Past, Present and Future Strategies in Management of Insect Pests

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When first approached about contributing to this symposium on "New Frontiers in Plant Protection", I considered that it would be worthwhile to give an overview of pest control practices in Saskatchewan past and present, and then try to foresee the direction pest management may take in the future. In my view, the story of insect pests and methods to combat them has been one of continuous evolution in approaches and practices. There were periods when prospects for control were drastically altered and outlooks interrupted, as for example by the introduction of synthetic pesticides. However, this in turn gave way to a more logical and progressive approach, both to pest problems and to problems generated by the introduction of the pesticides.

PESTS AND PEST CONTROL IN THE EARLY YEARS

At the turn of the century, agriculture development was just beginning to expand with the rapid settlement that occurred at that time. Great increases in wheat acreages took place during the first two decades of 1900 (Table 1), expanding from about 2 million to over 10 million acres by 1920. This explosion in agricultural development was accompanied by the build-up of several serious pests which by 1920 were inflicting heavy losses. These were grasshoppers, wheat stem sawfly, cutworms and wireworms. Except for the wheat stem sawfly, these are still our major pests today.

Grasshoppers - The association between farmers, grasshoppers and cereal production has been a long, expensive struggle. Grasshopper populations did not increase simply in response to the availability of food, since dense populations were observed before much agricultural development had occurred. Riegert (1980) chronicles the first impressions of the early explorers when they encountered "hordes" of grasshoppers in the pre-settlement era. One of the first outbreaks associated with crop production occurred from 1898 to 1904, the next from 1919 to 1923.

The outbreak of 1919 to 1923 saw the first concerted efforts of grasshopper control; this was primarily the use of poison baits prepared by mixing paris green with horse manure. Other outbreaks followed, the longest and most severe being during the thirties. Annual surveys were initiated in 1932 and have been part of the grasshopper program ever since. Forcasting for damage potential, cultural practices (tillage to destroy eggs), physical methods (hopperdozers) and poison baits were the main lines of defense.

Table 1. Wheat acreage in Saskatchewan (millions of acres or hectares).

Year	Acres	Hectares
1900	2.0	0.81
1905	2.5	1.01
1910	4.0	1.62
1915	9.0	3.64
1920	10.2	4.13
1925	12.8	5.18
1930	14.8	6.00
1935	15.0	6.08
1940	16.5	6.68
1945	13.6	5.51
1950	15.7	6.36
1955	13.1	5.31
1960	14.8	6.00
1965	17.8	7.21
1970	5.5	2.23
1975	12.7	5.14
1980	14.8	6.00
1983	17.8	7.20

Source - World Grain Exhibition and Conf. I, 1933.
Statistics Canada (Canadian Bureau of Statistics Rept.)

Although grasshopper control was a difficult operation during the thirties, it was well organized and baits were effective. In 1933, the Saskatchewan Department of Agriculture purchased 4550 tons of bran and oat hulls, 52 car loads of sawdust and 32,410 gallons of sodium arsenite, enough to treat 29 million acres (Riegert 1980). The arsenicals were the principle toxicants, and were used in baits until the introduction of the organochlorines.

Wheat stem sawfly - The wheat stem sawfly (Cephus cinctus Nort.), which had previously fed on native grasses, readily adapted to wheat and became widespread and destructive across southern Manitoba and Saskatchewan by 1920. This pest remained a problem until the late 1940's when a resistant variety was introduced. Although cultural methods such as guard strips and rotation were used for control, these methods were only partially effective. The sawfly story is, however, one of the great successes in plant-insect resistance research. A breeding program initiated in 1931, involving the Swift Current and Lethbridge Research Stations, led to the development of the sawfly resistant variety "Rescue" by 1946. Although the program took many years, the ultimate long-term benefits are obvious.

Cutworms - The most important cutworm species on cereal crops were the pale western cutworm (Agrotis orthogonia Morr.) and the red-backed cutworm (Euxoa ochrogaster (Guen.). Use of poison baits was attempted against the pale western larvae but was ineffective since this species did not come to the soil surface as did many other species. Biological studies showed that females would not lay their eggs in summerfallow fields that were allowed to crust over. This practice, along with starvation of young larvae in the spring, became important cultural controls for pale western; they are still recommended to suppress population increases of this pest today.

