① Dr. J.L. Houpeau ② – Service de Documentation
ORSTOM

Ⓝ

SCIENCE AND APPRORIATE TECHNOLOGY FOR VECTOR CONTROL

Jacques Hamon, Director, Division of Vector Biology and Control, World Health Organisation, Geneva, Switzerland

Introduction

Human and veterinary diseases with arthropod vectors, snail intermediate hosts or rodent reservoirs have been known since time immemorial. They account for a great deal of illness and death in tropical countries and remain surprisingly widespread even in temperate zones. The control of these diseases constitutes an important target for the many affected countries as well as for a number of regional and international organisations and agencies. Progress made during the last half century has resulted in considerable improvement of the prevention and control of vector-borne diseases through chemotherapy and immunotherapy while vector control often plays an important role in the implementation of modern control strategies.[1]

The extent of the problem of vector-borne diseases in Africa

Statistical information related to the prevalence and distribution of vector-borne diseases have not reached the same degree of accuracy in every country. Furthermore, each of the borne diseases does not receive the same attention in every part of its distribution range. The number of people at risk and the number of those actually infected is thus not known with accuracy and orders of magnitude have to be used instead.

Malaria, transmitted by anopheline mosquitos, remains the most widespread and socio-economically important of all vector-borne diseases due to the severity of its clinical attacks and its short transmission cycle. It affects about 100 million people in Africa and many more are at risk.[2] Schistosomiasis with snails as intermediate hosts, is probably as widespread and prevalent as malaria and the disease distribution and severity often increases as a result of the development of water resources as evidenced by the serious problems created by the Aswan Dam, the Volta and Kossou lakes and similar dam and irrigation schemes in many other African countries.[3] African trypanosomiasis, transmitted by tsetse flies, and specially in animal forms, constitutes the main obstacle to cattle and meat production over millions of square kilometres of the savannah zones of Africa, decreasing protein availability for people and indirectly interfering with food production by preventing the use of cattle as draught animals for ploughing the land.[4] Onchocerciasis, transmitted by tiny blackflies, is said to affect about 25 million people in Africa; its distribution is limited to certain river valleys, but the socio-economic importance of this disease is considerable as in the affected parts of the savannah zones it prevents the safe access to fertile lands and water while neighbouring plateau soils are overcropped, with a low productivity[5]. Lymphatic filariasis, transmitted by mosquitos is not well documented in Africa as its clinical effects are rarely dramatic there; it affects nevertheless millions of people and seems to spread with uncontrolled urbanisation and irrigation.[6] Yellow fever is probably the best known of African arthropod-borne viruses, but it represents just the tip of an iceberg;[7] many similar viruses, usually tick- or mosquito-borne, occur in Africa and almost all rural populations are at risk, with a high incidence of these diseases in the savannah zones.[8] Rodent-borne diseases are very many; plague is the most notorius, but many more people are suffering and sometimes dying from less known, but more widespread rodent-borne infections such as rickettsial diseases, leptospirosis and Lassa fever.[9]

The above list of vector-borne diseases is far from exhaustive and many more could be quoted such as sandfly-borne leishmaniasis and louse-borne typhus. Over and above vector control operations which are caried out for the prevention of vector-borne diseases, very large sums of money are also spent to suppress urban and peri-urban pests such as mosquitos, houseflies, bedbugs, cockroaches and fleas.[10] Furthermore, rodent control operations are carried out not so much to reduce the abundance of potential disease reservoirs as to protect crops and stored food.

Trends in vector ecology and control

Before the Second World War modern pesticides were either unknown or their biological properties not yet discovered. Vector control operations were thus mostly based on environmental management complemented by the use of the few inorganic and vegetal pesticides known at that time. Such an approach required a very thorough knowledge of the relevant aspects of vector ecology as well as of the epidemiology of the corresponding diseases. In spite of the limitation of the tools available the determination of the health services led to achieving outstanding results in priority areas of many countries, dramatically reducing the risk of malaria and yellow fever in large cities, harbours, airports and major agricultural development schemes and reducing the threat of sleeping sickness in large parts of the endemic zone.[11]

The discovery and massive use of modern organic synthetic pesticides which began about 30 to 35 years ago resulted in a complete revolution in the control of vector-borne diseases. DDT in particular was so cheap, so effective and had obviously such a broad safety margin for humans that it was felt at a time that it could constitute the supreme answer to most control problems related to arthropods.[12] Soon after the beginning of the DDT era new molluscicides and rodenticides induced also the hope that snail-borne and rodent-borne diseases would be prevented much more easily than in the past. In many instances simple vector control guidelines were developed resulting in the worldwide implementation of relatively rigid control strategies without much (and often without any) effort to adjust them to local conditions.[13] Studies on vector ecology were almost looked upon as a luxury while community involvement, as well as the need for public education and individual discipline were reduced to a bare minimum corresponding often to the mere passive acceptance by people of the minor inconveniences resulting from large-scale control operations planned by top managers at the national, and even international, level.

