Area-Wide Pest Management: Environmental, Economic, and Food Issues

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ABSTRACT Insect pests destroy approximately 14% of all potential food production despite the yearly application of more than 3000 million kilograms of pesticides. This contributes to rising human malnutrition which in 2004 was estimated by the World Health Organization to have reached 3700 million - the largest number in history. Several major insect pests of crops and livestock are effectively controlled using area-wide pest management practices. As an example, the New World screwworm fly *Cochliomyia hominivorax* (Coquerel) that attacks livestock, especially cattle, was successfully eradicated by releasing radiation-sterilized screwworm flies over large areas. Area-wide insecticide treatments in the USA have also proved effective in the control of the boll weevil, while timed crop-planting over wide areas enables crops like wheat to evade major pests and has also been proven highly successful against rice pests in the USA and Asia. Yet, when the basic ecology of the insect pests and crops are ignored, major crop losses can occur, as illustrated by the manipulation of corn production in the USA. Damages caused by invading insect pests that attack established crop, forest, and natural ecosystems continue to be challenges to pest management specialists. Approximately 40% of the insect and mite pests of crops grown in the USA are introduced species and they cause about USD 100 000 million in damage and control costs each year. The most recent introductions include the long-horned beetle *Anoplophora glabripennis* (Motschulsky) and the emerald ash borer *Agrilus planipennis* Fairmaire that were both accidentally introduced from Asia. Area-wide strategies to control these destructive forest pests are being implemented.

KEY WORDS insecticides, invasive species, economics, area-wide programmes, wheat, cotton, New World screwworm

1. Introduction

Meeting the food supply needs of an ever-increasing world population is both critical and at the same time stressing the natural resources needed for crop production. This paper examines the extent of crop and livestock damage caused by insect pests and how these losses affect human food supplies. It also reviews successful area-wide pest control programmes and assesses the impacts of invasive insect pest species on control projects needed to reduce crop losses.

2. Status of Food Security

According to the World Health Organization (WHO), more than 3700 million people were malnourished in 2004 (WHO 2004). This is the largest number and proportion of malnourished people ever reported! In assessing malnutrition, WHO includes deficiencies of calories, protein, iron, iodine, and shortages of vitamins A, B, C, and D in its evaluation (Sommer and West 1996, Tomashek et al. 2001). The current world hunger and shortages of nutrients for so many people alerts us to the growing insecurity of world food supplies and the vulnerability of human health and productivity.

The report of the Food and Agriculture Organization of the United Nations (FAO), confirms that available food per capita has been declining since 1984, based on available

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cereal grains (FAO 2003). This is alarming because cereal grains make up about 80% of the world's food supply (Pimentel and Pimentel 1996). Although grain yields per hectare in both developed and developing countries are increasing, the rate of increase is slowing. For example, according to the United States Department of Agriculture (USDA), grain yields in the USA increased by about 3% per year between 1950 and 1980, but since then the annual rate of increase for corn and other major grains has been only about 1% (USDA 1980, 2004). Meanwhile, according to the Population Reference Bureau (PRB), the human population has increased to 6500 million and continues to expand by around 70 million per year, placing ever-increasing demands on agricultural production (FAO 2003, PRB 2004). Many countries have populations that are expanding at a rate of about 1.3%. Others like China, with a population of 1300 million and a government policy of permitting only one child per couple, has a population that is increasing at a rate of 0.6% or eight million per year (PRB 2004). The US population also is growing rapidly. It currently stands at nearly 300 million, having doubled during the past 60 years, and based on a current growth rate of about 1.1%, it is projected to double to 600 million in less than 70 years (USCB 2004), i.e. it is growing at a per capita rate that is nearly twice that of China (PRB 2004).

3. Food Losses to Pests

Worldwide there are an estimated 70 000 pest species destroying agricultural crops and livestock. While approximately 10 000 of these are insects and mites, 50 000 are plant pathogens and 10 000 species are weeds; less than 10% of the total identified pest species are generally considered as major pests.

The species present vary both geographically and with each crop type. Approximately 99% of the crops grown in a country are introduced plant species (Pimentel et al. 2000). Frequently the insect and mite species are specific to a particular region and many have moved from feeding on native vegetation to feeding on crops that were introduced into the region (Hokkanen and Pimentel 1989). Indeed, usually insects moving to feed on a crop are new associations with their host plants and some become major pests (Pimentel 1988).

