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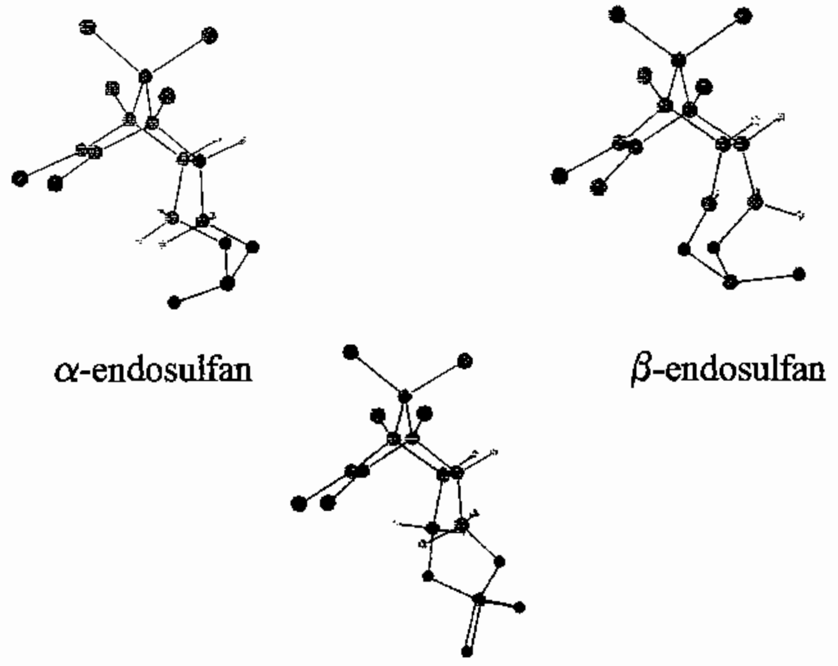
COTTON RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT

THE FATE OF ENDOSULFAN SPRAYED ON COTTON FOR INSECT CONTROL



UNIVERSITY OF SYDNEY
CRC for Sustainable Cotton Production

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COTTON RESEARCH AND DEVELOPMENT CORPORATION

Project title :	**THE FATE OF ENDOSULFAN SPRAYED ON COTTON FOR INSECT CONTROL**
Corporation's Code:	US2C/US15C

Organisation: University of Sydney

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A final report prepared for the Cotton Research and Development Corporation

SUMMARISED REPORT

During the past decade, endosulfan, an insecticide effective against *Heliothis*, has been considered as essential to the economic success of the cotton industry. Its availability has been a key factor in the development of the insecticide resistance strategy, in which endosulfan is sprayed in response to insect pressure during the early growth of cotton crops, during the period of canopy filling. As an organochlorine, but one from overseas data considered to have a relatively short lifetime compared to others in this class, its properties contrast sharply with those of other insecticides employed in the resistance strategy, such as the pyrethroids. Endosulfan also had the advantage that it does not accumulate in the body tissues of sheep and cattle, unlike most organochlorines. However, this chemical is of serious environmental concern, because of its acute toxicity to fish. Studies by the NSW Department of Water Resources in recent years have confirmed that endosulfan residues are entering river waters in amounts exceeding environmental recommendations. Unfortunately, no suitable chemical replacements are available for testing.

In order to obtain information of its environmental fate under conditions of use in the Australian cotton industry, this major study was initiated in 1990-91. It represented the first case of a systematic analysis of the fate of endosulfan under Australian conditions. The experimental strategy used was to conduct random sampling of soil throughout the year on several fields used for cotton growing. From analysis of these soil samples for endosulfan residues, it would be possible to discover the rate of breakdown and to estimate half-lives (the time to reduce the concentration in soil to half its current value) and to identify the chemical products. This would allow an assessment of whether endosulfan was likely to cause long-term problems related to its accumulation in soil and its potential threat to the environment.

The results of the study were:

- endosulfan disappearance from soil is relatively rapid, with very little carryover of the pesticide applied in formulations from one season to the next. Only minor amounts of endosulfan sulphate, a longer-lived metabolic product of the forms endosulfan sprayed also toxic to fish (the alpha- and beta- isomers), remain in soil from one season to the next. The study has also shown that where rotation with wheat and a summer legume such as *Dolichos lablab* is used in the farming system, the possibility of carryover is likely to be further reduced.

- the approximate half-lives in soil of the alpha- and beta-isomers were determined in the case of one cotton field as 43 and 76 days, while endosulfan sulphate required about 101 days to be degraded to half its concentration in soil once most of the isomers were dissipated under these field conditions. The results obtained from very intensive sampling over three successive seasons of several other cotton fields on different farms with different management systems are similar. Thus, there is no problem of long-term accumulation of endosulfan residues in soil used for growing cotton.

- a study of the distribution of endosulfan residues with depth in the soil profile has shown that endosulfan is not significantly leached in soils used for growing cotton. This has dual advantages. It shows that endosulfan presents no threat of contamination of groundwater during irrigation or rainfall, although its property of binding strongly to soil, probably to the organic fraction, means that it will instead be prone to transport in suspended sediments of runoff water. The second advantage of technical nature is the ability to estimate the total burden of endosulfan residues on cotton fields by sampling only the top 5-10 cm of the soil profile, rather than by using 20 cm cores as employed when the study commenced.

