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TOWARDS THE DEVELOPMENT OF INTEGRATED PEST MANAGEMENT IN DESERT LOCUST CONTROL

by

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For thousands of years now, the desert locust has been one of the most spectacular and feared pests. Apart from burning hoppers driven into ditches, farmers had no real means of fighting this insect until the beginning of this century. And even then no substantial impacts were had on swarms. For the last 50 years, synthetic insecticides have been used in locust control and, in this time, neither the strategy of survey and control nor the kind of products have undergone any serious changes, apart from the replacement of organochlorines by organophosphates, carbamates and synthetic pyrethroids in the 1980s. Monitoring of populations has been greatly improved, thanks to the introduction of the Global Positioning System (GPS). However, the present control objective is still to locate desert locust populations and control early outbreaks, in order to suppress upsurges and plagues. Despite the obvious failure of this strategy, no change is in sight. At present, control decisions are not based on thresholds, since they are unknown, and cost-benefit analyses are still very new, only having been attempted very recently. In short, the current strategies do not meet IPM requirements, are difficult to justify from an economic point of view and do not appear to be effective. And yet, over the past six years, some research programmes have developed environmentally sound products to replace the synthetic insecticides, and, what is more, discussions on new control strategies were launched less than three years ago; the results are reviewed in this paper. The new strategy aims at developing a cheap monitoring system to detect early upsurges and combat these when swarms have already formed. In other words, control is only to be initiated when crops are directly endangered. Finally, in line with IPM requirements, alternative products are also to be part of the control package.

For centuries, the desert locust (*Schistocerca gregaria*) has been a feared, unpredictable pest in both Africa and Asia. Appearing in swarms at periodic intervals, the desert locust is able to cause considerable damage regionwide. The exact relationship between the destruction of agricultural produce and subsequent famines is not clear (Steedman, 1990), but there is no doubt that the first decades of this century witnessed substantial, large-scale damage. Baron (1972) delivered impressive, albeit general reports on losses and the history of desert locust control. A key breakthrough in this field was made about fifty years ago with the introduction of synthetic insecticides; chlorinated hydrocarbons in particular have been used with great success for 40 years. Early outbreak detection systems have also undergone continual improvement.

The United Nations' Food and Agriculture Organization (FAO) in Rome has played a key role since the 1950s and is responsible for coordinating early-detection activities and control measures. This provides a striking example of the overall scale on which the fight against a key pest can be organised. And yet, in spite of these joint efforts, and in spite of rapid technological improvements, such as the use of weather satellites (NOAA, METEOSAT) and the introduction of the Global Positioning Systems (GPS), to name just two, reliable forecasts of locust development are still not possible in every case. What is more, the banning of chlorinated hydrocarbons with their high level of persistence has left a vacuum that no other control means have been able to fill to date. The rapidly degradable, synthetic insecticides that have been used for the past 10 years no longer allow the old barrier technique to be used in which only approximately 100-meter strips were sprayed at quite large distances from each other, thus poisoning the locusts as they passed through, and ultimately killing them. Instead, the rapid rate at which the insecticides degenerate mean that now large areas have to be sprayed, much to the detriment of the eco-system (Everts and Ba, in press).

Although research projects on the biological and integrated control of the desert locust have been ongoing for the best part of a decade (Krall et al., in press; Lomer, in press), decisive advances leading to an integrated control strategy are still not forthcoming, as opposed to many other areas where they are now considered quite normal (Grosse-Rüschkamp, 1994). However, certain approaches do exist and are described in more detail below.

Desert locust plagues and how they occur

More or less quantitative records of desert locust development have been kept for the past 135 years or so (Fig. 1). Various theories were put forward in the past to explain the periodic fluctuations. Shcherbinovskii (1952, 1964) attempted to link the plagues with sunspot activities. In his opinion, large-scale sun-spot activity leads to recessions, whilst years with less activity correlate positively with outbreaks and plagues. Similar correlations with sun-spots were confirmed by Schuster in 1872 in the context of wine-growing