Despite the annual investment of USD 35 000 million for the application of three million metric tons of pesticides (Table 1), plus the use of various biological and other non-chemical controls worldwide, more than 40% of world crop production valued at USD 750 000 million is destroyed by pests (Oerke et al. 1994). Considering all pests, insects cause an estimated 14% of crop losses, plant pathogens 13%, and weeds 13%. In total, the value of such losses is estimated to be USD 300 000 million per year.

In the USA, the proportion of annual crop production lost by pests is estimated to be similar to world pest losses or about 37% (13% to insects, 12% to plant pathogens, and 12% to weeds) (Pimentel et al. 1991). Since total crop production in the USA is valued at about USD 160 000 million/year (USDA 2004), pests are destroying an estimated USD 60 000 million/year in this country despite all efforts to control them with pesticides plus a wide array of non-chemical controls. Currently, the USA invests about USD 8000 million in pesticide applications which saves about USD 30 000 million per year in crops while the use of non-chemical controls like natural enemies also helps to save crops valued at an estimated USD 30 000 million per year (Pimentel 1997). In general, there is a USD three to four return per USD invested in pest control (Pimentel 1997).

The share of crops lost to insects in the USA has nearly doubled from 7% in 1945 to 13% at present (Pimentel et al. 1993), despite a more than ten-fold increase in both the amount and selective toxicity of synthetic insecticides applied. This is mainly because various changes have occurred in agricultural production technology. However, there have also been significant improvements in terms of increased target selectivity and decreased residue levels.

Without pesticides and non-chemical controls, the losses of crops due to pests would be even more severe than occurs at present. Oerke et al. (1994) estimated that without human-directed pest controls, world crop losses would increase to 70% and to USD 525 000 million annually, reducing world food supplies and increasing malnutrition dramatically (WHO 2004).

Added to the damage that pests inflict during the growing season are the substantial losses that occur during the lengthy time many food crops are stored prior to their use. Worldwide, an estimated additional 25% of harvested crops are lost to other pests during the postharvest period. This means that, in total, pests are causing a 52% loss of all crops despite all pest control technologies used.

Table 1. *Estimated annual pesticide use from 1995 to 2005*[1].

Country/region	Pesticide use (10^6 metric tons)
United States	0.5
Canada	0.2
Europe	1.0
Other, developed	0.5
Asia, developing	0.3
China	0.2
Latin America	0.2
Africa	0.1
Total	3.0

[1]Source: D. Pimentel, unpublished

4. Area-Wide Integrated Pest Management (AW-IPM) Programmes

Depending on the specifics of geographic region, the crop and animal pest problem, and the technologies available, some pests can be more effectively controlled by area-wide control strategies than by specific farm-by-farm control programmes.

4.1. New World Screwworm and the Sterile Insect Technique

The United States Animal and Plant Health Inspection Service (APHIS) estimates that the New World screwworm *Cochliomyia hominivorax* (Coquerel) caused more than USD 750 million in damage to livestock in the USA each year (APHIS 2004). In addition to cattle, other livestock, whitetail deer and other wildlife, are susceptible to New World screwworm infestations. The female New World screwworm lays its eggs in wounds, and the larvae bore deeply into the wound on warm-blooded animals and feed on the living tissue. In addition, facultative larvae of other fly species which feed on dead tissue are frequently present in the wounds along with the New World screwworm larvae, intensifying the damage (Spradbery 2002). Eventually the infected animal dies prematurely.

In 1957, an area-wide integrated pest management (AW-IPM) programme was initiated in Florida, by integrating the release of insects sterilized using ionizing radiation with population reduction methods such as insecticidal wound treatment (Meyer 1994, Spradbery 2002), and in due course this programme unfolded in phases to eradicate the New World screwworm from the USA in 1982, then Mexico in 2001 and finally all of Central America and Panama in 2004 (Wyss 2000, APHIS 2004). For the programmes in the USA and Mexico, up to 500 million sterile screwworm flies could be produced per week in a rearing facility at Tuxtla Gutiérrez, Chiapas, Mexico, and then released in the designated areas.

Another successful New World screwworm eradication programme was implemented in the Libyan Arab Jamahiriya in 1990-1992 (FAO 1992, Lindquist et al. 1993) by the Government of Libya and FAO. This dangerous pest had become established for the first time outside of the Western Hemisphere in an area of 26 500 square kilometres along the Mediterranean Sea with several million head of sheep and numerous camels. The pest was discovered attacking large mammals in the

Tripoli Zoo as well as humans, many of whom were treated in hospitals. Apparently the pest had been imported with a consignment of sheep air-freighted from a country in South America. The infestation was contained by establishing quarantine checkpoints along all routes leading out of the infested area, treating all wounds of animals every two to three weeks with an insecticide, and then releasing sterile flies. Forty million sterile flies were flown on a weekly basis from the rearing facility in Mexico and released from small aircraft over a total of 41 000 square kilometres in Libya and Tunisia (Lindquist et al. 1993).

