PLANT PESTICIDE ECONOMICS WITH SPECIAL REFERENCE TO COTTON INSECTICIDES

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The energy crisis and the current world food situation have both drawn attention to the importance of off-farm inputs in high-technology agricultural systems. Plant pesticides are one of the most important of these off-farm inputs. The correct use of chemical pesticides requires a high level of managerial competence since the issues involved are extremely complex. The development of an integrated approach to the management of plant pests offers an alternative to the increasingly expensive chemical control techniques. Cotton production illustrates both the complexities of the maagement involved in plant pest control and the feasibility of developing integrated control strategies. Plant pesticides, especially insecticides, also create externalities. The policy issues surrounding the use of cotton insecticides demonstrates the need for careful analysis before political action is taken. A feasible package of policy measures for the control of the use of insecticides in Australian cotton-growing areas is suggested.

Technological progress in the last half-century has had a dramatic impact on world agricultural production systems. The net effect of the new technology has been to substitute capital and managerial skills for labour and land. As a result agricultural production has become increasingly dependent on off-farm inputs such as fertilizer and pesticides. Although these changes have been primarily restricted to the more advanced economies, the so-called 'green revolution' in the late sixties created a similar shift in resource use in significant parts of the less developed world.

Agricultural economists have examined the economics of fertilizer use to the *n*th degree. Unfortunately, the profession has not, until recently, shown the same enthusiasm for tackling the more complex problems associated with pesticides.[1] The aim of this paper is to initiate a fresh examination of the economics of plant pesticide usage both at the farm-level and from the viewpoint of society.

Throughout the paper the control of insects on cotton will be used to illustrate the complexities of the issues involved. In Australia the plant pesticide problem which has caused the greatest concern in recent years has been the use of insecticides on cotton, particularly in the Ord

* At the time of writing both authors were members of a multidisciplinary research group within the Faculty of Agricultural Science, University of Queensland, known as the Integrated Pest Management Unit (IPMU). The major current research effort of the IPMU is concerned with the development of a pest management model for cotton in South-East Queensland. This project is being financed by the Australian Research Grants Committee.

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[1] Research in the field of pest control economics has been published in a wide range of journals (3, 4, 5, 6, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 25, 26, 27, 29, 30, 31, 33, 35, 36).

and Namoi Valleys.[2] Cotton growing in these two areas began in the early sixties. Initially the Australian government actively encouraged the production of cotton in these two valleys but since the phasing out of the raw cotton bounty, the industry has not been the recipient of any special government incentives. It is not the authors' intention to argue the case either for or against the growing of cotton in Australia.

Management Issues

Man's increasing capacity to manipulate (manage) plants for his own benefit has been (and will continue to be) largely responsible for the development of modern civilization. Other organisms, particularly insects, live on plants and frequently compete with man. The control of pests (as the competing organisms are collectively labelled) represents a continuing challenge to man's ingenuity. The discovery of chemical pesticides and their evolution from simple metallic compounds to modern complex organic molecules has provided modern man with some powerful weapons with which to control plant pests.[3] However, in many farming situations the question of how best to utilize these modern plant pesticides has not been resolved.

In the foreseeable future chemical pesticides are likely to remain a major means of combating man's competitors in the utilization of plants. For instance, it has been estimated that even in the United States where pesticide usage is the highest in the world, only about half the justifiable (on economic grounds) amount of pesticides is being applied to the nation's crops and pastures [3, p. 73]. The potential for further pesticide use in India and other similar food deficit countries is enormous. Nevertheless, in the more technologically advanced countries there has been a tendency to rely too heavily upon the use of chemicals to control pests in certain crops.

In response to the undesirable side-effects created by the excessive use of broad spectrum pesticides on certain crops, a new approach called 'pest management' or 'integrated control' has evolved. The basic idea of the integrated approach is to make the best use of all the available alternative techniques for combating the pests in question and thereby minimize the need for chemical pest control.

(i) *Controlling Plant Pests with Chemicals*

At the farm-level the individual manager considering the use of chemical plant pesticides faces a multi-dimensional management problem of great complexity. There are five distinct but interrelated sets of issues which the manager must consider.

(a) Which pesticide should be used? (Which pest is present? Is it resistant to certain chemicals? Are some chemicals dangerous to man and the environment? What effects do the chemicals have on beneficial pest parasites and predators?)

[2] *The Australian Financial Review* (Wednesday, February 28, 1974, p. 1) in an article entitled 'The Ord Eco Bomb' describes the projected ecological upsets in the Ord River District as cotton growers apply escalating quantities of persistent insecticides in their 'losing battle against insect pests'. The article also deals with the problem of human poisonings from pesticides in the Namoi Valley. On this point, see also Simpson and Penny [32].

[3] For a brief rundown on the history of insecticide use, see National Academy of Sciences [24].

(b) When should it be applied? (How does one measure pest abundance? What scouting procedure should be adopted? How does pest abundance relate to economic damage? Is there an 'economic threshold'?)

(c) What dosage rate should be used? (What is the shape of the control response curve? Does the pesticide have any detrimental effect on the crop?)

