Chapter 3

Strategies for the Future

CONTENTS

Figure

Tables

Chapter 3

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OTA's analysis found that the 1986-89 locust and grasshopper control campaigns in Africa were based on questionable premises, with partially effective to ineffective implementation. Yet, some things worked well and U.S. efforts contributed to these successes.

WHAT USAID DID WELL

Finding: USAID made commendable attempts: 1) to coordinate its efforts with other U.S. agencies, foreign donors, and African officials; 2) to ***provide training for Africans and U.S. personnel; and 3) to highlight issues of sound insecticide choice, storage, application, and disposal. Overall, the international control campaign lacked these characteristics, however. USAID did prevail successfully against the use of dieldrin.***

Promoting Internal and External Coordination

The U.S. Agency for International Development (USAID) coordinated its work successfully within USAID and with other U.S. Government agencies involved in the campaigns despite formidable institutional constraints. The Desert Locust Task Force, established within USAID's Office of Foreign Disaster Assistance (OFDA), was one of the most effective means of coordination within the U.S. Government. From July 1988 through June 1989, the Task Force held weekly meetings to share information, assign responsibility for implementing activities, and coordinate efforts.

Also, OFDA brought together people representing a variety of U.S. Departments and other organizations to review results from the previous year's efforts, to identify lessons learned, and to plan more effective future control. OFDA sponsored two workshops for Task Force members from Washington, DC, USAID mission staff from Africa, and outside experts. First, the U.S. Forest Service's Disaster Assistance Support Program managed a 3-day workshop in January 1988 in Harpers Ferry, West Virginia, for 69 officials, mostly from the U.S. Government, to evaluate the 1986 and 1987 campaigns and provide direction for a staff guidebook on locust and grasshopper programs. Then, 32 participants took part in a 4-day, February 1989, workshop in Dakar, Senegal; they reviewed each country's 1988 campaign and were introduced to the finalized USAID guidebook.

This 1989 ***Locust/Grasshopper Management Operations Guidebook is*** well-prepared and thorough, for the most part. It provides a comprehensive overview of USAID's policies regarding locust and grasshopper control, includes useful background information on the insects' biology and behavior, sets forth the rationale and procedures for mounting a control operation, provides details on conducting insect surveys and selecting appropriate control techniques, and includes helpful supplementary information (e.g., pesticide-use guidelines, procurement procedures).

OTA expects that the Guidebook will contribute to a more expert, consistent, and coordinated U.S. response to grasshopper and locust problems in the future. If used effectively, the Guidebook could achieve its purpose: "... to assist Missions to assess, prepare for, and organize locust/grasshopper control programs on an emergency and non-emergency basis" (118, p. I-2).

The Guidebook is the most up-to-date operational source for selecting insecticides for U.S.-funded work and lists a number of selection considerations. However, the database on insecticides constantly changes. For example, the U.N. World Health Organization's Hazard Classification, revised every 2 years, now has different ratings for approximately one-fourth of the pesticides included in the 1989 Guidebook. USAID is preparing Country Supplemental Environmental Assessments in 1990, with technical assistance from the U.S. Environmental Protection Agency (EPA), to apply the continent-wide Programmatic Environmental Assessment to the individual countries planning to use insecticides against grasshoppers and locusts. This process, which aims to make more site-specific plans, could allow updated information on different chemical products to be incorporated in the supplemental assessments simultaneously. However, these supplemental assessments also will need to be revised periodically to remain current.

USAID actively promoted coordination among other donors and African governments, and agreement exists that coordination and collaboration among countries increased as the recent campaigns progressed. For example, representatives of USAID or the U.S. Department of Agriculture's (USDA) Animal and Plant Health Inspection Service attended perhaps a dozen meetings sponsored by the U.N. Food and Agriculture Organization (FAO) to share information and plan future strategy. USAID funded FAO's Emergency Centre for Locust Operations (ECLO), the worldwide coordination site for locust and grasshopper control operations, and USAID staff provided ECLO with data on insect populations and U.S. control efforts. The Bureau for Science and Technology participated in the World Bank's Special Program for African Agricultural Research on locusts.

USAID required that recipient countries have an operational Country Coordinating Committee, composed of representatives from relevant government and donor organizations, before U.S. emergency funds were released. USAID mission staff participated in these committees and also maintained direct contact with the national crop protection services and other African agencies involved in control.

Providing Training

USAID provided training for its own personnel and African officials through workshops and the provision of technical assistance. Additionally, the United States funded training programs for Africans, conducted by FAO and regional organizations. For example, FAO trained Sahelian national crop protection personnel in locust surveillance and another group, Application of Agrometeorology and Hydrology for the Sahel (AGRHYMET) conducted an annual short course for African officials on using "greenness maps." This training and technical assistance, together with the provision of equipment and supplies, undoubtable strengthened the capacity of national institutions to mount future locust/grasshopper survey and control programs and to deal with other agricultural problems.

USAID conducted 10 training workshops from 1987 through late 1989 with a total of approximately 150 participants. One early workshop on how to plan and manage aerial spraying operations was attended by Africans from Senegal, Gambia, Niger, and Sudan. From April through June 1989, three regional workshops were held on: 1) aerial and ground ultra-low volume (ULV) application, 2) training extension workers to use new teaching materials on pesticide use, and 3) human health impacts of pesticide application (121). A February 1990 conference on pesticide disposal, held in Niamey, Niger, attracted 58 participants from 15 West African countries and international organizations such as Earthwatch and Greenpeace. Action plans were drawn up for each country. Other workshops planned for 1990 are on identification of immature Sahelian grasshoppers and crop loss assessment.

USAID developed some useful materials for its training efforts. For example, the ***Pesticide Users Guide,*** **prepared in four languages for African extension agents, details how to conduct pest surveys, plan insecticide applications, and apply, transport, store, and dispose of pesticides. In addition, USAID funded publication of a field manual for identifying immature grasshoppers (51).**

USAID attempted to increase its own technical capacity by borrowing experts from other U.S. agencies and hiring consultants from universities and private firms. An effort was made to pair senior and junior entomologists on technical assistance teams to increase the pool of expertise available in the future. USAID encouraged participation of African officials on the several dozen U.S. technical assistance teams sent to Africa. This practice imparts on-the-job training—for those U.S. scientists unfamiliar with African conditions as well as for African experts unfamiliar with some recent pest management technologies.

Advocating Sound Insecticide Use

USAID advocated safe and sound insecticide use throughout the 1986-89 campaign and enforced its relevant environmental policies. Its greatest success was persuading other donors and African governments not to use dieldrin, even though many African countries had existing dieldrin stocks and FAO and France urged its use. With encouragement from USAID, FAO is taking inventory of existing stocks of dieldrin, beginning a study of potential environmental risks of dieldrin use in areas where the Desert Locust is present, and intends to develop a plan for use or destruction of dieldrin based on these findings (104). USAID, too, has compiled some information on stocks of dieldrin (99) and sent EPA representatives to advise African officials on storage and disposal of surpluses.

