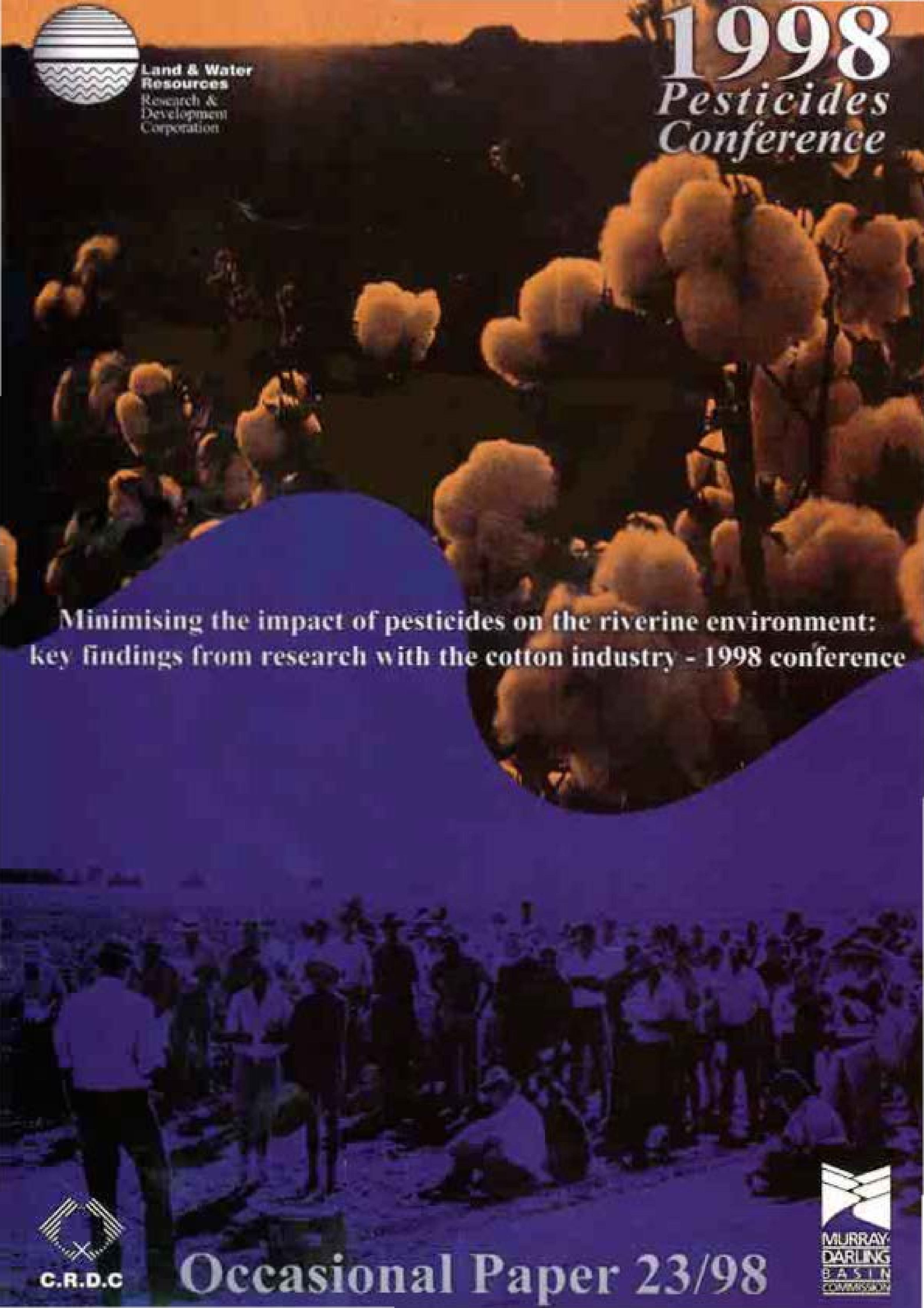

Land & Water Resources
Research & Development Corporation

1998 Pesticides Conference

Minimising the impact of pesticides on the riverine environment: key findings from research with the cotton industry - 1998 conference

C.R.D.C

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Preface

These proceedings represent the outcomes of one of Australia's most successful R&D programs in natural resources management — minimisation of the impact of pesticides on the riverine environment. Conducted over a period of four years, the program focussed on irrigated cotton in NSW and Queensland as a model for other industries that use pesticides. The reasons for choosing cotton were several: it is the highest agricultural user of pesticides, it has been subject to ongoing criticism by environmental groups, it is an expanding industry with a bright commercial future in Australia, and it was prepared to take on board the research required to address the perceived problems and moreover adopt the outcomes.

The program formally commenced in 1993 following a period of review of the issues and a collaborative funding agreement between the Land and Water Resources R&D Corporation, the Cotton R&D Corporation and the Murray-Darling Basin Commission. A Management Committee representing the three partners was established under a legal partnership agreement and took responsibility for the design, commissioning of R&D and delivery of the outcomes. Some key program management principles were established at the outset that provided for an integrated, multidisciplinary approach with continuous feedback and refinement.

The outcomes exceeded expectations. The understanding of pesticide application, transport, degradation and biological impact has taken a quantum leap forward, and this knowledge has been embodied in a Best Practice Manual which has been endorsed at all levels of the cotton industry and is currently being implemented. The program's aims of achieving a sustainable cotton industry and a healthy riverine environment have been further met by gaining the confidence of the regulatory agencies who now accept self-managed Best Practice Management (BMP), as structured in this program, as a viable way forward.

The stakeholders in this program, including the Management Committee, researchers, irrigators, resource managers and regulators, are all to be congratulated in contributing to these achievements. Whilst the program has formally been completed, the Australian Cotton Industry Council is supporting strongly the implementation of best pesticide management practice, CRDC is actively funding ongoing R&D, Environment Australia is using the techniques developed for field testing new chemicals, and LWRRDC is promoting the 'Cotton Model' to other rural industries.

Don Blackmore
Chairman, Program Management Committee

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1. Origins and design of the cotton pesticides program

N.J. Schofield

Land and Water Resources Research and Development Corporation

Abstract

The program Minimising the Impact of Pesticides on the Riverine Environment arose from concerns about the health of rivers and the potential adverse economic impacts of unsubstantiated regulation of the cotton industry. An integrated, focussed program of R&D was developed to achieve the outcomes of adoption of best pesticide management practice and sensible regulations, leading to a sustainable industry and healthy environment.

In the process much has been learnt about pesticide application, transport, degradation, fate and aquatic biological impact. Moreover the cotton industry and regulators have moved to adopt the research outputs in a best practice management framework. The approach or 'cotton model' is now being presented to other pesticide using industries.

Introduction

As the opening presentation, this paper attempts to give an insight into the origin of the program and describe how it was designed and implemented. The initial focus was strongly on protecting the riverine environment, which showed evidence, albeit largely anecdotal, of the impact of pesticides through fish kills in cotton growing regions.

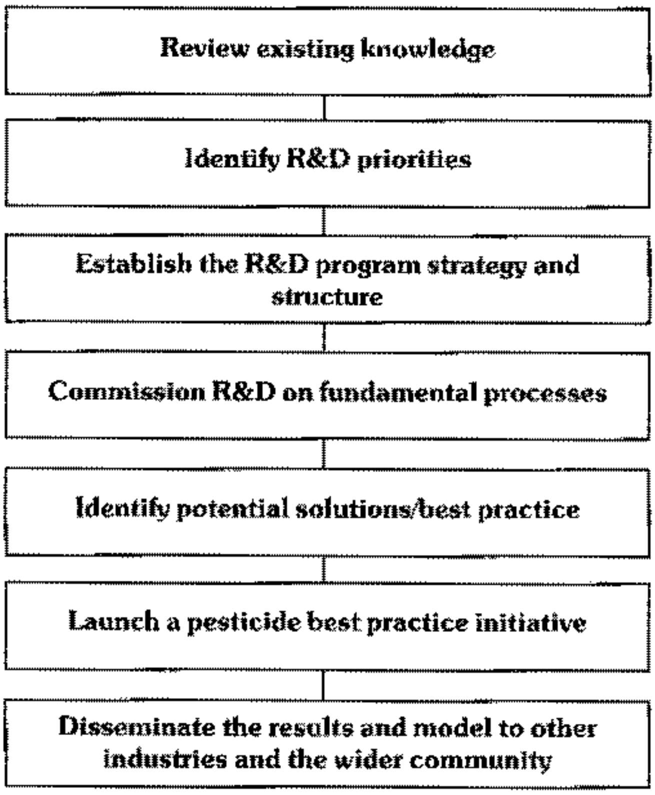
At the same time it was felt important not to rush into a strong regulatory response that would severely impact the cotton industry economically.

The appropriate approach was to undertake a focussed R&D program that would clearly determine the impact of pesticides on the riverine environment, and provide sufficient understanding of their behaviour to recommend practices that would minimise such impact.

In 1991, discussions were held between Land and Water Resources Research and Development Corporation (LWRRDC), the Cotton Research and Development Corporation (CRDC) and the Murray-Darling Basin Commission (MDBC), who subsequently formed a partnership to set up the program.

Several key phases can be identified in the establishment and implementation of the program (Figure 1.1.).

Figure 1.1. Phases of the Minimising the Impact of Pesticides on the Riverine Environment Program



Review existing knowledge and identification of R&D priorities

At the outset a detailed review of knowledge of the impact of pesticides on the riverine environment was conducted (Barrett et al, 1991). This was followed in May 1992 by a major workshop in Goondiwindi on the same topic where a wide range of stakeholders worked through priorities (CRDC, 1992). One of the immediate priorities was to summarise the existing knowledge and evidence on the condition of the river systems (see Arthington, 1995). Another early priority was to run a specialist ecotoxicology workshop as it was recognised that determining the ecological impacts of pesticides was a particularly difficult task (LWRRDC, 1993).