(d) How should it be applied? (From the air or from the ground? Does droplet size matter? Does time of day influence effectiveness? Are atmospheric conditions at the time of application important?)

(e) How many applications? (Can the plant compensate? What are the expected levels of pest abundance in the future?)

The control of insects on cotton illustrates these five groups of decisions very well. However, apart from providing an example, insecticide use on cotton is an important management question in its own right at present. Australian cotton producers face spiralling costs due to both inflation and the build-up of insect resistance to the cheaper chemicals. With the world price for cotton declining, growers are being forced to look closely at the economics of their enterprise. All seventeen growers in the Ord River Valley decided not to grow cotton (or any other crop) during the 1974/75 season. This decision was forced upon these farmers by the exceedingly high cost of controlling insect pests in the Ord Valley with chemicals. Growers in other areas are also desperately seeking cheaper ways of controlling the insects.

Which insecticide? The range of chemicals currently applied to cotton in Australia for insect control and the approximate cost of applying each of these chemicals at the recommended rate (the rate suggested by the manufacturer) are shown in Table 1. The table also indicates the target species for each of the chemicals. Obviously for Heliothis (the major insect pest on cotton over the last few years) there is a range of chemicals available and their costs differ considerably. The cheapest is straight DDT while the organo-phosphates are more expensive. Due to the build-up of resistance to DDT it is no longer always effective against Heliothis and the more expensive chemicals must be used.

Cotton-growers are not only faced with a range of chemicals from which to select to control their particular pest, but the proliferation of chemical companies marketing insecticides now presents them with a profusion of different brand names for the same active ingredient. Little wonder the growers' choice of insecticide is likely to be decided more by the salesmanship of the manufacturer's field representative than by any genuine assessment of the problem. There is an urgent need for standardization of the terminology associated with insecticides.

When should it be applied? Cotton is a plant which has a considerable capacity not only to withstand substantial damage to its vegetative parts due to, for example, loopers and tip worms [11, p. 35], but also to compensate for damage to squares and bolls caused by Heliothis.[4]

[4] See Evenson [10]. Rahman (pers. comm.) of the Department of Agriculture, University of Queensland, is currently investigating the effect of manual defoliation and disbudding on yield in cotton.

TABLE 1

Insecticides Used in Controlling Cotton Pests, Retail Cost of One Application of Insecticide at Recommended Rates, and Target Species

Insecticide Trade Name	Cost per Application per Hectare	Target Species: Scientific Name	Target Species: Common Name
	$		
Azinphos ethyl	7.80	*Anomis flava* *Tetranychus spp.*	Cotton looper Spider mites
Chlorphenamidine (Galecron, Acaron, Fundal)	12.00	*Heliothis spp.*	Heliothis
Demeton-S-methyl (Metasystox)	8.90	*Aphis gossypii*	Aphids
D.D.T.	1.60–3.30	*Agrotis spp.* *Austroasca terraereginae* *Crocidosema plebiana* *Dichocrocis punctiferalis* *Dysdercus spp.* *Heliothis spp.* *Loxostege affinitalis* *Nezara viridula* *Oxycarenus luctuosus* *Pectinophora scutigera* *Spodoptera spp.* *Tectocoris diophthalmus* *Thrips tabaci*	Cutworms Jassids Cotton tipworm Yellow peach moth Cotton stainers Heliothis Cotton web spinner Green vegetable bug Cotton seed bug Pink-spotted bollworm Armyworms Cotton harequin bug Thrips Mirids
Dicofol (Kelthane)	6.90	*Tetranychus spp.*	Spider mites
Dimethoate (Rogor)	3.50–6.00	*Aphis gossypii* *Austroasca terraereginae* *Tetranychus spp.* *Thrips tabaci*	Aphids Jassids Spider mites Thrips
Endosulphan (Thiodan)	6.90	*Agrotis spp.* *Aphis gossypii* *Austroasca terraereginae* *Crocidosema plebiana* *Earias huegeli* *Heliothis spp.* *Nezara viridula* *Thrips tabaci*	Cutworms Aphids Jassids Cotton tipworm Rough bollworm Heliothis Green vegetable bug Thrips
Endrin	3.00–6.00	*Anomis flava* *Crocidosema plebiana* *Earias huegeli*	Cotton looper Cotton tipworm Rough bollworm
Methomyl (Lannate)	5.20 per litre	*Heliothis spp.*	Heliothis
Monocrotophos (Azodrin, Nuvacron)	5.30	*Acrididae* *Aphis gossypii* *Austroasca terraereginae* *Heliothis spp.* *Tetranychus spp.* *Thrips tabaci*	Grasshoppers Aphids Jassids Heliothis Spider mites Thrips

TABLE 1 (continued)