Poison baits were partially effective against red-backed cutworm because of their habit of moving on the soil surface. However, use of another cultural method, that is, destruction of all weed growth in summerfallow, prevented egg-laying and became a standard practice in the pre-organochlorine era.

Wireworms - The prairie grain wireworm (Ctenicera destructor (Brown)) was indigenous to native grassland, but thrived in lands planted to wheat and other cereals. It was common during the 30's and 40's for cereals to be so severely thinned that re-seeding was necessary (King et al. 1933). In 1946, Arnason and McDonald (1947) estimated the monetary loss due to wireworms at 17 million dollars. Summer fallowing and shallow tillage were recommended to reduce the level of damage but this did little to reduce wireworm populations (King et al. 1933). Prior to 1946-47, wireworm control with chemicals was not effective. Seed treatment was of no value and had no prospect of success (Arnason et al. 1949).

INTRODUCTION OF THE ORGANOCHLORINES

Generally we must conclude that insect control, prior to the advent of the organochlorines, was a difficult and tedious operation, providing a much lower level of control than we expect at present. Sound cultural practices were developed that helped to suppress pest populations and damage. Many of these are still of value today. Except for the poison baits for grasshoppers, chemical controls were ineffective for the main crop pests.

The introduction of DDT and the organochlorines in the mid-late 1940's revolutionized pest control and pest control expectations. Against wireworms, for example, BHC gave spectacular results. Burrage (1956) stated that "development of effective seed treatments for wireworm control constitutes one of the most important recent advances in wireworm research." Rates of BHC of 1 ounce per acre reduced wireworm populations by 75 percent (Arnason et al. 1949). The same levels of control were observed for grasshoppers (Cowan 1958) and for many other insects (Lilly 1956). Great benefits were derived from the use of these insecticides, by controlling both agricultural pests and those of medical and veterinary importance.

They were cheap and effective and eliminated the need for many of the earlier biological and cultural controls (Muir 1978). In the United States, large amounts of the organochlorines were used for control of corn insects often as "insurance treatments" (Lilly 1956).

NEED FOR ALTERNATIVE CONTROL STRATEGIES

The heavy pesticide use during the 1950's and 1960's, with the persistent organochlorines, resulted in a number of problems, including insect resistance (Metcalf 1980; Georghiou and Saito 1983), negative effects on non-target organisms (Ripper 1956; Johanson 1977), environmental contamination (Gunther and Blinn 1956; Klein 1974; Anonymous 1975), emergence of secondary pests (Smith 1970) and pest resurgence (Lord 1947, 1949; Huffaker and Kenneth 1953).

By the 1960's, these problems led to the advocation of an integrated pest control approach where both biological and chemical agents could be integrated to give complementary controls. The term 'Integrated Pest Management' arose during the early 1970's and has essentially the same connotation as integrated control.

The main components of a generalized insect pest management system for crops are: chemical, biological, varietal resistance and cultural. Monitoring for pests and establishing economic thresholds of pest numbers and their damage potential are key factors in any IPM program. The economic threshold has been defined as "the density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level" (Stern 1973). In general, economic thresholds are only approximations because of the paucity of information on relation of pest density to damage. As such, they require a great deal of research so that rational decisions on the need for control measures may be made. Thresholds are not static but dynamic, and depend upon a number of factors, including pest density, crop growth conditions and potential economic return. The decision to use an insecticide should be determined by the cost/benefit ratio, that is, the cost of the control measure in relation to the increased value of the crop that can be recovered or protected (Stern 1973). Progress is being made, and with continuous refinement in thresholds, realistic figures for damage potentials at particular pest densities and under particular conditions of plant growth will be obtained.

Accurate pest monitoring is necessary to develop damage thresholds. There are many methods available. Those that depend upon the activity of the insect pest include light trapping, water traps, sticky board traps, pitfall traps and pheromone traps. Quantitative methods measure the density per unit area and make use of various types of sampling devices. Pheromone traps have proven extremely useful for monitoring because of their specificity for particular species. Tremendous progress has been made during the past 10 years in the identification, synthesis and practical use of pheromones for pest monitoring.