4.2. Synchronized Crop Rotations and Conservation of Natural Enemies for Control of Rice Pests

In the past, rice was normally grown all year-round in Indonesia, and during 1970-1980 there was a gradual build-up of pest populations, especially of the brown plant hopper *Nilaparvata lugens* (Stål). Rice yields declined despite the heavy use of insecticides that started in 1980 (Oka 1991, 1995) because these chemicals destroyed beneficial parasites and predators that helped control the brown plant hopper. By 1985 uncontrollable outbreaks of the pest were common, rice yields fell dramatically, and as many as 80 000 hectares of rice had to be abandoned (Oka 1988, 1991, 1997, Resosudarmo 2001, Phanthong and Patterson 2005). The loss of rice in just a two-year period totalled USD 1500 million (Oka 1991, 1995).

Eventually, a control programme for Indonesian rice was developed. The first step was to ban 57 of the 64 pesticides in use for Indonesian crops (Oka 1991, Poapungsakorn et al. 1997, Resosudermo 2001). Also, extension agents were trained to identify and protect beneficial parasites and predators, the overall goal being to treat with insecticides only when necessary since generally brown plant hoppers are effectively controlled by indigenous spiders and other predators (Heinrichs 1991, Oka 1991). Moreover, since insecticides have a greater impact on predators than on the pest, brown plant hopper populations are able to resurge after being sprayed. In the past farmers induced resurgence of plant hopper populations by beginning to spray 40 days after transplanting the rice. However, cage studies showed that smallholders who delayed spraying until 65 days after transplanting saved two insecticide applications and realized a yield increase worth USD 588/hectare (Reichelderfer et al. 1984).

Along with the insecticide management programme for the brown plant hopper, an innovative rice culture programme was implemented. Instead of growing rice year-round, production was restricted to a specified nine-month period of the year, leaving three months when no rice was produced. This three-month gap resulted in brown plant hopper populations declining to extremely low levels before the new rice crop was planted again (Oka 1991, Matteson 2000, van den Berg et al. 2004). This strategy also enabled beneficial predator and parasite populations to increase and help reduce the number of brown plant hoppers. As the numbers of the plant hoppers decreased, the amount of insecticide applied also declined. Equally important, insecticide resistance in the brown plant hopper population also declined. Thus, if and when the brown plant hopper populations reached outbreak levels, insecticides were more effective.

Within five years, total pesticide use fell by 65% and rice yields increased by 12% (Oka 1991, 1995, Resosudermo 2001). These changes in rice production practices in Indonesia based on the ecology of a major rice pest were successfully adapted to an AW-IPM programme.

4.3. Boll Weevil Area-Wide Eradication

For decades, the boll weevil caused more than USD 350 million each year in damages and control costs to cotton crops in the USA (Chenault 2005). However, an area-wide eradication programme was started in 1978 with joint funding from USDA/APHIS (30%) and cotton growers (70%). This programme has proven highly successful (ACRPC 2005, El-Lissy, this volume).

The programme, using annual spraying with malathion and pheromone traps to delimit infestations started in a large region covering about 1.1 million hectares of Virginia, North Carolina, South Carolina, Georgia, and Alabama. Insecticides were applied late in the growing season against weevils still reproducing and those entering diapause, with as many as 15 insecticide applications per year being made against dense persistent populations. Planting by all growers was synchronized and delayed, short-season varieties were grown, harvested as soon as possible, and stalks were destroyed immediately after harvest. Eradication was usually accomplished by the end of the third growing season (Dickerson et al. 2001). About nine years were required to complete this segment of boll weevil eradication (NCC 2005). The second area to be treated included California, Arizona, and New Mexico where the treatment continued from 1983 until 1987 to ensure eradication. The third area treated included the large cotton areas in Alabama and Tennessee and treatment lasted from 1993 until 1994 when the boll weevil was eliminated. The final programme started in 1996 in Mississippi, Arkansas, Oklahoma, Missouri, and Texas (NCC 2005), and is continuing to date. Texas is requiring a major effort because the area is extremely large (5.8 million hectares) and grows more cotton than any other state. Once this project is completed, a barrier will be established and maintained between Mexico and Texas. Concerted efforts will have to continue to deal with any infestation caused by boll weevils getting carried by wind or otherwise into parts of the vast cotton-growing regions of the USA.