Insecticide Trade Name	Cost per Application per Hectare	Target Species	
		Scientific Name	Common Name
Omethoate (Folimat)	6.90	*Aphis gossypii* *Austroasca terraereginae* *Thrips tabaci*	Aphids Jassids Thrips
Parathion (Folidol, Paramul)	$ 1.90	*Aphis gossypii* *Austroasca terraereginae* *Tetranychus spp.* *Thrips tabaci*	Aphids Jassids Spider mites Thrips
Parathion—methyl	2.80	*Tetranychus spp.*	Spider mites
Phosdrin (Mevinphos)	18.20 per litre	*Tetranychus spp.* *Coleoptera*	Spider mites Beetles
Toxaphene—D.D.T.	5.20	*Heliothis spp.*	Heliothis

This capacity to compensate makes the definition of an 'economic injury level' or an 'economic threshold' for cotton an extraordinarily difficult task [13]. Clearly, the critical level of pest abundance will vary over the life of the crop. The problem is to devise a quick (cheap) but accurate means of measuring pest abundance and to relate pest numbers at various stages of the plant's growth to eventual economic loss due to lower yields (and, perhaps, quality) of cotton.

In the absence of any firm guidance from research workers, growers have devised their own scouting procedures and rules-of-thumb which define when to apply insecticide. These rules-of-thumb are based on crude *ad hoc* scouting counts. For example, one common rule is to count Heliothis eggs and larvae for several metres along randomly selected rows. If, on the basis of this rough sampling, the average number of eggs plus larvae per metre of row exceeds 8, then it is time to spray. However, this is but one of many such heuristic decision rules.[5]

The basic motivation behind these ultra-conservative and simple rules is easy to understand. Growers are aware that a Heliothis larva can destroy many more cotton squares during its early instars than after it has grown beyond about 1 cm. in length. For this reason and because the larger caterpillars are harder to kill with chemicals, growers usually try to 'get them early'. This means killing the egg with an ovicide or killing the very young caterpillars within a few days of their emergence from the egg. In addition, the growers view chemical treatments as insurance. The amount of working capital invested in a cotton crop is exceedingly high (up to $400 per hectare) and it is understandable

[5] Don Rossiter (Queensland Department of Primary Industries, Toowoomba) in an unpublished mimeo 'Suggestions for Cotton Pest Control' suggests that the necessity for spraying is indicated when more than 5 per cent 'active' terminals are noted in a random selection of 25 terminals. An 'active' terminal is defined as one on which a larva is found or on which damage to the terminal bud, square or leaf is evident.

that growers should take steps to 'insure' this investment against the ravages of insects.[6]

Unfortunately, as with many forms of informal insurance practised by farmers, pesticides applied unnecessarily can prove extremely expensive forms of insurance cover. In the short-term there is not only the direct cost of the chemical and the cost of application but also the less obvious (but potentially far greater) cost created by wiping out the parasites and predators of the pest species. The loss of these beneficial insects dramatically increases the need for subsequent sprays. This point will be taken up again later. Of course in the longer run, the more frequently any given chemical is used against any given species the sooner that species evolves a resistance to the chemical in question. Once this occurs it will usually mean the growers have to turn to a more expensive chemical (if a suitable one is available) to control the pest.

Perhaps the area of research with the greatest immediate pay-off for growers would be investigations designed to establish simple but statistically sound sampling procedures for commercial cotton. If scouting techniques could be improved to take full account of the patchiness of insect attack and to record the abundance of both pests and beneficial insects, growers would be in a better position to decide when to spray their crops.[7] One suggestion which deserves further serious investigation is to identify patches of insect activity by infra-red aerial photography.[8]

What dosage rate? Currently cotton growers follow the manufacturers' instructions (unless practising the widely held belief that 'if a little chemical is good, more must be better') which are based on laboratory experimental results and which usually aim at an almost 100 per cent kill. The validity of these general recommendations to the field situation has not been investigated. Joyce [22] discusses a number of technological parameters which need to be considered when extrapolating laboratory results to commercial farming enterprises. The optimum field dosage rate depends upon such factors as the nature of the target organism and its accessibility, spray particle size, nature of lower air layers, aerial application materials and instrumentation.

Theoretically the combination of a control response curve and a

[6] Ross Lobegeiger (Queensland Department of Primary Industries, Rockhampton) surveyed growers of irrigated cotton in the Biloela district of Queensland in 1972 and 1973. In an unpublished mimeo 'Irrigated Cotton Production Expenses—Biloela District', Lobegeiger presents data which indicates that the average total working capital invested in cotton crops on the surveyed farms was \$278 per hectare in 1972 and \$271 per hectare in 1973. The Biloela District is regarded as a 'low cost' cotton-growing district.

[7] The need to consider the effect of pesticide usage on beneficial insect populations is illustrated in the model constructed by Shoemaker [29]. Using parameters obtained from laboratory populations of the Mediterranean flower moth and a parasite together with the not unreasonable assumption that the percentages of parasites and pests killed by any treatment were equal, Shoemaker found that the control decision is much more sensitive to parasite density than to the pest density. The findings of the Integrated Pest Management Unit field studies (Table 4) confirm the conclusion that the response by beneficial insect populations to pesticides application is an important component of the pest control decision.