USAID's efforts also increased awareness in Africa of the potential dangers of the persistent organochlorines and helped reduce the use of benzene hexachloride (BHC) and lindane. USAID encouraged the use of less toxic chemicals and, to a limited extent, tested new insecticides for locust and grasshopper control under African conditions.

USAID promoted increased efficiency in some spray operations, for example, by prepositioning insecticides in Africa to reduce high air freight costs. By supporting application of satellite remote sensing to locust surveillance and funding research on alternative control methods, USAID began to lay the groundwork for reduced reliance on spraying as the only available response to locust and grasshopper upsurges.

USAID included safety concerns in its technical assistance and training programs, e.g., by providing protective clothing for spray operators. USAID claims it was the first to introduce cholinesterase testing into locust control programs in Africa. Moroccan applicators were tested before, during, and after spraying in 1988 and 1989 to determine if the enzyme cholinesterase had been suppressed by pesticides (51).

Also, USAID exhibited concern about the environmental effects of control programs, in particular by preparing environmental assessments for Morocco, Tunisia, and all of Africa and Asia affected. Since mid-1989, USAID has been designing ways to implement the 38 recommendations of the Programmatic Environmental Assessment (app. E). Technical assistance teams are assisting African nations on the safe disposal of empty containers and surplus insecticides now that widespread spraying is unnecessary.

USAID is seen as among the strictest donors regarding safe pesticide disposal and is planning to take stronger measures in the future. Its operational Guidebook contains directions for storing, packaging, labeling and disposing of pesticides and empty containers. An annex contains a copy of FAO's 1985 *Guidelines for the Disposal of Waste Pesticide and Pesticide Containers on the Farm* that details physical, chemical, and biological disposal methods. Some other donors have similar interests and a recent workshop on disposal of obsolete pesticides and empty containers in Niamey demonstrated African concern as well.

In short, USAID succeeded in almost eliminating the use of the most hazardous chemical, dieldrin, and identified some lessons learned for improved strategies and tactics for future programs. The overall locust campaign, however, demonstrated the need for more coordinated action, far more training, better understanding of locust and grasshopper dynamics and effects on crop yields, and improved control methods. For example, the new *Locust/Grasshopper Management Operations Guidebook* fails to discuss the debate over the relative roles of control in insect declines; USAID's 1988 training sessions were sidelined when its resources were redirected to spraying activities; USAID's training and technical assistance reached only a few Africans; and, in some cases, USAID did not convince Africans of less toxic chemicals' effectiveness.

Admittedly, USAID is only one important actor, having provided about one-fifth of donor funding for recent control campaigns. Thus, USAID has limited responsibility for the failures of recent campaigns, as well as their successes.

HOW TO DO BETTER NEXT TIME

Finding: Donors and African governments cannot afford to fund expensive control campaigns without addressing fundamental questions regarding goals and implementation. Now is the time to find methods that contribute to long-term development, redouble preventive efforts, and decide what actions will be most effective during the next upsurge.

Doing better in the future, during recessions and upsurges of these insects, revolves a reexamination of fundamental questions regarding who should do what, and when, where, how, and why it should be done. These are broad policy questions encompassing all aspects of control programs. For example, which insects should be included in programs (individual pests or groups of similar pests), where control should be mounted ("strategic" areas, breeding sites, or anywhere), when control should be undertaken (when a plague threatens, when swarms threaten crops, or whenever insects become gregarious), why control is needed (e.g., to stop plagues, save crops, or prevent famine) and how control is best done (e.g., aerial or ground spraying, four- or single-engine planes or helicopters).

Control organizations, host governments, and donors have the responsibility to answer these questions. Here, OTA identifies some of the elements of the discussion and notes that resolution of these issues should be attempted now that upsurges have subsided for a time. The roles of various groups–who should do what–also need to be clarified. This question is addressed in chapter 4.

Further discussion and clarification are especially needed regarding the goals of the control programs and indicators to measure their results within specified times. Do the programs aim to prevent plagues, stop plagues, protect crops, or end famine? Different goals imply different strategies, action plans, and evaluation criteria.

The Feasibility and Price of Prevention

The FAO and USAID officials responsible for grasshopper and locust control programs maintain that knowledge is available that, if properly applied, could prevent future plagues of locusts and grasshoppers (12, 95, 121). Plague prevention has consisted, since the 1960s, of making surveys in seasonal breeding areas and controlling any already-gregarious resects or populations becoming gregarious (70). Certainly, the feasibility of prevention steadily increases as additional countries agree to participate in such an approach during recessions; as breeding areas are more clearly identified; as improved methods are developed for forecasting the rise and movement of insect populations, weather systems, and plant cover; and as more effective, carefully aimed control operations are mounted. However, some factors that contribute to plagues are unresolvable by existing technologies or largely beyond the control of donors. These constraints include the un re-dictability of weather and disputes within an X between countries. Also, wide-scale implementation of what is known, e.g., about effective spraying, is often exceedingly difficult under actual conditions. Thus, OTA questions whether donors and affected countries can prevent upsurges and plagues, although that goal is laudable and deserves to be foremost.

FAO finds that:

> . . . although there is a rational strategy for the prevention of desert locust plagues, and tactics and techniques have been evolved to implement that strategy, circumstances can still combine to lead to the threat of the development of a new major plague. Furthermore such combinations of circumstances, and **in particular sequences of widespread heavy rain, cannot yet be forecast**

and concluded that:

> . . . local outbreaks capable of leading to major upsurges are likely to be a recurrent but intermittent feature of Desert Locust population dynamics. . . (81, cited in 13).

The preventive strategy FAO and USAID advocate thus requires a certain amount of continuing monitoring and control. Usually, that has not been done between upsurges. FAO and USAID officials are requesting funds for applying this strategy now with the explicit objective of preventing future outbreaks from developing into plagues.

They, like others, assume that plague prevention costs less than plague control. This seems correct intuitively but it has yet to be proven. Donor costs of the 1986-89 control campaign, principally against the Desert Locust and Senegalese Grasshopper, were $275 million. In 1988, representatives from several governments met in Fez, Morocco and approved plans for a multinational ongoing survey and control operation to monitor the Desert Locust in its remote Sahelian breeding areas. This International Desert Locust Task Force, with 5 main units and 13 sub-units in strategic areas, carried a $77.4 million price tag. As the plague subsided, the estimate for Phase I in 1989 was revised down to $3.5 million (106). Thus, the cost of maintaining these mobile units is far less than the cost of the recent control campaign in an equivalent period. However, the costs of plague prevention v. control should be calculated over a longer time period from a broader base, e.g., perhaps including costs for monitoring and controlling other grasshoppers and locusts and the related expenses of the national crop protection services.