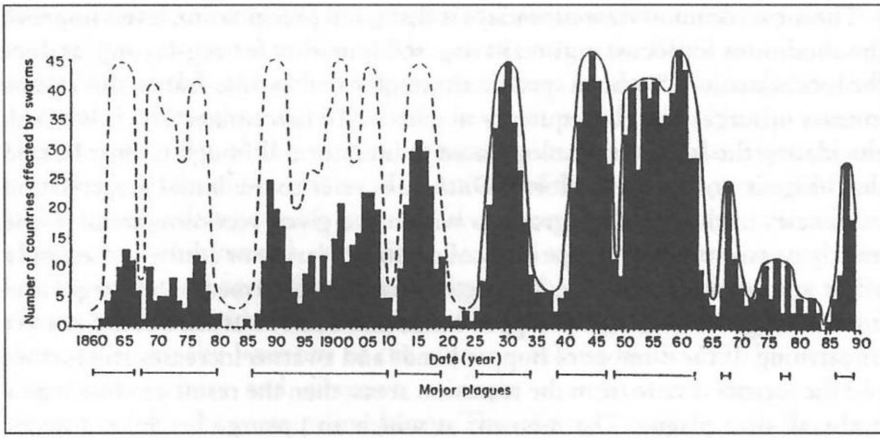

Fig. 1 - *Numbers of countries reporting either bands or swarms during a year. Broken lines denote estimated values (Symmons, 1992).*

in Germany. Shcherbinovskii talks of an 11-year cycle, and in some cases, a 22-year one. Eleven-year cycles of sun-spot activity with corresponding impacts on flora and fauna were confirmed by other authors for the past 500 million years (Berg, 1947). However, this correlation was no longer verifiable in the same regularity after 1920. In modern literature, the sun-spot correlation theory is no longer pursued, although considerable consequences could be derived from it with regard to forecasts. Current data on sun-spot activity and the dynamics of desert locust development do, however, point to a certain regularity over the last 20 years (Fig. 2).

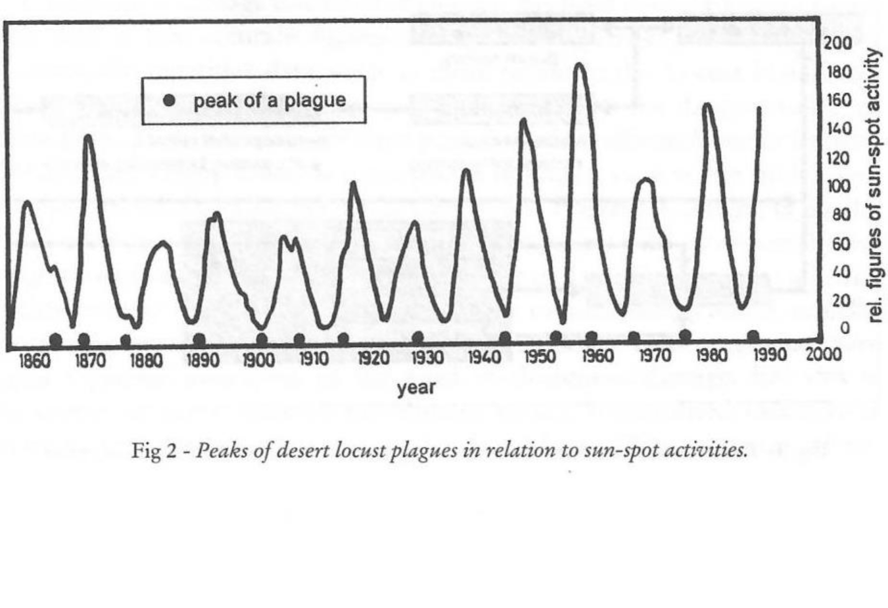

Fig 2 - *Peaks of desert locust plagues in relation to sun-spot activities.*

The most common view nowadays is that good precipitation levels improve the conditions for locust outbreaks (e.g. soil humidity for egg-laying), as does the food situation. Within a specific although variable time-frame, this results in mass upsurges and consequently migration. In this connection, it is worth elucidating the latest terminology used in literature, although it must be said that usage is not totally uniform. *Outbreaks* refer to the initial gregarisation tendencies in the breeding grounds within the given recession areas. These mostly consist of small, gregarious collections of larvae or adults and are only a few square meters in size. Larger outbreaks are termed as upsurges and involve bigger to large-scale hopper bands and adult swarms, but are not yet threatening. If the number of hopper bands and swarms increases still further and the locusts invade from the recession areas, then the result can be a major outbreak or a plague. The moment at which an upsurge becomes a major upsurge or a plague has not yet been clearly defined (Fig. 3).