[8] Noel E. Challinor (New South Wales Department of Agriculture, Narrabri) personal communication.

damage function should enable conventional production function analysis to determine the optimum rate of application and hence refine this decision [17 and 18].[9] However, in the case of Heliothis on cotton there may be a need for different control response curves for each instar. In addition, the damage function would have to make the final yield expressed in terms of dollars, a function not only of the current pest numbers and ages, but also of the damage which has already occurred in past stages of the plant's growth and of the expected level of damage which will be permitted in the remaining stages of growth of the crop. The conversion from physical damage to damage measured in dollar terms also necessitates making assumptions about the quality and price of the final product.

Although the dosage rate may appear to be an important variable in the total picture, the well-known steeply sigmoid shape of control response curves,[10] together with the complex nature of the analysis required, suggests that in practice this may be one case where 'aiming for the top of the production function' on the basis of technical information alone would not produce a level of resource use significantly different from the conventional 'marginal cost = marginal returns' rule.[11] Besides, the costs and uncertainties involved in obtaining sufficient data to apply the marginal approach would almost certainly cancel out any potential gain.

There is another feature of the dosage rate question. Insect resistance build-up is positively related to the intensity of selection pressure. Therefore, if higher dosages are used the selection pressure will normally be greater. As a result, the rate at which the dosage curve shifts to the right and flattens due to increasing resistance in the insect population being treated, depends on the dosage rates being applied. The relationship between selection pressure, immigration and the build-up of resistance has been measured for certain chemical/insect pairs.[12] However, no similar data for the Heliothis species are available. Research on this question is warranted.

[9] The control response (or dosage-mortality) curve expresses the relationship between units of insecticide applied to the crop and the percentage of the insect population killed. For any particular insect population, the curve is extremely difficult to predict *a priori* because of the non-uniformity of populations of the same strain in terms of resistance to insecticide. In the field situation, the relationship is further complicated by the extent to which insecticide applied to the crop reaches the target organisms and the extent to which the genetic composition of the pest population is modified by previous insecticide applications, immigration and other factors. The damage function describes the effect of various density levels of an insect pest upon the yield of a crop. The relationship is again a complex issue, depending upon such factors as the types of damage occurring and the ability of the crop plant to compensate for damage when it occurs.

[11] If the control response curve has the shape indicated in footnote 10, the top of the production function is a plateau. It may be important, therefore, to specify that 'aiming for the top of the production function' means choosing the lowest possible dosage rate compatible with being on the plateau. (The authors wish to thank an anonymous referee for drawing their attention to this point.)

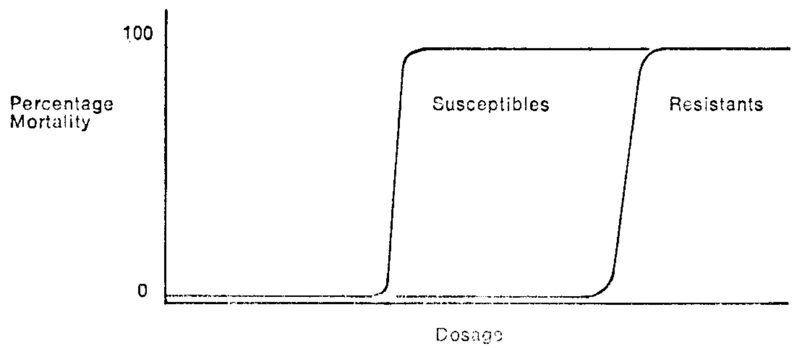
[12] These studies have been summarized in Brown and Pal (2). In general the sloped portion of the control response curve for a closed population of an insect species tends to shift rightwards and to flatten after repeated applications of a pesticide.

How should the insecticide be applied? Given the nature of the cotton crop and the insects which attack it, ground spraying may provide a more technically effective means of applying chemicals than the use of aircraft. However, since speed of application is critical, ground spraying is far too slow except in the very early stages of the crop when the timing of the application is not so important. The majority of the chemicals applied to cotton in Australia is applied from fixed wing aircraft.

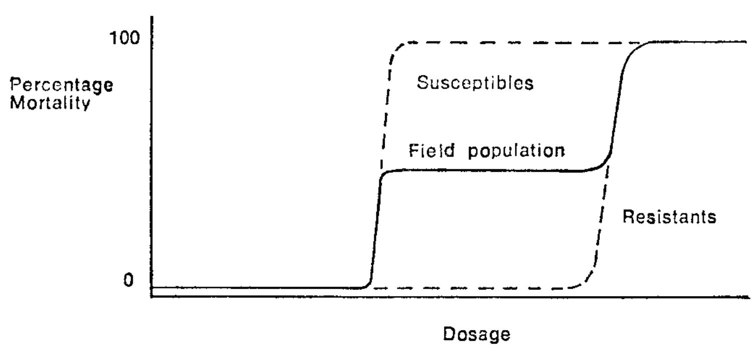
Joyce [22] discusses a number of parameters concerned with aerial application which have yet to be researched fully. Research into the technological relationships which need to be clarified is beyond the financial capacity of aircraft operators and chemical companies. On the other hand growers have not shown any interest in financing this kind of research.