This new approach paid initially very high dividends. Plague and louse-borne typhus outbreaks could be controlled in a matter of weeks if not days. *Aedes aegypti*, the dreadful vector of urban yellow fever, disappeared from most treated cities and many villages. Onchocerciasis vectors were eradicated from Kenya and trypanosomiasis vectors from South Africa. Houseflies could be destroyed without bothering too much about refuse disposal and household cleanliness. Large-scale malaria control schemes were implemented in rural areas of tropical Africa and were rather successful in a number of areas. Unfortunately this situation did not last.

The first setbacks were due to the development of insecticide resistance by houseflies and mosquitos. The simple shift from DDT to BHC or dieldrin (or the reverse in areas where BHC or dieldrin were used first) did not always solve the problem and many vectors and pests became resistant to both groups of insecticides and subsequently the resistance phenomenon involved as well organophosphorous and carbamate insecticides, synthetic pyrethroids and even insect growth regulators. In many instances the resistance of vectors resulted from the application of chemically-related agricultural pesticides; thus it could not be slowed down, or even prevented, by a more judicious use of public health insecticides. A similar situation arose with rodents whose certain species became immune to some of the most promising new rodenticides. Although in most instances the chemical control of vectors continues to be possible by the appropriate selection of pesticide and application strategies there are nevertheless a few vector species which are almost immune to nearly all conventional pesticides when applied at their usual target dosages.[14]

The development of insecticide resistance resulted sometimes in the application of higher dosages or more frequent intervals of the chemical having induced the selection of resistant vectors. More often it induced the replacement of a relatively cheap insecticide having a large safety margin to people (as far as acute toxicity was concerned) by more costly chemicals, requiring often more frequent applications due to their shorter residual life and sometimes having a narrower safety margin for spraymen. Both alternatives increased the cost of vector control applications.[15]

The problem of environmental contamination and side-effects of pesticides on nontarget organisms was considered soon after the modern organic insecticides became available for large-scale control operations.[16] However, the magnitude of the problem was only fully discovered in the early 1960s as a consequence of massive applications of residual and/or acutely toxic agricultural pesticides over large areas of a number of developed countries.[17] Residual insecticides which persist many years in the environment can accumulate through food-chains, as shown in laboratory model ecosystems which are nowadays used to forecast the environmental risks associated with the use of newly developed pesticides.[18] Highly residual chemicals, but in special instances, are thus replaced progressively for outdoor applications by compounds having a much shorter residual life due to their chemical instability, or their biological degradability, or both. This trend usually suits well crop protection requirements, but does not meet the technical requirements for the control of malaria and trypanosomiasis vectors when a relatively long residual activity is usually needed.[19] In view of the relatively small size public and veterinary health pesticide market the industry focuses its attention on the development of agricultural pesticides whose characteristics rarely meet public health needs. The number of new pesticides produced per year that meet public health traditional requirements is dwindling dramatically. Vector control must therefore adjust to the characteristics of the chemicals available on the market, with major modifications of the control strategies and associated increased costs and problems.

The above mentioned technical and financial problems had immediate repercussions on the progress of the campaigns directed against vector-borne diseases and in particular malaria. Many on-going malaria control operations were jeopardized. A number of developing countries simply could not afford the cost of already planned operations against vector-borne diseases. Routinely carried out pest and vector control activities gave decreasing returns. These events, associated with the development of new lands, the intensification of irrigation, and rapid uncontrolled urbanisation resulted in the persistence, or even recrudescence, of many vector-borne diseases.[20] It followed a renewed interest in human and vector ecology, the more selective use of pesticides, and an increased attention given to the development of nonchemical control methods. It also became obvious that more attention should be given to the relationships between environment, disease epidemiology and vector bionomics, thus rediscovering the landscape epidemiology approach developed in the USSR many years earlier.[21]

The intensification of biological studies (and sometimes biochemical investigations as well) was required because the development of new control methods often required detailed information which was not needed for controlling the same vectors 25 years ago, or could not be obtained at that time due to the lack of appropriate technology. A few examples can illustrate the situation.

Science and appropriate technology for vector control

The control of malaria vectors is extensively based on the residual application of insecticides inside houses. In countries where the vectors are resistant to DDT and cyclodiene insecticides (dieldrin and BHC), malathion is often considered as the best alternative.[22] Pure malathion has a very broad safety margin for mammals and technical malathion has normally a large safety margin.[23] As a consequence malathion water dispersable powders were extensively used by many malaria control programmes without any problem other than refusals of treatment due to the unpleasant odour of this formulation. However, malathion spraying several years ago in Pakistan resulted in many acute intoxications and several deaths amongst the spray teams. On the spot investigations showed that routine safety precautions had been neglected, but toxicity determinations carried out on samples of the malathion wdps used indicated also an unusual toxicity of the formulation, reducing the safety margin to nothing in the case of certain samples. Inquiries showed that the technical malathion used for formulating these wdps has the right degree of purity and that wdp formulations had a normal malathion content and level of toxicity when despatched from the formulation plants. Worldwide surveys indicated that toxic samples could be found in a number of other countries using malathion for malaria control. A cooperative research programme carried out by biochemists and toxicologists in cooperation with malathion producers discovered that the wdp toxicity developed with time during shipping and storage under tropical conditions and was due to an unusual level of isomalathion. It was shown that not only isomalathion was by itself about 100-fold more toxic than pure malathion, but also that it inhibited the normal detoxification of malathion by mammals, enabling the production and accumulation of malaoxon in mammals.[24] Experimental ageing of technical malathion and formulated wdps under simulated tropical conditions indicated that certain so-called "inert" supports and some emulsifiers were favouring the decomposition of malathion into isomalathion and that the phenomenon could be forecast by proceeding to an "accelerated tropical storage test". Chemists developed a reliable method to quantify the occurrence of isomalathion in malathion wdp before and after such an accelerated tropical storage. New malathion wdp specifications were prepared accordingly to ensure that purchased malathion wdp would preserve their safety margin even after prolonged tropical storage. Guidelines were provided to carry out all the tests required to ensure the compliance of formulations with these new specifications.[25] Thus epidemiological investigations backed by chemists, biochemists and toxicologists solved this acute problem. The experience thus acquired will be used to further assess the stability of other organophosphoruous insecticides wdp formulations.