FAO proposed recently a 5-year regional preventive Desert Locust control program for the 8 countries of Maghreb and the Sahel. FAO asserts that control measures in a generalized invasion would cost, in 1 year, what preventive control activities would cost in 15 to 20 years. FAO anticipates that this preventive program would cost $6 million to $8 million per year (108,109) and result in less insecticide use over a smaller area, e.g., 50,000 to 100,000 ha per year sprayed compared to the 15 million ha treated in 1987/88 (108). The availability of funding for such a broad international program has not yet been determined. Even if the preventive approaches advocated by FAO, USAID, and other officials were fully funded, it seems likely that emergency efforts would still be needed when the insects escape strategic control efforts.

Shifting to a preventive approach first requires a reorientation of thinking by African and donor policymakers, followed by corresponding changes in programs and financing. Crises mobilize attention and resources: emergency locust and grasshopper programs garner far more policy interest than long-term efforts, such as integrated pest management (1PM). Africans favored faster-act-ing insecticides. Emergency spraying operations fit within what some find is a "cowboy" mentality among U.S. officials: a tendency to promote large interventions and quick solutions. For example, U.S. officials emphasized use of four-engine planes while FAO and other donors preferred smaller planes. Thus, preventive approaches present psychological as well as technical challenges and their implementation would require attitudinal shifts and technical training within USAID, among other donors, within African countries, and in Congress.

Integrating Emergency Control Programs Into Long-Term Development

Donor groups often classify their activities as relief or development focussed. Generally, relief activities are short-term and address symptoms or consequences of deeply rooted problems. They can include actual control efforts and other activities to help people recover from losses, e.g., providing food to areas where locusts have destroyed crops, or providing seeds for replanting. Some also describe activities that help recipients recover from control programs (e.g., destruction of pesticide containers, disposal of surplus stocks, testing operators for over-exposure to insecticides) as "relief and rehabilitation." Development activities, in contrast, tend to deal with the underlying causes of problems and are necessarily longer term. For example, entomological research to develop safer or more effective control methods and efforts to prevent locust or grasshopper upsurges would be development activities.

Individuals and organizations generally concentrate their efforts on one approach or the other because of the difficulties of combining the two. Some relief efforts incorporate development objectives better than others: e.g., providing seeds rather than food aid, and training farmer brigades to conduct local survey and control programs rather than replacing local efforts with expatriate-run operations. Some relief programs can hamper development efforts. For example, food aid has long been criticized as lessening incentives for small farmer production although this is not always the case.

The U.S. foreign assistance mandate encompasses both relief and development programs. However, the recent grasshopper and locust control programs seem overweighted by short-term emergency responses despite the well-known weaknesses of crisis management. Nearly all U.S. funds for locust and grasshopper programs in fiscal years 1986 and 1987 were OFDA funds (table 1-3) and 58 percent of the Africa Emergency Locust/Grasshopper Assistance (AELGA) project's budget for fiscal years 1988 through 1990 was allocated to emergency assistance (chemicals, equipment, and short-term technical assistance) v. 42 percent for development assistance (research, training, and institutional support) (99). Respondents to OTA'S survey agreed that crisis management (e.g., spraying programs) was the major type of activity undertaken in recent campaigns (table 3-l). Most noted the need for a decrease in crisis management per se and an increase in both preventive measures and specific types of relief, although they did not advocate decreasing the overall total amount of resources (10). Their analysis agrees with that of others (e.g., 95).

The farmers and herders who are the intended beneficiaries of donors' programs do not distinguish between crisis management, subsequent relief activities, and long-term development assis-

Table 3-1-OTA Survey Respondents: Percent of Current and Ideal Locust Efforts Focused on Crisis, Relief, and Prevention (N = 25)

	Current effort		Ideal effort	
	Median	(Range)	Median	(Range)
Crisis	90%	(25 - 100%)	50%	(O - 80%)
Relief	5%	(o - 30%)	10%	(o - 50%)
Prevention	1%	(O - 32%)	30%	(5 - 100%)

SOURCE: Dale G. Bottrell. ‘locusts in Africa and the Middle East: Summary of Response% to OTA Questionnaire,” contractor report prepared for the Office of Technology Assessment, May 1989.

tance. For them, locusts and grassho pers represent one more crisis in lives that are full of crises, each further narrowing their options and contributing to the downward spiral of poverty (20). Likewise, locusts and grasshoppers are only two of many types of pests that threaten their crops. For long-term development to succeed, it seems that far more attention must be paid to how pest problems interact with other difficulties and to the development implications of grasshopper and locust control.

In this context, plant protection needs to be viewed as a process that integrates local, national, regional, and international components. Many farmers and herders have few options for controlling large upsurges of locusts and grasshoppers when prevention fails. They may need assistance during that difficult, but brief, period in which their losses can be severe. Thus, short-term relief may be needed locally, either to prevent crop damage or to enable farmers to recover from that damage, preferably in forms that contribute to long-term development.

Individual or Multipest Strategies?

General agreement exists that sustainable protection of crops and livestock requires comprehensive, multipest management solutions. But, some do not agree that management strategies for locusts and grasshoppers should be integrated into multipest management schemes of single organizations, such as the national crop protection services. They note that certain insects require distinctly different control efforts by actors at different levels. Some species, e.g., the Senegalese grasshopper and African Migratory Locust, breed in areas where dryland farming predominates and can be monitored by farmer committees and integrated into multipest management by the national crop protection services and farmers. Generally this approach could apply to most grasshoppers. On the other hand, species such as the Red Locust, Brown Locust, and especially the Desert Locust, breed in remote areas and migrate across boundaries. They may be more effectively dealt with as individual species based on interstate or regional cooperation. Proposals are now being considered for a regional ad hoc task force to control the Desert Locust in “strategic” areas outside of West Africa’s croplands. The same role was proposed for the regional organization DLCO-EA in Eastern Africa.

However, addressing locust and grasshopper problems within the context of broader pest problems would have several advantages: costs would drop relative to benefits because benefits would accrue each year rather than sporadically; institutional continuity and expertise would be built; already-existing organizations could respond more quicly to outbreaks and they could accommodate shifting pest problems methodically; pesticides could be turned over and replenished more rapidly so less waste would occur (95). The constraints to adopting a multipest strategy are often political and institutional rather than technical. If they can be overcome, economic savings and improved chances of sustainability maybe achieved.

When and Where Should Control Programs Be Mounted?

