Pesticides ~ the pests are fighting back

Malaria has staged a disturbing resurgence in many tropical countries recently. In India, for example, the number of reported cases fell from 100 million in 1952 to just 60 000 in 1962, but had risen again to 6 million by 1976. A large part of the cause of the disease's comeback is the development by malaria-spreading mosquitoes of resistance to insecticides used in control programs.

Throughout the world, resistance of pests to pesticides is causing growing concern. To some extent the problem is one of economics, as pesticides brought in to replace chemicals made ineffective by resistance are often more expensive than their predecessors. But there is always a risk that no satisfactory alternative will be available when a resistance problem arises, or that the alternative will be considerably less satisfactory than the chemical it replaces.

The debut of the cheap and potent insecticide DDT during World War II marked the beginning of large-scale use of chemical pest killers. More than 1000 different pesticides have since become available, and world consumption now totals something like 700 000 tonnes per year.

The benefits have been great. According to the World Health Organization (WHO), deaths throughout the world from malaria dropped from about six million per year in the 1930s to fewer than a million in 1968 — largely as a result of DDT-spraying programs. Some control has also been achieved over other insect-borne diseases, including encephalitis, yellow fever, and typhus.

The impact on agricultural production is more difficult to quantify, but it is unlikely that food supply could have kept pace with the world's rapidly growing population since that War without DDT and its successors. In Australia, the Pesticides Coordinator with the Commonwealth Department of Primary Industry, Mr Jack Snelson, estimates that the value of farm products would fall by about $600 million if pesticides were not used. Annual expenditure on pesticides in this country is about $50 million.

Problems

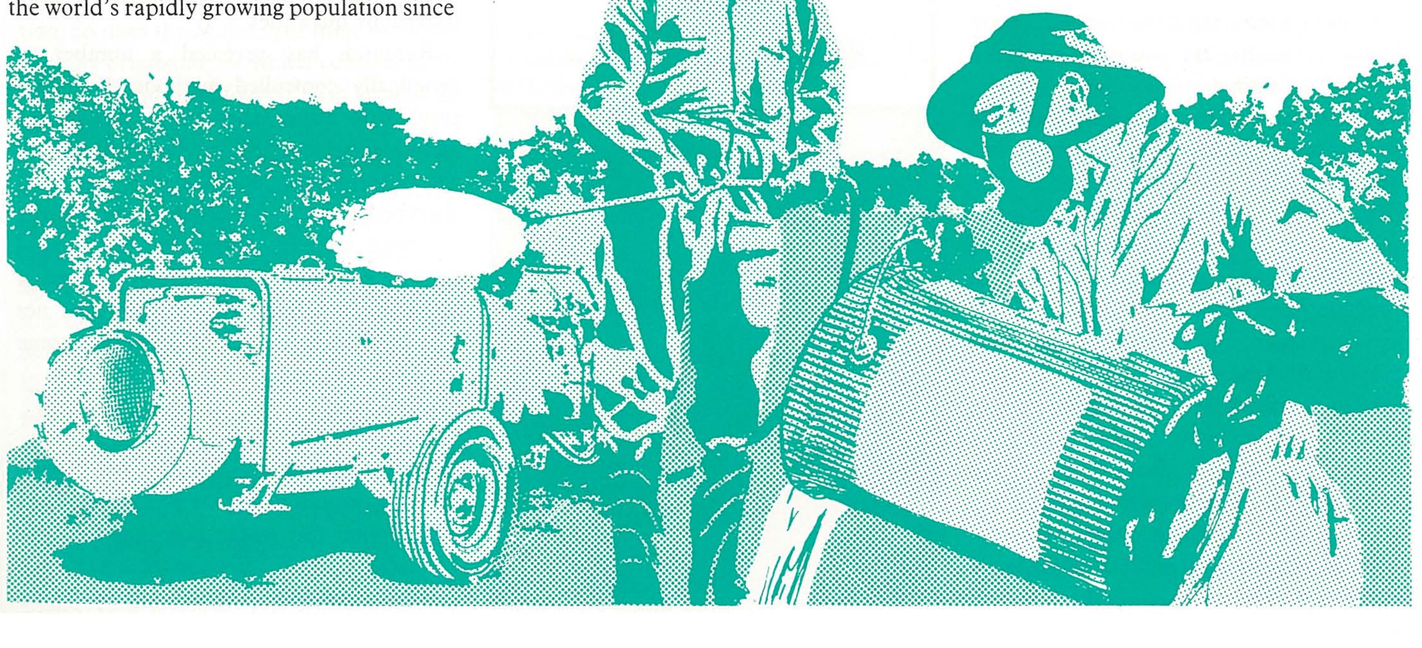
But, of course, pesticides also have drawbacks. Some are deadly poisons and, if not handled with sufficient care, can kill people or make them very sick. These, and some less toxic but more persistent pesticides, can kill birds, fish, and other wildlife — directly or by destroying their food sources. And precautions have to be taken to ensure that food for human consumption does not contain harmful residues.

The development of resistance poses the risk that some farmers, desperate to control pests that are threatening their livelihood, will increase application rates to dangerous levels.

Australia has introduced elaborate procedures, involving both the Commonwealth and State governments, aimed at ensuring that pesticides registered for use are effective and safe if users follow the instructions. Residue limits, designed to give a large margin of safety, are set by the National Health and Medical Research Council, and residues are monitored in more than 20 000 food samples collected each year by the Department of Primary Industry.