Migration directions are primarily determined by the prevalent wind currents, because although locusts are good at flying, they unable or only seldom able to fly against the wind. However, since the wind directions are recurrent, certain forecasts can be made as to the direction of migration, although a lot is still down to pure chance. The Intertropical Convergence Zone (Meinzingen, 1993) has an important role to play in this context.

Another theory that has since been forgotten was put forward by Presman as far back as 1963 and 1971. The theory which he applied to the migration of birds, fish and other animals, including the desert locust, is basically that the earth's electromagnetic fields exert a great influence on practically all vital

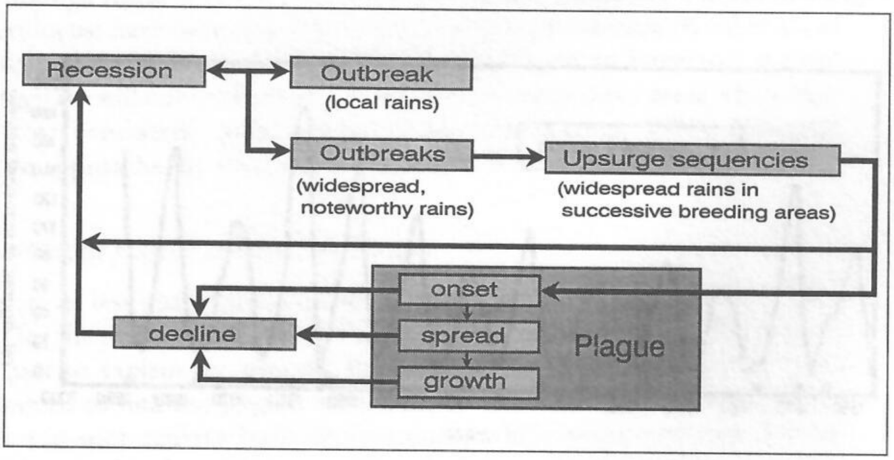

Fig. 3 - *Desert locust cycle from recession to plague (modified after Krall et al., in press).*

processes in organisms. From a geophysical point of view, the theory revolves around the intensity of the earth's electromagnetic fields which change according to the latitudes, being most intense in central latitudes in both hemispheres, and decreasing towards the equator and poles. He also stressed that the intensity of the electromagnetic fields has a regular seasonal and circadian rhythm of fluctuation. The activity of the electromagnetic fields can influence organisms directly, but can also affect the organisms indirectly by changing environmental conditions in the atmosphere and water. Bird migration, according to Presman, is triggered by the seasonal changes in the electromagnetic fields. The direction of flight, navigation and orientation is determined by the intensity of the electromagnetic fields. He also suggests that flight activity and direction of flight among desert locusts can be determined by the same prime factor. This theory, however, calls for more experimental data before it can be confirmed.

The theory of wind migration and that put forward by Presman do not necessarily contradict each other, as the weather is, to a large extent, determined by solar radiation which, in turn, affects the electromagnetic fields in the atmosphere and on earth.

Whether or not desert locusts have always migrated in the form known for the past 1000 years or so is not clear. The development and expansion of the Sahara might have influenced migratory behaviour. Other species from the genus Schistocerca do not migrate or at least not to extent of *S. gregaria* (Anonymous, 1982).

Damage to agricultural crops

Catastrophic damage due to desert locusts has been described many times, but only a few accurate figures are on hand (Herok and Krall, 1995). Continually repetitive data, such as those found in the Locust Handbook (Steedman, 1990) (Table 1), are quoted to underline the dangerousness of these pests. Historical data are often passed on via traditional stories (Byron, 1972) or are simply found as descriptions in books, such as the Bible (Joel, Exodus; Revelation Chapter 10; 2 Chronicles, Proverbs). Attempts by the FAO and other organisations to link locust campaigns with surveys of the damage caused have not met with great response to date. The countries affected tacitly assume that desert locusts can cause catastrophes without actually possessing any concrete evidence to this effect. Only in recent times has there been a greater awareness of the need to document damage, but this is hampered in many cases by the absence of any standardised methods of determining the actual harm sustained and crop losses (Wewetzer et al., 1993).