How many applications? The twin questions of 'when to apply' and 'how often' are the two issues which cause growers the greatest concern. The cost of an aerial application of chemical (excluding the cost of the chemical) has risen in recent years from approximately \$2.20/ha in 1968/69 to \$2.60/ha for the 1974/75 cotton season. The number of applications has been as high as 35 per year on the Ord, 30 per year in the Namoi and from 5 to 20 in the various cotton-growing areas of

[10] Typically, the control response curve for a population of insects which are genetically homozygous for resistance or susceptibility is as shown below.



The dosage-mortality relationship of a population composed of a mixture of genotypes can be estimated from the curves characteristic of each genotype and varies according to the exact genetic composition of the population. Thus, the control response curve for a typical field insect population may resemble the curve below.



Queensland. Simple arithmetic suggests that growers have an enormous economic incentive to reduce the number of sprays per cotton crop.

(ii) *The Integrated Pest Management Approach*

In the previous discussion only one pest control technique was considered, namely the application of a chemical pesticide. The basic conclusion which emerges is that it is extremely difficult to determine an *ex ante* optimum (profit maximizing) pest control strategy. The integrated pest management approach seeks to combine all feasible methods of control in an optimal fashion.[13] The feasibility of achieving such an optimum integrated control strategy *ex ante* is open to serious question. However, economically viable programmes based on the integrated control approach have been developed for a wide range of crops in many different countries. For example, Falcon and Smith [11] cite sixteen operationally successful examples of the integrated approach with such diverse crops as lucerne, apples, cabbages, tobacco, cotton and sugarcane.

Cotton has been one of the crops most amenable to integrated pest management techniques overseas [11 and 33]. In one commercial application Sterling and Haney [33, p. 7] report that pest control costs were reduced from $27 per acre to less than $7 per acre between 1969 and 1972 while the yields of cotton climbed from 196 lbs of lint per acre to 635 lbs per acre. Similar outstanding results are some distance away in the case of Australia. However, one would expect the chances of developing viable integrated control strategies for the Australian cotton-growing industry are reasonably bright. As Table 2 indicates, there are many different cotton pest control and pest influencing techniques to be evaluated.

Strangely enough, very little attention has been given to studying the pest/parasite/predator/pathogen complex in unsprayed cotton in Australia. The initial objective of the University of Queensland Integrated Pest Management Unit has been to document this aspect of the cotton agro-ecosystem in South-East Queensland.[14] As indicated by the data in Table 3, natural biological control may be capable of producing yields comparable with commercial crops. These results could be questioned on a number of grounds. First, since the data available related only to one season, it is possible that 1973/74 was an abnormally good cotton-growing season unusually free of pest problems. Table 4 demonstrates, however, that this was not the case. Heliothis were present in

[13] Integrated control is a 'pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury' [11]. The literature on integrated control is not always explicit as to what is to be optimized since economic injury levels are not rigorously defined. However, the usual implication is that the net returns of the farmer is the item to be maximized, subject to the resulting control techniques having lower social costs.

[14] See Integrated Pest Management Unit, 'A Progress Report on Research into the Control of Cotton Pests during the period September 1973 to August 1974' (unpublished mimeo, August, 1974). A number of papers documenting the entomological studies carried out during this period are currently being prepared by A. L. Bishop and P. R. B. Blood of the Integrated Pest Management Unit.

TABLE 2

Classified List of Pest Controlling or Pest Influencing Techniques Applicable to Cotton Grown in Australia

Component of Ecosystem Manipulated	Type of Control	Examples of Control Type
Crop plant	Regulatory	*Quarantines (e.g., prevents import of pests/diseases) *Rattoon cotton controls
	Cultural	*Cariety (e.g., nectariless, high gossypol, earliness, fregobract) *Management (e.g., Crop residue disposal, narrow rows, low plant density, volunteer cotton controls, planting and harvesting times, selection of crop site)
Other plants	Regulatory	*Quarantines on weeds, etc. *Eradication, etc. of weed species.
	Cultural	*Elimination of unwanted plants (e.g., weed control cultivation, destruction of surrounding alternate hosts) *Management of desirable plants (e.g., as over-wintering sites for beneficial insects, as trap crops for pest species)
Insect populations	Regulatory	*Pest quarantines *Pest eradication, etc. programs *Pest population monitoring (e.g., light trapping *Heliothis spp.*) *Introduction of beneficial species (e.g., *Trichogramma sp.*)
	Biological	*Release of beneficial insects (e.g., predators (see Table 4)), parasites (see Table 4), pathogens (e.g., *Bacillus thuringiensis*, Nuclear polyhedrosis virus)
	Autocidal	*Mass release of sterile males *Genetic manipulation of pest *Pheromones
Abiotic environment	Regulatory	*Control over use of irrigation *Control over use of insecticides
	Cultural	*Water management (e.g., stressing for influencing Heliothis, flooding for control of over-wintering pupae) *Nutrient management (e.g., nitrogen stressing for influencing Heliothis)
	Chemical	*Insecticides (see Table 1)

significant numbers on all plots for at least a portion of the growing season. In addition, Table 3 shows that two of the three commercial growers upon whose properties the unsprayed experimental plots were grown, did not obtain outstanding yields in 1973/74.