Establishing the R&D program strategy and structure

LWRRDC, CRDC and MDBC formally signed a legal partnership agreement in 1993.

This agreement required the formation of a Management Committee who had responsibility for setting strategic directions, agreeing R&D priorities, program design and financial management.

A program strategy was prepared with the following three key objectives:

1. To assess the impact, if any, of current pesticide use on the riverine environment.

2. To develop practical and economic methods to minimise the transport of pesticides from application sites, and to minimise their effects on the riverine environment.

3. To provide a sound scientific basis for the development of management guidelines and regulatory codes.

The program was structured to meet its objectives in three phases. The phases are strongly linear in the sense that the actions of the second phase could not realistically be determined until the first phase was well advanced and similarly with the third phase. However, given the compressed time frame, the phases overlapped one another, which had the advantage of providing continuous feedback.

Phase I had two principal objectives — to determine and quantify the major pathways of pesticide movement to rivers, and to determine the level of impact of these pesticides on riverine biota.

Phase II was to identify and test potential 'solutions' or methods of ameliorating the problems identified in Phase I. The approaches and relative resource allocations to these solutions could not be assigned until the outcomes of Phase I began to emerge.

Phase III was to incorporate research outcomes into practice. The favoured approach was through best management practice, which the industry would eventually 'own' and run with. The BMP initiative was centred on preparation of a BMP manual and development of an effective implementation plan. The best practices, if adequately audited, were seen as a key means of satisfying regulatory requirements.

Criteria for outcomes and achievement

Clear criteria for outcomes and achievements from the program and its various phases were set early on:

Overall program

1. The source or sources of pesticides in the riverine environment are identified;

2. The impacts of these pesticides on the aquatic ecosystem are determined;

3. Management practices for water, sediment, chemical, spray and river management are developed;

4. Management practices of irrigators, sprayers and water managers change where the results of the research indicate change is required;

5. The various agencies working on the program cooperate in research activities and exchange of findings; and

6. Regulations are based on the findings of this program.

Phase I

1. The sources, types and quantities of water-borne pesticides moving off-farm are determined;

2. The processes involved and factors affecting the movement of pesticides in water and sediment are determined;

3. The movement of water-borne pesticides within and off cotton farms is modelled;

4. The magnitude and frequency of tailwater pesticide releases to rivers from irrigated cotton crops are determined;

5. The quantities of pesticides moving to rivers by aerial transport as spray drift, volatilised material and airborne particulate material (dust) under specified conditions are determined;

6. The persistence of pesticides, particularly endosulfan, in soil and water bodies is determined through degradation studies;

7. The impacts of endosulfan, profenofos and pyrethroids on the aquatic biota of the rivers of the cotton growing regions are determined through laboratory and field studies; and

8. The factors and processes influencing the impact of pesticides on the aquatic riverine biota, including sources and forms of chemical, local habitat effects, organism lifecycles and climatic events are determined.

Phase II

1. Potential solutions or amelioration approaches are identified;

2. Resources are allocated according to highest potential payoff solutions/approaches; and

3. Solutions/approaches are evaluated and compared.

Phase III

1. Regulatory guidelines (if required) are developed on the basis of outcomes from Phases I and II; and

2. Best management practice in terms of farm, spray, chemical and river management, as identified in Phase II, are implemented.

Principles

When the Program Management Committee was formed, it established a number of policies that amounted to principles for program management. These were:

1. To define the problem specifically. Some 18 months of pre-program review and planning was conducted to develop broad stakeholder agreement on the priorities and sufficient scientific detail to structure the program activities.

2. To be proactive. Rather than wait for the consequences of current practice to unfold, develop a process in which those needing to achieve change were empowered to make this happen.

3. To be collaborative. A diverse range of stakeholders were involved through workshop, newsletters, briefing tours and so on. Stakeholders included the cotton farmers, cotton industry, environment protection agencies, river managers, chemical industries, researchers, other industries and the wider community.

4. To establish adequate funding. If the achievement criteria were to be met, it was clear that a critical level of funding was required, so that a fully integrated, comprehensive set of R&D projects could be funded, as well as the implementation of results. Final funding totalled about $6m, with R&D provider organisations contributing almost half. Irrigators contributed about 10 % of the funding directly.

5. Model for other industries. Cotton was a natural focus as it is the highest user of pesticides, is a fairly widespread industry, and was perceived as culpable by the community. It was envisaged that the program could act as a model for other pesticide-using industries, and was dubbed the 'Cotton Model'.

Commissioning and implementing R&D

Given Australia's relatively small skill base in pesticide management, and the need to address specific research questions, most projects were tendered or directly commissioned.

Initially a strong emphasis was given to fundamental field-based R&D to understand the behaviour of pesticide application (including drift), deposition on canopy and soils, washoff and runoff, degradation in soil and water, transmission into waterbodies and impact on the riverine environment.

Once the first results emerged it became apparent that further work was required on aerial transport mechanisms, particularly drift, vapour (following volatilisation) and on dust, on transfer between farm and river, and on tailwater discharges. Work was then commissioned in these areas.

After about two years the focus turned to identifying 'solutions' or best practices. Two consultancies (Doak 1995, 1998) developed a structure for pesticide best practice and a major initiative was launched.

Dissemination and transfer

A conservative approach to releasing research results was adopted, given the contentious nature of and the high stakes involved in, pesticide issues. This approach had three main requirements:

1. Satisfactory program and peer review of results,

2. Integrated and contextual release of results, and

3. Rapid uptake of results into best practice.

The third of these requirements has been satisfied first with the release of the Australian Cotton Industry Best Management Practices Manual (1998). This first manual not only incorporates some of the early R&D findings but has had a wide range of "commonsense practices" vetted by the program researchers and cotton irrigators. This conference provides much more information on the program results, whilst a package of 12-15 papers to be published in the *Journal of Environmental Quality* will largely take account of the science (along with numerous other specific publications).

The transfer of the 'Cotton Model' is in progress at the time of writing. Round-table discussions have been organised with a number of key industries such as sugar, banana, rice and horticulture to see where the cotton model has application and which elements other industries can utilise. An enthusiastic response has been received to date.

The transfer process is being supported by two projects which (a) enable a quick assessment of the likely risk current pesticide practices may have for water resources and (b) allow quantification and mapping of current pesticide use and details of their environmental fate.

Achievements

Some of the major achievements of this program have been:

Scientific

1. Understanding of pesticide application, transport, degradation, fate and biological impact;

2. Quantification of spray drift and development of improved application and management practices;

3. Role and significance of volatilisation and transport via vapour and dust;

4. Degradation rates of pesticides and their breakdown products in soil and plants;

5. Pesticide movement with sediment and water in runoff;

6. Importance of storm runoff;

7. Pesticide behaviour in river water and sediments; and

8. Biological impact of pesticides in rivers.

Management and regulation

1. Agreement on the best practice approach by the cotton industry and regulators;

2. Definition of best practices;

3. Conceptual and practical basis for BMP implementation;

4. Basis for focussing future management effort;

5. Improvement to farm design and management;

6. Methods to monitor pesticides and their impacts;

7. Techniques for testing new chemicals;

8. Input to the review of endosulfan use by the National Registration Authority;

9. Input to guideline pesticide values for environmental protection; and

10. Rapid methods for assessing pesticide use and risk.

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2. Outcomes of the program for the Australian cotton industry and directions for the future

D. Anthony

Cotton Research and Development Corporation

Abstract

We live in an era where three forces — environmental ideals, community perceptions of agriculture and production agriculture — are not in harmony. Like the earth's tectonic plates, these forces continually thrust against one another building tension eventually spilling into controversy, anxiety and uncertainty. Into this state of tension in 1993 was thrust a five year scientific research and biological monitoring program examining aspects of the cotton industry's interaction with the riverine environment.

Emerging from the program in 1998 are outcomes which are spearheading action to meet long-term environmental, social and agricultural needs.

When Land and Water Resources Research and Development Corporation (LWRRDC), Cotton Research and Development Corporation (CRDC), Murray-Darling Basin Commission (MDBC) and NSW Environmental Protection Agency (NSW EPA) initiated the joint program, 'Minimising the impact of pesticides in the riverine environment — using cotton as a model', (known as 'the program') in 1993, there was no certainty as to what the program might encounter.

As with most journeys these organisations had an end in mind — a better understanding of cotton's interaction with the riverine environment and the development of ways to minimise any negative impacts.

A cooperative effort leading to ongoing action

The study was a huge cooperative venture involving research funders, a range of research providers and the cotton industry. Progress is usually achieved through cooperative effort and this program has highlighted such benefit. The mark of a successful program is also reflected by the activities that follow the formal end of the program.

With the cotton industry actively moving into formalised best management practice (BMP) as an outcome of the program, ongoing progress and activities driven by the industry are assured.

Perceptions and facts

The Australian cotton industry, perhaps more than any other agricultural enterprise, has been at the epicentre of tension over agricultural practice. Clearly the use of chemicals and concern for the riverine environment have been key pressure triggers. With today's expanding chasm between the world of urban life and the techniques of agricultural production in the bush the perceptions by an increasingly urbanised community that agricultural practices are harmful are adding greater tension but not solutions to society's supply needs for food and fibre.