Table 1 – *Crop losses due to the desert locust (Steedman, 1990)*

Year	Country	Amount of crop eaten by the Desert Locust
1944	Libya	7 000 000 grapevines; 19 % of total vine cultivation
1954	Sudan	55 000 tonnes of grain
1957	Senegal	16 000 tonnes of millet, 2000 tonnes of other crops
1957	Guinea	6000 tonnes of oranges
1958	Ethiopia	167 000 tonnes of grain, which is enough to feed 1 000 000 people for a year
1962	India	4000 hectares of cotton (value £ 300 000)

Monitoring and early-warning strategies

There is general consensus that well-organised and carefully implemented early-detection systems are a basic prerequisite for targeted control measures. However, the type of monitoring and detection system is still a matter of dispute. At present, it is common practice in the countries with *S. gregaria* breeding grounds to drive through or fly over as much of the gregarisation areas as possible in the risk months, provided sufficient funds are available, of course. This approach involves considerable time and money, since the areas concerned are frequently difficult to reach and, in some cases, only accessible with a military escort for reasons of safety (e.g. Niger and Mali). Certain areas that are totally impassable with road vehicles are controlled with helicopters or fixed-wing aircraft, although, finances permitting, the latter are quite often used in areas that could really be monitored by car.

The lack of cartographic material means that surveys are not only complicated, but also time and cost intensive. Since the funds mostly come from external sources, at least in Africa, no great importance is attached to their rational usage.

Consequently, for example, specifying the right size of a survey team for monitoring and determining just when the very expensive helicopters and aircraft are justified are a matter of dispute. It is also questionable whether it is really necessary to investigate absolutely all areas that can be reached, in order to obtain an overview of locust development. However, since monitoring is frequently linked with the practice of preventive control described below, people are particularly reticent to renounce a comprehensive monitoring system.

The introduction of the Global Positioning System (GPS) heralded a significant improvement. This satellite-supported system, which is continually becoming cheaper to procure, enables the determination of precise locations, something which is vital to the retracing of gregarisation areas or swarms and hopper bands. GPS is the greatest and most innovative breakthrough in the field of prospecting in the last decades.

The use of satellite technology as tested by Voss and Dreiser (1994), has constantly improved the cartographic material available for prospecting. Maps produced on a model basis for classic breeding areas not only contained details of the vegetation necessary and suitable for propagation but also described the geomorphology and infrastructure of the respective region (Voss and Dreiser, 1996). Direct methods of locating migrating locusts on the ground or in the air are not yet available, although this is merely a question of time given the rapid pace at which satellite technology is developing.

Desert locust control strategies

There are basically two approaches to desert locust control: preventive control and plague control. These methods could also be described as *proactive* and *reactive*. Proactive control is geared to preventing locust plagues, an approach that is theoretically feasible at various junctures as described in Fig. 2. Attempts could be made to prevent any outbreaks whatsoever by prospecting for initial tendencies to hopper-spot formation and then counteracting them immediately. However, in view of the tough terrain and the difficulty in finding the locusts in the first place, this approach would seem to be thoroughly unrealistic and is not generally attempted in practice. In contrast, there is wide-spread belief that existent outbreaks could be controlled in such a way as to significantly reduce the overall population, thus precluding a later upsurge. This is why today most survey teams carry control equipment with them which they use to combat initial gregarisation tendencies of this kind. Although the inaccessibility of the given areas and the difficulty of locating the small-sized spots from a vehicle would seem to negate the effectiveness of such an approach, the countries concerned all agree that this theory is both realistic and promising.

Another approach focuses on the control of upsurges, i.e. hopper bands and adult swarms, both at the point where outbreaks transmute into upsurges or also during an ongoing sequence of upsurges. Controlling early and mid-upsurges is considered absolutely imperative and meaningful, at least in Africa and the Middle East. On the one hand, the targets are easily located and, on the other, intervention at the earliest possible juncture is regarded as most expedient. And yet, opposition also exists to this theory. Symmons (1992) considers the control of early and mid-upsurges to be of little use, as, in most cases, the targets are not only difficult to locate, but the national plant-protection services and regional locust organisations do not have the requisite logistical infrastructure and striking power. Van Huis (1994) goes on to state that successful control would have to encompass at least 80 % of all gregarious locusts, in order to attain any significant reductions in the overall population.