- trial sprayings with immediate sampling of soil conducted at the Myall Vale Research Station indicate that there is incomplete recovery of the total endosulfan applied when the total amount of insecticide and degradation products are estimated several days later. This indicates that loss by volatilization of endosulfan from the soil surface may be significant soon after spraying.

- in some cases, the non-toxic product of endosulfan known as endosulfan diol was found in soil in significant amounts. Associated laboratory research has indicated that toxic endosulfan sulphate is formed in well-aerated soils, while non-toxic endosulfan diol is likely to be formed in saturated soil, run-off water or bottom sediments.

- from a greenhouse study, endosulfan sprayed on cotton plants was found to disappear rapidly, probably mainly by volatilization, during the first three days after spraying, with about 10-15% being converted on leaves to endosulfan sulphate. However, analyses of samples of cotton lint from several field sites showed that the commercial product does not carry any detectable residues of endosulfan or any other common insecticide or herbicide used in cotton growing, despite the presence of wax on cotton fibres that could potentially dissolve pesticide residues. Apparently, there is no transfer of residues into the cotton boll.

The main conclusion from these results is that endosulfan residues retained on cotton farms do not present long-term problems of worsening soil contamination by toxic forms of endosulfan. If residues could be strictly retained within the boundaries of cotton farms - for example by strict retention of all tail waters on farms - there would be no major environmental problems associated with its use.

However, there are independent results showing that significant contamination of the rivers is occurring each spraying season. Thus, it is obvious that direct movement off farms is occurring within a few weeks of application, perhaps associated with transport of residues on soil sediments carried in occasional storm runoff, or by the process of volatilization from soil or cotton foliage to the atmosphere indicated in this study. A third possibility is related to direct drift off-farm during spraying. Further research is required to explore these transport mechanisms, before final recommendations aimed at minimising river contamination can be made. The results of the study described in this report provide information essential to conducting this new research, now in progress in the joint program of Land & Water Resources Research & Development Corporation, the Cotton Research & Development Corporation and the Murray-Darling Basin Commission.

ABSTRACT

The environmental fate of endosulfan, a key insecticide sprayed on Australian cotton farms for insect control, was examined in a project extending over three successive years. The study involved periodic sampling of soil throughout the year, to determine the variation in concentration of pesticide residues on cotton farms, both with time and spatially.

Endosulfan residues in soil were at peak values in soil during each period of spraying (November-January each year; ca. 0.5mg/kg in the top 5-10 cm), most of the application of the two isomers applied being converted to endosulfan sulphate (also toxic to fish), to non-toxic endosulfan diol or related compounds, or dissipated by other means such as volatilization within about two months from the end of the spraying season. There was no accumulation of soil residues observed during the 3-year period of study, with most of the endosulfan sulphate formed having been degraded by the beginning of the following cotton season (<0.05mg/kg).

From the results of this study it can be concluded that the threat posed by endosulfan to the riverine environment and individual species such as fish and other aquatic biota results from transport processes operating from cotton farms during the growing season. The relative significance of different mechanisms by which such transport may occur, such as runoff of storm water, drift during spray application or some other means of aerial transport still requires experimental assessment.

FINAL REPORT

INTRODUCTION

Industry significance

Endosulfan is a key insecticide in the strategy for the control of *Helicoverpa (Heliothis)* spp. in cotton. The loss of this chemical could cause very serious problems for the industry. This is because of resistance readily developed by *Helicoverpa* to other insecticides (e.g. pyrethroids) and the high cost of alternatives to endosulfan.

The research proposal requested support for an integrated study on the fate of endosulfan sprayed on cotton. By sampling both farms and nearby sites including soils, it was intended to discover the longevity and rate of breakdown of endosulfan, the chemical identity of the products of endosulfan and the potential threat to the environment (Fig. 1). From the field survey, an understanding of degradation and possible transport of endosulfan was to be gained that would allow future decisions about its use to be based on scientific evidence.

As an insecticide for use on cotton, endosulfan has considerable advantages. Unlike other insecticides, early use of endosulfan does not lead to problems with spider mites later in the season. Endosulfan is also a vital chemical in the management strategy for insecticide resistance with *Helicoverpa*, since it is the only chemical registered in the organochlorine group.

Endosulfan and its products have markedly different chemical properties to other related cyclodiene insecticides such as aldrin and dieldrin, being much more polar; from the environmental point of view, endosulfan definitely should not be included as part of this group. Thus it is not found as a residue in the carcases of farm animals. However, previous work showed that some wildlife, including fish and birds of prey, could be contaminated with endosulfan or its products. Overseas studies on endosulfan have shown similar contamination.

Laboratory studies using technical grade endosulfan showed that fish suffer severely from toxic effects (LC50, 0.09-11.2 ppb), depending on species and temperature. For this result to be validly applied to the field, a knowledge of the chemical isomeric forms being applied for insect control, their rate of dissipation and their environmental products would be required. Because of the likely toxicity to fish, however, it is particularly important to prevent contamination of waterways. Some contamination is occurring, indicated by fish-kills caused by endosulfan recorded in the Mungindi.