During the recent grasshopper and locust campaigns vast areas were sprayed with insecticides. The high costs of these efforts, including the less clearly documented environmental costs, require a reexamination of where and when spraying should be done when future outbreaks occur. Some decisions could be worked out ahead of time, e.g., the level of infestation required for control of the various species, by representatives of African and donor organizations. Alternately, various control strategies could be selected and coupled with improved plans for carefully monitoring their impact.

Many experts conclude that early treatment, especially of hopper bands, is most efficient, and the economic, institutional, and environmental costs of control increase with waiting (99). For example, carbaryl and malathion are much more economically applied against U.S. rangeland grasshoppers earl in their life cycle; optimal control occurred at tie fourth instar when grasshoppers were beginning to cause enough crop damage to justify control costs yet populations were still relatively small so control could be limited (66).

On the other hand, some propose later treatment, perhaps waiting until swarms pose an actual threat to crops and not spraying rangeland and forests at all unless they border threatened cropland. This approach increases the risk of crop damage because insects can move quickly and significant time is required to mount a spray operation. When environmental conditions are right, for example, gregarious swarms of the Desert Locust appear more or less simultaneously over a large area (4). Under these conditions insects could threaten crops before a spray operation could be mounted. Thus, a late spraying approach may have high political costs (71, 121).

Others propose careful review of the lessons learned in controlling analogous pests, such as the Australian Plague Locust or quelea birds. Quelea bird populations can increase rapidly after rains, but the control strategy is to kill only those birds actually attacking crops. Likewise, methods developed elsewhere to make pest control more effective could be applied to locust programs. For example, general information is available on the relative merits, disadvantages, costs, and uses of various ground- and aerial-spraying methods (95, 118). Some pest surveys have been organized for international chemical control efforts, but little information is available on nonchemical efforts (37). And few of the recent grasshopper and locust spray operations were followed by post-application assessments of numbers of insects killed that would help in future decision-making regarding control tactics.

The U.S. Forest Service (USFS) developed a system for monitoring gypsy moth populations to determine when and whereto mount control and for assessing control operations to determine which were most effective. This program illustrates the type of work needed to improve locust and grasshopper control. Special "forest pest management" groups lay out plots for gypsy-moth treatment and decide the appropriate time to do treatment, based on a threshold number of eggpods and stage of development of the caterpillar. Aerial treatment is done during specified weather conditions. Then, the pest management groups revisit anumberof treated plots at 7, 14, and 21 days to check the number of insects killed. Usually thesameteamdoes pre-and post-application assessments. Dataonapplication (e.g., formulation, characteristics of the equipment and plane, pilot's name) and, when possible, treatment results for each plot are recorded on standardized forms. From this data, the USFS learned that results depended significantly on which pilot did the spraying, and that treatment should begin at lower thresholds so that smaller areas could be sprayed (59). These methods and lessons may be directly applicable to grasshopper and locust programs.

Resolving issues of when and whereto control locusts and grasshoppers is USAID's responsibility. Policymakers need to listen to all sides of the debate, examine available evidence, and then determine ways to be more selective regarding timing and target sites to reduce costs (including environmental costs) and maximize effectiveness.

WHAT CONTRALTO USE: THE ROLE OF TECHNOLOGY

The choice of technology to control grasshoppers and locusts, as for other purposes, carries with it a variety of consequences. Some technologies can play a strong development role while others can hinder development. Often, support for in-

dividual types of technologies sets up complex trade-offs.

The decision to support widespread pesticide use for agriculture is such a case. In effect, donor-supplied pesticides subsidize high pesticide use. Because of these subsidies, users paid from 85 percent to only 10 percent of the real cost of pesticides in one study of nine developing countries. Users paid only 11 percent of the real cost in Senegal and 33 percent in Ghana, the two African countries included; these subsidies were worth $4 million and $20 million, respectively (80). As a result, farmers have decreased or abandoned alternative control methods–such as sound agronomic practices and varietal selection–in favor of pesticides. The social and environmental side effects of these changes are largely undocumented but may be significant. For example, increased pesticide use was among the factors that accompanied the increased commercialization of agriculture. This process has increased demands on women farmers' labor, reduced the amount of food grown for local consumption, and encouraged planting higher value crops.

Today, widespread pesticide spraying is the predominant technology used against grasshoppers and locusts. Usually, effective pest management for crops includes a larger number and wider variety of options (table 3-2). Implementing a long-term development approach to locust and grasshopper management requires broadening the current range of technologies and identifying or developing ones that can be used by various groups in environmentally, economically, and institutionally sustainable ways. Integrated pest management, joined with various forms of early warning, are two types of technology that hold promise. Both require additional research to be fully operational.

Integrated Pest Management

Finding: Integrated pest management is USAID's stated policy, but many elements of such an approach were not adequately emphasized during the recent grasshopper and locust campaigns, partly because of lack of available technology and partly because of the poor performance of donors and African agencies. If USAID intends to implement &policy fully, the Agency must support research to develop alternatives to widespread spraying, collect data on economic injury levels of crops, assess the effectiveness of various control strategies, and revise its approach based on these efforts.

Integrated pest management is "the optimization of pest control in an economically and ecologically sound manner accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below economic injury level while minimizing hazards to humans, animals, plants, and the environment. In its broadest form an 1PM program encompasses all significant components of the agroecosystem–soil, crops, water, air, insects, pathogens, weeds, nematodes, and other organisms--which interact among themselves and with other components of the system." (125).

Integrated pest management combines a variety of control techniques to reduce and keep pest populations at acceptable levels, based on criteria of crop yield, profit, and safety. It seeks maximum use of biological control, pest-resistant crop varieties, and cultural practices. Pesticides are normally used only after the target pest reaches an infestation level called economic threshold or economic injury level, i.e., a pest density at which the costs of control "just equal crop returns. Even if insecticides are the only control option available, an 1PM approach stipulates that the chemicals be used as effectively and efficiently as possible and their environmental and health impacts be monitored carefully.

Furthermore, 1PM can be described as a way of thinking, a process of dealing with a problem holistically. This approach requires flexibility and the ability to deal with multiple factors at one time. Practitioners must be discriminating, adapting the same principles to different situations, rather than applying a single solution to all cases in a narrow, black or white way of thinking. In this sense, mediating diplomatic solutions to border disputes could be considered part of an 1PM strategy for locust control in Africa.