As just indicated malathion wdp has an unpleasant smell which usually increases with storage time while adequately prepared technical malathion has a more acceptable odour. During spraying operations the 50% malathion wdp is mixed with water to produce a 5% malathion suspension. Thus most of the shipping deals with 50% inert ingredient, and the spray teams carry up to 95% inert ingredient. It would thus be very advantageous to directly apply technical malathion which is a liquid at ambient temperature. Laboratory and field trials have shown that the direct application of technical malathion to wood and mud surfaces at the usual target dosage of $2g/m^2$ produces an acceptable residual effect. Laboratory prototypes of spraying equipment were produced for the direct application of technical malathion inside houses as a residual spray. Unfortunately the output and ease of handling of these prototypes did not comply with the requirements of malaria control operations and more engineering research is needed. Hopefully the cooperation of biologists, engineers and the industry will solve this problem one day, sharply decreasing altogether the problems related to the toxicity, evil smell and logistics of malathion residual application for malaria control.

The main African malaria vector *Anopheles gambiae* is actually a complex of six sibling species.[26] Certain crosses between siblings can produce an offspring almost exclusively composed of sterile males. Cage experiments indicated that such sterile hybrids constituted a promising tool for the genetic control of *An. gambiae s.l.* However, the only field trial carried out to date gave rather disappointing results, which were attributed to the use of an inadequate hybrid combination, as a hybrid between two species (*melas* and *arabiensis*) had been used to control a third species (*gambiae s. str.*).[27] The survival and dispersal of the sterile hybrids were adequate, but in nature these hybrids did not mate with wild females. We know now that the explanation might be more complex. Parallel studies carried out in west and east Africa have shown that intraspecific characteristics which can be linked with detailed chromosome images are often more important than interspecific differences found in areas of sympatry.[28] Thus at least in certain cases genetic control should be based on the use of sterile males having the same intraspecific characteristics as the local vector population under attack and ecological/behavioural genetics definitely have a great role to play in genetic control operations.

Trypanosomiasis

For about 25 years the control of trypanosomiasis vectors has generally been based on the sequential application of nonresidual insecticide sprays or single application of residual sprays, either from the ground or by aircraft.[29] These direct applications of pesticides to the environment have a noticeable effect on nontarget organisms while for obvious economic reasons it is preferable to limit the pesticide application to proven resting sites of the target species of *Glossina*.[30] In the past these *Glossina* resting places were determined by direct search for resting tsetse flies by daytime and were impossible to carry out by night. Even by day the yield was very low. The use of phosphorescent dusts, reflectory paints and radio-labelling has drastically changed the situation, enabling, to study with great accuracy, the distribution and relative importance of *Glossina* resting sites by day as well as by night. Recent investigations made in west Africa on riverine species, *Glossina palpalis gambiensis* and *G. tachinoides* have shown that in the savannah zone resting places were concentrated within a much smaller transveral section of the gallery forest than believed.[31] Very selective applications of residual and nonresidual insecticide sprays to these resting places produced the same impact on *Glossina* populations as much more extensive insecticide treatments, indicating that it was possible to achieve a great degree of control with a minimal contamination of the environment.[32]

Another important parameter of the chemical control of tsetse flies is constituted by the duration of the pupal stage and of the interval between emergence and the first larviposition by the same female. The residual effectiveness of single residual insecticide application should always exceed the maximum duration of the pupal life. The interval between the application of consecutive nonresidual sprays should always be shorter than *Glossina* age at its first larviposition. The development of micrometeorological recording equipment has enabled the determination with reasonable accuracy of environmental conditions of *Glossina* pupae and adults and their reproduction in the laboratory.[33] Simultaneously the development of modern marking methods has helped studies of *Glossina* population dynamics under field conditions.[34] It is now possible to adjust the insecticide applications to *Glossina* populations dynamics and to extrapolate the finding to neighbouring areas.