Experts normally only recommend intervention when upsurges have reached a cross-border level and are no longer restricted to the typical regression areas. Again, however, there is a series of unanswered questions:

- Can a plague that is in the process of development really be stopped by intervention?
- Should all hopper bands and swarms that can be reached be combated?
- Does it make sense to concentrate on areas with cultivated plants?
- How endangered is pasture?
- Is the control of hopper bands meaningful or should control activities target adult swarms only?

If, in spite of preventive action, a plague has developed and is now threatening large areas of cultivated plants and possibly also pastures, then general consensus is that this plague needs to be combated with a view to terminating it (reactive); however, once again, there are various ways of going about this. Protection of cultivated areas could be a priority, for example, or activities could focus on swarm control. Given the fact that numerous natural factors such as dryness, prevalent seaward wind directions, inter alia, could lead to the plague's breakdown, it might be conceivable that the overall aim is not to terminate the plague with the aid of chemical (and in future perhaps also biological) means, but to regard these as merely one of the many factors in the overall breakdown. The discussion is still extremely controversial and it can even be said that is has really only just begun (Van Huis, 1996; Krall, 1996; Krall et al., in press). For this reason, several of our own potential integrated control approaches are outlined below, the aim being to contribute to the ongoing debate and not to make a final judgement.

Potential approaches to integrated desert locust control

Economic aspects

Whilst economic aspects play an important role in the choice and application of plant protection for nearly all cultivated plants, it has been more or less completely neglected for decades in the field of desert locust control, thus making it all the more difficult to comment on. Since key data are missing in many areas, there is no basis for any reliable facts. Given this situation, the only option open to us today is that of working with relatively coarse estimates and models, as put forward by Herok and Krall (1995), who conclude that the current control methods used are no match for the potential damage to be expected from the desert locust. Considering other factors such as the potential impact of the locust in the African countries concerned (based on FAO data), the potential extent of the damage caused (damage is not always 100 %), and the limited efficiency of control measures, as is usually the case, any conclusions must be seen in very relative terms (Fig. 4).

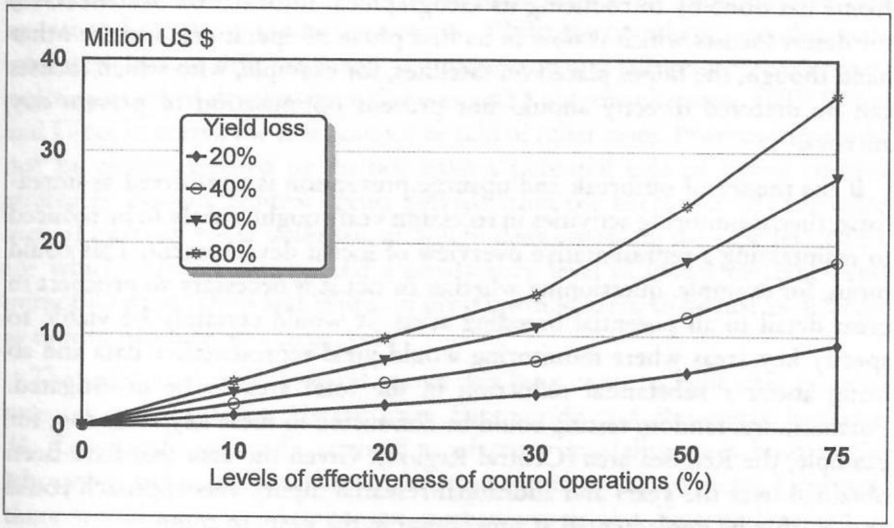

Fig. 4 - *Possible prevented annual yield losses due to locust control (in million US$) (Herok and Krall, 1995)*

Fig. 4 clearly illustrates that a high financial input is only justified when the potential loss is dramatic and the control measures are highly efficient. Taking an average loss of 40 % (which is even a bit higher than normal) and a control efficiency of 50 % (a realistic figure), the break-even point would be an (Africa-wide) input of US$ 12 million. Thus, the funds used for monitoring and control in all African countries together should not exceed the total of approx. US$ 10 million per annum (and should preferably be lower). However, according to the FAO, the donor input alone in recent years was somewhere in the order of US$ 25 million (Krall, 1995). And that is not all: considerable funds are made available by the countries themselves in the form of logistic inputs, salaries or contributions to international control organisations such as the Desert Locust Control Organisation for Eastern Africa (DLCO-EA).