Endosulfan and its products require considerable skill to and analyse with accuracy. As a result, its residues may sometimes have been overlooked. It could also be a false assumption that endosulfan always disappears from the environment rapidly one of the few studies available on persistence has shown that endosulfan (in its beta-form) and other immediate products were not significantly degraded in a sandy-loam soil for at least three years. The fate of endosulfan under Australian conditions is unknown.

The system of tail-water management with retention on farms helps prevent direct contamination of the rivers from the various agents applied to crops on cotton farms. But there was an acute need to understand the short and long-term fate of endosulfan currently being used on Australian cotton farms. Whether it was

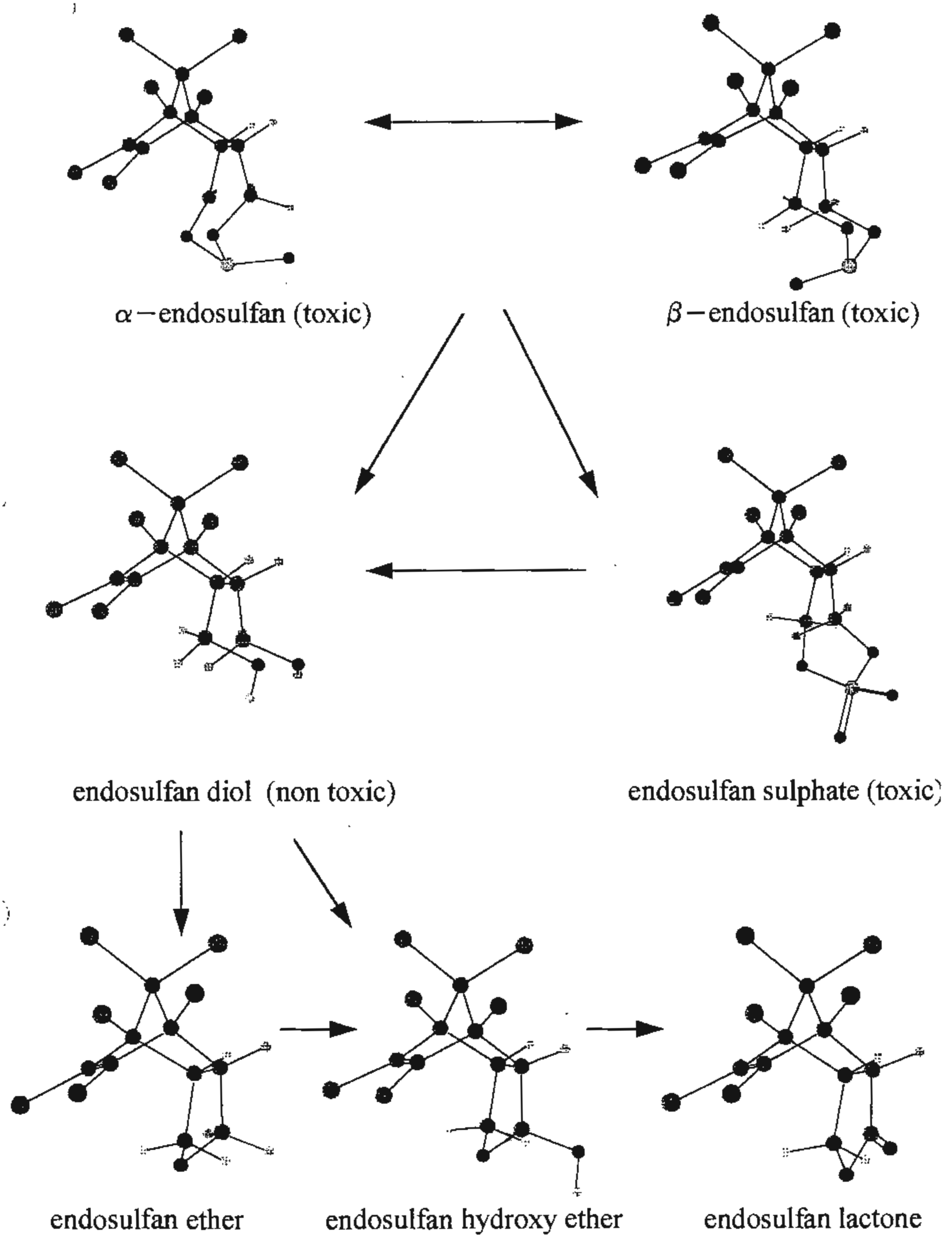


Figure 1. Endosulfan and its five breakdown products. Pathway after Miles and Moy (1979)

Key : C O Cl S H

accumulating or at what rate it was degrading in situ was not known. Prudence suggested that these possibilities should be assessed.

OBJECTIVES

This project sought to determine the environmental fate of endosulfan applied to cotton and to investigate residue levels in non-target species.