Due to their low reproduction rate *Glossina* constitute an attractive target for genetic control methods based on the massive release of chemo- or radio-sterilized males. Extensive laboratory studies have been carried out to compare a great variety of sterilisation procedures and develop satisfactory methods which ensure the production of rather competitive although sterile males.[35] Studies on population dynamics provided all required parameters for the production of mathematical population dynamics models and computer simulations were carried out to determine suitable strategies for achieving a maximum impact with a given production of sterilised males. As in the case of chemical control methods it is usually not possible to treat at once all the tsetse habitats of a given area. Thus treated areas must be protected by physical or chemical barriers against the repopulation of *Glossina* living in neighbouring untreated areas. The size and nature of the barriers should always be based on local studies, but accurate flight range data are scarce and are often replaced by guess estimates. During an on-going large scale field evaluation of the potential of genetic control against *G. palpalis gambiensis* all sterile flies released were marked. Simultaneous insecticide evaluations against tsetse flies carried out nearby were monitored by systematic trapping and proved conclusively that the flight range of *G.p. gambiensis* was considerably greater than anticipated (present maximum *circa* 18 km) and that flies could easily cross several kilometres of open savannah (Baldry, personal communication 1978).

Onchocerciasis

Until a few years ago the epidemiology of onchocerciasis in west Africa was well documented, but opinions of specialists in this subject differed. For the last 15 years it was clear that the bionomics of the single proven vector, *Simulium damnosum*, did not vary from one ecological zone to the neighbouring one in a homogeneous manner, and that the pathogenicity of the single known parasite *Onchocerca volvulus* was not the same everywhere. What was originally considered as population variability was progressively treated as a relatively simple complex of well individualised vector and parasite populations.[36] Cytotaxonomic studies then proved that in west Africa *S. damnosum* was a complex species with probably eight species and subspecies and simple isoenzyme studies suggested that, in the same area, two or three "populations" of *O. volvulus* might co-exist.[37] Extensive studies of the vector–parasite relationships carried out over a series of small areas representative of a zone of about 1 000 000 km² have shown a much more complex picture suggesting the occurrence of a great variety of *O. volvulus* populations of unknown taxonomic status.[38] Detailed isoenzymatic studies are planned on both the known vector species and the parasite strains to analyse further the phenomenon.

In the same general area a large-scale onchocerciasis control programme was planned during 1971–73 on the basis of the information available, provided by *S. damnosum s.l.* a pilot control scheme covering 60 000 km². Long range flights of *S. damnosum s.l.* were already known and it was then considered, after scrutinizing local findings, all based on indirect evidence, that the maximum effective flight range was of the order of 100 km to 150 km and probably less. The large-scale control programme is based on periodic larviciding of the breeding places and entomologically evaluated by a large network of adult catching stations.[39] It became obvious very soon that the flight range of *S. damnosum s.l.* was probably greater than anticipated. Special studies were carried out with the cytotaxonomic identification of the progeny of invading flies and showed conclusively that the reinvasion of the treated area was due to savannah-inhabiting species of unknown origin. A major research project was thus planned involving the comparison of the relative abundance of rare metals amongst adult vectors obtained from a large series of untreated and some treated breeding places and those adult vectors collected within the treated area. The spectrum of abundance of the rare metals was determined for each of these samples by X-ray energy-dispersive spectroscopy ("fingerprinting method"). It was thus established that during the early part of the rainy season the vectors were coming from breeding places situated as far as 200 km to 300 km southwest of the catching stations. Simultaneous meteorological studies suggested that these long range flights were correlated with the movement of the intertropical front and the direction of the prevailing wind and associated storm movements.[40] The treated area is being increased so as to include all breeding places of the savannah species of the *S. damnosum* complex, but it is anticipated that a modest reinfestation might persist due to breeding places situated 350 km away in a country not yet included in the control programme.

The above mentioned programme now covers about 800 000 km^2 and about 15 000 linear km of breeding sites. Most of the insecticide applications are made with light fixed-wing aircraft and medium helicopters using specially devised application equipment so that each focal insecticide application results in the formation of an insecticide barrier across the river which moves downstream with the water and kills the vector larvae on its way. This technique maximised the effectiveness of the very low insecticide doses applied and under optimal conditions one single application can be effective for 50 km downstream.[41] Special difficulties however occur, especially when the vector-breeding places are constituted by the spillways of lake-forming dams. Hydraulic engineers had to be called to study the water movements up the man-made lakes and advise on the most favourable site for insecticide application so that the treated water would reach the spillway before the insecticide was too diluted to have any effect.

Schistosomiasis

Schistosomiasis is a major man-made problem around many artificial lakes. The tremendous length of the lake shore requiring molluscide treatment to destroy the schistosomiasis intermediate hosts and prevent the transmission of the disease usually discourages public health specialists who do not even dare to consider the use of molluscicides. Detailed epidemiological studies carried out along the shore of the Volta Lake and extensively based on the abundance and distribution of infective snails have, however, shown that the transmission was very focal in space and time and that very spectacular results could be obtained by treating only a very small proportion of the lake shore at the appropriate seasons, so that the molluscicide treatments would not unduly affect nontarget freshwater organisms and in particular fish.[42] The study was made difficult by the simultaneous occurrence of animal schistosomes whose developmental stages within the snails are extremely similar to those of *S. haematobium* and *S. mansoni*. The development of appropriate identification techniques is definitely needed. A similar situation might occur under other environmental conditions making the prevention of schistosomiasis somewhat simpler than presently believed.

Arboviral diseases

The epidemiology of many important arboviruses is not yet well known, particularly dengue and yellow fever whose viruses are easy to isolate during epidemic outbreaks, but are rarely found during interepidemic periods.

