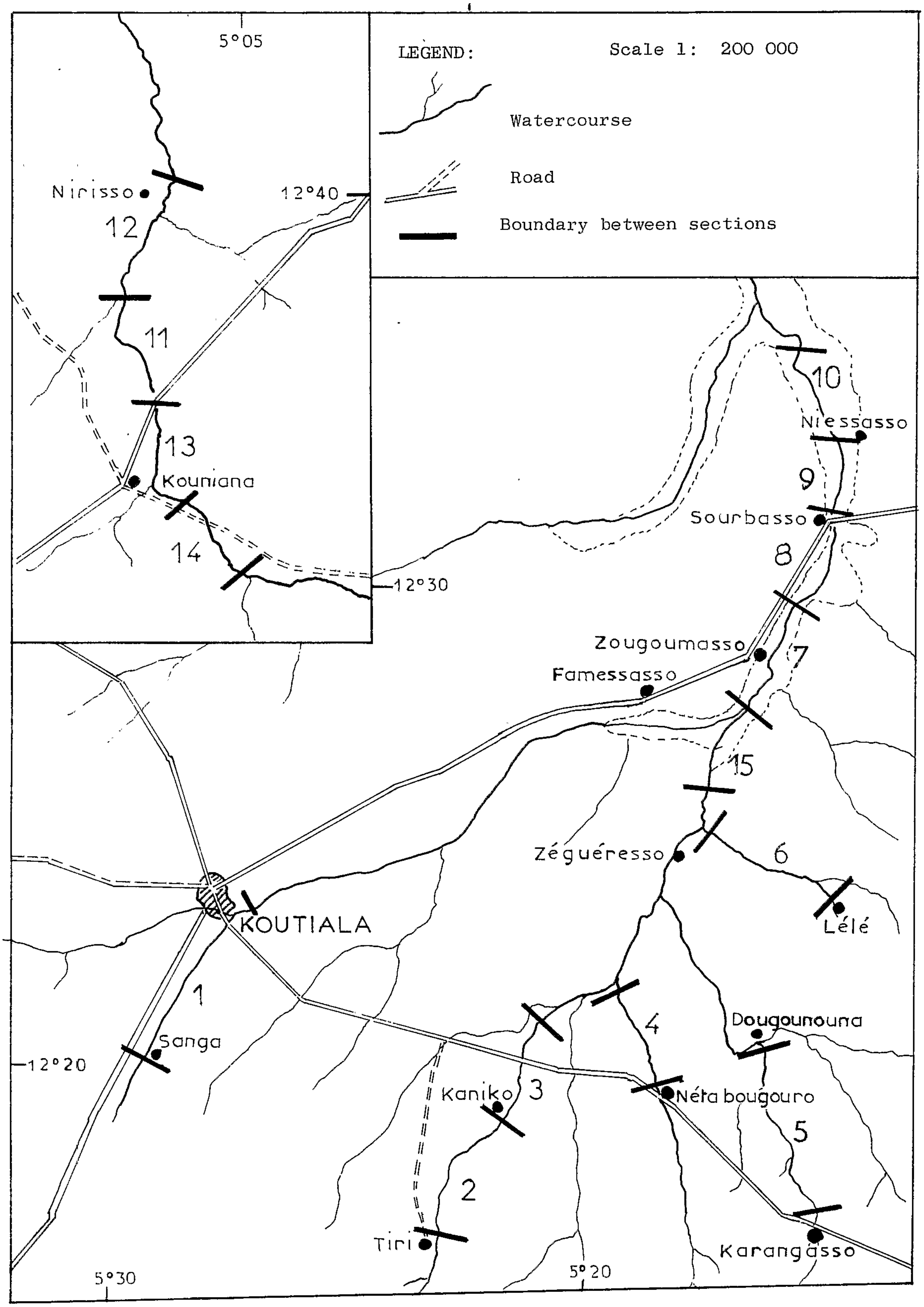
[b] Effect on tsetse flies in gallery forests with a very dense canopy.

[c] p = palpalis; t = tachinoides.