Other countries also impose strict checks. One result is that a company developing a new pesticide must do extensive toxicological and other research to ensure that its product meets countries' requirements. This can take up to 8 years and cost more than $10 million. Last year, the United Nations Food and Agriculture Organization (FAO) and WHO convened an international gathering to look at the prospects of achieving greater uniformity among countries in registration requirements. The hope is that this will reduce development costs.

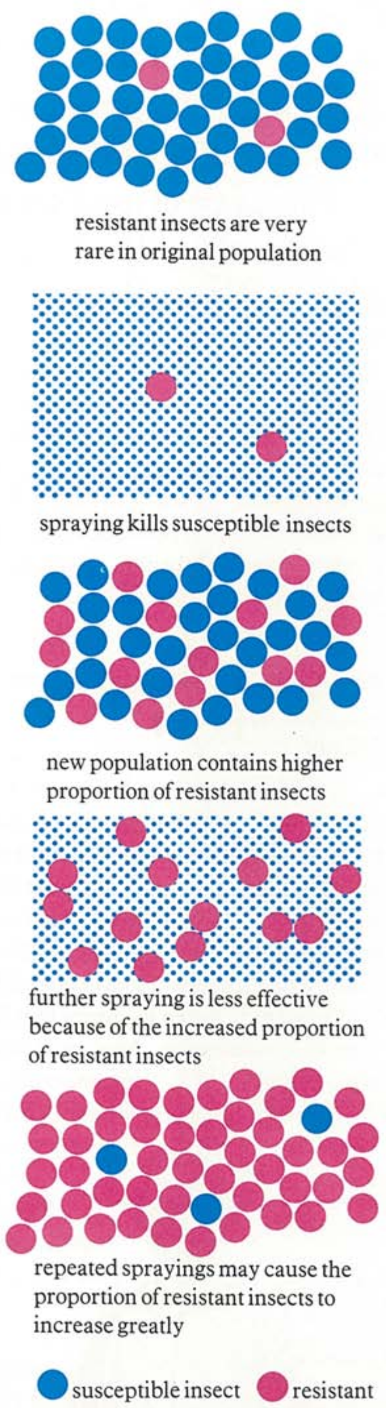
Partly because of the rapid cost increases, the number of new pesticides under development has fallen in recent years. Resistance is also part of the reason; the risk that a product may become virtually useless within a few years or even a few months of its release is a serious discouragement to the development of new pesticides. But new pesticides are essential if the pest control challenges posed by resistance are to be met. It's a Catch-22 situation.



Throughout the world, resistance of pests to pesticides is causing growing concern.

The number of new pesticides under development has fallen in recent years.

How resistance develops




Cotton crops are sprayed many times before harvest.

World surveys

FAO has conducted two world surveys of resistance, and a third is under way. The first, in 1965, found 182 pests that were resistant, or suspected of being resistant, to one pesticide or more. By the time of the second survey, 3 years later, the total had risen to 228. The third survey is expected to show another big increase. In many countries, pests of major crops are among those that have developed resistance.

According to Dr Douglas Waterhouse, Chairman of FAO's Panel on Pest Resistance to Pesticides and Crop Loss Assessment, and Chief of the CSIRO Division of Entomology, the surveys show a correlation between the general level of pesticide usage in a region and the number of resistance problems that have arisen. He says resistance problems of great and sometimes critical importance have arisen wherever pests have been exposed to heavy pressure from pesticides.

Although new pests continue to develop resistance, he regards the spread of resistance — both geographically and in terms of the number of chemicals that can no longer be used safely or effectively for pest control — as a more striking problem.

In 1972–73, Dr Bruce Champ of the Division of Entomology and Mr Peter Dyte of the United Kingdom Ministry of Agriculture, Fisheries, and Food conducted a more detailed survey of resistance in pests of stored grain for FAO. Dr Champ visited 61 countries to collect insects and other pests for resistance tests, which were carried out in Britain. A further 24 countries provided samples for testing.

The scientists found some resistance to the commonly used protective chemical, lindane, in 82 countries. Resistance to malathion, also widely used, showed up in samples from 78. Serious losses of stored grain due to pest attack occur in most developing countries, and growing resistance can only make the problem more severe. FAO recently launched a project aimed at seeing what can be done to improve the situation.

In Australia, 33 pest species had exhibited resistance by the end of 1976 when, with the cooperation of all State Departments of Agriculture, Mr Ray Kerr of the Division of Entomology reviewed the position. This is an increase of 13 over the number of resistant species recorded 8 years earlier. Mr Kerr also recorded 13 cases where resistance problems had spread interstate since the 1968 survey, and four cases of pests showing new forms of resistance.

Evolution

The development of resistant pest strains is a dramatic illustration of Darwinian evolution. Spraying with pesticides creates a new and deadly environment for a pest species. But if a few individuals have an inherited characteristic that enables them to survive the spray, or if mutation produces such a characteristic, then these individuals will produce a new generation and pass on their resistance. Insects and other pest species have great reproductive potential, and numbers can build up from low levels very quickly.

In the absence of pesticides, individuals with the characteristic that confers resistance have no survival advantage over those without it. In the new environment, however, they have an enormous advantage, and a new resistant population arises.

Levels of resistance vary greatly. In some cases they are spectacularly high, with the result that pests are virtually insensitive to a pesticide. Spraying is pointless in situations like that. Even low levels of resistance can cause severe problems. For example, a four- or fivefold increase in the dose needed to control a pest may make spraying uneconomic. Or it may mean that control can be achieved only if the pesticide is used in hazardous quantities.