A second reason for questioning the results presented in Table 3 arises from the location of the relatively small experimental plots. All of the unsprayed plots were situated within agro-ecosystems substantially modified by the chemical sprays being applied to commercial crops. Perhaps the pest/parasite/predator/pathogen complex recorded on the experimental plots is not genuinely representative of what would occur in a completely virgin area. The testing of this important hypothesis is beyond the current financial resources of the University of Queensland research team.

In summary, the research which is aimed at developing a pest management approach for cotton pests in South-East Queensland, has already indicated a number of tentative conclusions. First, under certain conditions, it is possible to grow commercial yields of cotton without any chemical insecticide treatments (see Table 3). Second, the presence of large numbers of pests, especially early in the season, does not necessarily reduce the final yield (see Tables 3 and 4). Third, a natural predator/parasite/pathogen complex exists in the cotton agro-ecosystem of South-East Queensland which is capable of controlling all serious cotton pests.[15] Fourth, certain cultural procedures encourage these natural biological control agents (e.g., natural bushland in the vicinity of cotton) while others effectively eliminate them (e.g., chemical spraying). Fifth, the natural control agents are more susceptible to the commonly used chemicals than Heliothis.[16] Sixth, chemical control imposed relatively late in the season can complement natural control factors and ensure a commercial yield should the pests appear to be outstripping their biological control agents.[17]

Policy Issues

Pesticides, especially insecticides, rank high as environmental pollutants. The story of the persistent chlorinated hydrocarbons is well

TABLE 3

Details of Unsprayed Experimental Cotton Plots and Nearby Commercial Crops Grown in South-East Queensland During 1973/74 Growing Season

Unsprayed Plot Number	Area	Location	Yield of Lint	Yields of Co-operating Growers	
				1973/74 Season	Average for last 9 Seasons
	(ha)		(kg/ha)	(kg/ha)	(kg/ha)
1	1·0	Lawes	590	(Experimental Farm)	
2	2·0	Forest Hill	748	1304	1080
3	2·0	Gatton	67	732	853
4	2·5	Brookstead	60	877	976

[15] Although the major beneficial insect species are listed in Table 4, approximately 120 species of arthropods in all were recorded in the cotton ecosystem of South-East Queensland during the 1973/74 growing season.

[16] A paper currently being prepared by Bishop and Blood describes the effect of drift of aerially applied insecticide on cotton pests and beneficial insects and yields. An unsprayed trial adjacent to a commercial cotton crop suffered wind drift of insecticide. Yields increased progressively and the Heliothis population decreased progressively as one moved away from the sprayed area.

[17] The figures contained in Table 4 help to substantiate the contention that had there not been an outbreak of Heliothis late in the growing season in trial plot 4 (when natural control agents had declined in number) a reasonable yield may have been obtained.

TABLE 4

Average Weekly Counts of Insect Species[1] in South-East Queensland Cotton, 1973/74 Growing Season
(Insects per Hectare)

Unsprayed Plot Number and Month	MAJOR PEST SPECIES[2]			MAJOR PREDATORY SPECIES[3]				
	Heliothis spp. (Heliothis)	*Aromis flava* (Cotton looper)	*Earias huegeli* (Rough bollworm)	*Chrysopa sp.* (Green lacewing)	*Nabis capsiformis* (Nabis)	*Geocoris sp.* (Green-eyed bug)	*Oechalia schellenbergii* (Predatory shield bug)	Spiders
Dec.	1288	6822	0	0	0	12,520	335	25,425
Jan.	25,750	84,917	657	0	0	0	1500	15,000
1—Feb.	6687	48,458	0	3500	1000	0	8000	49,000
Mar.	7950	17,503	3502	5000	0	1000	500	57,500
Apr.	1250	2532	1265	3500	0	0	0	70,000
Dec.	793	1090	0	0	0	0	0	5695
Jan.	0	21,888	0	4000	4000	4000	0	24,000
2—Feb.	26,235	3029	1250	2500	1000	0	0	9500
Mar.	8912	0	1666	1333	0	0	0	4666
Apr.	8591	0	2386	1000	0	0	0	6000
Dec.	125	735	0	0	0	0	0	4650
Jan.	16,133	18,823	0	0	2000	0	0	23,333
3—Feb.	24,500	60,952	0	0	0	500	0	10,375
Mar.	48,875	11,629	13,385	0	1000	0	0	24,050
Apr.	28,000	2911	12,220	0	0	0	500	60,625
Dec.	360	275	0	103	567	0	0	4725
Jan.	2035	2730	272	3500	662	1000	3587	44,662
4—Feb.	11,997	26,152	1115	1500	0	0	0	63,500
Mar.	66,000	75,475	6837	1000	0	0	1000	41,000
Apr.	5957	4760	21,947	500	500	500	2000	100,000

[1] All insect species were grouped in the following categories—pests, predators, and parasites. Of the eggs and larvae of *Heliothis spp.* collected in all samples from each plot, less than four per cent were parasitized. Egg parasites were *Telenomus sp. and Trichogramma sp.* Larval parasites included a Braconid, a Tachinid and Ichneumonids.