Promotion of 1PM is USAID policy. However, it still is not used widely within USAID's agricultural and health projects. The Agency tends to support 1PM in special projects rather than integrating it into overall development strategy and programs (22). Many feel that USAID should support increased research on 1PM and make in-

Table 3-2–Control Tactics Now Employed Against Major Pests **of Wheat in** the U.S. Great Plains and Sorghum in Texas

	Biological		Host plant resistance	Cultural								Chemical			Other	
Major pests	Pred.[a] and para.	Microbial	Host plant resistance	Sanitation	Eliminating hosts	Crop rotation	Planting date	Clean Seed	Water mgnt.	Fertility mgnt.	Tillage	Soil	Seed	Foliar	Monitoring	Predictive models
Wheat:																
Hessian fly[b]	1	1	3	2	2	1	2	1	1	1	2	2	1	1	3	1
Greenbug[b]	1	1	1	1	2	1	1	1	1	2	1	1	1	3	2	1
Wheat stem sawfly’	1	1	2	1	2	1	1	1	1	1	2	1	1	1	2	1
Army worms[c]	1	1	1	1	1	1	1	1	1	1	1	1	1	3	2	2
Cutworms[c]	1	1	1	1	1	1	2	1	1	1	2	1	1	3	2	2
Aphids[c]	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	1
Grasshoppers[c]	1	1	1	1	1	1	2	1	1	1	1	2	1	3	2	1
Wheat stem maggot[c]	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
False wireworm[c]	1	1	1	1	1	2	1	1	1	1	2	2	1	1	2	1
True wireworm[c]	1	1	1	1	1	2	1	1	1	1	2	2	1	1	2	1
Sorghum:																
White grub	1	1	1	2	2	2	2	1	1	1	1	3	1	1	1	1
Wireworms	1	1	1	2	2	3	2	1	1	1	1	2	3	1	1	1
Greenbug aphid[b]	2	1	3	1	1	1	2	1	1	1	1	1	1	3	2	1
Fall army worm[b]	1	1	1	1	1	1	3	1	1	1	1	1	1	2	1	1
Beet army worm[b]	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
S.W. corn borer[b]	1	1	1	3	1	2	2	1	1	1	1	1	1	1	1	1
Sugarcane borer	1	1	1	3	1	2	3	1	1	1	1	1	1	1	1	1
Chinch bug	1	“ 1	2	1	2	1	2	1	1	1	1	1	1	2	1	1
Sorghum midge[b]	1	1	1	1	1	1	3	1	1	1	1	1	1	3	1	1
Sorghum webworm	1															

NOTES:
[a]Predators and parasites
[b]introduced pest
‘native pest

KEY: 1 = little or no use
2 = some use
3 = major use

SOURCE: U.S. Congress, Office of Technology Assessment, ***Pest Management Strategies in Crop Protection, vol.*** 1- Summary (Springfield, VA: National Technical Information Service, October 1979, pp.22, 54).

creased efforts to integrate 1PM in the majority of its agricultural programs. Generally, the concept of IPM is not well-understood by decisionmakers. For example, most USAID officials responsible for the grasshopper and locust program maintain that 1PM does not apply to grasshopper and locust control during upsurges (44).

However, various elements of 1PM nevertheless were clearly appropriate during the recent campaigns and poorly implemented:

Optimization of control–This refers to efficient and effective use of resources, differing from maximization of control. The large numbers of hectares sprayed could have been treated far more effectively with available technologies. Pinpointing targets, improved consideration of wind drift, ground temperature, time of day, stage of insect development–among other things–would have greatly unproved efficiency.

Multiple control tactics-These were not used because control methods against migrating swarms are limited. The lack of alternative methods, however, reflects the lack of resources and low priority given to developing them. Donors could have set aside more resources for developing alternatives rather than spending the overwhelming proportion of their funds on emergency spraying.

Pest damage kept below the economic injury level (EIL) to maintain stable crop production-Major crop loss due to grasshoppers and locusts did not seem to occur at the national level in 1986 to 1989, although some individual farms suffered significant losses (18). By and large, swarms did not affect croplands. In some cases, spraying seemed to protect crops. The lack of damage cannot be attributed automatically to control, however, because of the complex relationship among increased rainfall, insect upsurges, and crop yield. High rainfall in the mid-1980s increased crop growth in many areas, making "stable crop production" difficult to calculate. Reliable data needed to sort out these various factors are lacking so it is also difficult to determine economic injury level accurately. Even so, little, if any, effort was made to base decisions to spray particular areas on such a determination.

Minimal hazards to people and the environment–At best, this element of IPM was not carried out consistently, despite efforts by USAID and others. For example, broad-spectrum insecticides killed nontarget organisms, and disposal of excess pesticides and their containers remains problematic.

Relatively workable 1PM programs have been developed for a range of pests and crops and are being used in some developing areas (103). The cost-benefit analyses of those programs evaluated generally show a reduction in pesticide use and an increase in profits (35). 1PM has not been emphasized in locust and grasshopper control in Africa and the Middle East, however (95). Today, biological control, cultural practices, and other nonchemical components of 1PM cannot provide the high level of control needed to stop gregarious hopper bands and swarms of adults. These methods might, however, contribute significantly when used together or at early stages of an infestation (9).

An effective 1PM program would aim to prevent serious locust and grasshopper outbreaks. It could include activities at a variety of levels, but regional aspects would be necessary due to the cross-boundary migration of insects. New 1PM approaches would rely on controlling locusts and grasshoppers at earlier points than achieved in the recent campaign, similar to the "strategic control" advocated by FAO for the Desert Locust, but place a greater emphasis on using alternatives to spraying as these become known or available.

Examples of 1PM strategies for grasshoppers and locusts might include planting alternative crops that are less susceptible to these insects; increasing animal production; developing cottage industries to produce locust meal for food or to produce extracts from neem trees for use as an antifeedant (126), and developing pesticide regulations to improve chemical use. Sound land management-especially reforestation, upgrading range quality, and avoidance of overgrazing and widespread burning-can suppress grasshoppers and locusts and decrease suitable breeding sites (95). This and other approaches might be part of an IPM approach for some other species as well.

Certain aspects of an IPM approach to grasshopper and locust problems could be implemented immediately, e.g., improved use of pesticides. In the short-term, improved regulation, selection, storage, application, and disposal of pesticides maybe the best strategy, especially for reasserting control after an upsurge (95). Mechanical and cultural methods of control are also currently available and these might be suitable for controlling small infestations in crops. They are most likely to be useful for the Variegated Grasshopper, especially if paired with additional training for extension agents.

Research on microbial and botanical pesticides, insect population modeling, forecasting, developing resistant crop varieties, and further improvements in insecticide application offer a better outlook in the medium and long-term (95). Distinct approaches will have to be developed for each of the major locust and grasshopper species, however. For example, since the Desert Locust eats many types of vegetation, developing resistant plant varieties does not seem to be a feasible approach to controlling it.