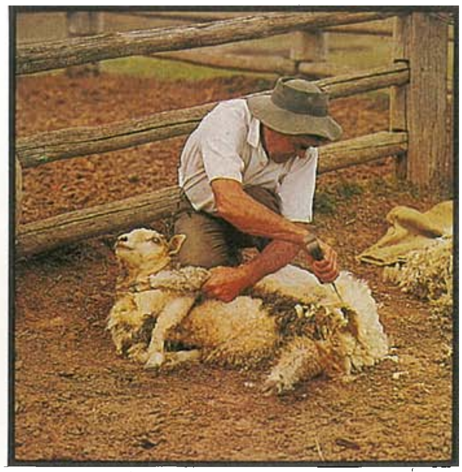
Research has revealed a number of genetically controlled methods that pests employ to resist chemical attack. They include restricting the rate of absorption of a pesticide, detoxification once it has been absorbed, and rapid elimination of the absorbed material. Sometimes pests resist poisoning in more than one way. Strains of resistant houseflies, for example, can not only reduce the rate of absorption of some pesticides but also detoxify them.

The sheep blowfly

Multiple resistance — where pests have been fought with a number of chemicals and have become resistant to more than one — is a growing problem. Even more worrying is the development of cross resistance — where

The sheep blowfly.

Blowfly larvae in a fleece.



A flyblown sheep receives attention.

pests exposed to only one pesticide develop resistance to two or more. Australia's sheep blowfly provides an example. Some strains that had developed resistance to organophosphate insecticides were found to be resistant to carbamates as well, even though these had not been used against them.

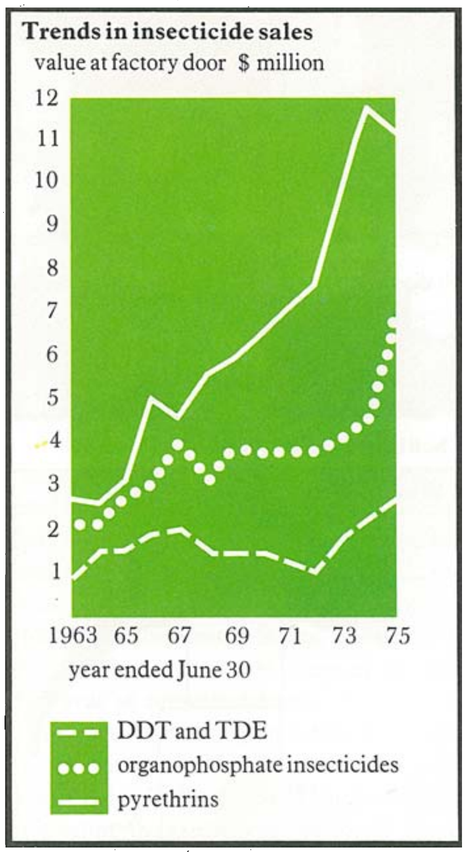
This blowfly's adjustment to chemical attack is one of the four Australian pesticide resistance problems that CSIRO entomologists regard as most serious. The others involve the cattle tick, the cotton bollworm, and ten pests of stored grain.

The sheep blowfly costs the sheep industry something like $30–40 million a year. Flystrike can kill sheep, or cause big losses of wool. The trouble begins when female flies deposit clusters of eggs in the fleece. These produce larvae that break the sheep's skin and feed on fluid from the wound. Sometimes more flies lay eggs nearby, and the wound may spread until it kills the sheep.

Farmers achieve considerable control of flystrike by performing operations that reduce moisture retention in the fleece. Flies are attracted by moisture, and their eggs require it if they are to hatch. The routine practice of crutching provides much protection. So does the Mules operation — named after its originator — which consists of the surgical removal of folds of skin around the breech in ewes.

But these operations do not entirely prevent flystrike, and a succession of pesticides has been used over the years to give greater control. In the 1930s some farmers used arsenic-based chemicals, but jetting these into the wool gave no more than 5 weeks' protection. DDT was used after the war, until dieldrin and aldrin appeared in 1955 and proved cheaper and easier to apply. But 2 years later, resistant strains of the blowfly appeared, and resistance spread rapidly.

Farmers then turned to organophosphorus insecticides, particularly diazinon, and to a lesser extent to carbamates. Low levels of resistance appeared in



These figures, from the Bureau of Statistics, show the increased importance of pyrethroid insecticides. It should be noted that the values are not corrected for inflation.

Cattle in the Queensland tropics, where ticks are a major pest.

the late 1960s, reducing the period of protection from about 12 weeks to less than 4. All mainland sheep-producing areas are affected, but so far the organophosphates have maintained their effectiveness in Tasmania.

The search for a safe alternative insecticide giving lasting protection has not succeeded yet. Researchers are also looking at other possible control methods, notably genetic control. On the West Indian island of Curacao, scientists have attacked a blowfly species by releasing sterile male flies into the wild population. The Division of Entomology is examining the prospects of using a similar strategy against the sheep blowfly.

Cattle tick

The cattle tick, which causes serious losses to the beef industry, has developed resistance to a string of pesticides over the years. One tick can suck as much as 3 ml of blood from an animal, and infestation reduces cattle growth rates. Ticks also spread a disease known as tick fever.

The first recorded use of a pesticidal dip to control the cattle tick dates back to 1895, when farmers in Queensland applied an arsenic preparation. Resistance to arsenic seems to have appeared about 1936; that is when complaints about the failure of dipping to kill ticks began to be heard. Farmers could not attack the problem by increasing doses, as just a doubling of the dose rate was enough to scald the animals' hides.

DDT and other organochlorines were introduced for tick control from 1945, and were highly toxic to ticks and safe and easy to use. However, resistance to one of the organochlorines, BHC, emerged on a Queensland property only 18 months after it was first used. Resistance to two more, camphechlor and dieldrin, also developed rapidly. The ticks took longer to acquire resistance to DDT, but it too was beginning to lose its effectiveness by 1962. In that year, use of all the organochlorines in cattle dips was banned, because the residues they left in meat exceeded newly set safety limits.