For some people this perception of agricultural practice has developed into a crusade. Like all crusades, one has to ask what are the real issues, the true facts and what are the desired long-term outcomes for our community at the end of the engagement. The riverine pesticide program set out to base its results on facts and realities.

Some findings

The outcomes of the program are and will be many and varied. Numerous scientific authors have and will continue to produce a myriad of technical and public interest publications. There will be some purely technical articles adding to the techniques and knowledge of science. Others add to our understanding of the riverine environment while still others have drawn out social and economic issues.

Strongest and likely to be most long lasting of all the outcomes has been the initiation of a world class BMP system for cotton growers that should serve as a model for may other broad acre agricultural industries.

BMP provides a process for benchmarking and where necessary methodical and rational change in management systems. It also provides a vehicle for cultural change, a necessary step in any improvement process. BMP is arguably the most exciting and responsible outcome of this research program.
The scientific information generated from the program indicated no major impact of agricultural chemicals on the riverine environment. Our river systems are complex environments where both natural and man induced agents are in a constant state of flux.

Extrapolating pesticide findings from laboratory test to Australian rivers has been clearly shown as inappropriate for deciding on impacts in a western river system. A clear example of this is the situation presented by European carp which frequent rivers in cotton growing and other western areas in huge numbers yet which are reported as being one of the most sensitive fish species to cotton pesticides.

Traces of insecticides are detected in our rivers albeit generally at low levels. The most commonly found pesticide in the rivers however was Atrazine a non-cotton chemical. The next pesticide found in order of frequency was endosulfan, widely used on a range of field crops including cotton. Endosulfan formed a large part of the program study, partly because of the controversy surrounding the chemical and partly due to the ability to use this chemical as an indicator of pathways for fate and transport studies of other chemicals.

Modern chemical analytical procedures have reached a level of sensitivity enabling them to detect chemical levels down to less than 1 part in a 100 billion parts. This is less than an eye drop of chemical delivered into the vastness of an olympic size swimming pool. With these procedures and environmental thresholds set at the limit of modern analytical detection it is impossible for any of man's activities, urban, industrial or agricultural to operate under a nil tolerance regime.

The critical issue is to understand the impacts of chemicals in the environment and minimise their escapes. The cotton industry realises that it must make every attempt to prevent pesticides moving off target and into the river systems.

Whilst some information generated from the program showed relationships between chemical levels and temporal population levels of a species of minute invertebrates living in the Namoi River, it was equally true that other riverine factors including turbidity had an equal or greater correlation with species numbers. Another important finding was the non-accumulation of endosulfan from season to season.

Considerable work clearly showed that endosulfan does not accumulate and breaks down well within a season on agricultural fields contrary to some beliefs. Studies of endosulfan residues in aquatic sediments have not shown any conclusive results and further work will continue on this matter.

Significant chemical application work has focused on the need to pay particular attention to weather conditions when applying chemicals. Formulation choice and spray volume were also found to be important. The chemical application work has highlighted a need for down wind buffers under certain circumstances combined with the adoption of spray protocols to prevent off-target problems.

Control of irrigation tailwater was identified as a key component of cotton farm management. Clearly farmers have to ensure they have adequate recycling and storage facilities which prevent tailwater being transported to the riverine environment.

BMP — a key outcome

Of all the outcomes of the program, BMP is by far the most far reaching and challenging. BMP has been embraced by the Australian Cotton Industry Council (ACIC), the body which represents all the key cotton industry groups, and which has the full support of the industry's most influential grower, research and consultant bodies including Cotton Australia, CRDC, the Australian Cotton Grower's Research Association and the Cotton Consultants Association of Australia.

The adoption of a best management practice system which is scientifically sound, auditable and continually improving is one of the key methods by which agriculture can move forward in a more harmonious way with the broader community.

Society is continually bombarded with environmental awareness programs and examples of pending environmental disasters, many of which are purported to have agricultural origins. Often, as in the example of Asia's Aral Sea where cotton, rice and irrigation were blamed for environmental problems, people failed to see the real causes.

By any measure the Aral Sea saga has been a disaster but it need not have been that way if a different management approach had been taken. Unfortunately emotive reporting concentrated on the symptoms and not the causes. Misguided political decision making, poor use of science and inadequate management systems lacking proper accountability led to the Aral Sea debacle.

For the Aral Sea example there was no encouragement of long term stewardship of resources nor was there any development of sound agricultural practices or management. In no way can the Australian cotton industry be compared to the events in the Soviet case.

BMP offers the cotton industry ownership of its environmental and corporate performance. By its very definition BMP offers recognition, ownership and stewardship of issues. What more powerful tool could an industry adopt than one driven by its participants to world's best standards and performance benchmarks? There has to be realism about BMP — it cannot be magically instituted overnight.

Firstly BMP must be based on good science — a key goal of the program. Perceptions often cloud the true picture. Facts and information have to be developed, tested and communicated. The latter often being the most difficult to achieve. Previous knowledge and experience have to be integrated as well.

Secondly a realistic phase for uptake and adoption is required. In the cotton industry's case the industry leaders are looking for 80 % adoption of BMP by core cotton producers within three years from 1998 with 100 % awareness by that time. With the strong support of Cotton Australia and the CRDC considerable funds and human resources have been allocated to BMP communications, training and use. Already a large number of trained cotton producers are using BMP but the real in-roads will take place in the 1998-99 cotton growing season.

Thirdly BMP has to be a credible process recognised by the industry and the community. Accreditation, the right to access certain chemicals, random auditing and perhaps farm certification under a quality assurance program are all possibilities being looked at by the cotton industry to provide teeth to the BMP process. Already one Australian cotton farm has achieved ISO 14001 certification and several other farms have won awards for environmental management and resource stewardship.

Publicly there are groups who would denigrate cotton farms however the reality is that cotton farms are in general amongst the most well designed and managed agricultural operations in Australia. It is this drive for professionalism that provides an excellent basis and confidence for a very effective BMP program.

Further supporting work

Whilst the program has focused on existing chemical use the CRDC with the support of Cotton Australia and the ACIC is continuing a major effort to develop integrated pest management (IPM) and integrated farm management (IFM) systems. The most significant breakthroughs in recent times have been the introduction of genetically engineered cotton that provides significant control of *Heliothis* caterpillars.

Most growers report chemical application savings of 50 to 60 % when using cotton containing the *Bacillus thuringiensis* (B.t.) gene. The biggest controversy with the first wave of genetically engineered cotton has been the cost. Australian growers have had to pay around two-and-a-half times the price American farmers pay for the same technology. Despite this short-term problem the future for engineered cotton is very promising.

Currently around 15 % of the area planted to cotton is permitted to be B.t. cotton. Most growers plant this cotton in 'sensitive' areas such as near neighbours or areas closest to waterways or stock routes. Currently cotton containing two *Heliothis* resistance genes has been showing excellent results in trials with Australian varieties providing more robust control and potentially greater chemical savings than the single gene lines. Further research on promoter genes to improve the expression of insecticide genes in cotton, new insect controlling genes and investigations into ways to reduce the attractiveness of cotton to *Heliothis* are underway.

Genetically engineered cottons provide a valuable base for IPM that has been identified as an important component of BMP. Natural control of *Heliothis* is an important aspect of IPM. Increased utilisation of natural predatory insects is under development and is being considerably helped by the introduction of B.t. cottons.

It is well recognised that a range of other issues influence river health including erosion and sediment transport from upper catchment areas, European carp populations, sewerage effluent discharge, urban runoff, unsuitable vegetation clearing, and poor management of riparian vegetation.

While clearly outside the scope of this program these aspects must still be seen as key issues for riverine health. Work by community and irrigator groups looking at ways to deal with these issues is underway. The program does not draw any inference of the relative importance of pesticides to riverine health compared with other critical factors.

Conclusion

There is no doubt that agriculture has to perform responsibly and minimise its impact on the environment. At the same time it has to satisfy an ever increasing demand by providing good quality food and fibre at competitive prices. It is impossible for any of man's activities to have nil environmental impacts.

Cities, farms, factories and leisure activities all create impacts to a lesser or greater degree. Some impacts we acknowledge, others we take for granted. Most activities can be done in ways which minimise their effects. Nil tolerance or impact of any activity is a false dream which can be likened to trying to return Sydney to pre-1788.

Through the joint program the cotton industry and the community have gained valuable information regarding pesticides and the riverine environment. The cotton industry accepts its responsibilities to minimise any impacts to the environment as a result of its activities. Considerable investment of funds and human resources is now going into BMP as a means of demonstrating high levels of stewardship and responsible operating procedures both now and into the future.

The program has been an important initiative to an industry which provides substantial national benefits and creates significant regional employment, in many of the nation's riverine agricultural areas.

3. Environment Australia's views

J. Holland
Environment Australia

Abstract

Environment Australia (EA) has been following the results of the LWRRDC/CRDC/MDBC cooperative study to minimise the impact of pesticides on the riverine environment using the cotton industry as a model with great interest. The paper outlines the value of the work of the project in relation to that carried out in the Risk Assessment and Policy Section of EA, in whose view it has set the benchmark for field studies examining the fate of chemicals in Australia. The value of translating the results into widely adopted best management practices for the cotton industry, and the importance of extending the principles into other areas of high chemical use in Australia are highlighted.

Introduction

Since attending the first, largely planning, annual workshop in August 1993, the Risk Assessment and Policy Section of Environment Australia has followed with great interest the results of the LWRRDC/CRDC/MDBC co-operative study to minimise the impact of pesticides on the riverine environment using the cotton industry as a model. In fact it might be said we have been a rather passionate supporter of the program.