The facts outlined briefly above make it quite clear that any integrated monitoring and control strategy that is developed would have to be considerably cheaper, unless other reasons were put forward that would justify heavy subsidies, an issue that is not to be delved into any further here.

Potential early-warning systems

As already stated above, monitoring technology has changed little in past years, apart from better climatic forecasts and the introduction of the GPS. On the one hand, it is meaningful to improve technology, as the FAO in Rome has done by introducing its Geographical Information System (GIS) for desert locusts which is now in its first phase of operations. On the other hand though, the hopes placed on satellites, for example, with which locusts can be detected directly should not prevent optimisation of present-day surveys.

If the theory of outbreak and upsurge prevention is considered as unrealistic, then monitoring activities in recession years ought simply to be reduced to maintaining a representative overview of locust development. This could mean, for example, questioning whether or not it is necessary to prospect in great detail in all potential breeding areas. It would certainly be viable to specify key areas where monitoring would yield representative data and so bring about a substantial reduction in the total area to be investigated. Furthermore, random testing could be conducted in these key areas too, for example, the Red Sea area (Central Region). Given the data that have been obtained over the years and additional research inputs, this approach could conceivably be implemented at some point in the years to come.

It would thus be feasible to restrict surveys in specific countries to an absolute minimum (e.g. Chad, Niger and Mali) and to conduct strategic prospecting in key regions (e.g. Mauritania, South Algeria, Central Region) in the form of (random) samples. Besides the GPS mentioned above and weather data, the cartographic material described earlier on could be of assistance in this context (Voss and Dreiser, 1994, in press).

If prospecting is to serve this purpose only, then it would be time to rethink the way in which the teams are put together. If control does not play a role in prospecting, since monitoring is now the main focus, it would be totally unnecessary to take along any control equipment. This would save on additional vehicles and application technicians and, above all, reduce the risks associated with the transport of application equipment and dangerous insecticides. If the teams were limited to two vehicles (as a rule) and a maximum of four to five persons, costs could be reduced quite substantially.

Another factor deserving a critical review is the use of helicopters and fixed-wing aircraft. Detailed assessment should be conducted in every case to determine whether or not they are really needed and/or economically justifiable. As things currently stand, the immense expense involved is by no means a deterrent when enough money is on hand.

Biological and ecologically sound control agents

Great hopes were placed on environmentally sound control as of the '90s. National and international research programmes were launched (Lomer and Prior, 1992; Krall and Wilps, 1994) which appeared to produce promising approaches. However, after years of research, only a few approaches would appear to have the potential for success. Whilst the (synthetic) development inhibitors such as diflubenzuron, teflubenzuron and triflumuron underwent practice-oriented development (Scherer and Rakotonandrasana, 1993; Wilps and Diop, in press), the same cannot be said of other cases. Pheromones could not be clearly isolated or do not have a potential role in future control strategies. Natural control agents derived from the neem tree (*Azadirachta indica*) or from *Melia volkensii*, although demonstrating the repellent effect for which they are known and a satisfactory level of locust mortality and immobilisation (Diop and Wilps, in press), would seem to be just as difficult as ever to produce on a large scale.

The only potential biological agents that have come to light after years of research are the fungi *Metarhizium flavovoride* and *Beauveria bassiana*. *M. flavovoride* especially attained satisfactory mortality rates both in the laboratory and in the field (Lomer, in press; Stephan et al., in press). However, there would seem to be unknown mechanisms at play here with regard to locusts that we have only just begun to understand. It was discovered, for example, that once a fungal preparation had been applied, the locusts deliberately allowed themselves to heat up to a temperature of 42°C in the sun, thus, in many cases, actually killing off the fungus or at least reducing the rate of infection (Goettel and Fargue, 1996). Yet another, perhaps insolvable, problem in the near future, is the great instability of the biological products under the given climatic conditions in the respective areas in Africa. Just brief exposure to high temperatures, as is common in practice, renders the products less effective (Stephan et al., in press). Another problem is that of finding producers for the frequently more expensive, biological products. These products that have been specially developed for locusts cannot serve a large, ongoing and thus profitable market and so large chemical companies have hardly any interest in developing and selling them.