[2] Larvae only. [3] All instars.

known. More recently the danger to mammals (including man) from the organo-phosphate group of chemicals has received increasing attention. However, there appears to have been a general re-assessment of the danger to man and wild-life from pesticides. For example, a recent United Nations publication reviewed all the known major studies relating to this question [34]. The basic conclusion which emerged was that, with a few important exceptions, the environmentalists have overstated their case. Closer to home, the Australian Government has recently decided to accept the recommendation of the Australian Academy of Sciences not to ban DDT.[18] Nevertheless DDT may persist in some environments almost indefinitely. The organo-phosphate chemicals are capable of poisoning (killing) man and wild-life. Pesticides do 'dirty' the environment. Each society must, therefore, devise a means of achieving an acceptable trade-off between the consumption of the plant material which the plant pesticides make it possible to produce and the consumption of a 'clean' environment free of plant pesticide residues [7]. Given that the demand for a clean environment is highly income elastic, one would predict different trade-offs in societies with different standards of living.[19]

(i) *Externalities and All That*

One school of thought suggests that society can best achieve the appropriate trade-off between a clean environment and other items of consumption through the market mechanism [1]. At the other extreme there are those who want the environment preserved at all costs and urge governments to ban completely certain pesticides by making their application illegal. It is highly unlikely that either of these approaches to the problem is the socially optimum strategy.

In the case of pesticides there are often substantial externalities [23]. Society needs to develop measures to ensure that these externalities are not overlooked. Chisholm *et al.* [7] have concluded there are essentially three approaches. First, the externalities may be eliminated (or internalized) by negotiation. This approach, which may involve mergers and/or bribes, assumes the parties creating the undesirable externality and the people suffering the damage can be brought together. Second, the society may resort to political action either directly through legislation designed to manipulate property rights or indirectly through fiscal measures such as taxes and subsidies. Third, the groups adversely affected by the externality can resort to moral suasion.

The Australian cotton-growing industry has been subjected to the last mentioned possibility in connection with its use of plant pesticides but it is doubtful if the public outcry has had any real influence. The

[18] See Australian Academy of Sciences, *The Use of DDT in Australia* (February, 1972), p. 45.

[19] Schultz [28] points out that in those countries in which incomes are low, people place a higher value on the agricultural services of the natural environment relative to its aesthetic 'clean environment' appeal than do people in wealthier countries. Environmentalists in the more developed countries who claim that their respect for the preservation of the natural environment should be reflected globally, are either not conversant with the economic or social implications of their recommendations, or they are willing to trade-off the lives of starving peasants today for the (uncertain) benefit of tomorrow's communities.

first approach suggested by Chisholm *et al.* is also inappropriate in the case of cotton pesticides. The only real possibility is, therefore for society to consider political action of some form. However, society should not proceed on the assumption that if the market mechanism has failed, then the political process must (of necessity) yield a more socially acceptable solution.[20] In fact, the community through its elected representatives, should endeavour to have two interrelated questions answered before any political action is taken. First, what kind of political action (policy measure) would be most appropriate? Second, would this most appropriate form of public action achieve a higher level of community welfare than the 'invisible-hand' solution?

The final choice of the 'best' public policy should (among other things) depend on a complete cost/benefit analysis of all the feasible alternatives (including the free-market alternative).[21] The first step, therefore, towards finding a solution to the cotton pesticide problem is to devise some feasible (in both a technical and political sense) policy measures which can then be subjected to a cost/benefit analysis.

(ii) *Towards a Feasible Package of Public Policies on Cotton Insecticides*

If the Australian people wish to have cotton grown in this country by private enterprise, then the fact that chemical insecticides will have to be used must be accepted. The objective of public policy should, therefore, be to devise an institutional package which will reduce production costs and risks (and hence be attractive to growers), while at the same time ensuring that chemicals are used only when absolutely necessary and then only in the correct manner (thus substantially reducing the threat of pollution). One way to achieve this end would be to combine a tax on the dangerous insecticides with both a crop insurance scheme and the injection of pest management expertise.

A range of proposals has been put forward with a view to enlarging the pest control decision-making unit. Most writers recognize that government intervention may be necessary to meet the cost of collective organization, decision-making and enforcement. The form of government action suggested has varied widely. Norton [26] emphasizes the 'police-

[20] The very factors which cause the market mechanism to fail to take account of externalities may also cause political action to fail. Chisholm *et al.* [7] elaborate on this point. In particular, they cite two important reasons why governments may fail to improve resource allocation: (a) Governments will aim to redistribute income in favour of electorally important individuals; and (b) Government effectiveness is constrained by the information made available regarding individuals' preferences. These two conditions are the political analogues of monopoly power and lack of knowledge of market opportunities, the two factors most commonly said to distort the ability of the price mechanism to correctly allocate resources.