We have attended all workshops held since and have seen firstly the initial results start to come in, followed by a more substantial body of research results, and then watched the beginnings of the translation of the experimental results into best management practices. We are now here at this Conference to listen to the "wrap up" of the program with the realisation that the program has largely been completed and that the Best Management Practices Manual has been introduced into the cotton industry. We congratulate all involved in this very important program, and particularly those who have been with it from its very beginnings to its now successful fruition.

Risk Assessment and Policy Section's role

It is worth spending a few moments discussing why in the view of the Risk Assessment and Policy Section of Environment Australia it has been such an important program. Many participants in this Conference will be aware that the Section evaluates the potential impact of agricultural (and veterinary) chemicals on the Australian environment. We undertake these assessments in the form of provision of advice to the National Registration Authority for Agricultural and Veterinary Chemicals (NRA), which has the legal authority to register chemicals in Australia.

We have done this for all new chemicals before they are allowed on the market since mid-1986, during which time we have assessed well over 100 new active constituents, as well as many further extensions of these chemicals. More recently we also became part of a systematic review of the older chemicals which were put on the market well before 1986 through the NRA's Existing Chemicals Review Program (ECRP), which began in the mid 1990s.

Environmental assessment of chemicals in Australia

In performing these assessments we look at how a chemical is introduced into, and may be transported through, the environment, how persistent it is likely to be and the potential toxic effects it may present to a range of non target organisms such as native mammals, birds, fish, crustaceae and other aquatic invertebrates, terrestrial invertebrates, both above ground and in the soil, as well as native plants. In undertaking this task, we have to generally rely on a package of overseas data.

Most people would agree that it could not be justified by reasons of duplication, let alone costs, that a package of data for a new chemical should be generated solely for Australia.

Further our experience with the assessment of chemicals indicates that generation of local toxicity data is generally not the issue. Work in this area over the past 10 years has indicated that Australian species generally do not differ greatly in their sensitivity to a broad range of toxicants. Some unique situations might arise, however, due to differences in the physico-chemical characteristics of the water such as higher temperatures, which tend to increase toxicity.

Our assessments are very much exposure based. Knowledge of the level of exposure experienced by non-target organisms is much more important to predicting impacts than small differences in susceptibility between related species.

An understanding of the fate of a chemical following release into the environment is fundamental to determining levels of non-target exposure.

Relevance of program to our assessments

One area of difficulty we have encountered lies in drawing conclusions on fate in the Australian environment based on overseas (laboratory and field) data. We have requested the generation of a number of trials examining the persistence and movement of chemicals under local conditions.

This is an area in which the LWRRDC/CRDC/MDBC cooperative study has focussed much of its attention and undertaken some pioneering work, by looking at the way in which endosulfan moves through the environment once it is applied (usually by air) onto cotton, and following its movement through air, and down the irrigation furrow etc, as well as how long it persists on the plant and in soil/sediments etc where it either lands or is washed off by rain.

A feature of the program has been how the various research elements were integrated in the one overall experiment.

As noted the comprehensive studies seem to us to be unique, allowing a complete budget to be drawn up of what happens to a chemical once it is applied to the cotton field. In my plenary presentation entitled 'Environmental Fate, a Downunder Perspective' given at the 9th IUPAC Pesticide Congress in London in August 1998, I highlighted the program as a primary example of what can be done to understand the fate of chemicals once they are released into the environment.

The program provides a model for industry, both in Australia and overseas, to look at its use of chemicals in a holistic way in order to minimise their impact on the environment.

The studies have set the benchmark for new insecticides or other agvet chemicals for which registration has been sought in Australia over the past couple of years. Particularly since the ECRP was implemented the hazard part of our assessments have been evolving. Once we were very qualitative, but we are becoming increasingly more quantitative as we try to define the "real world" hazard.

As one can imagine the results formed a very important part of our assessment of the insecticide endosulfan under the NRA's ECRP program, the final report of which has recently been published.

Not only have we been able to use the results of the program directly in our assessment of endosulfan, but there have also been other important spinoffs for our other assessments, particularly of new cotton chemicals.

The published results of the program have allowed us make more robust assumptions about the amount that spray drift is likely to result from particular formulations applied to cotton, the amount of interception by the crop at various stages of its growth, or the likelihood of the chemical washing off the plant onto the soil and its further transport down the irrigation furrow.

In other cases we have actually required the generation of similar data for new chemicals, in particular when there have been concerns about persistence or potential off-field movement. It should be emphasised that these have shown different results from those found for endosulfan, in particular in respect of being less volatile.

The importance of the best management practices concept

We have also been very aware of the need to translate the experimental results into practice and have been strong supporters of the Best Management Practices concept since it was first raised. Our assessment experience, particularly the emphasis on exposure, has underlined to us the importance of chemicals being applied professionally and safely in order to help reduce the off-target impact on the environment.

Our assessment work may become redundant if assumptions we use about the way a chemical is applied, which may be pivotal to our ensuing recommendation to the NRA that the chemical may be registered as the potential environmental impact is minimised, if in practice it is in fact used much less carefully.

We have been particularly keen that not only the cotton farmers adopt this concept, but also that the chemical industry which sells pesticides to the cotton farmer is both aware of the Best Management Practices Manual (BMPM) and embraces it wholeheartedly. In fact some will say that we have been overzealous at times, but it has been accepted that our heart has been in the right place.

It certainly has been very useful over the past six months or so to be able to alert the chemical industry to the BMPM and to allude to it on labels, particularly in respect of the need to observe the guidelines for down wind buffers when applying chemicals near to environmentally sensitive areas.

The need to extend the concepts to other sectors

We also see the program and the BMPM concept as an important signal to other sectors of the crop production industry to take into their own hands the ownership to ensure responsible use of chemicals they employ in their own particular industry.

Ideally these should be based on field experiments similar to those generated by this program.

However, I understand the LWRRDC and the Murray-Darling Basin Commission do not envisage providing similar funding to other segments of the industry. Rather they plan, and indeed have already started, to export the principles garnered by this program.

We cannot underline too strongly the need for this, particularly for those industries which are intensive users of agvet chemicals to take up the challenge and develop their own best management practices manuals, if need be based on self-funded research.

Indeed the development and adoption of Best Management Practice guidelines for the safe use of chemicals is an important strategic action included in the National Strategy for Agricultural and Veterinary Chemicals launched earlier this week. I expect that in the Strategy implementation documentation that will follow, the cotton industry will be highlighted as the pathfinder in this regard.

I understand that the cotton industry plan to continue and extend some of their own research, again giving leadership to the rest of the industry. We strongly support this continuing initiative.

In spite of all the work carried out on endosulfan so far, there are still some areas where in our view further information is desirable, in particular the persistence and aquatic toxicity of endosulfan sulphate and the role of sediment in transporting and also possibly attenuating the toxicity of both endosulfan and its sulphate degradation product. This could help explain why in many cases fish seem to live happily in areas where apparently lethal concentrations of endosulfan occur in the water.

The need to adopt consistent assumptions for spray drift for aerial, orchard and boom sprayers in our assessment work has been identified and will be the basis for a consultancy we propose to let this financial year. Also more recently identified is the need to have a better handle on crop situations, eg. likely distance and depth of water from say pome fruit orchards, or the amount that may run off from particular field situations.

We are currently slowly gathering this information in a very incremental way, and this would be helped considerably by data generated by the industries in which intensive chemicals use is a part of life. This could only result in a greater confidence by both the regulators and the farmer that the chemicals they need to use in their particular industry can be used safely and with minimal impact on the environment.

4. Aerial transport: spray application and drift

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Summary

This report presents results from field studies carried out during the 1996/97 cotton season to monitor off-target droplet movement of endosulfan insecticide applied to a commercial cotton crop. The broad range in results obtained implies that spray drift is a complex process dependent upon a large number of factors, for example windspeed, temperature, humidity, atmospheric stability and crop structure. With Ultra Low Volume (ULV) aerial application, an average of 14 % of the applied dose (normalised to a 500 m wide field) moved across the downwind edge of the field, with approximately half of this quantity depositing upon ground surfaces within 500 m of the field boundary.

Mean ULV deposition at 500 m downwind was approximately 2 % of the field applied rate which compared with 1 % for water based Large Droplet Placement (LDP) applications. Mean airborne drift values recorded 100 m downwind of a single flight line were significantly less with LDP application compared to ULV application. Coverage levels on cotton leaves were dependent upon crop maturity and decreased logarithmically with depth through the canopy. This information has quantified the effectiveness of buffer distances and application technology aimed at reducing spray drift. The database will provide a useful benchmark against which the success of best management strategies can be tested in future monitoring programs.

Introduction

Agricultural aircraft are of great importance to the Australian cotton industry. Specialised aircraft are used to apply selected herbicides and fertilisers prior to planting, insecticides throughout the growing season and defoliants prior to harvest. The use of agricultural aircraft has developed largely as a result of the greater speed, better timing and efficiency of application offered by aerial distribution. Crossing the ground in excess of 200 km/hr, aircraft are able to apply agricultural products rapidly over large areas within narrow optimum application windows. When crop height and irrigated areas restrict the passage of wheeled vehicles, aircraft are able to place pesticides strategically on crops in response to economic thresholds, without contributing to soil compaction and structural breakdown. Some ultra-low formulations of pesticide (ULV) are applied at rates as low as 2 L/ha (neat). Previous studies (LWRRDC project UQL5, 1998) demonstrated that, on average, downwind deposition levels with aerial Ultra Low Volume application fell to approximately one to two percent of the field applied rate at 500 m downwind of the field boundary. These levels suggested that the aerial transport of pesticide droplets can pose a potential source of contamination to the riverine environment, unless the application process could be effectively managed.