The objectives to be achieved in each year of the grant were:

> Year one: Analysis of pesticide levels on selected farms from planting to commencement of next cotton season; statistical verification of sampling procedures.
>
> Year two: Replication of on-farm sampling, extension of data collection to include nearby sites such as tail-waters and biota; studies on endosulfan movement in storm-events, through and across soil profiles will be made.
>
> Year three: Completion of surveys needed to produce an input-output model of the fate of endosulfan in the sampling areas; estimation of degradation, fixation, or transportation to other sites; identification of any fraction of the applied endosulfan that presents a threat to wild-life and the environment.

The experimental approach involved the collection of field data from selected farms in the Namoi valley over three growing seasons, with chemical analysis of endosulfan and its products in soil and cotton lint.

The project was based in the Department of Agricultural Chemistry at the University of Sydney, where electron-capture gas chromatographs were available. A Hewlett-Packard Gas chromatograph-Mass spectrometer was also available by the first half of 1992. This $100,000 facility was partly funded by the CRDC ($19,542), benefiting the project by increasing the throughput and the quality of the residue analyses performed on behalf of the CRDC in this project. Considerable time (perhaps 12 weeks per year) was required for field sampling and the research staff are based in the Namoi valley at intervals during the year.

RESULTS AND DISCUSSION

Soil samples were collected from five sites on four farms in the Namoi Valley between Wee Waa and Narrabri. This provided data from sites varying significantly in farm management, although all sites involved growth of irrigated cotton. The sites are detailed in Table 1.

TABLE 1

Site	Location	Bed Width	Field Area
Field 16	Auscott, Narrabri	2m, permanent	48ha
Field 33	Auscott, Narrabri	2m, permanent	100ha
1A	'Glenara', Wee Waa	1m	20ha
1	'Glenarvon', Wee Waa	1m	72ha
1	'Beaconsfield', Wee Waa	1m	50ha

Since the main purpose of the project was to determine the soil burden of endosulfan residues from spraying and the extent of persistence of residues from one year to the next, a strategy based on soil sampling throughout the year was chosen. No attempt was made to synchronize sampling with spraying schedules and soil sampling was essentially independent of on-farm operations. However, a key factor in determining sampling dates was the soil condition. In order to obtain good quality soil samples representative of residues in soil, it was necessary to restrict sampling when cotton fields were too wet. Approximately 1500 soil samples were collected and analysed during the project.

Of the breakdown products shown on Figure 1, only endosulfan sulphate and endosulfan diol were usually found, although traces of the others shown other than the lactone were detectable.

Depth of sampling

Samples were initially taken to 20 cm depth to ensure that all residues were recovered, given that there was a possibility of leaching and that fields would be cultivated before the next cotton season. However, by the end of the first season it was obvious that cores of 10 cm depth would be adequate because of an absence of downwards leaching noted from analyses of the soil samples (Fig. 2). Samplings of the sites indicated in the table above continued from the 1990-91 season through to the 1993-94 season at about 6-8 week intervals, using cores of 10 cm depth.

Analyses

Nearly all samples collected were analysed. Initially, the analytical methods required needed to be developed. Protocols for endosulfan residues from soil were not available in the literature, so it was necessary to prove these from first principles, as part of this project. During 1991, satisfactory methods for the analysis of all significant residues associated with endosulfan were developed, bar endosulfan lactone. This polar 'end-product' is not considered likely to be of great significance. The identity of the residues was confirmed using gas chromatography-mass spectrometry (Hewlett-Packard GC-MS), initially in cooperative work at the Arncliffe laboratories of the Department of Water Resources and during the latter stages of the project using similar equipment, purchased in part with a separate grant from the CRDC.

Detailed results

Figure 3 shows representative sets of analyses (the full data set will be published in a thesis in preparation; Kimber (1996) of residues from the 'Beaconsfield' site, sampled at intervals throughout the 1990/91 growing season and into the subsequent winter season. As shown in the graph, the main endosulfan residue found in soil was