Biological Control

Normally, naturally occurring biological control is not sufficient to prevent outbreaks of major locust and grasshopper species (93). But enhanced biological control-the use or encouragement of natural enemies for the reduction of pests-is one potential component of an improved IPM approach. Locusts and grasshoppers have an array of natural enemies. So far, these have not been used in control campaigns, nor has what is known about natural pest mortality been exploited to produce predictable or consistent results (95). Some feel that biological control offers considerable potential, although additional research and field testing are required before their real value will be known. Because of the priority currently given to chemical control, much of the research on alternative methods is in its early stages.

Some biological control agents, when packaged, are called microbial pesticides. Most have the advantage of easy deployment; they could be formulated and sprayed or used as baits in much the same way that chemical insecticides are now. Some newer biotechnology may be helpful in developing these alternatives. However, microbial controls require EPA registration for commercialization and such approval is difficult to obtain for genetically engineered microorganisms. Similarly, African governments want reassurance that these biological control agents do not pose hazards to human or animal health.

Grasshoppers and locusts are susceptible to infection by bacteria, viruses, fungi, and protozoa and several potential new microbial control methods are being tested. *Nosema locustae*, the first protozoa registered by EPA for use against an insect, is approved for control of U.S. rangeland grasshoppers. Developed at USDA's Agricultural Research Service's Range Insect Control Research Unit in Bozeman, Montana, it is sold commercially as Nolobait. Used with a wheat-bran bait, it takes 3 to 4 weeks to kill 50 to 60 percent of the insects and persists for two seasons because it is passed from one generation to another. It is less expensive than chemical insecticides and does not adversely affect beneficial species or other natural enemies (21, 88). Field experiments in Cape Verde and Mauritania showed that native grasshoppers were infected with *Nosema* (39) but did not determine whether it could suppress grasshopper outbreaks (9). USAID supported *Nosema* research in Mali; it was stopped in 1988 due to Malian Government fears of possible hazards (99). USAID supports further work on *Nosema* and other microorganisms in Cape Verde by USDA scientists and the national agricultural research service. Several recent studies suggest that further research in Africa on various species of *Nosema* may pay off for grasshopper and locust control (95, 99). USDA and other researchers began examining viruses as potential control agents because viruses are more deadly, kill faster, and could be used in combination with slower-acting microbial. For example, an entomopoxvirus for the Senegalese grasshopper shows potential as a microbial control agent (94). The fungal pathogen Entomophaga grylli attacks some locusts and grasshoppers. It has not been studied in Africa or the Middle East (95), but its potential in semi-arid areas where most grasshoppers occur seems small because fungal development depends on high humidity (94). It may be useful in Africa's humid areas, however, for these same reasons. Some new strains of spore- or toxin-forming bacteria (like those used already for biological control for other insects) might be isolated from locusts and grasshoppers (78). Rickettsia are virulent to grasshoppers, but their use may be too hazardous to have much potential because they also infect vertebrates (94).

Other *Biorational Controls Materials*

These include botanical pesticides and pheromone traps-alternatives to Synthetic chemical insecticides. One botanical insecticide has received attention, especially for its antifeedant effects. Extracts from neem trees (Azadirachta indica) discourage locusts, grasshoppers, and other insects from feeding on plants to which it is applied (9). In India, neem spray and dust protected crops from Desert Locusts and, in Togo, neem repelled grasshoppers. However, 1988 trials at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Niger were less than successful and indicated that farmers might be unwilling to invest the labor or funds to use neem on grain crops, since repeat applications are needed (99). A neem insecticide, Margosan-0, is being distributed in the United States by W.R. Grace and Co., but EPA has not approved its use for food crops. The authors of USAID's Programmatic Environmental Review and the AELGA evaluation supported further research on neem as an antifeedant.

The Egyptian Government supports research on the antifeedant properties of a number of indigenous plants, and the German Agency for Technical Cooperation (GTZ) funds trials with neem, *Nosema,* and other natural agents as part of its program of developing alternative methods of locust and grasshopper control (107).

The International Center on Insect Physiology and Ecology (ICIPE) and others are attempting to identify natural attractants. Recently, ICIPE achieved some success using pheromones (natural attractants) as bait to trap certain species of the tsetse fly (Washington Post, April 3, 1989). Like biological control agents, attractants are usually narrow-spectrum and thus less harmful to nontarget organisms and the environment than broad-spectrum chemical insecticides. The potential for using pheromones for grasshopper or locust control is not known and many fear that pheromone work is not justified for this reason (6).

New Research on Alternative Controls

Those engaged in planning and conducting research on biological control agents, especially the microbial ones, stress that it maybe 8 to 10 years or longer before these will be ready for large-scale use (55, 65). First, the microorganisms have to be identified and isolated from locusts and grasshoppers in Africa (40). Then various formulations must be field tested against target species and nontarget organisms under various conditions and these results corroborated. Finally, ways to mass-produce and apply the agents must be developed and tested. Research projects such as these require long-term institutional support for an agency to attract qualified scientists and sustain their work.

The International Institute for Tropical Agriculture (IITA) recently began a major research effort on biological control of grasshopper and locusts. The $1.0 million USAID-funded project aims to develop strains of two fungal pathogens recovered from locusts and grasshoppers in Africa as biological pesticides and field test them in the Sahel. WorkWill be led by scientists from the London-based Commonwealth Agricultural Bureau International's Institute for Biological Control at IITA's facility in Benin.

ICIPE also proposes a major research initiative. By late 1989, ICIPE had received $0.5 million from the World Bank and African Development Bank toward the $14 million requested for the first 5-year phase, 1989 to 1993. ICIPE's proposal encompasses five areas of research on alternative control methods, including biorational agents and improved chemical insecticides:

- **population dynamics (to detect potentially dangerous populations during recessions);**
- **pheromones and kairomones (to use as attractants in locust control);**
- **endocrinology of locust phase-changes and gregarious behavior (to pinpoint targets for growth regulators and broad-spectrum chemical insecticides);**
- **biological control (to augment role of pathogens and parasites, including enhancing their virulence by genetic manipulation); and**
- **new approaches to the use of baits (since they tend not to affect natural enemies and nontarget organisms).**

Monitoring Insects, Weather, and Vegetation

Finding: Technologies for ground monitoring insect populations are adequate but sometimes are used ineffectively. Technologies for monitoring from the air tend to be imprecise and their results often delivered late. Therefore, technological and institutional improvements are needed for ground and aerial surveillance and forecasting, necessary components of a preventive strategy.

Monitoring is essential for a number of purposes. A preventive approach to locust and grasshopper control requires forecasting, ground monitoring, and early treatment to interrupt swarm formation. Effective pest management strategies require monitoring, or tracking, insect populations before control to find, identify, and delimit infestations and further monitoring after control to assess its effectiveness. Famine early warning systems benefit from information on fluctuating insect populations.