It is therefore important that when pesticides are applied close to sensitive areas, management strategies are employed that can significantly reduce the off-target aerial movement of pesticides. This report outlines work undertaken over the last two years to further measure the aerial transport of pesticides on selected cotton properties and develop effective spray drift management strategies.

Objectives

To monitor the aerial transport of commercially applied pesticides by aircraft in the cotton industry and to determine the effect of droplet size (and volume) on efficacy and deposition of endosulfan on the crop and soil.

Methods

Further to the 1993-96 programme (LWRRDC UQL5, 1998), aerial spraying trials continued at Auscott Narrabri throughout the 96/97 growing season (LWRRDC UQL13, 1998). Some follow up field trials were also conducted during the 97/98 program funded by the Cotton Research and Development Corporation. Since the findings of these tests can be considered part of the overall national Best Management Practice program, they were included as part of the final report for LWRRDC UQL13 and are also presented here (with permission).

The full field application of commercial endosulfan was monitored on seven occasions. The off-target transport of droplets was determined using an array of collection surfaces consisting of chromatography paper placed upon horizontal flat plates, pipe cleaners and cotton string suspended from 20 m high towers. Applications of both endosulfan ULV (applied at a rate of 3 L/ha using Micronair AU5000 equipment), and endosulfan emulsifiable concentrate (EC); (generally applied at a rate of 2.1 L/ha in 30 L/ha using CP hydraulic nozzles) were assessed.

A data logger was used to record wind speed, direction, temperature and relative humidity during each trial. An additional meteorological station was used to measure wind speed (at 2.5 m and 5 m), wind direction, temperature (at 2.5 m and 10 m), relative humidity, solar radiation and rainfall. Samples were analysed using an ELISA immunoassay technique developed by CSIRO and the University of Sydney. In addition, some collection devices were analysed by the NSW Agriculture Chemical Residue Laboratory using high performance gas chromotography (GC).

Results

Downwind drift

Mean off-target deposition profiles obtained on paper covered flat plates placed downwind of the field boundary at a height of 1 m above the ground are presented in Figure 4.1.

The figure shows the decline in mean deposit with distance from the edge of the sprayed area when ULV and LDP technologies were used. The downwind distances of some data points were corrected to account for variation in wind direction. Substantial variation in deposition was observed between the trials, which may correspond to the wide range of operating conditions observed.

Figure 4.1 also shows the output from an overlapped Gaussian Diffusion Model. Experimental data was in agreement with Gaussian Diffusion Model (GDM) predictions for downwind distances greater than 100 m.

In-crop deposition

The monitoring of commercial spray application was progressively undertaken through the season. Trials were undertaken at an early (19/12/96), mid (31/12/96) and a late (21/01/97) crop growth stage. As well as monitoring the off-target movement of droplets, endosulfan deposit levels on leaves and artificial targets placed within the crop canopy were determined. Ten sampling positions were marked in each treated field at distances of 20, 40, 60, 80 and 100 m into the crop from the downwind field margin.

At each sampling position, 4 leaves were taken from lower, middle and upper canopy positions.

Chromatography paper covered ground sticks (3 cm x 50 cm) and chromatography covered flat plates (19 cm x 46 cm) were placed at each sampling location. Endosulfan residues were determined using gas chromatography (for the leaf samples, Lismore Chemical Residue Laboratory) and immunoassay (for the paper samples, University of Sydney).

The distribution of sprays through the canopy is shown graphically in Figure 4.2. The data showed that endosulfan leaf deposition (log) verses canopy depth was approximately linear. Deposition values were higher on the leaves when the plants were small and the row structure was open.

Compared with ULV application, approximately two times more endosulfan was deposited on the ground when LDP techniques were used (Table 4.1.).

Airborne profiles

A series of experiments were also conducted to compare airborne pesticide levels above a fallow field and full

Figure 4.1. Downwind deposition values obtained on horizontal flat plates. Bars represent two times standard error.

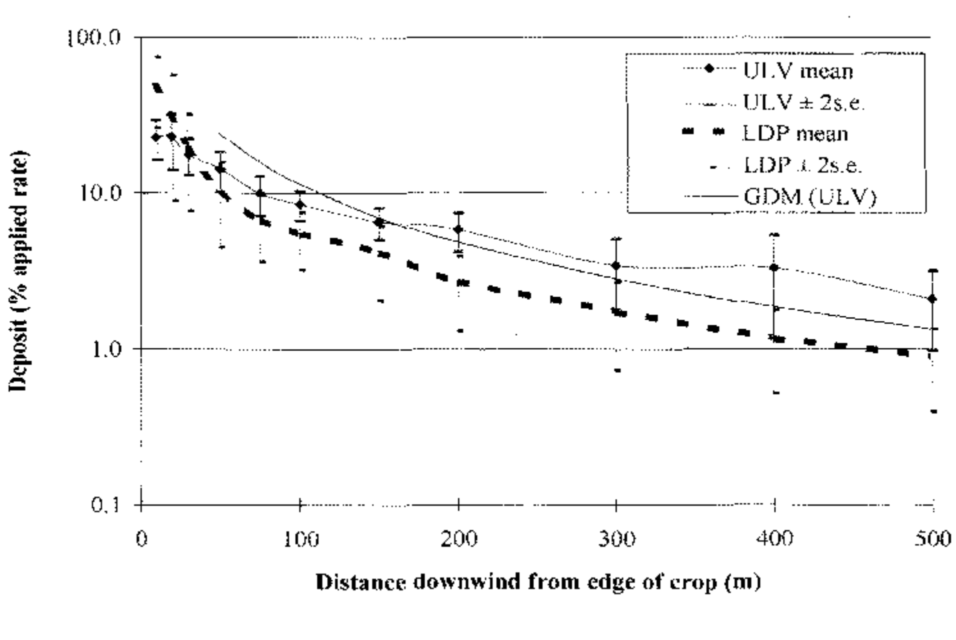
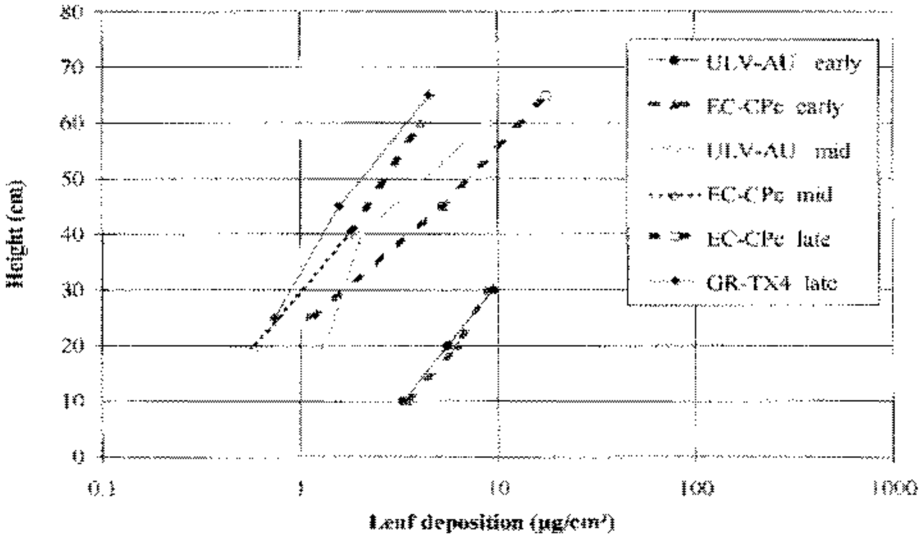


Figure 4.2. Leaf deposition with depth through canopy



cotton canopy. Unbleached cotton string was suspended from two 20 m high mobile masts positioned 100 m downwind of a sprayed area.

Single flight line (SFL) passes were made with an agricultural aircraft and the pesticide drift monitored by recovering a fluorescent tracer (Helios) added to the insecticide tank mix. Some tests were conducted simultaneously using two aircraft to compare the combined effect of droplet size (ie ULV or LDP) and ground characteristics (mature cotton or fallow). Results are expressed in Figure 4.3.

The total amounts recorded on the towers were calculated to produce percentage airborne drift values. With ULV spray applied as a single swath over fallow ground, on average, 18 % of total emitted from the aircraft was still airborne at 100 m downwind. With LDP spraying, airborne drift was reduced to approximately one third of the ULV value. When similar applications were made over a mature cotton canopy, airborne drift values were approximately halved for both ULV and LDP cases.

LDP technology

A series of single flight line studies were also performed to determine the influence of nozzle type and droplet size on airborne drift values. Mobile masts were positioned 100 m downwind of a sprayed area and simultaneous single flight line (SFL) passes conducted with two agricultural aircraft.

In the paired treatments, the airborne fraction of tracer recovered on vertical string using hydraulic nozzles was directly compared with levels generated by the ULV application, (Figure 4,4). This data showed clearly that the selection of large droplets (volume median diameters or VMD value, about 250 µm) in this case using CP hydraulic nozzles with a 30° deflector plate significantly reduced the detected airborne fraction measured at 100 m downwind.