Considering the main component of IPM again, I would like to stress the chemical and the biological aspects, because of their immediate importance in control programs and because of the importance of using them in a complimentary manner.

INSECTICIDES FOR DIRECT CONTROL

The main groups of insecticides used for direct control are organochlorines, organophosphates, carbamates, pyrethroids, insect growth regulators and the bioinsecticides such as Bacillus thuringiensis (BT). Unfortunately, insects have, or are able to develop, resistance to all these groups except to BT. The problem of resistance will continue to influence our pest control strategies as long as we use chemicals to protect crops. Therefore, I would like to comment further on the magnitude of the resistance problem.

Resistance is not limited to insects and mites, but occurs with bacteria, protozoa nematodes, plants and mammals. The potential of a new compound for developing resistance becomes a crucial consideration in the market assessment of a new product by industry (Georghiou and Mellon 1983). Costs of developing a pesticide are said to have increased from 10 million dollars in 1970 to more than 20 million in 1980 (Braunholtze 1981). Approximately 15000 compounds had to be screened for one commercial success in 1975 as compared to 1800 in 1956.

By the end of 1980, there were 428 resistant species of arthropods compared to 224 in 1970 (Table 2), (Georgiou and Mellon 1983). Of these, 61 percent are of agricultural importance and 39 percent of medical importance. Worldwide pesticide sales, including fungicides and herbicides, have increased from 1.1 billion dollars in 1960 to almost 10 billion by 1979, indicating the tremendous selection pressure populations have been under during that 20 year period. Resistance to specific pesticides and cross resistance are seen within and between all major groups of insecticides (Table 3), (Georgiou and Mellon 1983).

Therefore, as well as using pesticides to minimize environmental side effects, it is essential to both agriculture and industry that they be used as far as possible to delay the onset of resistance. As indicated by A. W. A. Brown (1976), (cited in Georghiou 1983), we need pesticide management as much as we need pest management.

Table 2. Approximate numbers of pesticide resistant arthropods, plant pathogens, weeds and nematodes, 1940-1980.

YEAR	NEMATODES	WEEDS	PLANT PATHOGENS	ARTHROPODS
1940	-	-	-	5
1948	-	-	-	12
1951	-	-	-	16
1954	-	-	-	25
1957	-	-	5	76
1960	-	-	10	159
1968	-	-	25	224
1976	-	-	75	268
1980	2	5	91	428

(After Metcalf 1980; Georghiou and Mellon 1983).

Table 3. Numbers of species of pesticide resistant arthropods, 1970-1980.

	1970	1980
Species with reported resistance	224	428
By pesticide group		
DDT	98	229
Cyclodiene	140	269
Organophosphate	54	200
Carbamate	3	51
Pyrethroid	3	22
Fumigant	3	17
Other	12	41
Total all groups	313	829

(After Georghiou and Mellon 1983).

Considering insecticide use, there are a number of ways to reduce selection pressure and coincidentally reduce the impact on the non-pest crop fauna (Glass 1975; Metcalf 1980; Georghiou 1983; van Emden 1982). These include the following:

- choice of active ingredient and formulation;
- choice of application method and insecticide placement;
- consideration of dosage reduction;
- restriction of portion of crop treated;
- raising economic thresholds;

- interact insecticides with tolerant varieties;
- use of alternate insecticides.

I will discuss these briefly and where possible give some examples of these approaches from research in progress in Saskatchewan.

Choice of active ingredient - Generally the efficacy of the chemical will have been established against a particular pest. However, choice of an insecticide may not depend solely on its toxicity, but should also consider its effectiveness within the IPM program. How does it affect non-target species such as pollinators? Does it have selectivity for natural enemies of the pest if these are known?

Stern et al. (1960) evaluated the toxicity of six insecticides to six species of predator insects in California. Parathion and DDT were generally highly toxic to all six species of predators; toxaphene somewhat less toxic, carbaryl (Sevin) toxic to three species, heptachlor moderately toxic to two, and trichlorfon (Dylox), least toxic to all predators.