Next off the rank were five organophosphates and a carbamate, all able to provide better than 99% tick control. But late in 1963 a strain of ticks resistant in varying degrees to all these chemicals was found.

Although more resistant strains have appeared since, the organophosphates still perform well in some cattle areas. Newer pesticides, including synthetic pyrethroids and chemicals known as amidines, some of which make ticks drop off their cattle hosts, are giving good protection in other areas.

However, given the ticks' history of resistance development, future prospects for chemical control are, at best, uncertain. At the CSIRO National Cattle Breeding Station near Rockhampton, researchers are breeding tick-resistant cattle — an approach that may give better prospects for long-term success.

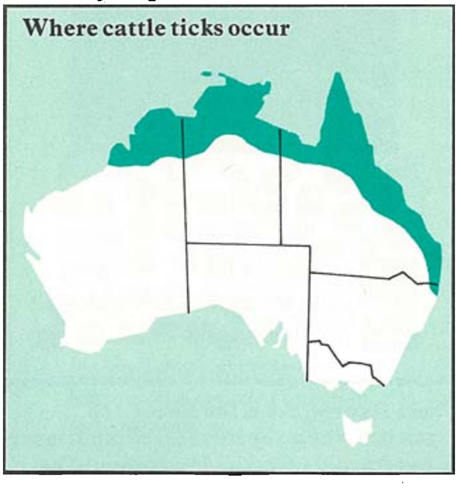
Cotton pests

For the cotton industry, pesticide resistance is a major problem throughout the world. In Australia it has forced the abandonment of cotton-growing in the Ord Irrigation Area, and it is a cause of much worry to growers in New South Wales and Queensland.

Australia has had a cotton industry for more than a century, near the central Queensland coast. But until 1961 it was a small industry and yields were low. In that year irrigated cotton-growing began in the Namoi valley in northern New South Wales, and yields rose from the average of 150 kg per ha for dryland production in Queensland to 1000 kg per ha or more. The irrigation-based industry is still expanding, and more than 90% of Australia's total cotton acreage is now located on black soil plains irrigated from the Namoi and other rivers of the upper Darling basin in New South Wales and Queensland (see the map opposite).

The development of resistant pest strains is a dramatic illustration of Darwinian evolution.

A healthy crop of bolls.



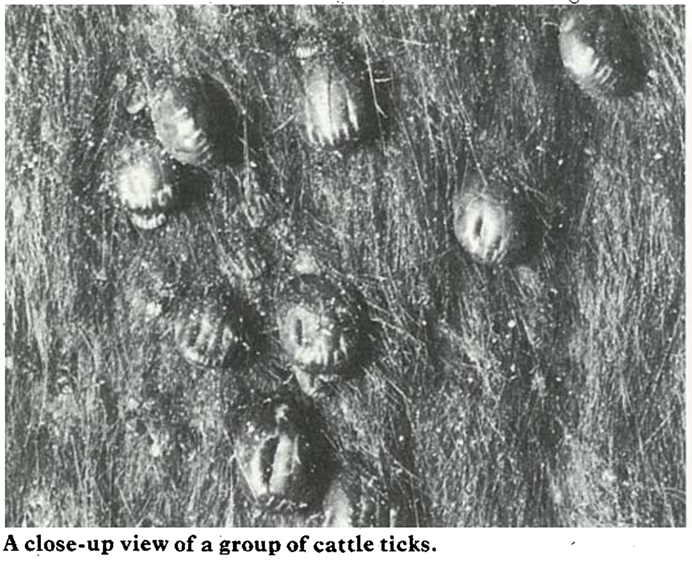
Cotton-growing began in the Ord valley in 1962, and yields were high. But, both there and in the eastern States, the use of irrigation, large amounts of fertilizer, and high-yield varieties favoured pests as well as production. Crops had to be sprayed with pesticides ten or more times a year, compared with three or four times a year in the dryland areas. The more often pests are exposed to pesticides, of course, the greater are the chances of resistance developing.

The first signs of resistance appeared on the Ord — where considerably more spraying was done than in the east — in 1970. A pest that had previously been one of the least important, the cotton bollworm, emerged as the most difficult to control. Growers found that greatly increased pesticide applications were needed to protect developing buds and bolls against the bollworm grubs.

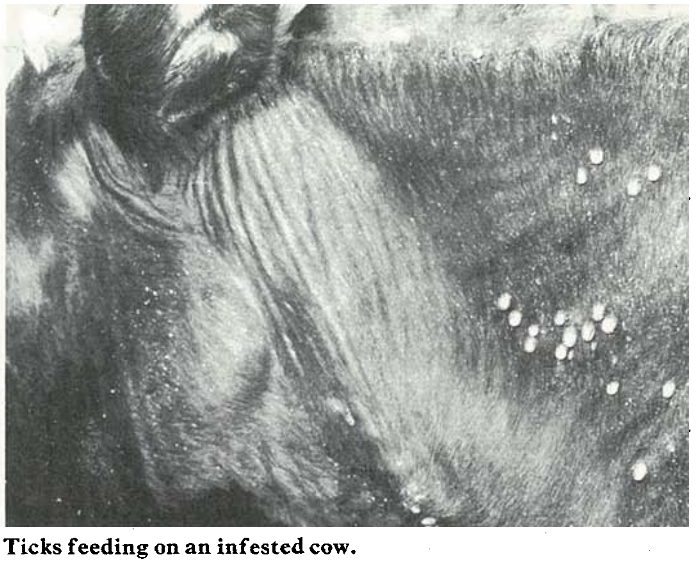
Up to 1970, growers used DDT against the bollworm and against the native budworm, a related and until then more damaging pest. Then they tried a DDT–camphechlor mixture. This worked for a couple of years, but then the bollworm again developed a level of resistance that made effective control impossible. After more-expensive and less-effective organophosphate insecticides were tried with little success, commercial cotton-growing was abandoned on the Ord in 1974.