Figure 4.3. Vertical drift profiles for ULV and LDP sprays, with and without a mature cotton canopy, approximately 100 m downwind of a single flight line

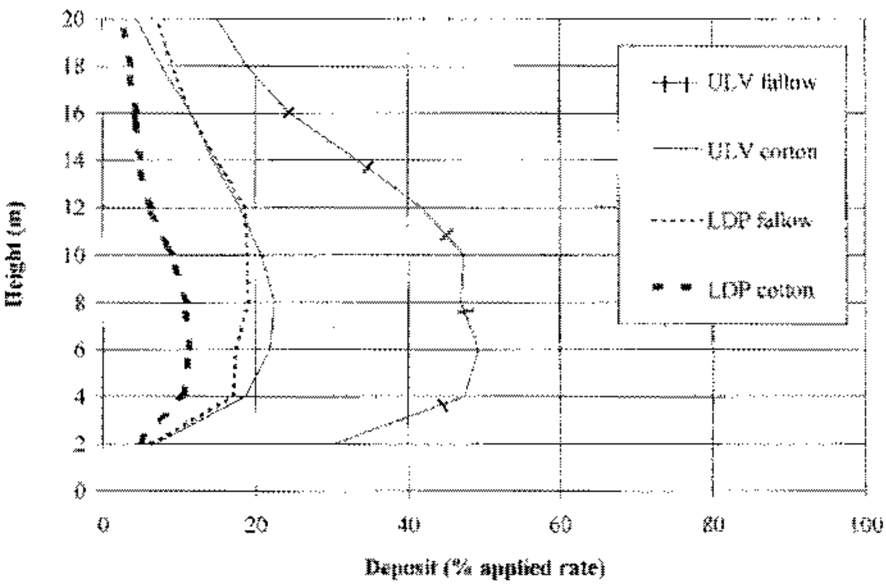
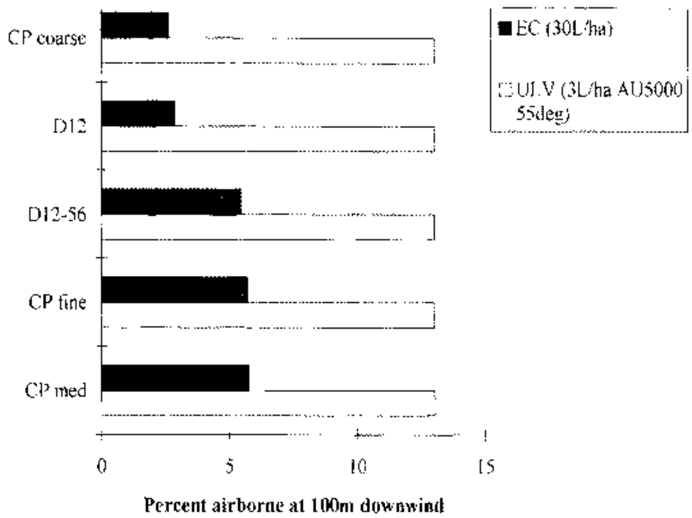


Table 4.1. Summary of aerial transport characteristics of endosulfan application

Parameter	ULV application	LDP application
Nozzle type	AU5000 @ 4500 rpm	Hydraulic CP @ 30°
Formulation	Endosulfan ULV	Endosulfan EC
Application Rate	3 L/ha	2.1 L/ha
Application	applied as oil	in 30 L/ha water
Approximate VMD	85 µm	182 µm
Airborne drift @ 100 m (single flight line)	**18 %**	**6 %**
Leaf coverage (full field)	**60 %**	**50 %**
Ground deposit (full field)	**25 %**	**50 %**
Fraction leaving field	**14 %** (500 m field)	**~7 %** (500 m field)
Depositing within 500 m	**7 %** (500 m field)	**5 %** (500 m field)
Deposition at 200 m	**5 %** applied rate	**2 %** applied rate
Deposition at 500 m	**2 %** applied rate	**1 %** applied rate

Figure 4.4. Airborne drift measured on 20 m high mobile towers placed 100 m downwind of an endosulfan EC single flight line application, normalised against simultaneous ULV application.



Summary of data

Results from all these trials are summarised in Table 4.1.

Conclusions

Data from this series of studies has quantified levels of droplet drift moving away cotton fields during commercial ULV and LDP aerial application. Considerable variation in deposition data was encountered, probably as a result of a wide range in windspeed, temperature, humidity, atmospheric stability and crop structure encountered throughout the growing season.

However, the large body of data accumulated has allowed mean deposition levels to be set with some confidence for both ULV and LDP application under typical environmental conditions. Mean residue levels also tend to support results derived using GDM. The data is able to form the basis for establishing management strategies for limiting drift based upon application technology and buffer distances and provides a useful benchmark against which the success of new management strategies (Woods et al 1998) can be tested in future monitoring programs.

1. Monitoring has shown that a certain percentage of spray droplets move downwind away from sprayed cotton fields. During ULV application, on average, some 14 % of the total applied, normalised to a 500 m wide field, moved across the downwind edge of the field.
2. A characteristic downwind fall out deposit tail on the ground is formed which can account for 7 % of the of the total applied, normalised to a 500 m wide field, with ULV spraying.
3. The experimental data agreed with GDM and the newly available US (EPA-SOTF) AgDRIFT model.
4. Measurements have shown that coverage levels on cotton leaves decrease (logarithmically) down through the crop canopy and the highest leaf deposition occurs when the crop is immature and the canopy is open.
5. Single fight line tests showed that, when compared with an open fallow area, the presence of a cotton canopy can lower levels of downwind airborne spray drift at 100 m downwind by up to 50 %.
6. The selection of LDP application techniques (eg. selecting CP hydraulic nozzles with a 30° deflector plate) reduced the detected airborne fraction by up to three times at 100 m downwind.

The significance of this data to the adoption of best management practices is discussed in a following paper.

Acknowledgements

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Reference

Woods, N., Dorr, G. and Graig, I.P. 1998, 'Practices for minimising spray drift and dust', in *Minimising the Impact of Pesticides on the Riverine Environment: Key Findings from Research with the Cotton Industry*, LWRRDC Occasional Paper 23/98, Land and Water Resources Research and Development Corporation, Canberra.

5. Aerial transport of endosulfan: vapour and dust movement

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Summary

The movement of endosulfan vapour, its deposition in water and the movement of contaminated dust were monitored following aerial applications to cotton. Measurements of droplet deposition were also made for comparison. Levels of endosulfan in water-filled trays located around cotton fields indicated that endosulfan vapour could result in concentrations around 0.01 ug/L (the Australian and New Zealand Environment and Conservation Council, ANZECC) guideline for the protection of aquatic ecosystems) in water bodies 1 m in depth for several days after spraying up to 1 km from the crop. Dust movement appeared to be an order of magnitude less important, while droplet deposition could result in high levels of contamination within 400 m of the crop immediately after spraying.

Introduction

Endosulfan is used extensively early in the season to control heliothis caterpillars in cotton. Monitoring of rivers in cotton growing areas of central and north western NSW from 1991-1997 by the NSW Department of Land and Water Conservation has shown that endosulfan levels regularly exceed the ANZECC guideline for the protection of aquatic ecosystems during the cotton growing season (Muschal 1997). Aerial transport contributes to this contamination through droplet movement immediately following spray application (spray drift) and by the movement of endosulfan vapour and contaminated dust which occurs for some time after spraying.

To estimate the importance of vapour and dust movement in the contamination of the riverine environment, the movement of volatilised endosulfan, its subsequent deposition in water, and the movement of contaminated dust were monitored following commercial applications of endosulfan to cotton.

Methods

1994/95 Trials

Two trials were carried out at Auscott Warren, starting on 21/12/94 and 7/1/95 and continuing for five days. In each trial 3 L/ha of ULV Thiodan) (240 g/L endosulfan – 720 gai/ha (grams of active ingredient per hectare)) plus 0.5 L/ha of a Bt formulation were aerially applied to 182 ha of cotton in fields 4 and 5. An air sampler was set up 100 m into field 4 with the air intake positioned 1m above the crop. A second air sampler was placed 200 m to the south of field 4 at the same height. The air intake of each sampler was connected to a carbon cartridge with a fibre glass filter place in the line to remove dust. The air samplers were started 1 hr after spraying and operated at 4 L/min air flow. The cartridges were removed at 4 hr intervals for the first 24 hrs and then at 12 hr intervals for the next 4 days. Leaf samples were taken over the same period and endosulfan residues determined for comparison with the data obtained from air sampling.

Galvanised trays (0.5 m^2 in surface area and 10 cm in depth) were placed on wooden pallets in fallow fields around fields 4 and 5. Trays were located at 200 m and 400 m from the crop to the N, S, E and W, at 800 m to the S,E, and W and at 1000 m to the S and W. The distribution of trays was determined by the physical configuration of the site. Clean water was placed in the trays and maintained at 5 cm in depth throughout the monitoring period. Each tray was covered during spraying with a tightly fitting lid which was removed 1 hr after spraying and 1 L water samples were taken at 24 hr intervals for five days. Endosulfan was extracted in the field using dichloromethane. Four additional trays were placed at the 200 m sampling points. Oil-filled polymeric membranes, which absorb endosulfan, were placed in the water in these trays 1 hr after spraying and removed after five days. This technique gives an indication of total endosulfan deposited over the sampling period, while the concentrations in the water were the result of endosulfan vapour absorption, subsequent volatilisation, and degradation. The trays were emptied and cleaned at the end of each trial. All samples were analysed for α and β endosulfan and endosulfan sulphate.

1995/96 Trials

Two trials were carried out at Auscott Warren starting on 18/12/95 and 27/12/95 and continuing for two and three days respectively. In the first trial 3 L/ha of ULV Thiodan) (240 g/L of endosulfan – 720 gai/ha plus

0.5 L/ha Cybout) was aerially applied to 120 ha of cotton in field 7 which is adjacent to fields 4 and 5 (fields 4 and 5 were fallow). The second spray was Thiodan EC), aerially applied at 2.1 L/ha (350 g/L endosulfan – 735 gai/ha) plus Pix) 0.45 L/ha with a total application rate of 20 L/ha.