Several factors contributed to the successful area-wide control of the boll weevil. Systematic area-wide treatment prevented the possibility of isolated populations of boll weevils surviving in the areas under eradication. Furthermore, malathion is highly effective against the boll weevil and the pest did not evolve resistance to the pesticide. This lack of resistance in the boll weevil contrasts to the housefly *Musca domestica* L. and several other species of insects that have evolved high levels of resistance to insecticides within about eight generations (Pimentel and Bellotti 1976).

4.4. Hessian Fly Control

Wheat was brought to the USA in the late 1600s and is now grown on 30 million hectares. The Hessian fly *Mayetiola destructor* (Say) was first found on Long Island, New York, in 1799, probably having been inadvertently introduced on straw by troops engaged in the American War of Independence (Metcalf et al. 1962). Soon the fly established itself and became a major wheat pest (Pauly 2002, Davis et al. 2004).

In the USA, wheat production includes spring and autumn plantings. Similarly, there are autumn and spring generations of the Hessian fly. Winter wheat, which is planted in September, coincides with the late August emergence of the Hessian fly. The emergence of the Hessian fly is triggered by rains coming in mid to late August. One of the effective controls is an area-wide “fly-free date” which is determined by extension entomologists in each major wheat-growing region (Foster and Hein 1998, PSU 2005).

After the flies emerge and die, the farmers then plant their winter wheat. The prime challenge is to plant the wheat early enough that the wheat germinates and starts to grow before the growing season ends due to the increasingly cold temperatures.

Another generation of the Hessian fly emerges in spring. Again extension entomologists observe the emergence of the fly, usually about April, and a designated fly-free date is established for farmers to plant spring wheat. Again timing is crucial, as late planting in the spring may reduce yields (Foster and Hein 1998).

A second strategy is to plant Hessian fly-resistant varieties of wheat (Gallun et al. 1975, ACES 2005). Because Hessian flies develop resistance to the resistant wheat varieties in four or five generations, a new genotype of resistant wheat must be planted in the region every five years.

Although several parasitic wasps attack the Hessian fly and help reduce its numbers, they cannot be relied on to provide effective control. Also, the extensive use of insecticides is not recommended because they are costly.

Numerous other area-wide environmental controls are available for farmers to implement, including burying all wheat stubble after harvesting and destroying any volunteer plants that grow. However, the most economical and effective controls for the Hessian fly are establishing area-wide "fly-free dates" combined with the planting of Hessian fly-resistant wheat varieties.

4.5. Wheat Aphid Control

The Russian wheat aphid *Diuraphis noxia* (Kurdj.) and the green bug *Schizaphis graminum* (Rodani) are major pests in the wheat-growing region of Oklahoma in the USA (Wright 2005). The Russian wheat aphid invaded Texas in 1986, spread rapidly across the Great Plains, and proved difficult to suppress. The green bug, native to Europe, was first reported in Virginia in 1882 and because of its capacity to disperse and its great prolificacy it has become a key pest of wheat, sorghum and barley. Both species have a considerable capacity to develop new biotypes that can overcome resistant cultivars of wheat (Porter et al. 1997, Burd et al. 1998).

To help control these pests, the USDA designated a six-state area in the region around Oklahoma for their area-wide control. First, an effective educational programme was started to provide farmers with detailed information concerning the ecology of the pests. The control programme includes the planting of aphid-resistant varieties and applying insecticides only when treatment is required.

Both types of area-wide control have been successful in preventing Russian wheat aphid and green bug populations from reaching the high levels of infestations that cause major economic losses to the wheat crop.

4.6. Area-Wide Control of Corn Pests: Past and Present

Not all pest control projects (even those including area-wide management) are successful, one example being with corn in the USA when several changes occurred in corn production following the passage of the 1950 Farm Bill by the United States Congress.

The 1950 Farm Bill legislation provided commodity price support for corn, wheat, peanuts, cotton, and several other crops (NAS 1989). However, the bill stipulated that only a single crop could be grown if the farmer was to receive commodity price support, forcing many farmers to raise only one crop and abandon crop rotations. This change in corn production was followed by increased insect, plant pathogen, and weed problems for corn and other crops, plus greater use of pesticides and fertilizers (NAS 1989).