[21] Cost-benefit analysis of crop protection policies is not, however, a simple task. The evaluation of pest control measures is considerably more complex than fertilizer use evaluation. Apart from the usual difficulties associated with estimating benefits (e.g., the price responsiveness of supply and demand, constraints on the price mechanism preventing it from indicating true social scarcity values, government policies, external effects, monopoly power, lack of market information, and average rather than marginal valuations), there are problems associated with determining the technical relationships between various policy measures, their resulting output, and their input requirements.

man' role with government influencing the decisions of growers by taxes, subsidies and regulations. Davidson and Norgaard [8] introduce the concept of pest management co-operatives operating partly under government subsidy and government direction. Norgaard, Seckler and Radosevich [25] expand this concept to include a 'professional licensed pest manager', licensed by the government but operating as a free agent. Carlson [5] mentions the need to evaluate policies for making less expensive crop insurance available so that the trade-off between insurance and pesticides can be a realistic decision for primary producers.

The particular policy 'package' suggested by the authors of this paper would work as follows. The government could impose a heavy tax on the purchase of all dangerous insecticides used on cotton. This tax, however, would be subject to a large percentage rebate if the grower participated in the crop insurance program and if he hired a licensed pest manager. The pest manager would be a highly trained and experienced individual familiar with all the latest information on insect control in cotton. His initial training would be subsidized by the State. He would not, however, be a public servant. Rather, he would be a private practitioner responsible to the courts in the same way as doctors, lawyers and accountants. Any grower who hired the pest management specialist would hand over control of the pests in his crop to this outsider. In return he would be protected against any culpable negligence on the part of the pest manager by being able to bring litigation against him in the courts. In addition, since he would also be participating in the crop insurance scheme, the grower would be protected should his crop be wiped out by an 'Act of God'.[22]

Most cotton-growers in Australia could replace cotton with many other crops (e.g., sunflowers, soybeans, sorghum, etc.). Heliothis and the other major pests of cotton also attack these crops although the potential damage is generally not as great. In 1974 the relative profitability of cotton compared with many of these crops suggests that any policy decisions which made cotton-growing less attractive (psychologically, as well as in money terms) would cause a shift of resources out of cotton. To avoid creating this resource distortion and to make the policy package more effective, it could apply to all crops in designated areas. That is, dangerous insecticides, irrespective of the crop or pest on which they are to be used, could be taxed. Pest managers would need to be prepared to manage pests in any crop in their area and the crop insurance scheme could cover all crops, not just cotton.

The nature of biological control is such that it is unlikely to be successful if applied on a farm-by-farm basis. With pest control for whole groups of farms being the responsibility of the pest manager(s), the integrated approach would have a much greater chance of substantially reducing production costs. The suggested policy package would, therefore, internalize one important externality associated with pest control.

But what of the innocent third parties who are currently unable to obtain compensation for 'damage' due to pest control practices? The

[22] In connection with pest management, the question of what constitutes 'culpable negligence' on the part of the management expert and what would be classified as an 'Act of God' would need to be closely examined.

policy proposals in this paper will not completely eliminate this kind of externality. However, one would expect a competent pest manager, whose livelihood was dependent upon his being able to reduce the costs of growing crops, to use substantially less expensive chemicals with more care than the 'average' farm manager has in the past. Besides, if damage to a third party can be demonstrated, the pest manager will be an easy culprit to identify and challenge in the courts. The pest manager would, therefore, have both a greater private incentive and a greater identifiable public responsibility to act in a socially desirable manner than the current independent farm managers.

Where are we to find the dozen or so individuals with the ability and the willingness to assume the role of a licensed pest manager? How are they to be trained and by whom? Who is going to certify their qualifications before the issue of their licences? These and other questions need to be answered before the feasibiliy of the whole package can be accepted. Nevertheless pest management in cotton (and associated crops) is a highly complex business. It is unlikely that integrated pest management strategies will be rapidly adopted without the injection of off-farm expertise. Pest managers are operating successfully overseas (e.g., California). It is, therefore, important for the Australian Government to consider not only investing in the development of integrated control strategies by funding research, but also to consider training people in the practical application of these findings.

Conclusions

The application of pest control techniques to both crops and pastures involves manipulating complex dynamic systems. Technologically advanced agriculture over the last two decades has relied increasingly on one relatively cheap control technique, namely chemical control. The energy crisis, the build-up of insect resistance, and sometimes government policy decisions, have dramatically increased the cost of these off-farm inputs. There is, therefore, considerable incentive first, to refine the management of chemical plant pesticides to ensure that these expensive resources are being utilized to their full economic potential, and second, to devise cheaper, more ecologically sound and socially acceptable integrated control techniques.

Increasing public interest in the externalities associated with the chemical plant pesticides is another strong reason for increasing the efficiency of pest management. It may, therefore, be in the interests of both society and primary producers to create a new institution, namely the 'pest manager'. To enable the pest manager concept to gain acceptance, it may also be necessary to introduce it as part of a policy package which includes both a 'big stick' (in the form of a tax on dangerous pesticides) and a 'carrot' (a crop insurance scheme).

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