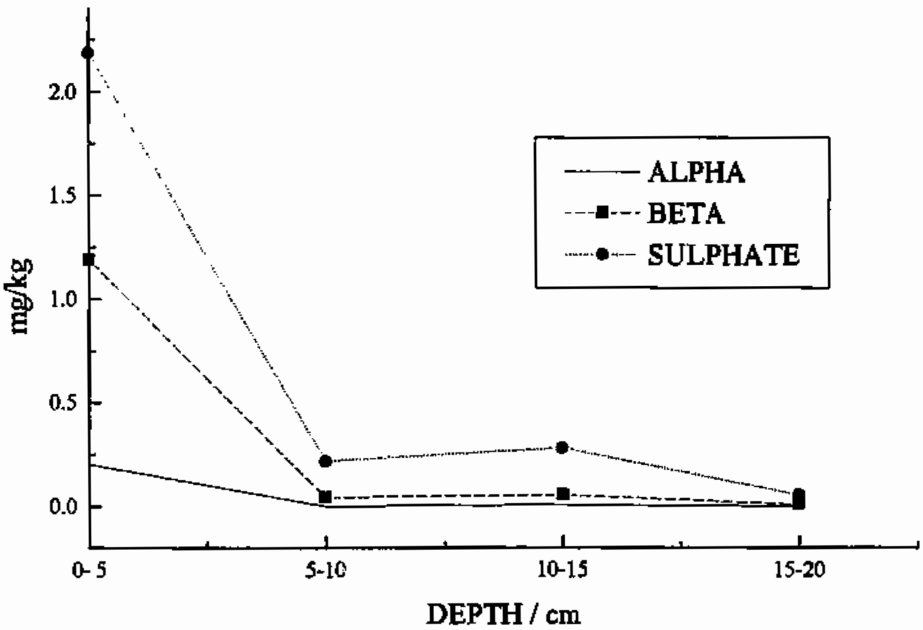


Figure 2. The distribution of endosulfan with depth in soil. Results of a single core stratified into four 5cm layers. (Samples taken from the 'Glenara' field site.).

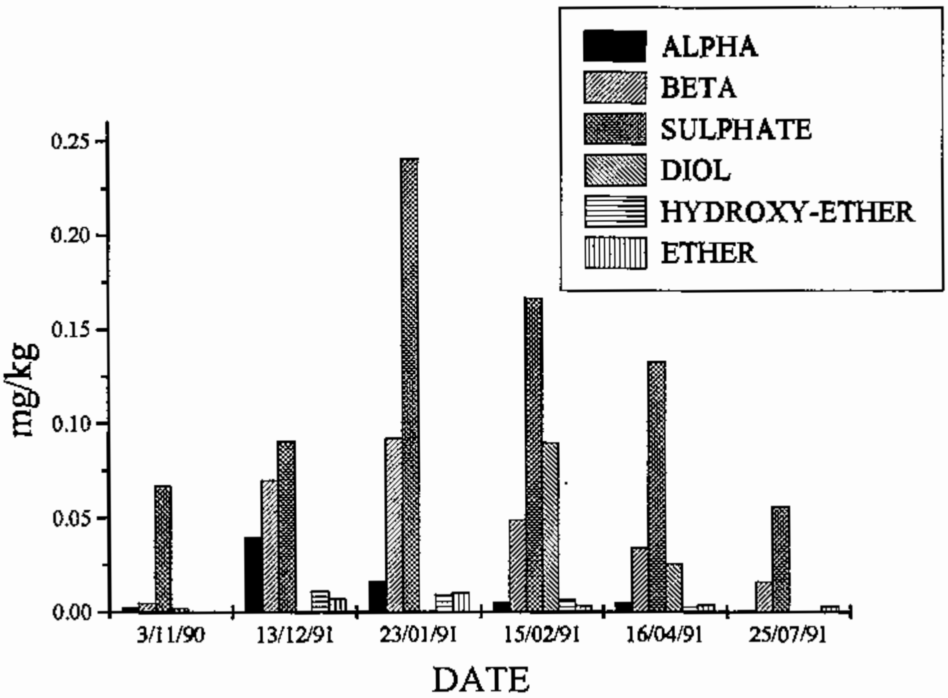


Figure 3. Seasonal soil burden of endosulfan residues. Soil cores of depth 20cm were taken over an 8 month period from 3/11/90 to 25/7/91. Each data point is based on 20 individual samples. (Samples taken from the 'Beaconsfield' field site.)

endosulfan sulphate; the alpha- and beta-isomers of endosulfan sprayed on crops (70:30 ratio) were only significant during the spraying season and were not observed to exceed concentrations of endosulfan sulphate. Possibly, if sampling had been targeted immediately after spraying, this would not have been the case.

Quantities of all three of these toxic endosulfan residues in soil increased from a low level at the beginning of each season during the November-January spraying period. By the following spring, residues declined to a significantly lower level (Fig. 4).

The following general conclusions can be made from the data obtained:

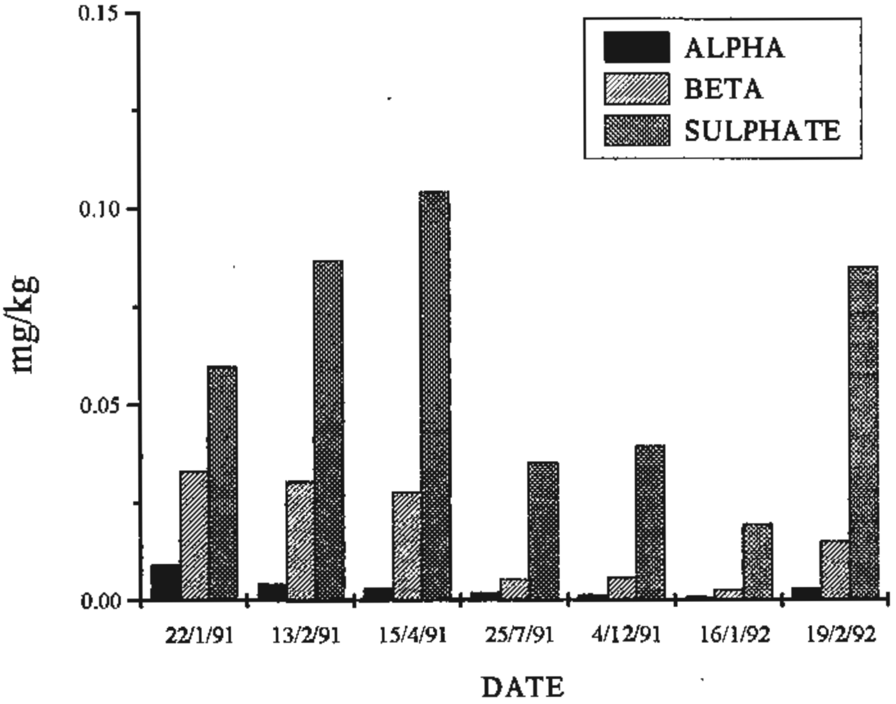
1. The maximum burden of toxic endosulfan residues in the soil during the growing season never accumulated to a level greater that the amount applied in a single spraying at the recommended rate. This conclusion is based on the observation that endosulfan residues were fully retained within the top 5-10 cm of the soil cores sampled, allowing estimation of the total burden of these residues in cotton fields. Within three months of spraying, the total soil burden declined to less than 20% of the maximum and less than 5-10% of total endosulfan applications remained by the first spraying of the next cotton season.