The bioinsecticide BT may have particular application in some situations because of its selective toxicity for lepidopterous pests and not for their parasites. Wide spectrum insecticides must be used with caution because of effects on organisms other than the pest. Pyrethoids have the advantages of high toxicity at low dosages and low-mammalian toxicity. However, their use in IPM programs must be carefully considered because of their high toxicity to fish and aquatic invertebrates, and generally wide spectrum of activity to insects (Metcalf 1980).

Application method - What application methods give adequate control but have the least environmental impact? For example, if the pest species is a sucking insect such as an aphid, a systemic insecticide might be used as a seed treatment. This would mean less insecticide applied, less danger to beneficial insects and less cost than a general application. Seed treatments markedly reduce the amount of toxicant per hectare and are more selective for the pest involved.

Use of poison baits also reduces toxicant per hectare and if the bait is fed upon only by the pest being controlled, danger to other arthropod fauna is eliminated. Recently Mukerji et al. (1981) have shown that dimethoate-treated bran for grasshoppers gave 70% mortality, while 4-6 times this amount as a spray would be required to obtain 90% mortality. In many cases, 70% mortality is sufficient to keep populations below the economic threshold. In addition, baits would be less likely to be toxic to predators or parasites.

Time of day of application - Many pests and beneficial insects may position themselves on plants or enter fields at different times of the day so if possible, spraying or other control measure should be done to give the pest maximum exposure and the non-target species least exposure. Recommendations for plant bug control in Saskatchewan state that Dylox be applied only in early morning or evening to crops in bloom to avoid toxicity to pollinators (Craig 1973).

Dosage reduction - In some cases it may be possible to reduce the amount of insecticide used and still achieve acceptable levels of control, particularly when insecticides are used in conjunction with other methods. This may have the added advantage of preserving natural enemies and leaving a residue of the pest so that the natural enemy populations are sustained.

Restrict treated area - Some IPM specialists (van Emden 1982) advocate that a small portion of the crop be left untreated as a natural enemy refuge. Also hedge rows and windbreaks may act as refuges for natural enemies and general beneficials. The effect of leaving such refuges seems largely untested however, and needs to be demonstrated experimentally.

Raise economic thresholds - More study is needed to determine realistic economic thresholds as I indicated in an earlier section. Often crops can sustain considerable damage and show little or no yield decrease. In the United States it has been shown that soybeans can suffer considerable damage by insects without adverse effects on yield or quality. This has allowed establishing economic thresholds three to ten times higher than in earlier years (Newsom 1978).

Interact insecticides with tolerant varieties - According to van Emden (1982) there are many commercial varieties that have some degree of resistance or tolerance to specific pests. Insects on partially resistant plants have a lower tolerance to pesticides. Leaf-hoppers on partially resistant plants required 30% less insecticide than those on a susceptible variety (Raman 1977 as cited by van Emden 1982).

Alternate insecticides - Alternating conventional insecticides with bioinsecticides to delay the onset of resistance may be possible with some insects, especially lepidopterous species. Pesticide mixtures and using pesticides in rotation has also been considered for delaying resistance (Georghiou 1983). However, this approach will need a great deal of research before specific recommendations arise.

BIOLOGICAL CONTROL

Biological control should be applied to suppress populations and, along with other methods, result in stabilization of pest populations below the economic threshold. Biological controls within IPM programs may involve the introduction of parasites of predators from other countries or identification, preservation, and in some cases augmentation of natural or indigenous control agents.

Viruses, bacteria, fungi, protozoa and nematodes that attack insects may also be employed as biological control agents. It is not possible in a discussion such as this to cover all these aspects, but I will mention three areas of research of biological control being conducted at the Agriculture Research Station in Saskatoon.

Parasites from Europe are being evaluated for their control of the alfalfa plant bug (*Adelphocoris lineolatus (Goeze)) and the bertha armyworm (Mamestra configurata* Wlk.). These are collected in Europe through the cooperation of the Commonwealth Institute of Biological Control.

In Europe and other regions of Canada, carabid beetles, commonly known as ground beetles, have been shown to be predators of crop pests (Wishart et al. 1956; Fox and MacLellan 1956; Frank 1971). Little is known about the non-pest and predatory fauna in Saskatchewan, although carabids are known to attack and consume eggs of grasshoppers and wireworms. The initial stage of work on this aspect is to identify the non-pest fauna and determine their importance as predators. Research is in progress at the Saskatoon Research Station to identify the predators of wireworms in cereal crops and of flea beetles and other Canola pests. An extension of this work will be to determine the effect of insecticides on the major predators and where possible, select those insecticides that give adequate control but are least toxic to natural enemies.