The movement of volatilised endosulfan and subsequent absorption by water following the two sprays was evaluated using water filled trays as described above. Site configuration prevented samples being taken more than 400 m from the edge of field 7. The sampling periods were reduced from five days to three and two days for the first and second sprays respectively because the previous season's results had shown that peak concentrations were achieved after two days.

For comparison, the deposition of spray droplets was measured using horizontal collectors mounted on pallets, 200 m and 400 m to the N, S, E and W of field 7 and exposed during spraying. Dust samples were taken from 0.1 m of unsealed roads surrounding field 7 after both sprays. Sampling was carried out 1 hour after spraying.

Semi-field experiments were conducted to determine the loss of endosulfan from trays following 'spiking' the water with endosulfan EC and then sampling over 24 hrs. An aqueous suspension of finely powdered soil was added to the trays to estimate the effect of dust on the retention and breakdown of endosulfan.

Results and discussion

1994/95 Trials

The levels of endosulfan on leaves fell more rapidly after the first spray than after the second spray. The half lives for α and β endosulfan on the upper leaves were 12 hrs and 36 hrs respectively for the first spray and 24 hrs and 60 hrs for the second spray. These differences are almost certainly due to the very much higher temperatures prevailing after the first spray, particularly for the first 48 hrs when the average maximum temperature was 40 °C for the same period after the second spray. However, after 5 days the levels had fallen by over 85 % for both sprays. The decreases were due to losses of α and β endosulfan, particularly the former, while the level of endosulfan sulphate actually rose.

Five hours after spraying endosulfan sulphate represented around 1 % of total endosulfan, but after five days it was around 50 % of the total.

The results obtained from air sampling showed the rate of volatilisation was higher after the first spray with 82 % and 89 % of volatilisation occurring in the first 24 and 48 hrs respectively after spraying compared to only 49 % and 69 % for the same periods for the second spray. After 5 days the cumulative amount of volatilised endosulfan that was recorded for the second spray was 82 % of the first spray. These differences can also be attributed to the higher temperatures that prevailed following the first spray. Volatilised endosulfan was monitored outside the crop (200 m to the south) for the first spray. As expected, the levels of endosulfan in the air outside the crop were lower than above the crop and the recoveries were more erratic due to wind direction. Fortunately, the wind was predominantly northerly for the first two days after the first spray.

Equipment failure prevented data being obtained for the second spray. The levels of endosulfan that were recorded in the fibre glass filters were very much lower than in the carbon cartridges (around 10 % outside the crop and 5 % above the crop for the first spray, and 10 % above the crop for the second spray), indicating that the movement of contaminated dust is relatively unimportant compared to vapour movement in the aerial transport of endosulfan.

The mean concentrations of endosulfan that were recorded in water samples taken from trays located in predominantly downwind locations to the south and west have been converted from water 5 cm in depth to 1 m (Table 5.1.). This gives a more meaningful indication of the potential of endosulfan vapour to cause contamination of natural water bodies.

Following both sprays, the highest concentrations of endosulfan were generally recorded 48 hrs after exposure. The concentrations tended to fall as the distance from the sprayed fields increased, but this was somewhat variable and far more pronounced for the first spray than the second spray.

As expected, the average levels recorded predominantly upwind to the north over five days were much lower than to the south, eg. at 200 m the levels were only around one third for both sprays.

The highest levels of endosulfan recorded were equivalent to a concentration of 0.025 µg/L in water 1 m in depth, while the average levels downwind over the five days ranged from 0.015 µg/L – 0.004 µg/L (Table 5.1.). The ANZECC endosulfan guideline for the protection of aquatic ecosystems is 0.01 µg/L. The levels recorded for the first spray tended to be higher than for the second. The temperatures were also higher following the first spray.

The relative quantities of endosulfan extracted by the polymeric membranes were in general agreement with the average daily levels of endosulfan in samples of water from the trays at the same locations.

The average amounts of endosulfan extracted per litre of water by the membranes over the five days were 1.9x and 1.7x greater than the average daily concentrations in the water samples for the first and second sprays respectively, indicating that at least half of the endosulfan absorbed by the water subsequently revolatilised, or was broken down. Very little endosulfan sulphate was recorded in the water, or from the polymeric membranes.

Table 5.1. Mean concentrations of endosulfan ($\mu g/L$) in water samples from trays located to the south and west that were exposed 1 hr after spraying and sampled daily.*

Spray 1 – ULV (21 December 1994)

	Hrs after exposure					
Distance (m)	**24**	**48**	**72**	**96**	**120**	**Average**
200	0.018	0.018	0.015	0.014	0.012	0.015
400	0.004	0.022	0.010	0.004	0.007	0.009
800	0.007	0.003	0.001	0.002	0.005	0.004
1000	0.004	0.006	0.003	0.002	0.006	0.004

Spray 2 – ULV (7 January 1995)

	Hrs after exposure					
Distance (m)	**24**	**48**	**72**	**96**	**120**	**Average**
200	0.007 (0.010)	0.016 (0.009)	0.008 (0.005)	0.006 (0.004)	0.007 (0.004)	0.009 (0.006)
400	0.006	0.012	0.014	0.003	0.007	0.008
800	0.005	0.011	0.005	0.004	0.005	0.006
1000	0.005	0.011	0.003	<0.001	0.005	0.005

*Concentration converted to 1 m depth water (actual concentrations in 5 cm of water ÷ 20); ( ) duplicate

1995/96 Trials

Generally lower levels of endosulfan were recorded in water samples from trays at 200 m and 400 m, following the two sprays in 1995/96 compared to the previous season. The temperatures following spraying were also lower. There was no obvious difference between the concentrations recorded for the ULV and EC formulations. The average levels of endosulfan recorded in all directions did not exceed the ANZECC guideline for both sprays, but peak levels did (Table 5.2.).

The levels of endosulfan fell equally rapidly in both clear water and water containing 200 mg/L soil particles, following spiking with endosulfan. On average, levels fell by 90 % in the first 24 hrs due to volatilisation and breakdown of the parent isomers. No endosulfan sulphate was detected, showing that any endosulfan sulphate found in samples of water from trays in the field was due to the deposition of contaminated dust.

Significant levels of endosulfan diol were detected, but the results were erratic, indicating the analytical method needs refinement. These results indicate that levels of α and β endosulfan in the water-filled trays due to vapour deposition would be rapidly reduced, if the wind changed direction and the air passing over the trays did not contain endosulfan vapour.

In natural water bodies this process would also operate, but would be complicated by some conversion of the parent isomers to endosulfan sulphate which has a much lower volatility. This would tend to increase the persistence of endosulfan in the water column, but sequestration of endosulfan by sediment may reduce concentrations in the water column.

Kennedy et al (1997) found that around 70 % of endosulfan applied to cotton fields dissipates due to volatilisation in the first two-three weeks after spraying. However, our results have shown that this should not result in high concentrations of endosulfan in water bodies.

Endosulfan vapour may account for diffuse low level contamination of the riverine environment, but its contribution to major contamination of river systems in cotton growing areas appears to have been minor based on results from the long term monitoring of endosulfan concentrations by the NSW Department of Land and Water Conservation's Central and North West Region's Water Quality Program.

Table 5.2. Concentrations of endosulfan (μg/L) in water samples from trays that were exposed 1 hr after spraying and sampled daily*

Distance (m)	Direction	24	48	72
Spray 1 – ULV (18 December 1995)				
		Hrs after exposure		
200	N	0.011	0.010	0.010
	S	0.009	0.015	0.007
	W	0.001	0.008	0.002
	E	0.009	0.002	0.004
	Average	0.007	0.009	0.006
400	N	0.003	0.003	0.003
	S	0.015	0.001	0.005
	W	0.001	<0.001	0.002
	E	0.005	0.011	0.001
	Average	0.006	0.006	0.003
Spray 2 – EC (27 December 1995)				
		24	48	
200	N	0.001	0.006	
	S	<0.001	0.002	
	W	0.003	0.002	
	E	0.006	0.024	
	Average	0.002	0.008	
400	N	0.009	0.001	
	S	<0.001	0.005	
	W	0.012	0.002	
	E	0.005	0.026	
	Average	0.006	0.009	

*Concentration converted to 1 m depth water (actual concentrations in 5 cm of water ÷ 20)

For instance, endosulfan concentrations in 32 % and 22 % of samples taken in the 1995/96 and 1996/97 cotton growing seasons respectively exceeded 0.05 μg/L (NSW DLWC, 1997) with far higher peak levels (Muschal, 1997).

High deposition levels of endosulfan (up to 40 % of the emission rate) were recorded on dust taken from the roads immediately adjacent to field 7 and downwind during spraying. Endosulfan deposited on unsealed roads can be relocated by vehicular movement assisted by wind. This is likely to be the most important mechanism of contaminated dust movement on cotton farms (Leys et al 1997). These authors studied the movement and deposition of endosulfan contaminated dust at Auscott Narrabri and off-farm. The endosulfan deposition rates recorded would result in endosulfan levels in water bodies 1 m in depth well below the ANZECC guideline, except within a few metres of unsealed roads.

These results and our data on air sampling, indicate that contaminated dust movement is likely to be an order of magnitude less important than endosulfan vapour in the contamination of the riverine environment in cotton growing areas.