Naturally, it is expected that significant residues of endosulfan will be found in soil during the spraying season, especially since it is mainly sprayed prior to closure of the canopy. Other data suggest a short 'half-life' for endosulfan in water of less than a week and it is clear that soil has a stabilising effect.

2. The data shows that the acutely toxic forms do not accumulate in these soils used for cotton growing. (That was 'the worst case scenario'). Thus, on an annual basis, the rate of application of endosulfan does not exceed the capacity of natural processes to dissipate and degrade it. On the other hand, the levels of endosulfan and endosulfan sulphate present in these cotton soils during the spraying season and soon afterwards is certainly not trivial. It remains to be shown whether these endosulfan residues in soil are the cause of the significant levels observed recently in river water (see NSW Department of Water Resources Reports, 1991-94).

3. The levels of non-toxic endosulfan diol observed are variable. Formation of this relatively non-toxic residue rather than endosulfan sulphate would be preferable. Associated work (Guerin, 1993; S. Southan, University of Sydney, unpublished), also supported by CRDC, indicated that endosulfan sulphate formation was a soil-related process, not occurring in wet or marine environments. Endosulfan diol formation, a hydrolytic reaction, occurs in runoff water or wet soil and would be expected to proceed at a significant rate in aquatic sediments. Therefore, it is possible that the endosulfan diol residues observed in this study reflect a high moisture status of soils.

4. Other positive outcomes of this project include the development of sampling and analytical procedures for studying endosulfan residues (Kimber *et al.*, 1995) using electron-capture gas chromatography and mass spectrometry to obtain definite identification of residues and breakdown products. In a subsidiary project, it has also been established that cotton lint carried no residues of endosulfan or of other commonly applied pesticides. (NB. Chlorfluazuron, or 'Helix', was not assayed).



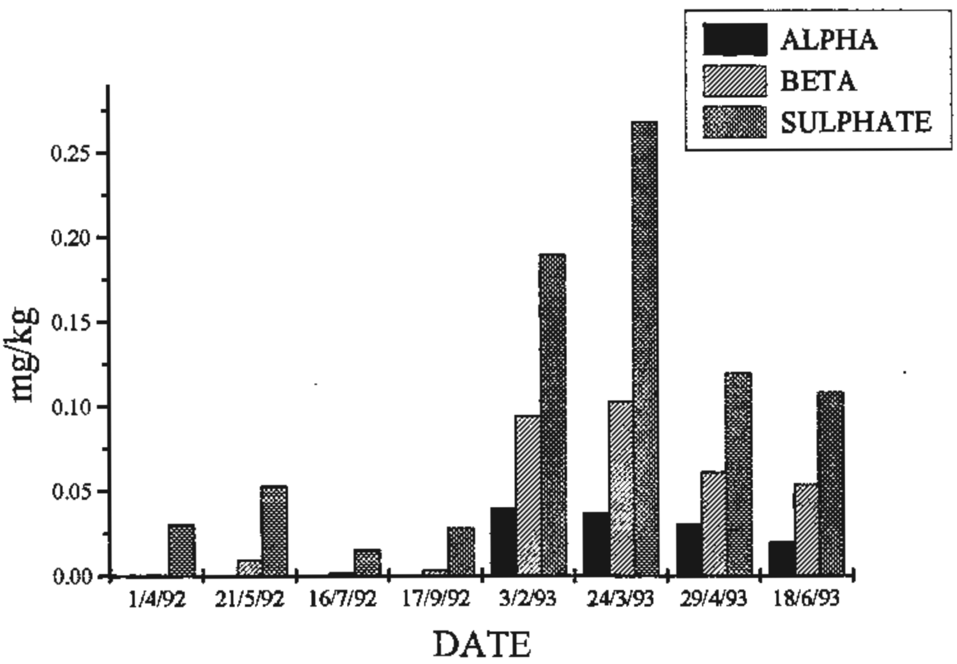


Figure 4. Seasonal soil burden of endosulfan residues for Auscott field 16. 22/1/91 to 19/2/92 cores taken to 20cm depth. 1/4/92 to 18/6/93 taken to 10cm depth. Cotton was grown in the 1990/91 season and in the 1992/93 season. In the 1991/92 season, wheat was grown and no endosulfan was applied.