In 1945, no pesticides were used in corn production (Pimentel et al. 1991, Pimentel 1997). Today, corn receives significantly more insecticide and more herbicide than any other crop grown in the USA (USDA 2004). Specifically, corn production now uses a thousand-fold more insecticide than in 1945, while at the same time crop losses to insects have increased nearly four-fold from 3.5 to 12% today (Pimentel 1997). The main reason for the increased crop losses due to insects is that now only half of the corn area is grown in rotation, the other half being grown as corn-on-corn (USDA 2004). This continuous corn production has increased insect pest problems, primarily the corn rootworm complex (northern corn rootworm *Diabrotica barberi* Smith and Lawrence, western corn rootworm *Diabrotica virgifera* LeConte, Mexican rootworm *Diabrotica virgifera zea* Krysan and Smith, and southern corn rootworm *Diabrotica undecimpunctata howardi* (Barber)), as well as other insect pests, all of which require insecticide treatments. The corn rootworm complex is among the most economically and environmentally damaging insect pest problem of corn production systems in the USA. Annually, crop losses and control costs attributed to the corn rootworm complex approach USD one billion (Gray 1999, Tollefson and Levine 1999) and ten million hectares of corn are treated with soil insecticides to protect the crop from larval feeding damage.

The changes in agricultural technology of corn production fostered by the 1950 Farm Bill have had numerous other negative impacts including: increased insecticide and herbicide use causing chemical pollution of ground and surface waters; increased soil erosion and soil infertility; increased use of nitrogen fertilizer caused in part by leaching in rapid water run-off from the corn fields and resulting in increased pollution of waterways as far downstream as the Gulf of Mexico; increased dependence on fossil energy; and increased water, air, and soil pollution from animal wastes as a result of livestock once produced on grain-farms being transferred to large livestock feeding units.

The rotation of corn with soybeans, wheat, and other non-corn crops reduces several insect pests of corn, including: the corn rootworm complex, corn root aphid *Anuraphis maidiradicis* (Forbes), corn leaf aphid *Rhopalosiphum maidis* (Fitch), and fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Wright 2005). Corn rotation with other non-host crops also helps reduce plant pathogens and weed pest pressure. With reduced pest problems because of crop rotations, corn yields increased about 8%; which compares favourably with the ineffective results of recommended insecticide treatments (Pimentel et al. 1993).

Populations of the European corn borer *Ostrinia nubilalis* (Hübner) are not reduced significantly by rotations because this species can fly long distances. When the European corn borer arrived in New England in 1917 from southern Europe, it caused complete crop loss in early-planted sweet corn. Between 1948 and 1958, this invasive species became widely established west of the Mississippi River and caused enormous losses of corn (Metcalf et al. 1962). A major effort led by the USDA failed to eradicate the pest (Klassen 1989), while the numerous species of natural enemies of the pest introduced from abroad have provided only marginal control (Bradley 1952). However, the assiduous effort to develop resistant hybrid corn has gradually but decisively reduced the destructiveness of this pest (Brindley and Dicke 1963, Brindley et al. 1975, Gallun et al. 1975). Currently only about 10% of the corn area is treated with insecticides for the corn borer. One difficulty in treating for the corn borer is that the treatment has to be perfectly timed to kill the larvae just after they hatch and before they bore into the corn. Once inside the corn, the young larvae are not susceptible to insecticide treatments.

Recent changes in corn rootworm population behaviour are now severely hindering the utility of traditional corn rootworm management approaches. These include increased incidence of extended diapause in northern corn rootworm populations (eggs remain dormant for an entire year), insecticide resistance in Nebraska western corn rootworm populations, and western corn rootworm adaptation to crop rotation strategies in Illinois, Indiana, and Ohio. As a result, there is a need to develop an area-wide approach to protect corn production across the country.

In order to determine whether rootworm populations could be strongly suppressed and the use of soil insecticides reduced by using the adult rootworm attractant, cucurbitacin, in an aerially applied bait, a pilot area-wide programme was conducted from 1997 through 2001 by the USDA in cooperation with five Land Grant universities in corn-producing states (Chandler 1998, 2003, Parimi et al. 2003, Chandler 2005). Individual fields were aerially sprayed with the baited insecticides when the number of corn rootworms captured in yellow sticky traps reached a set threshold. Suppressing adult rootworms minimized the number of eggs laid and resulted in fewer larvae available to damage corn roots in the following growing season.