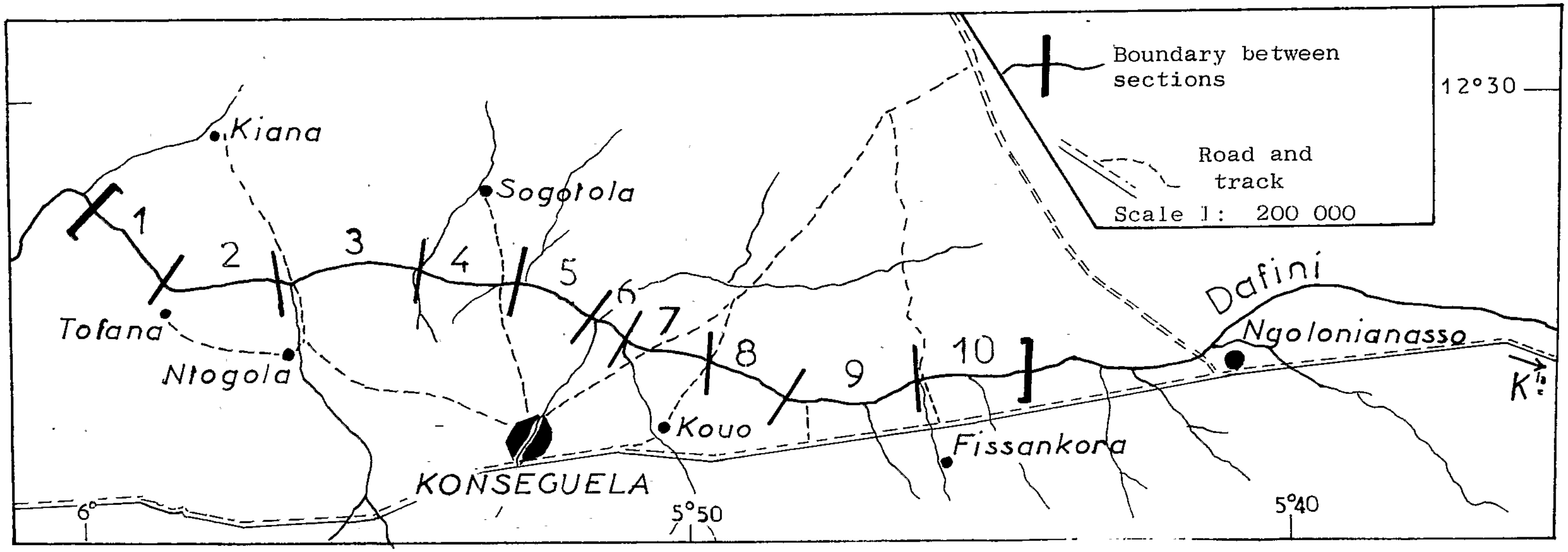
MAP 1. KOUTIALA FOCUS, MALI



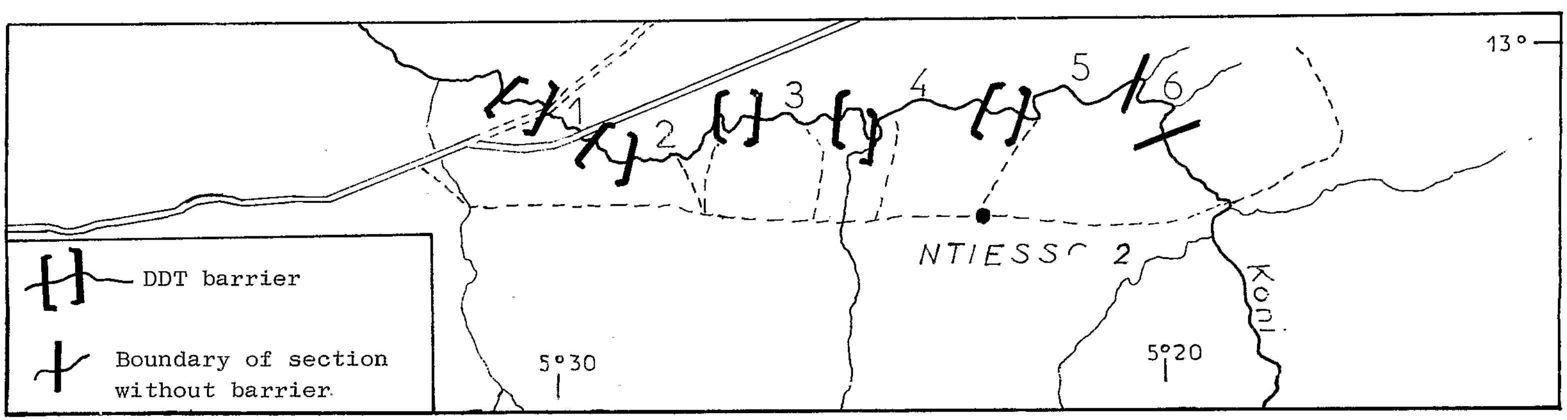
MAP 2. TEST AREAS I AND II, KOUTIALA



MAP 3. TEST AREA III, KONSEGUELA



MAP 4. TEST AREA IV, KONI



Scale 1: 200 000