5. Not all the objectives nominated for this project were achieved. It was decided early to restrict sampling to on-farm sites to provide focus to the study. Another initial objective - to assess the major means of transport of residues from cotton fields - was also abandoned when the magnitude of the task became evident. In particular, the desirable objective of sampling runoff in storms not possible to achieve within the resources of this project.

GENERAL DISCUSSION

The results of this study provide key information needed to develop strategies to reduce the impact of endosulfan and other pesticides on the riverine environment. Other work conducted by the NSW Department of Water Resources provides clear evidence that significant contamination of river waters by each of the toxic forms of endosulfan residues occurs annually during the growing season. It is noteworthy that soil stabilises endosulfan residues compared to water, where half-lives have been found in other studies to be much shorter of the order of several days only under summer conditions of temperature. Since multiple processes of volatilisation (particularly immediately after application), chemical hydrolysis and biodegradation are likely to be involved in the disappearance of endosulfan residues, no great accuracy can be assigned to the half-lives given above. However, similar half-lives to those found in this CRDC study for the α- and β-isomers of about 30 and 50 days in soil have recently been estimated from the results of the more intensive research conducted on behalf of the LWRRDC/CRDC/MDBC joint program, confirming these significant dissipation rates.

Another positive outcome of this project has been to provide essential preliminary data and methods for new research now being conducted by several collaborating research groups in both New South Wales and Queensland. The methods developed in this project have materially benefited this new research, which is aimed at obtaining improved understanding of possible mechanisms of medium to long range transport of pesticide residues from cotton farms. By 1993, it was decided that this objective would be a main focus of new studies, commissioned as part of the LWRRDC/CRDC/MDBC joint research program on "Minimising the impact of pesticides on the riverine environment using the cotton industry as a model". Some aspects of transport, containment and bioremediation of pesticide residues on cotton farms are also now being studied in Subprogram 1.1 of the Cooperative Research Centre for Sustainable Cotton production at the University of Sydney and in the field.

CONCLUSIONS AND RECOMMENDATIONS

This project has had positive outcomes in providing information vital to understanding the fate of endosulfan sprayed on cotton. It provided independent and objective data for the first time revealing that, under Australian conditions, endosulfan residues are not accumulating in the soils used in cotton growing, but that they are almost totally dissipated on-field by the beginning of the subsequent spraying season. Thus, measured as soil contamination, endosulfan is less objectionable than DDT was.

Despite these positive findings, there are significant problems related to acute toxicity from the direct transport of endosulfan and endosulfan sulphate from cotton fields during the growing season. It is a clear conclusion from the results of this study that further research is necessary to define the mechanisms of dissipation and to obtain solutions that will be satisfactory for the cotton industry to apply.

COMMUNICATION OF RESULTS

The results of this project have been communicated to other research workers at workshops and conferences over the past 2-3 years and have been incorporated into the general knowledge base for Australian conditions. Aspects of the study appear in the following formal publications and a full dataset description will be publisbed in the PhD thesis of S.W.L. Kimber.

Refereed papers

Kimber, S.W.L., Southan, S.K., Ahmad, N. and Kennedy, I.R. (1995) The fate of endosulfan sprayed on cotton. *World Cotton Conference* 1, N. Forrester and G. Constable, eds., in press.

Guerin, T.F., Kimber, S. and Kennedy, I.R. (1992) Efficient one-step method for the extraction of cyclodiene pesticides from aqueous media and the analysis of their metabolites. *J. Agric. Food Chem.* 40,2309-2314.

Theses

Guerin, T.F. (1993) The relative significance of biodegradation and physicochemical dissipation of endosulfan from water and soil. PhD Thesis. University of Sydney.

Kimber, S.W.L. (1996) The fate of endosulfan sprayed on cotton. In preparation (full data set).

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Kennedy, I.R. (1993) The environmental fate and transport of pesticides. The impact of pesticides on the riverine environment. *Research Workshop Report, LWRRDC/CRDC/MDBC,* The Australian Cotton Foundation, Sydney, NSW

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Kimber, S.W.L., Coleman, S., Caldwell, R.A. and Kennedy, I.R. (1994) The environmental fate of endosulfan sprayed on cotton. *In:* Abstracts 8th International Congress for Pesticide Chemistry, Washington DC, USA July 4-9. p. 234.

Kennedy, I.R. (1994) The fate and transport of chemicals on farm. *In* Proceedings 7th Australian Cotton Conference, Brisbane, August, pp. 515-522.

Other publications

Guerin, T.F. and Kennedy, I.R. (1992) Distribution and dissipation of endosulfan and related cyclodienes in sterile aqueous media: Implications for studies on biodegradation. *J. Agric. Food Chem.* 40, 2315-2323.