In the case of dengue one of the problem was the low susceptibility of baby mice to the virus making the most usual virus isolation technique very insensitive. A great progress was made a few years ago when samples suspected to contain dengue virus were first intrathoracically injected into susceptible *Aedes aegypti*, providing for a large increase of the virus titre before injecting the second generation sample in baby mice.[43] A second more important step was made by directly identifying the dengue virus within the intrathoracically injected mosquito by immuno-fluorescent assays. A last improvement was made by replacing the small *Ae. aegypti* or *Ae. albopictus* by large nonbiting mosquito species, such as *Toxorhynchites*, which can now be mass-produced and constitute the standard laboratory animal replacing baby mice for dengue epidemilogical studies.

The improvements made for the detection of dengue virus initiated studies along these and other lines on the yellow fever virus. Laboratory investigations were made in west Africa to quantify the impact of the routine isolation procedures on the titre of yellow fever virus of the isolate. A new method was developed to minimise the decrease of titre resulting from the laboratory manipulations. It was furthermore observed that a number of common arboviruses were developing in the baby mice much faster than yellow fever. Thus large mosquito pools containing both yellow fever and one of the "fast" viruses would kill the baby mice in a few days, but only the latter would be isolated. Statistical studies were thus made to determine the ideal number of mosquitos by pool which would provide a reasonable chance of obtaining the yellow fever virus alone without making the process too cumbersome and costly for the isolation laboratory. The laboratory protocols were adjusted accordingly. These two successive modifications were quite rewarding as the laboratories using them have since isolated a large number of strains of yellow fever from wild mosquitos collected in areas which had been unsuccessfully monitored for many years before despite the serological evidence of yellow fever virus circulation amongst wild primates and humans. As the known transmission cycles could not satisfactorily explain the persistence of yellow fever virus in certain areas laboratory investigations were done to determine if Group B viruses could be transovarially transmitted as was shown to be the case with Koutango virus. This encouraged subsequent studies on Japanese B Encephalitis, dengue and yellow fever viruses. These investigations showed that transovarial transmission of arboviruses takes place with a great variety of vectors and arborviruses including, in particular, the viruses of dengue and Japanese B Encephalitis and more recently of yellow fever.[45] During the same period, in eastern Senegal, yellow fever virus was isolated not only from wild female mosquitos, but also from wild male mosquitos (Y. Robin, personal communication 1978).

Conclusions

Many other examples could be provided. The intelligent use of scientific discoveries and the development of an appropriate technology constitute some of the keys to the effective control of vectors and vector-borne diseases at a cost that endemic countries could afford. However, producing the tool is not enough. It must be applied after adjusting it to the local ecological, epidemiological and socio-economic conditions and we must remember that many useful, safe and reasonably cheap tools are not used, or not used properly.

Science and appropriate technology development depend upon research workers and suitably equipped laboratories and usually results from a multidisciplinary teamwork. However, most of the epidemiological and ecological work on which this development is based has to be done in the field. Without a large number of scientists and technicians working in the field, the prospect of making relevant contributions to the prevention and control of vector-borne diseases and, in particular, the control of vectors would be remote. And the improved tools, once produced, can only be effective if actually used in the field, in full cooperation with the people concerned at the individual and community levels.

To be worthwhile the development of science and technology for disease prevention and control must be based on field observation and aim at field application under the prevailing socio-economic conditions and taking into account human ecology and beliefs. The training and effective use of field staff at all levels together with proper information of the people forms the basis without which relevant development of science and technology cannot be fully exploited. And this is too often forgotten.

Notes

1. N.G. Gratz, and J. Hamon, "Ecology and vector control" *Interdisciplinary Science Reviews, World Health for Tommorrow, Its Science and Technology*, (Geneva: WHO, 1978).
2. WHO. "Information on the world malaria situation, January —December 1976." *Weekly Epidemilogy Record* 52: 325-339, 349-353, 359-362 and 366-370.
3. WHO. "Schistosomiasis control. Report of a WHO expert committee". *World Health Organisation Technical Report. Ser.* 515; Vol. 47.

? A. Coumbaras, "Travaux hydrauliques et problèmes de santé dans les pays en voie de développement", *Acta Tropica*, 34: 229-248.

4. WHO. "African trypanosomiasis. Report of a joint FAO/WHO expert committee". *World Health Organisation Technical Report. Ser.* 434: 84 pp. FAO. "Programme for the control of African animal trypanosomiasis". Mimeographed document AGA/TRYP/74/1E, (Rome: FAO, 1974).
5. WHO. Epidemiology of onchocerciasis. Report of a WHO expert committee. *World Health Organisation Technical Report. Ser.*, 597: 94 pp.
6. WHO. "WHO expert committee on filariasis—third report". *World Health Organisation Technical Report. Ser.*, 542: 54 pp.

? N.G. Gratz, "Mosquito-borne disease problems in the urbanisation of tropical countries". *Crit. Rev. in Environ. Control*, 3: 455-495.

7. WHO. "WHO expert committee on yellow fever—third report". *World Health Organisation Technical Report Series.* 479: 56 pp.
8. P. Bres, J.L. Camicas, M. Cornet, Y. Robin, and R. Taufflieb, "Considérations sur l'épidémiologie des arboviroses au Sénégal". *Bull. Soc. Pathol. Exot.*, 62: 253-259.