In conclusion, it can therefore be said that of all the products investigated and researched to date, probably only the insect-growth regulators have a real chance of being used on a large scale. However, since they take several days to take effect, it would not be expedient to apply them close to cultivated areas. Natural preparations could be used to fill certain niches, but could also be applied on a more extensive scale in those areas that have sufficient plant resources for large-scale, local production. The future of biological agents depends, on the one hand, on whether products can be developed that are able to withstand the harsh climatic conditions, and, on the other, whether small, medium or even large companies can be found that are willing to produce them.

Using different application techniques in control activities

Without going into too much detail of this specialised area, this section is designed to provide some discussion points. The great number of individual application techniques available for insecticidal agents is confusing enough, but the greatest probable difficulty at present is their correct usage. Indeed, their frequently incorrect application results in corresponding losses in effectiveness and endangers both humans and animals; in most cases though the products are wasted due to what is sometimes immense overdosing, a practice costing thousands of dollars and causing the cost of locust control to soar sky high. Making overdosing of this nature transparent is not as easy as it is in other areas, since it is not possible to compare a directly treated field with a specific amount of substance used. In locust control the area treated is calculated from the total amount of substance used, on the basis of active ingredient per hectare as recommended. Whether or not this was really the case is difficult to check after it has happened, but from our own experience and a lot information we have received from experienced colleagues, it would hardly be right to assume so.

Improving application could therefore already result in drastic cutbacks in expenditure, whilst concomitantly enhancing efficiency. Furthermore, continual developments in application techniques are naturally most expedient. The ultra low volume (ULV) method that has been in use for a number of years now would, however, seem to be the ideal application technique in locust control. Whether it is to be applied on the ground, by vehicle or from the air is to be decided in each individual situation. But once again, it is most important to carefully weigh up the costs involved before resorting to the helicopters and fixed-wing aircraft which are very expensive to use in Africa. However, when large areas have to be covered, these not only fulfil their purpose, but are the cheapest method of application.

An integrated approach - the strategy

Given the great gaps in present-day knowledge, it is extremely difficult to draw any final conclusions as to integrated desert locust control. And yet, inter alia, various elements of the above are beginning to take on more concrete form:

- Since locusts know no borders, the coordination of monitoring and control activities requires a central institution. The FAO in Rome is currently fulfilling this task, one for which it is surely the best suited. Regional organisations such as OCLALAV (Organisation commune de lutte anitaviaire et de lutte antiacridienne) in West Africa have not proven themselves to be viable options in the long term.
- Monitoring activities should be conducted separately from control measures in future and take the form of random testing in key regions. Less important regions should restrict such activities to a minimum. Prospecting teams should be kept as small as possible and helicopters and fixed-wing aircraft only used in urgent cases.
- Control measures should only be launched once the target, in the form of hopper bands and adult swarms, is not only easily detectable but in acceptable proximity to the next control team. Priorities should always focus on the fact that control is not for its own sake but for the protection of agricultural crops. Consequently, control activities are only meaningful in the case of advanced-stage upsurges.
- Control should only ever be understood as an aid to naturally limiting factors, with the aim of making upsurges or plagues revert back to a recession phase. Thus, control should only be started when natural recession can no longer be expected, e.g. for climatic reasons.
- Natural products or biological control agents will in future probably only be able to contribute to integrated control as niche products (e.g. in frail eco-systems). They will not bring about any fundamental changes in strategy; this will be determined by other factors.
- Greater efforts should be made to improve the application of control agents – a great money-saving factor. When selecting application equipment and techniques, the costs should be considered in relation to the overall efficiency, whereby the cheapest solution should always be chosen.
- Economic studies, such as those currently supported by the FAO, should be promoted in the medium to long term, so as to obtain a better insight into the economic aspects of the desert locust problem. A precondition for such studies is ongoing data collection, e.g. together with control activities.

Final conclusions on integrated control will not be possible for a number of years. The project within the scope of the Emergency Prevention Systems (EMPRES) for Transboundary Animal and Plant Pests and Diseases, which is being supported by the FAO and various other donors in the Central Region, represents a sound approach to developing an integrated monitoring and control strategy for desert locusts.

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