The feasibility of using the microsporidian, *Nosema locustae*, for suppression of grasshopper populations has been under study for several years. Field experiments by Ewen and Mukerji (1980) showed that 50 percent of the grasshoppers of three species were affected 5 weeks after application of the pathogen. By 9-12 weeks up to 95 to 100% infection was evident. Reproductive capacity of two of the species was also lowered in plots treated with the pathogens. In cooperation with the Soil Science Department, University of Saskatchewan, studies on this pathogen continue, with emphasis upon the relation of *Nosema* to the soil ecosystem and survivability of spores in soil.

FUTURE PROSPECTS

What are the future prospects for insect pest management in the next 10 years. In my view we will see a steady evolution in entomological research and in integrated pest management strategies. We need to refine our methods and attitudes toward IPM and its implementation. We need better pest monitoring, realistic economic threshold levels, and more knowledge and application of biocontrol. Certainly well established cultural methods of insect pest suppression will also form part of IPM. It will be necessary to test and evaluate IPM programs and then if they prove practical, convince the farmer-producer of their worth.

New pesticides - Certainly conventional pesticides and pesticide research will continue to form a major part of IPM systems. The insect growth regulators, sometimes called the third generation insecticides, should see increasing application in coming years. These compounds act on the insect endrocrine system to prevent maturation, or in the case of the anti-juvenile hormones, or hormone mimics, induce premature maturation. Thousands of juvenile hormone analogs have been synthesized, described and evaluated. Many have excellent activity to produce extra moults. However, production of extra instars is not always an advantage if they cause more damage than the untreated pest. Another problem, lack of stability in the field (Bower 1982), will have to be overcome before these compounds have general application for agricultural pests.

Diflubenzuron, a benzoylphenyl urea, has promise as a selective insecticide and displays low mammalian toxicity. This material has both larvicidal and ovicidal activity. In larvae it inhibits moulting through interference with chitin synthesis. Particularly high activity is shown against dipterous insects and some lepidopterous pests of crops and forests (Grosscurt 1978).

Continued research into the bioinsecticides, particularly *Bacillus thuringiensis* will no doubt increase the range of species susceptible to this material. Development of new strains and isolation of specific toxins may enhance its control spectrum. Even now, this is the most common microbial insecticide in the United States where over 1.5 million acres were treated by the mid-1970's (Longworth and Kalmakoff 1982).

Behavior modifying chemicals - There are many chemicals that affect the behavior of insects. Some are synthetic chemicals, some are produced by plants and some are produced by insects. They are classified as attractants, arrestants, feeding stimulants, egg-laying stimulants, repellents and antifeedants. Some chemicals in plants also have direct toxic effects, or inhibit growth, or act as hormone mimics to disrupt maturation or development.

Probably the best known behavioral modifying chemicals are the sex pheromones. Personnel at the Prairie Regional Laboratory and the Agriculture Research Stations at Saskatoon and Lethbridge have made significant contributions to the world fund of information on pheromones during the past 10 years. At present, pheromones are used mainly for monitoring, but in future, more use will be made of these chemicals and chemical complexes as mating disruptants to lower reproductive potential of the pest populations. In Saskatchewan mating disruption experiments have already had success experimentally for several insects, including diamond-back moth (Plutella xylostella (L.)) and the forest tent caterpillar (Malacosoma disstria (Hubner)) (Palaniswamy, P. et al. 1983; Chisholm et al. (in press).

Secondary plant substances may attract insects to a food source, or to egg-laying sites, or may protect the plant by acting as a repellent or antifeedant. Obviously these characteristics of plant chemicals have potential for selecting for plant resistance to insects. Presently the research input into behavior modifying chemicals in Saskatchewan and Canada is at a low level. Similiarly, very little is being done on plant resistance even though this would appear to have particular significance as a long-term strategy for pest management. In my view, research into behavioral modifying chemicals and plant resistance would eventually be an excellent investment and is well worth considering in setting our research priorities.

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