5. Challenges of Insect Invaders

Worldwide, the movement of exotic insects, mite species and plant species from one ecosystem to another is a continuing problem for all agriculturists dealing with pest control (Pimentel et al. 2000). Borders are becoming increasingly irrelevant in the context of international travel and trade, and this facilitates the movement of invasive species (National Plant Board 1999). Technological advances in transportation in recent decades also actually facilitate both the survival and successful colonization of invasive species. The volume of air cargo of perishable agricultural commodities such as cut flowers, fruits and vegetables as well as the rate of arrival of damaging species at ports of entry in the USA is doubling every five to six years (Zadig 1999, Klassen et al. 2002). Frank and McCoy (1992) found an average rate of establishment of exotic arthropods species in Florida of 14.2 per year, and Thomas (2000) listed 150 exotic arthropod species that had been established in Florida from 1986 through 2000.

As noted by Evans (2004) there is growing concern with regard to the level of resources that countries now have to put aside to address this growing problem. For example, the average annual spending of APHIS on its emergency programmes for the period 1989-2002 rose exponentially from about USD 6.4 million in 1989 to USD 334.8 million in 2001, which is not sustainable. Also, new technologies needed to combat invasive species cannot be developed with sufficient rapidity to meet this challenge.

The damage caused by invading insect pests that attack established crop, forest, and natural ecosystems is enormous (Pimentel 2002). For example, approximately 40% of insect and mite pests of crops in the USA are introduced species. Yearly they cause about USD 10 000 million in crop damage and control costs. The most recent introductions include the long-horned beetle *Anoplophora glabripennis* (Motschulsky) and the emerald ash borer *Agrilus planipennis* Fairmaire that were both accidentally introduced from Asia. The long-horned beetle is now destroying maple trees, while the emerald ash borer is killing ash trees in the same region (Hoebeke 2004). Area-wide strategies to control these destructive pests are being implemented because they are major threats to valuable tree species in the North American forest ecosystems.

Although port-of-entry inspection is important, it must be greatly augmented with a risk-based management strategy that requires mitigation of pest risk at origin, i.e., where the commodity to be imported is being produced. Risk mitigation conducted at origin assures that clean products arrive at the port of entry (McDonell 2004). An important approach to offshore mitigation is the creation of pest free areas. Indeed countries, which export raw agricultural commodities, can effectively remove the threat of exotic pests to the importing country by creating and maintaining pest free areas of production (Malavasi et al. 1994). According to the FAO, a pest free area is:

> *An area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained (FAO 2005b).*

There are two officially recognized situations where a pest free area can be applied: (1) large geographic areas, such as the entire country of Chile that is certified free of fruit flies of economic importance and where this condition is officially maintained (FAO 1996), and (2) pest free places of production or production sites (a defined portion of a place of production) in which a specific pest does not occur and in which this condition is officially maintained. In contrast with the pest free area, in this case, the condition is maintained for a defined period and the area is managed as a separate unit (FAO 1999). To facilitate this approach the Secretariat of the International Plant Protection Convention has developed International Standards for the establishment and maintenance of pest free areas.

Requirements to establish pest free fields of crop production include a sensitive detection programme, suppression of the quarantine-significant pest to non-detectable levels, strict control of the fields, and safeguards to prevent infestation during packing and transit to the port of export (Riherd 1993, Malavasi et al. 1994). Florida is able to export grapefruit to Japan by creating pest free grapefruit groves in about 22 counties. Regulatory experts from Japan inspect the entire process of production, packing and transit. By 1980, Chile had succeeded in eliminating the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) and since then Chilean fruits in huge volumes have entered the markets in the USA without the need for any quarantine treatments. Likewise the Mexican States of Baja California, Chihuahua and Sonora have been freed of all economically-important species of fruit flies, so that citrus, stone fruits, apples and vegetables are being exported from these states without any postharvest treatment.

6. Conclusions

Balancing the production of an adequate food supply against the basic needs of humans to sustain their nutritional needs will become more difficult in the coming decades. Fortunately the development of successful pest control operations is improving, especially those based on area-wide interventions. Yet, with all control projects, the basic ecology of the pests, the role of biological control and the safe use of insecticides must be major factors in the development of all pest management programmes. Insect control tactics applied on an area-wide basis have a number of advantages (Klassen 2005), including the use of approaches that may prevent or retard the development of insecticide resistance. In addition, area-wide approaches offer the potential to take advantage of methods friendly to the environment (SIT, parasitoids, semiochemicals, mating inhibitors, etc.) which cannot be applied on a farm-by-farm basis and which all contribute to the reduction of the use of broad-spectrum insecticides.

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