? D. Metselaar, B.E. Henderson, G.B. Kirya, P.M. Tukei, and A. de Geus, "Isolations of arbovirus in Kenya, 1966-1971". *Trans. R. Soc. Trop. Med. Hyg.* 68: 114-123.

? B.M., McIntosh, "Mosquitos as vectors of viruses in Southern Africa". *South African Department of Agricultural Service, Entomology Memoir no.* 43, 19 pp. (1975).

9. WHO. "Ecology and control of rodents of public health importance", Report of a WHO scientific group. *World Health Organisation Technical Report Series*, Vol. 553, 42 pp. (1974).

? WHO. "International symposium on arenaviral infections of public health importance", 14-16 July 1975, Atlanta, USA. *Bulletin of World Health Organisation.*, 52: 381-765.

10. J. Graham, and N.G. Gratz, "Urban vector control services in the developing countries", *Pest Abstracts and News Summaries*, 21: 365-384.
11. R.C., Muirhead-Thomson, *Mosquito Behaviour in Relation to Malaria Transmission and Control in the Tropics.* (London: Edward Arnold and Co., 1951) 219 pp.
12. WHO. "Expert committee on insecticides: Report on the first session." *World Health Organisation Technical Report Series*, Vol. 4, 46 pp.
13. WHO. "Expert committee on malaria: Sixth report." *World Health Organisation Technical Report Series.*, vol. 123, 84 pp.
    WHO. "Insecticide resistance and vector control: Eighth report of the expert committee on insecticides", *World Health Organisation Technical Report Series.*, vol. 153, 67 pp.
    United States Department of Health, Education and Welfare/CDC. *Handbook of General Information on Aedes aegypti Eradication.* no. 1 to 6, (1967) 168 pp.
14. WHO. "Resistance of vectors and reservoirs of diseases to pesticides: Twenty-second report of the WHO expert committee on insecticides", *World Health Organisation Technical Report Series.*, Vol. 585, 88 pp.
15. WHO. "Ecology and control of vectors in public health: Twenty-first report of the WHO expert committee on insecticides," *World Health Organisation Technical Report Series.*, Vol. 561, 35 pp. (1975).
    A.D. Hess, and G.G., Kenner, "Effect of airplane-distributed DDT thermal aerosols on fish and fish food organisms". *Journal of Wildlife Management.*, 11: 1-10.
    A.B. Erickson, "Effects of DDT mosquito larviciding on wildlife. II Effects of routine airplane lavriciding on bird and mammal populations." *US. Publication of Health Reports.* 62: 1254-1262.
    C.H. Hoffman H.K. Townes, H.H. Swift, and R.I. Sailer "Field studies on the effects of airplane applications of DDT on forest invertebrates", *Ecol. Monogr.* 19: 1-46.
17. R. Carson, *Silent Spring*, edited by Plon, (Paris: 1963) 283 pp.
18. I.P. Kapoor, R.L. Metcalf, R.F. Nystrom, and G.K. Sangha, "Comparative metabolism of methoxychlor, methiochlor, and DDT in mouse, insects and in a model ecosystem". *J. Agri. Food Chem.*, 18: 1145-1152.
19. WHO. "The place of DDT in vector control." *WHO Chronicle*, 25: 201-205.
20. N.G. Gratz, "The persistence and recrudescence of some arthropod- and vector-borne diseases. *Public Health Reviews*, 3: 117-148.
21. Y.N. Pavlovsky, *Human Diseases with Natural Voci.* (Moscow: Foreign Languages Publishing House, 1960) 346 pp.
22. N.G. Gratz, "The importance of chemicals in the control of tropical diseases." *Chemie der Pfanzenschutz-und Schädlingsbekämpfungsmittel*, 3: 85-181.
23. J.A. Najera, G.R. Shidrawi, F.D. Gibson, and J.S. Stafford, "A large-scale field trial of malathion as an insecticide for anti-malarial work in southern Uganda". *Bull. W. H.O.*, 36: 913-935.
24. G. Pellegrini, and R. Santi, "Potentiation of toxicity of organophosphorus compounds containing carboxylic ester functions toward warm-blooded animals by some organophosphorus impurities." *J. Agri. Food Chem.* 20: 944-950.
25. WHO. "Chemistry and specifications of pesticides: Second report of the WHO expert committee on vector biology and control." *World Health Organisation Technical Report Series.* Vol. 620: (1978) 36 pp.
26. G. Davidson, "The problem of the *Anopheles gambiae* complex (Diptera)" *Proceedings of the Twelfth International Congregation of Entomologists* (London: 1965).
    G. Davidson, and R.H. Hunt, "The crossing and chromosome characteristics of a new, sixth species in the *Anopheles gambiae* complex." *Parassitologia,* 15: 121-128.
27. G. Davidson, J.A. Odetoyinbo, B. Colussa, and J. Coz "A field attempt to assess the mating competitiveness of strile males produced by crossing two member species of the *Anopheles gambiae* complex." *Bull. W. H. O.*, 42: 55-67.
28. G.B. White, "*Anopheles gambiae* complex and disease transmission in Africa". *Trans. R. Soc. Trop. Med. Hyg.*, 68: 278-301.
    M. Coluzzi, A. Sabatini, V. Petrarca, and M.A. di Decot "Behavioural divergences between mosquitos with different, inversion karyotypes in polymorphic populations of the *Anopheles gambiae* complex. *Nature (London)*, 266: 832.
29. G.F. Burnett, "Control by insecticides", in *The African Trypanosomiasis,* edited by A.W. Mulligan (London: G. Allen and Unwin Ltd., 1971) pp. 464-520.
    U. Spielberger, B.K. Na'Isa, and Abdurrahim. "Tsetse (Diptera: Glossinidae) eradication by aerial (helicopter) spraying of persistent insecticides in Nigeria." *Bull. Entomal. Res.* 67: 589-598.
30. J.H. Koeman, and J.H. Pennings, "An orientational survey on the side effects and environmental distribution of insecticides used in tsetse-control in Africa." *Bull. Environ. Contam. Toxicol.* 5: 164-170.
    J.H. Koeman, H.D. Rijksen, M. Smies, B.K. Na'Isa, and K.J.R. Maclennan, "Faunal changes in a swamp habitat in Nigeria sprayed with insecticide to exterminate *Glossina. Neth. J. Zool.*, 21: 443-463.
    J.H. Koeman, W.M.J. Den Boer, A.F. Feith, H.H., de Iongh, P.C. Spliethoff, B.K. Na'Isa, and U. Spielberger, "Three years' observation on side effects of helicopter applications of insecticides used to exterminate *Glossina* species in Nigeria." *Environ. Pollut.* 15: 31-59.
31. A. Challier, "Ecologie de *Glossina palpalis gambiensis* Vanderplank, 1949 (Diptera-Muscidae) en Savane d'Afrique Occidentale." *Mem. ORSTOM*, vol. 64.
    J.F. Bois, A. Challier, C. Laveissiere, and V. Ouedraogo, "Recherche des lieux de repos diurnes des glossines (*Glossina palpalis gambiensis* Vanderplank, 1949: Diptera, Glossinidae) par détection de specimens marqués au 59 Fe." *Cah. ORSTOM, sér. Entomol Med. Parasitol.* 15: 3-13.
    C. Laveissiere, "Ecologie de *Glossina tachinoides* Westwood 1850, en savane humide d'Afrique de l'Ouest. II. Lieux de repos nocturnes." *Cah. ORSTOM, ser. Entomol. Med. Parasitol.* vol. 16.
32. A. Challier, C. Laveissiere, S. Sales, and J.P. Gouteux, "Progrès récents en matière de lutte contre les glossines par application d'insecticides. OCCGE-Centre Muraz mimeographed report," Bobo-Dioulasso, 05/ENT. 78, 5 pp. (1978)
    D.H. Molyneux, D.A.T. Baldry, P. de Raadt, J.P. Parker, C.W. Lee, and J. Hamon, "Helicopter application of insecticides for the control of riverine *Glossina* vectors of African human trypanosomiasis in the moist savannah zones." *Bull. W. H. O.*, (1978).