Kimber, S.W.L., Ahmad, N. and Kennedy, I.R. The environmental fate of endosulfan. In preparation for *Arch.Env.Contamin.Toxicol.*

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Acknowledgements
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Our thanks, also, to Dr Francisco Sanchez-Bayo for his assistance with the preparation of this report and his contribution to the cost-benefit analysis of this project.

APPENDIX:

The total funding costs to conduct this project are given in Table 1. In addition to direct CRDC grants, the contribution of time by the project supervisor is given. No infrastructure costs or the value of access to equipment and laboratories is given in the table. Particularly in the initial stages, Mr. Nazir Ahmad, NSW Agriculture, Rydalmere provided advice on setting up this project.

TABLE 1 TOTAL FUNDING

BUDGET				
Item	1990/91	1991/92	1992/93	1993/94
Salaries	20000*	24000	28500	29785*
US15C fellowship	*includes $18000 scholarship	*includes $18000 scholarship	*includes $18500 scholarship	*includes $22785 scholarship
Travel	9075	5200	4600	2300
Operating	9550	14500	13800	16900
Capital	12435	6500	3500	-
TOTAL CRDC FUNDING	51060	50200	50400	48985
			1990-94	200645
Salaries + overheads, University of Sydney (0.1FTE, IRK)	18900	19200	19500	19900
TOTAL FUNDING	69960	69400	69900	68785
OVERALL TOTAL			1990-94	269430

Cost-benefit

The total CRDC funding for this project is given in Table 2.

TABLE 2 CRDC FUNDING

YEAR	SALARIES *	TRAVEL	OPERATING	CAPITAL	TOTAL
1990/91	20,000 (18,000*)	9,075	9,550	12,435	51,060
1991/92	24,000 (18,000*)	5,200	14,500	6,500	50,200
1992/93	28,500 (18,000*)	4,600	13,800	3,500	50,400
1993/94	29,785 (22,785*)	2,300	16,900	-	48,985
TOTAL	102,285	21,175	54,750	22,435	200,645

* US 15C scholarship

We estimated the cost of endosulfan based on its usage in the cotton industry, as shown in Table 3. Endosulfan represents 56.9 of the total insecticides used for insect control. However, being a relatively cheap pesticide, endosulfan cost per hectare is only $56 (or 4.55 % of the total production costs), based on four sprays; it is assumed that other chemicals such as pyrethroids would cost 4 times as much as endosulfan, raising the total insect control costs by 45.4 %.

TABLE 3 ENDOSULFAN COST AND USAGE IN THE INSECT CONTROL PROGRAM

	% of production cost	$ per hectare	Total in Australia ($)
Insect control	30	370	96,940,000
Insecticides	18.05	222	58,164,000
Endosulfan ($14/ha)	4.55	56	14,672,000
Without endosulfan*		538	140,956,000
Insect control increase	45.4	168	44,016,000

* assuming any substitute of endosulfan would cost 4 times as much

	% insecticide usage	% endosulfan/stage	Weighted % endosulfan
First stage	54	94	50.76
Second stage	41	15	6.15
Third stage	5	0	0
TOTAL	100		56.91

In 1994, the area planted to cotton in Australia was 262,000 hectares, the same as in 1992-93. The average yield for the past three years was 1,400 kg, and the current price for a kilogram of cotton fibre is about $1.8. From these figures we estimated: (I) the production costs with and without endosulfan, according to Table 3; (ii) the net benefit resulting from using or not using endosulfan. As shown in Table 4, endosulfan brings a total benefit of $170 per hectare, which represents a total $44.5 million/year for the whole Australian Cotton Industry.

TABLE 4 THE COTTON INDUSTRY WITH & WITHOUT ENDOSULFAN

1994	$ per hectare	Australian Cotton Industry ($)
yield (kg)	1,400	366,800,000
With endosulfan		
Production costs	1,230	322,260,000
Cotton sales ($1.8/kg)	2,520	660,240,000
(A) Net benefit	1,290	337,980,000
Without endosulfan		
Production costs	1,400	366,800,000
Cotton sales ($1.8/kg)	2,520	660,240,000
(B) Net benefit	1,120	293,440,000
(A) - (B) Net benefit	170	44,540,000

A simple benefit-cost ratio can be calculated as: Costs / Benefits
For a project to be worth its cost a ratio > 1 is required. Assuming that the continued use of endosulfan by the cotton industry for one year has depended on the good faith shown by CRDC's funding of environmentally related research, a benefit-cost ratio of 222 can be calculated (Table 5), based on the total cost to CRDC of the project.

TABLE 5 BENEFIT COST RATIO

present value of costs (project)	200,645
present value of benefits	44,540,000
benefit-cost ratio	221.98

This ratio may be considered as inflated and too specific, given other environmental research now being funded by the CRDC. However, other factors that should be considered include the value of conducting research aimed at protecting and improving the riverine environment - a value set by the community as a whole. The advent of new technology such as transgenic cotton resistant to *Heliothis* is also relevant, but it is too early to say if this will allow reduced environmental impacts from applications of chemicals to protect cotton from insect damage.