Before resistance appeared there, growers generally sprayed less than 10 kg of DDT on each hectare of their crops in a year. By 1973–74, use of DDT and alternatives had jumped to between 80 and 125 kg per ha.

In the Namoi valley, the bollworm developed resistance to DDT in the 1972–73 growing season. The first sign was the same as in the Ord — the bollworm's replacement of the native budworm as the most damaging pest. Resistance appeared in Queensland the same year.



A close-up view of a group of cattle ticks.

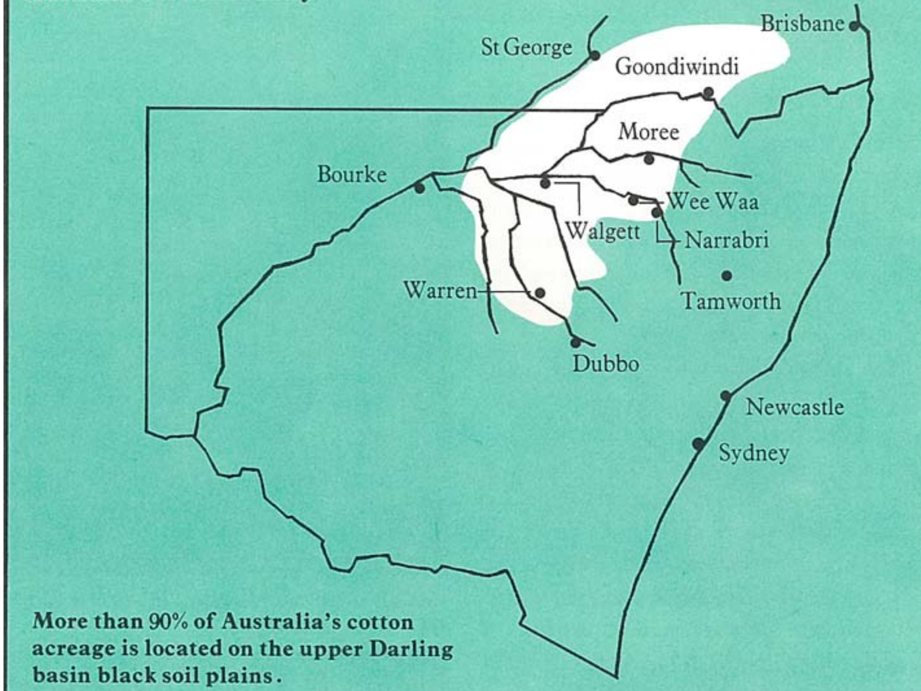


Ticks feeding on an infested cow.

Tests by scientists from the CSIRO Division of Plant Industry's Cotton Research Unit and the New South Wales Agriculture Department showed that, by January 1973, Namoi bollworms were 21 times more resistant to DDT than bollworms from a locality remote from the cotton-growing area. Two months later, DDT was practically useless; the Namoi specimens had become as much as 300 times more resistant.

Bollworms developed resistance to DDT–camphechlor at the same time, but in a much less dramatic fashion. In March 1973, specimens from the Namoi were about 15 times more resistant than the susceptible bollworms.

Australia's cotton country



More than 90% of Australia's cotton acreage is located on the upper Darling basin black soil plains.

Good news

At that time, with the Ord experience fresh in people's minds, the prospects for cotton production in the Namoi and surrounding areas looked grim. But the picture has brightened since. The level of resistance to DDT–camphechlor has remained fairly stable, and growers can still keep bollworm numbers under control using this combined spray.

Equally good news is the arrival on the scene of four new insecticides — two pyrethroids and two organophosphates — that perform well against the bollworm. Growers have found that, under some conditions, they can double the period between sprayings when they use one of the pyrethroids. This is fortunate, because treatment with the new insecticides costs about twice as much per hectare as the use of DDT–camphechlor.

Conditions were unusually favourable for the bollworm the year resistance appeared in the Namoi area. The winter was exceptionally mild, and the moths emerged early from their dormancy. They were able to feed on the district's wheat crop, and unusually hot and humid spring weather also favoured them. So did the record sorghum crop that year; sorghum is another plant that the bollworm attacks. By the time the cotton began bursting out in buds and bolls in February, a very large bollworm population was ready to attack it.

Subsequent seasons have been much less favourable for pests, and bollworm numbers have not built up early in the season as they did that year — easing control problems. But another bad season could come any time, and resistance to the new insecticides could emerge. In the United States, resistance to the pyrethroids began to show up in their first year of commercial use.