33. J.M.B. Harley, "The influence of temperature on reproduction and development in four species of *Glossina* (Diptera: Muscidae)." *Proc. R. Entomol Soc. Lond.* (*A*), 43: 170-177.

R.J. Phelps, and P.M. Burrows, "Puparial duration in *Glossina morsitans orientalis* under conditions of constant temperature." *Entomol Exp. Appl.*, 12: 33-43.

R.J. Phelps, and P.M. Burrows, "Prediction of the pupal duration of *Glossina morsitans orientalis* Vanderplank under field conditions." *J. Appl. Ecol.* 6: 323-337.

34. A. Challier, Ecologie de *Glossina palpalis gambiensis* Vanderplank, 1949." *Rev. Elev. Med. Vét. Pays Trop.*, 29: 131-140.

C. Laveissiere, "Ecologie de *Glossina tachinoides* Westwood, 1850 en savane humide d'Afrique de l'Ouest. Etat d'avancement des travaux. OCCGE-Centre Muraz mimeographed document." Bobo Dioulasso, 03/ENT. 77, 8 pp. (1977).

35. C.F. Curtis, and P.A. Langley, "Use of nitrogen and chilling in the production of radiation-induced sterility in the tsetse fly *Glossina morsitans*. *Entomol. Exp.. Appl.* 15: 360-376.

P.A. Langley, C.F. Curtis, and J. Brady, "The viability, fertility and behaviour of tsetse flies (*Glossina morsitans*) sterilized by irradiation under various conditions." *Entomol. Exp. Appl.* 17: 97-111.

Y. Taze, D. Cuisance, H. Politzar, M. Clair, and E. Sellin, "Essais de détermination de la dose optimale d'irradiation des mâles de *Glossina palpalis gambiensis* (Vanderplank, 1949) en vue de la lutte biologique par lâchers de mâles stériles dans la région de Bobo Dioulasso (Haute Volta)". *Rev. Elev. Méd. Vét. Pays. Trop.* 30: 269-279.

36. B.O.L. Duke. D.J. Lewis, and P.J. Moore, "*Onchocerca-Simulium* complexes. 1. Transmission of forest and Sudan-savanna strains of *Onchocerca volvulus*, from Cameroon, by *Simulium damnosum* from various west African bioclimatic zones." *Ann. Trop. Med. Parasitol.*, 60: 318-336.