Technologies

Methods already exist for monitoring pest populations on the ground and for measuring the impacts of control but their use needs to be improved, especially by increasing national capacity.

Today, most remote sensing and forecasting work is done by expatriates at scientific centers in Europe, the United States, or regional centers without adequate, timely, and accurate field data. Consequently, African field programs remain largely untouched by the technological advances at remote sensing centers; quickly exchanging information between the field and centers is difficult (95); and often forecasts are wrong.

An array of detection strategies, each appropriate for specific times and locations, can improve forecasting. Some information can be obtained only by ground survey teams (insect species, stage of development, population density). Other information can be obtained best from aircraft and satellites (current and likely future vegetation, wind and rainfall patterns). Combining remote sensing data with maps showing: 1) political boundaries, roads, and landmarks, 2) historic breeding areas and migration patterns, and 3) insects' soil and vegetation preferences can be used to help ground survey teams select high priority areas for monitoring. (George Popov prepared maps on the preferred habitats of the Desert Locust in the Sahel for FAO but these are not yet available to national crop protection services.)

All aerial survey methods require ground verification. Thus, they cannot substitute for crucial ground monitoring and improved integration of the two methods is critical. For example, information from remote sensing could better guide the work of ground teams just as insect population data from ground teams could supplement the vegetative cover data provided by remote sensing.

The most critical component of early detection of pest populations is a network of trained ground observers (37) with adequate equipment. Thus, training remains one of the most important needs for improved field applications of forecasting. Training could encourage managers to make greater use of remote sensing and provide a cadre of field officers for various early warning and survey activities, including data interpretation (95). Certain aspects of monitoring programs are unresolved. For example, some feel that a monitoring system designed for pest complexes would be a more efficient use of resources than ones designed for single insect pests. Any effective system, however, must include many levels of organizations, working within the framework of national and regional programs, to improve accuracy and sustainability.

Types of Early Warning and Forecasting Systems

Current early warning systems combine remote sensing data with other aerial, ground, and statistical information for a variety of purposes, such as agricultural and environmental assessment and resource management (45). AGRHYMET data, for example, are used for crop and pasture monitoring in the Sahel.

Several groups monitor pest damage as one of several major risks to agricultural production to predict food shortages and famine, and thus anticipate the need for food aid and other forms of assistance. USAID's Famine Early Warning System (FEWS) and FAO'S Global Information and Early Warning System are examples.

Three major organizations make or plan to make locust and grasshopper forecasts specifically: 1) FAO/ECLO through the ARTEMI (Africa Real-Time Environmental Modeling Using Imaging Satellites) project, 2) the French research agency, PRIFAS (Programme de Recherches Interdisciplinary Francais sur les Acridiens au Sahel, reorganized now as Acridologie Operationnelle-Ecoforce Internationale), and 3) the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) meteorology agency, AGRHYMET (99). These type of programs have significant potential. For example, a model predicting upsurges and locations of the African Migratory Locust, developed by a pint FAO/U.N. Development Programme project, reduced annual scouting efforts from 144 to 90 person-months (2).

Current programs also have serious limitations. Reports from PRIFAS and ELCO often are not quantified, detailed, or timely enough to be useful in the field. For example, Operation SAS (Surveillance des Acridiens au Sahel) was established within the French PRIFAS for rapid collection of field observations from a Sahel-wide network. However, data collection has been slow, sporadic, and incomplete, preventing reliable prediction (99). Also, the biweekly SAS newsletter has been istributed too slowly for recipients to use it for planning; it is used primarily as a situation summary. SAS first constructed a predictive model for the Senegalese Grasshopper and used historical records, G. Popov's qualitative vegetation and soil maps, and AGRHYMET weather data (often relying on 30-year averages) but not remote sensing data. In the past 5 years, PRIFAS has been developing a similar model for the Desert Locust and is working with AGRHYMET to set u a locust survey and warning service for the CILSS countries (75).

The ECLO in FAO/Rome provides faster information because its monthly "Desert Locust Summary" is sent by fax. FAO combines data from field reports and remote sensing. Originally, FAO used Landsat data, but now uses Meteosat and National Oceanic and Atmospheric Administration (NOAA) imagery in the Dutch-designed ARTEMIS system. FAO also uses this technology to produce 10- and 30-day rainfall maps, relying on the European Centre for Medium-Range Weather Forecasting for forecasts of temperature, pressure, wind, and rain for up to 5 days in advance (13). Like the SAS Bulletin, however, FAO'S "Desert Locust Summary" is plagued by gaps in coverage due to missing field data (95).

FAO'S separate "Update" includes a general status report, a 1-month forecast, descriptions of weather and ecological conditions, specific country information on pests sighted and assistance requested, and assistance provided bydonors. Recently, ECLO entered historical data on locust plagues in its computerized database and plans to use it in forecasting locust migration patterns.

Remote Sensing and Greenness Maps

Satellite-based weather, vegetation and land surveys, maps, etc., are all likely to be useful for building scientific institutional capacity in African countries. Such information can be used for government @arming and regulation and for monitoring desertification, vegetation, surface features, wind patterns, etc. Probably satellite-based remote sensing will be used less for locust and grasshopper forecasting and control than for these purposes. In 1988, the multidonor Club du Sahel commissioned a study of 50 remote sensing projects in the Sahel. Remote sensing seemed very useful for climatological applications, less useful for crop monitoring (although vegetation indexes were of some use), and least useful for forecasting yields because of difficulties in measuring crop acreage and discriminating between crops (67).

USAID sponsored the development of greenness maps, one particular type of vegetation index, by the U.S. Geological Survey (USGS) in 1987. Greenness maps were furnished to five Sahelian countries every 2 weeks between 1987 and 1989 by the USGS EROS (Earth Resources Observation Systems) data center in South Dakota, using data from NOAA satellites. These maps showed changes in vegetation over time. FAO's ARTEMIS program also monitors rainfall and changes in vegetative cover. These maps helped field teams identify places where locusts might be found and areas where ground surveillance was not needed (95), especially in places where rainfall is irregular and ground cover inconsistent.

The USGS greenness maps were valued highly by those interviewed during the AELGA evaluation but were judged not too useful for making control decisions because delivery to Africa took up to 2 weeks (in 1987) or 8 days (in 1988). As a result, maps were sent by fax to Mauritania and

Niger by late 1989 (121). Both USGS and the ARTEMIS maps have another weakness that is less easily corrected. Areas with very low amounts of vegetative cover may not show up on existing satellite imagery yet be areas where potentially damaging Desert Locust populations develop (13).