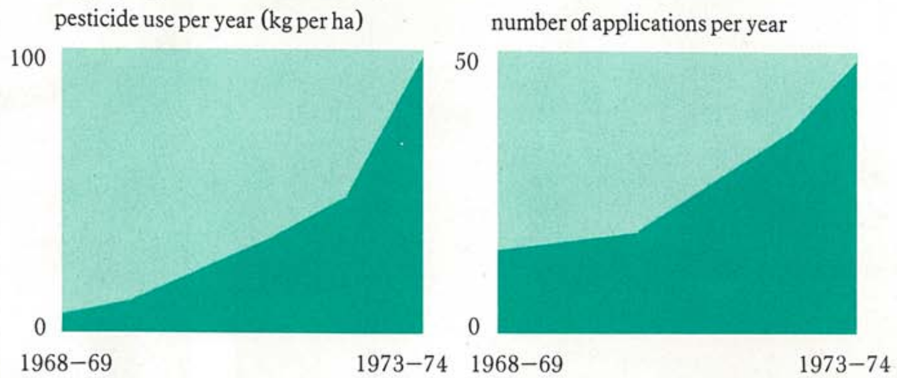
So non-chemical approaches to control are clearly desirable. One method being looked at by the Division of Plant Industry is cultivating the remains of the cotton plants into the soil in winter. This should kill most of the bollworm pupae, and greatly reduce the number of moths emerging in the spring.

The scientists are also examining the prospects for tackling the bollworm problem by breeding improved cotton varieties. One approach showing promise is the breeding of varieties resistant to bollworm attack. Another approach, which has been used successfully in the United States, is the breeding of varieties with a shorter-than-normal growing period.

The scientists are also looking at the possible use of bacterial and viral pathogens of the bollworm against the pests. These have the advantage of killing only the bollworm and budworm. One virus, administered as a spray, is showing considerable promise.

Techniques are also being developed for recognizing when spraying is necessary to keep pest populations below damaging levels, and for choosing the most appropriate spray. One aim is to reduce the number of pesticide applications per season to the

How spraying increased on the Ord



After resistance appeared in the bollworm in 1970, spraying with chlorinated hydrocarbon insecticides increased dramatically until commercial cotton-growing stopped in 1974.

necessary minimum. Another is to ensure that sprays specific to the insect causing problems are used whenever possible.

Stored-grain pests

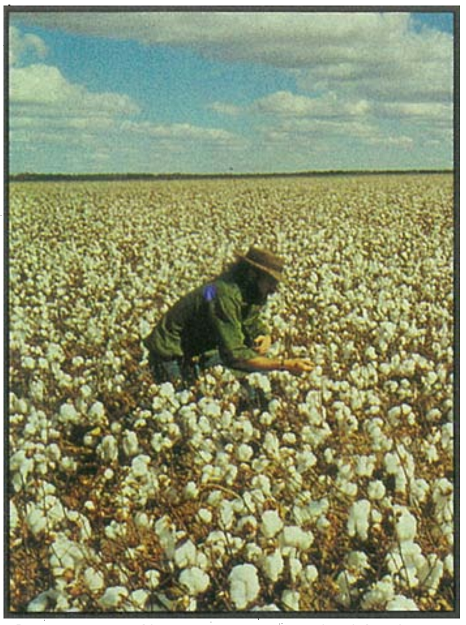
Australia's fourth major pesticide resistance problem affects stored grain, mainly wheat. Beetles and moths of many kinds find grain attractive and 10 species have developed resistance to malathion, an organophosphate insecticide that has been used against them since the early 1960s.

Insects have not caused serious grain losses in Australia in recent years. But our major markets are overseas — about 75% of Australia's annual cereal production of 10–12 million tonnes is exported — and our biggest customers demand pest-free deliveries. This is partly for aesthetic reasons, but also because grain imported and then stored will gradually deteriorate if it contains a growing insect population, however small that population is initially.

Up to 1963–64, the United Kingdom was the main importer of Australian wheat, and it tolerated some infestation. But then China and the USSR entered the market in a big way, and demanded insect-free grain. Keen to retain its new customers, the Australian government introduced regulations requiring that all grain for export should be free of infestation.

Fortunately malathion, an insecticide that, if used carefully, could make the clean-up a reality without leaving significant residues in the grain, had recently become available. Until resistance began to emerge, one application gave good protection against all grain pests for up to 6 months.

The first problems appeared in 1968 in peanut storages around Kingaroy, Qld, when the rust-red flour beetle developed resistance to malathion. Before long, resistant beetles were showing up in produce stores and grain storages, and resistance spread rapidly around the country.



Cotton in boll at Warren, in the black-soil-plain country.

Moths of the cotton bollworm (top) and the budworm. Before the bollworm developed resistance, the budworm was the more important pest.

A more important grain pest, the rice weevil, was the next to display resistance. Then came the turn of the most damaging pest of stored wheat, the lesser grain borer. At first it was resistant only to malathion, but then strains appeared that were resistant to other organophosphates as well — including dichlorvos, which was being used against the other resistant beetles.

Greatly concerned by these developments, the Australian Wheat Board set up a working party in 1974 to identify satisfactory alternative insecticides and expedite their introduction. Under the working party arrangements, promising chemicals undergo laboratory tests at the CSIRO Division of Entomology or the Queensland Department of Primary Industries, and then field trials in silos. The best prospects at present seem to be some of the synthetic pyrethroids.