37. C.G. Vajime, and R.W. Dunbar, "Chromosomal identification of eight species of the subgenus *Edwardsellum* near and including *Simulium* (*Edwardsellum*) *damnosum* Theobald (Diptera: Simuliidae)." *Tropenmed. Parasitol.* 26: 111-138.

38. D. Quillevere, Y. Sechan, and B. Pendriez, Recherches cytotaxonomiques sur le complexe *Simulium damnosum*. OCCGE—Institut de Recherches sur l'Onchocercose, mimeographed document, Bouak, 1/*Oncho/Rap/78*, 9 pp. (1978).

39. UNDP, FAO, IBRD, and WHO. "Onchocerciasis control in the Volta River Basin Area. Report of the preparatory assistance mission to the governments of Dahomey, Ghana, Ivory Coast, Mali, Niger, Togo and Upper Volta." WHO mimeographed document, Geneva, OCP/78-1, 86+1250 pp. (1973).

40. J.I. Magor, L.J. Rosenberg, and D.E. Pedgley, "Windborne movement of *Simulium damnosum*. Final report of the WHO-COPR studies in 1975." COPR mimeographed document, London, CORP/39/3/3, 12 pp. (1975).

R. Le Berre, R. Garms, J.G. Davies, J.F. Walsh, and B. Philippon, "Déplacements de *Simulium damnosum* et stratégie de la lutte contre l'onchocercose." OCP mimeographed document, Ouagadougou, 29 pp. (1977).

41. J.D. Parker, "The use of aircraft in the WHO onchocerciasis control programme. *Proceedings of the Fifth Annual Agricultural Aviation Congress*, Warwick, UK; 1975 pp. 127-136).

42. R.K. Klumpp, and K.Y. Chu, "Ecological studies of *Bulinus rohlfsi* the intermediate host of *Schistosoma haematobium* in the Volta Lake." *Bull. W. H.O.* 55: 715-730.

K.Y. Chu, "Trials of ecological and chemical measures for the control of *Schistosoma haematobium* transmission in a Volta Lake village." *Bull. W.H.O.*, 56: 313-322.

43. L. Rosen, and Gubler, D. "The use of mosquitos to detect and propagate dengue viruses". *Am. J. Trop. Med. Hyg.* 23: 1153-1160.

44. J. Hamon, G. Pichon, and M. Cornet, "La transmission du virus amaril en Afrique occidentale. Ecologie, répartition, fréquence et contrôle des vecteurs, et observations concernant l'écologie de la fièvre jaune." *Cah. ORSTOM, Ser. Entomol. Med. Parasitol.* 9: 3-60.

45 J. Coz, M. Valade, M. Cornet, and Y. Robin, "Transmission transovarienne d'un *Flavivirus* le virus Koutango chez *Aedes aegypti*." *C.R. Acad. Sci. Sér. D.* 283: 109-110.

45. M. Germain, "*Activités de recherche de l'ORSTOM dans le domaine des arboviroses. Rapport pour l'année* 1977. ORSTOM mimeographed document, 14 pp. (1978).

47 L. Rosen, R.B. Tesh, J.C. Lieu, and J.H. Cross, "Transovarial transmission of Japanese encephalitis virus by mosquitos." *Science*. 199: 909-911.

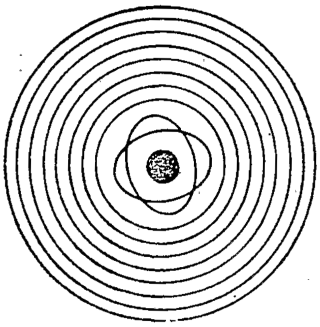
POST Promotion of Science and Technology
Vol. VI nº1 Jan-Apr. 1981

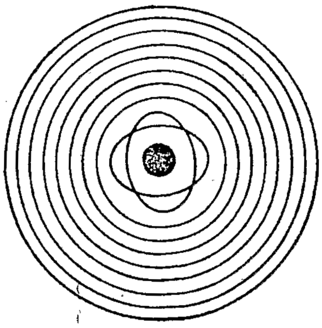
What is POST

A magazine for Promotion of Science and Technology, POST (KENYA) aims at:

Helping in the inculcation of scientific attitudes among young people; Laying special emphasis on those least understood areas of science and technology and to initiate active programmes for their understanding. Helping disseminate as widely as possible those aspects of science and technology which have immediate bearing on people's welfare and health.

A magazine of the Kenya National Academy





POST Committee

Chairman: Mr. E.M. Mugiri, Kenya Institute of Education, Nairobi
Members: Mr. M. Odindo, ICIPE, Mombasa
Mr. S.N. Muturi, National Council for Science and Technology
Mrs. Ongoma, Kenya National Commission for UNESCO
Mr. H. Muthui, Inspectorate, Ministry of Higher Education
Dr. P.N. Kariuki Ministry of Energy
Professor J.K.G. Mati, University of Nairobi
Mr. M.B. Atkinson, British Council
Mr. F. Wakhu, Kenya Science Teachers College
Mr. P. ArapKoech, Kenya National Academy
Editor: Mr. K. A. Buigutt, Kenya National Academy

POST address

POST (Kenya)
P.O. Box 47288, Nairobi.