Imagery for grasshopper and locust control is or can be provided by several types of satellites:

- Meteosat, operated by the European Space Agency;
- weather satellites operated by NOAA (part of the U.S. Commerce Department);
- Landsat, developed by the National Aeronautics and Space Administration but owned since 1984 by the private U.S. Earth Observation Satellite Co.; and
- the French Systeme Probatoire d'Observation de la Terre (SPOT) (figure 3-1).

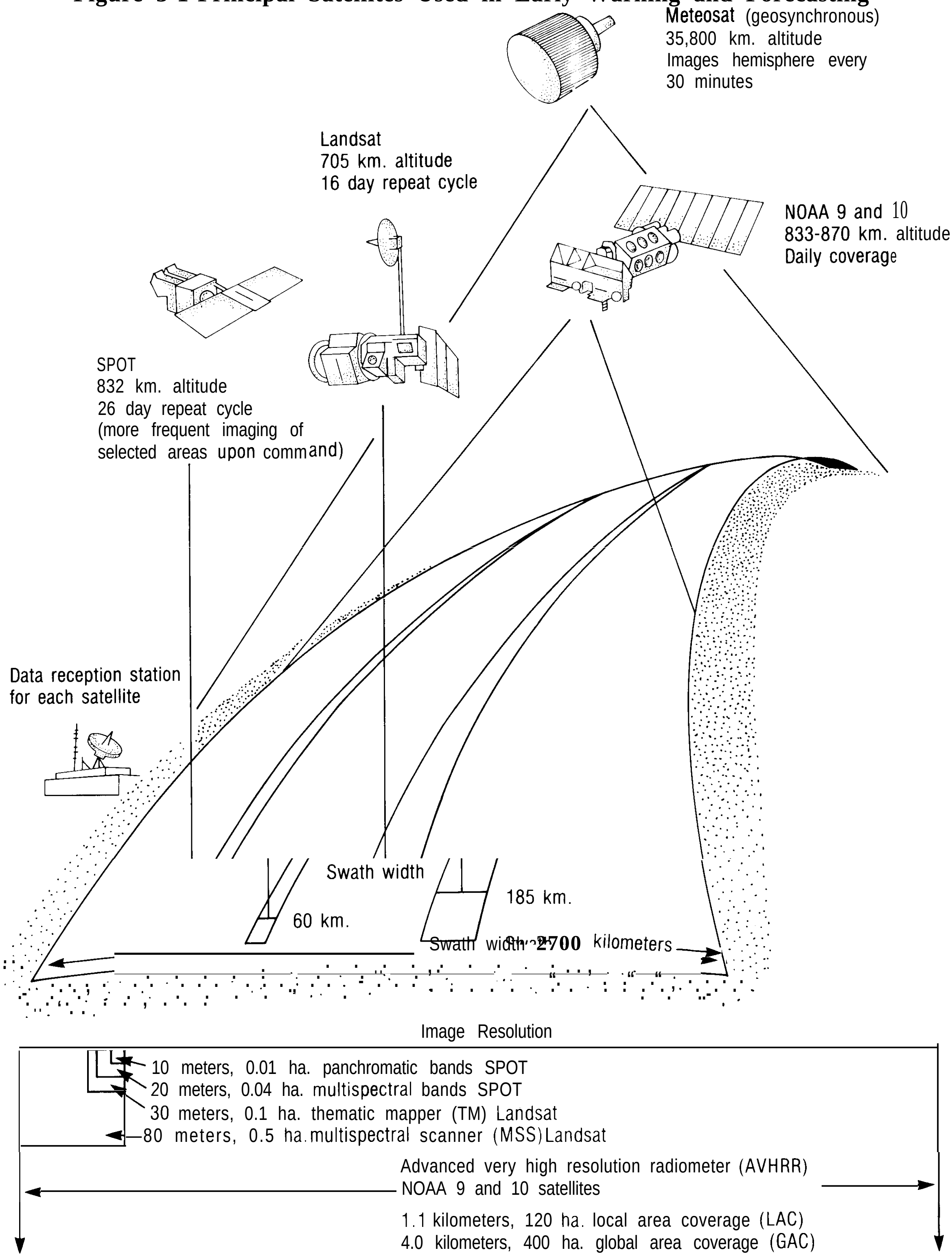
The first two are used by those monitoring insects now; the second two provide more detailed information on land cover. Landsat has greater resolution than NOAA's polar orbiting satellites but NOAA provides daily coverage while Landsat passes over the same areas only once every 16 days. Landsat has not proven capable of monitoring crop production (26) and obtaining Landsat data is more expensive than from NOAA satellites so FEWS and USGS rely on NOAA's system. In general, a confusing array of Earth-monitoring satellites exist, and the U.S. Government has been criticized by scientists and others for having spent too much on satellite hardware that produces too much inaccessible and unanalyzed data (56).

USAID plans to transfer significant aspects of U.S. remote sensing application to locust forecasting to African countries or regional organizations (62). USGS, which has supported AGRHYMET for a number of years, recently trained AGRHYMET staff and key personnel of the Sahelian national crop protection services to use greenness maps. Also, USGS technicians are training AGRHYMET staff to produce and distribute their own greenness maps (99). AGRYHMET is expected to provide this service to its nine member states in 1990, according to some sources (45,62), or within the next 3 years, according to others (99). Similarly, USGS is transferring greenness map-making capability to Tunisia for Northwest African and planning to develop it in Djibouti for the six East African nations (62). USAID is funding installation of a satellite dish in Niger so AGRHYMET will be able to receive data directly from the NOAA weather satellites.

Currently, remote sensing for early warning of grasshopper and locust upsurges is not considered fully operational nor does rapid transmission from satellite to Earth ensure that all stages of data gathering, analysis, and use are coordinated and rapid (95). One perceived danger is that, as these programs develop, remote sensing will dominate other types of information-gathering, thereby reducing the resources available for field scouting. For example, observers are concerned that FAO's interest in a very expensive, centralized program based in Rome may preclude other, less glamorous, approaches. On the more promising side, plans exist to extend satellite-based monitoring to other important migratory pests such as the grain-eating quelea bird, the African Migratory Locust, the Senegalese Grasshopper, armyworms, and the Red Locust (95).

The various groups conducting early warning and remote sensing activities do not necessarily duplicate efforts because they operate with different mandates for research, applications, information dissemination, and training. Nevertheless, clear duplication of effort exists and improved coordination and cooperation is needed (95). International organizations are most suited to provide support for remote sensing, due to the high cost of equipment and the complexity of support services, but regional groups might be responsible for establishing uniform reporting systems.

Figure 3-1-Principal Satellites Used in Early Warning and Forecasting



SOURCE: TAMS Consultants, Inc. and Consortium for International Crop Protection, *Locust and Grasshopper Control in Africa/Asia: A Programmatic Environmental Assessment*, Main Report, contractor report prepared for the Agency for International Development, March 1989, p. D-7.