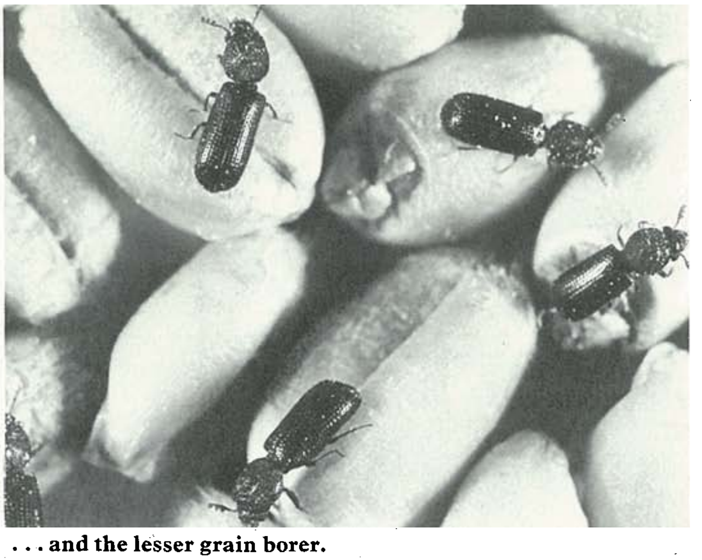
Because of the resistance problem, increasing use is being made of fumigants to mop up surviving insects before grain leaves Australia. These give an immediate kill, but don't provide lasting protection. Grain pests are now beginning to show resistance to some of the fumigants. Fortunately, no serious problems have resulted so far.

Physical controls

The CSIRO Divisions of Entomology and Mechanical Engineering are putting a big research effort into devising ways to protect grain without chemicals, or with much reduced quantities. An approach being examined by these scientists is to expose insects in the grain to conditions that are too cold or too hot for them. At the Division of Entomology, scientists are also looking at ways to alter the relative concentrations of atmospheric gases to disinfest silos and other storages.

At 27°C, grain insects can double their numbers in a week. But below 15°C and

Two damaging grain pests: the rice weevil . . .



. . . and the lesser grain borer.

One gene is enough

One of the problems with pesticide resistance is that there is no way of predicting when it will strike or how severe any case will be. But quick detection and accurate measurement of the level of resistance can be the key to introducing effective countermeasures.

In 1970 FAO began publishing a series of standardized tests for resistance in major pest species. The aim is to ensure that tests done in different places and at different times will produce results that can be realistically compared.

Generally, susceptibility to a pesticide is measured by exposing batches of the pest to a range of doses to estimate the LD50 — the dose that kills 50%. Resistance is measured by running such tests on resistant and non-resistant types at the same time and dividing the LD50 for the resistant types by that for the non-resistant types.

Geneticists now know quite a lot about the mechanisms that produce resistance. Unlike most inherited characteristics, resistance has usually been found to be due to a change in efficiency of only one gene. Such resistances are particularly stable. Characteristics that depend on combinations of genes are likely to alter significantly from generation to generation.

However, a pest can have more than one changed gene with the power, on its own, to confer resistance. For example, scientists at the Division of Entomology have shown that one form (or allele) of a gene on one chromosome in the sheep blowfly produces resistance to organophosphate insecticides. Quite independently, three alleles of another gene on another chromosome also produce resistance to these insecticides. The level of resistance depends on which of these alleles a fly possesses.

Studies are now in progress to determine what defence mechanism each of the resistance-producing alleles activates.

above 35°C, conditions are too extreme for them and reproduction stops. Silos in southern Australia have installed equipment that blows cool air through the grain — a technique fostered by research in the two Divisions. This has proved an effective means of slowing grain deterioration by reducing insect reproduction rates.

The Division of Mechanical Engineering is now looking at the prospects of adding refrigeration to the aeration system (the aim is to eliminate insects from the grain during the normal storage period). The Division's scientists are also examining a method of killing the insects by subjecting them to a brief blast of hot air. The effect should be the same as that of fumigation.

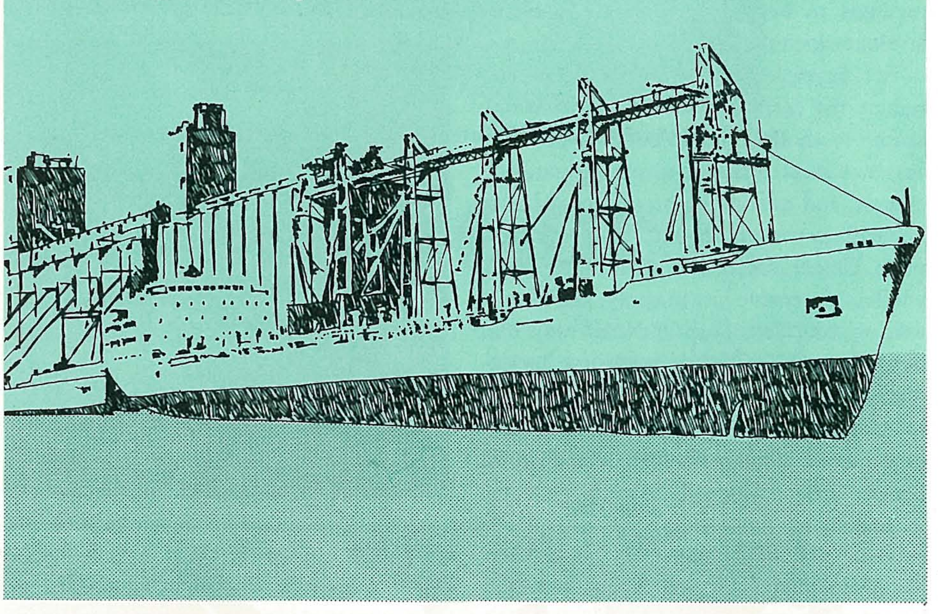
The Entomology group has used nitrogen and carbon dioxide to produce lethal atmospheres for grain pests in large silos and transport containers. Carbon dioxide seems to offer the best prospects. The scientists have found they can prevent infestation by keeping the carbon dioxide content of the container's air at about 35%. When nitrogen is used, it has to reduce the amount of oxygen in the air to as little as 1·5%. With either gas, the container has to be virtually air-tight if protection is to last for a useful length of time.

The research shows that the grain pests can be controlled by non-chemical means. But the switch to these methods will probably be gradual, as it will involve very expensive changes to the existing storage and transport systems. Meanwhile, the battle to maintain effective chemical control in the face of developing resistance will continue.

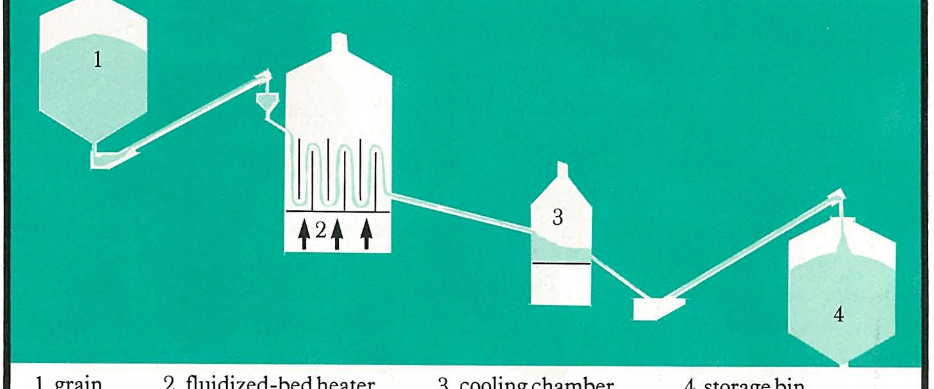
Pest management

All these Australian examples point to the need to reduce reliance on pesticides, where

Grain for export must be pest-free.



A way to kill grain pests



1 grain 2 fluidized-bed heater 3 cooling chamber 4 storage bin

The Division of Mechanical Engineering is testing this continuous-flow system that disinfests grain by heating it rapidly to about 60°C.

this is possible. They also point to the necessity for a continuing flow of new pesticides onto the market. Resistance can emerge at any time, and if a satisfactory alternative is not immediately available the consequences can be very serious.

There are some rather obvious rules that should be followed to reduce the risk of resistance developing. For example, pesticide application should be restricted, as far as possible, to the target area. It should be timed to catch pests at their most vulnerable stage of development. And it should be resorted to only at times of economically significant infestation or threat of infestation — not as a fixed routine. Unnecessarily persistent chemicals should be avoided, so that selection will not continue after pests have been adequately dealt with.

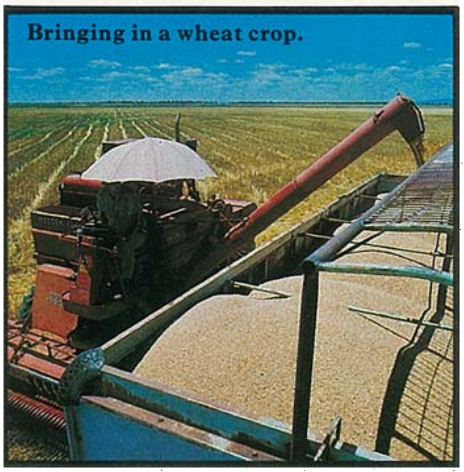
The Division of Entomology, and many other bodies, advocate 'pest management' as a means of minimizing pesticide use. The idea is to use a combination of all available methods to keep pest populations below levels at which they cause economic damage.

For example, cultivation practices that reduce the carry-over of insects from one season to another should be followed, crop varieties most resistant to pests should be chosen, and quarantine precautions should be taken to prevent the introduction of new pests. Unfortunately it is often much easier and less expensive just to spray, and people tend to take the cheap and easy way out, despite the risk of future adverse consequences.

As the use of pesticides continues, more cases of resistance seem certain to arise. At present, the developed countries use the bulk of the world's pesticide output; North America accounts for nearly half the total. But use is growing in the developing countries and appears certain to expand greatly with the continued introduction of high-yielding crop varieties and pressure to produce more and more food and fibre.

Clearly, the problems of resistance are not about to go away.


Harvesting cotton on the Ord — a scene from better days.


Bringing in a wheat crop.

More about the topic

Resistance to control chemicals in Australian arthropod pests. R. W. Kerr. *Journal of the Australian Entomological Society*, 1977, **16**, 327–34.

Pesticide susceptibility of stored grain pests. B. R. Champ and C. E. Dyte. *FAO Plant Production and Protection Series* No. 5, 1976.

FAO activities in the field of pesticide resistance. D. F. Waterhouse. *Proceedings, Fifteenth International Congress of Entomology*, 1977, 786–93.

The Australian sheep blowfly, *Lucilia cuprina*. M. J. Whitten, G. G. Foster, J. T. Arnold, and C. Konowalow. In 'Handbook of Genetics', Vol. 3, ed. R. C. King. (Plenum Publishing Corporation: New York, 1975.)

The sequential development of insecticide resistance problems in *Lucilia cuprina* Wied. in Australia. G. J. Shanahan and N. A. Roxburgh. *PANS*, 1974, **20**, 190–202.

Tick-borne livestock diseases and their vectors. 5. Acaricide resistance and alternative methods of tick control. R. H. Wharton. *FAO World Animal Review* No. 20, 1976, 8–15.

Resistance of *Heliothis armigera* to insecticides in the Ord Irrigation Area, north-western Australia. A. G. L. Wilson. *Journal of Economic Entomology*, 1974, **67**, 256–8.

The relative injuriousness of insect pests of cotton in the Namoi Valley, New South Wales. A. G. L. Wilson and L. R. Greenup. *Australian Journal of Ecology*, 1977, **2**, 319–28.

The map shows the known spread of malathion-resistant and susceptible strains of the lesser grain borer following the 1972–73 survey of stored-grain pests.