We were concerned that the levels of endosulfan we recorded in the water filled trays may have been influenced significantly by contaminated dust deposition. However, our air sampling data and the results of Leys et al. (1997) indicate that the contribution of contaminated dust to the overall levels of endosulfan recorded was probably minor.

Endosulfan vapour does not have the potential to cause high level contamination of riverine systems, but spray drift does. Our limited measurements indicate that spray drift has the potential to result in concentrations of endosulfan in water bodies within 400 m of a cotton field that exceed the ANZECC guideline by well over 100 times. However, it should be emphasised that the effects of spray drift are more transient and diminish more rapidly with distance away from the crop than for endosulfan vapour contamination (Raupach and Briggs, 1996).

Implications of results, uptake and adoption

Our results indicate that endosulfan vapour is relatively unimportant in the contamination of the riverine environment in cotton growing areas when compared to the levels of endosulfan contamination that have been recorded in rivers during the cotton growing season over several years. It is unlikely that low volatility formulations of endosulfan can be produced to control endosulfan vapour. However, avoiding the use of endosulfan during periods of extremely high temperatures would reduce peak vapour emissions.

Although the movement of endosulfan contaminated dust appears to have very little importance in the contamination of the riverine environment, it could be reduced by not spraying up to the downwind edge of the crop. This would substantially reduce the deposition of endosulfan on roads surrounding cotton fields which are usually the major source of contaminated dust.

Spray drift has the potential to cause high level contamination of water bodies close to cotton farms. Further research to reduce spray drift is justified, but additional studies on the transport of endosulfan vapour and the movement of contaminated dust is considered unnecessary.

Conclusions

1. The movement of endosulfan vapour may result in concentrations at around the ANZECC guideline of 0.01 mg/L in water bodies 1m in depth and within 1 km of cotton fields for several days after spraying.

2. The movement of endosulfan contaminated dust appears to be an order of magnitude less important than vapour transport in the contamination of the riverine environment.

3. Droplet movement (spray drift) has the potential to cause high level contamination of water bodies within 400 m of sprayed cotton, but the effect is likely to be more transient and localised than contamination from endosulfan vapour.

4. It is unlikely that improved management practices, or changes in formulation can significantly reduce the emission of endosulfan vapour from cotton, although avoiding the use of endosulfan during periods of very high temperature will reduce volatilisation.

5. Strategies to reduce spray drift should be developed and promoted through Best Management Practice.

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6. Aeolian transport: dust and endosulfan

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Abstract

Dust emissions from agricultural land can travel significant distances and be deposited well away from the source area. While dust emissions have widely been studied for their impact on off-site air-quality, few studies have investigated the dust pathway as a means of transporting herbicides and pesticides off-farm. This study quantified: (1) the dust and endosulfan emissions caused by wind erosion, cultivation and vehicle movement on unsealed roads; and (2) the deposition of dust and endosulfan both on- and off-farm in the cotton growing region of northern New South Wales over the summer of 1996-7.

Results indicated that wind erosion from roads is more significant than the cotton fields and that erosion rates are related to the mass of loose erodible sediment. Endosulfan fluxes off roads are potentially high (20 micrograms (μg) per metre length of road). Dust emission from a vehicle travelling at 80 km/h on an unsealed road (3.7 grams per metre travelled) was about double that for inter-row cultivation at 8 km/h (1.7 g/m). Endosulfan source strength was 3.6 μg/m for inter-row cultivation and 3.1 for vehicle on the unsealed road.

Unsealed roads are a greater source of endosulfan because of the greater frequency of vehicle movements, however, emissions are only a problem for the few days after aerial spraying. Dust deposition was greatest near roads and decreased logarithmically with distance. Endosulfan source strength (combination of dust and vapour) is highest close to roads with a measured peak deposition rate of 35 μg/m² at 100 m for a two day period.

When endosulfan deposition rates were measured over longer periods (weekly), on-farm deposition rates of 0.35 μg/m²/day and off-farm rates of 0.16 μg/m²/day were recorded. When these deposition rates are applied to a non-flowing river, of 1 m depth, calculated endosulfan concentrations are 100 times less than that measured in rivers at the same time as this study, implying that dust is not a major pathway of endosulfan to the riverine environment.

Dust and endosulfan emissions can be reduced by restricting cultivation and vehicle movements on recently sprayed areas for a period of about three days after application and by leaving a buffer strip, in the order of 100 m, between sensitive areas and sprayed areas. The use of interception barriers such as windbreaks is a possible option for filtering dust from the air before it is transported off-farm. Increased aerial spraying precision could also reduce spray drift to roads, thereby further reducing endosulfan source strength.

Introduction

Assessments of the condition of the environment have seen agricultural areas identified as a major source of dust (Chow and Watson 1992), with 34 % of emissions in 1990 in the United States from unsealed roads, 16 % from cultivation and 9 % from erosion. As a result, there has been increased interest in the impact of windblown dust emanating from agricultural land on off-site air quality (Saxton 1995, Saxton 1996, Stetler and Saxton 1995, Stetler and Saxton 1996) and human health (Clausnitzer and Singer 1996). Dust storms often lead to dust concentrations of particulates less than 10 μm diameter (PM_{10}) which exceed air quality health standards.

These particulates may travel significant distances from source. In Australia, urban areas such as Brisbane (Knight et al. 1995) and Melbourne (Raupach et al. 1994) have experienced dust storms whose source material originated hundreds to thousands of kilometres up-wind.

The deposition of dust in itself is a problem, however, recent studies have also identified herbicides and pesticides are associated with the dust and their deposition in sensitive areas can create environmental problems.

Although most of the suspended dust emitted by agricultural operations is deposited within less than 100 m of its source (Larney *et al.* 1998), a portion of it may be transported long distances by wind (Chow and Watson 1992) and may also carry herbicides and pesticides. Gaynor and MacTavish (1981) reported that approximately 43 % of simazine was removed from a treated area by wind erosion on a sandy soil in southwestern Ontario, Canada.

The simazine was deposited downwind at quantities sufficiently high to be phytotoxic to susceptible crops or to impair the quality of adjacent irrigation ponds or waterways. Glotfelty et al. (1989) reported movement of atrazine, simazine and alachlor by wind erosion, while Larney et al. (1996) found 2,4-D enrichment in windblown sediment compared with the source soil. In recent years, endosulfan has been detected in waterways of the cotton-growing region of south-eastern Australia (Arthington 1995, Cooper 1996).

This has implications for the long-term sustainability of both the cotton industry (the major user of endosulfan) and Australia's natural environment. Dust transport has been identified as one of four possible pathways by which the pesticide endosulfan entered the riverine environment, the others being spray drift, waterborne runoff and vapour transport initiated by volatilisation (Raupach and Briggs 1996). A recent study in Australia quantified the dust and associated endosulfan emission caused by wind and on-farm activities and the deposition of the dust both on- and off-farm (Leys, Larney and McTainsh 1998).

Methods

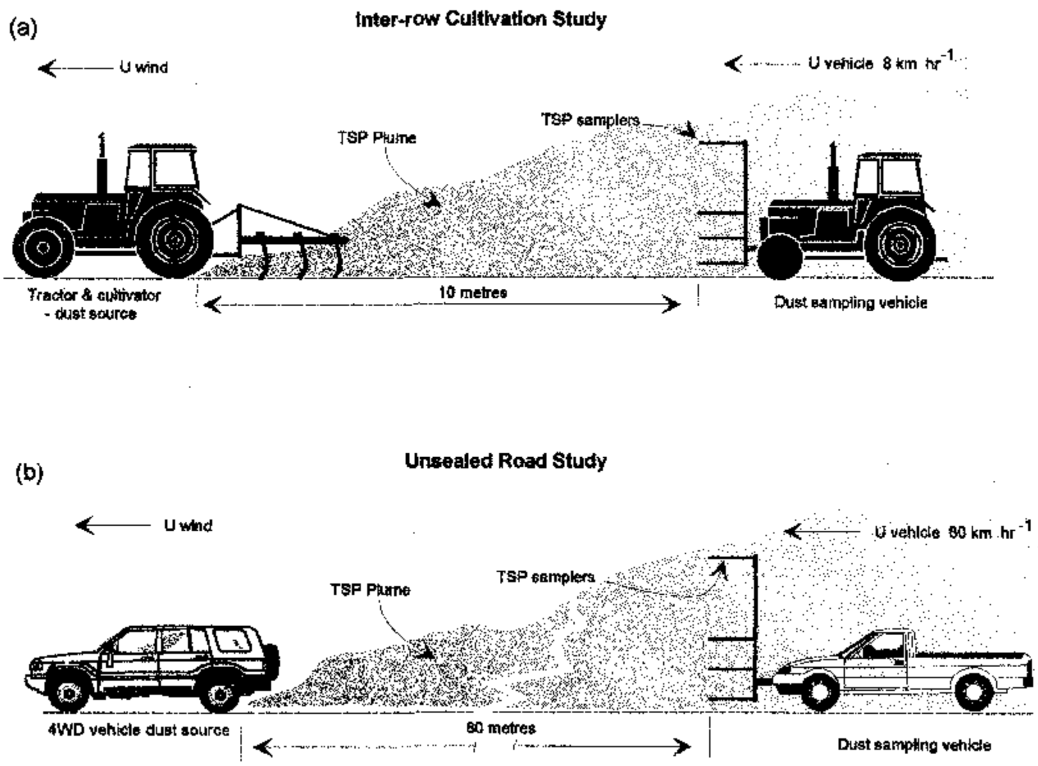
The methods are fully described for the wind erosion of fields and tracks in Leys, Larney and McTainsh, 1998. In brief, a portable field push type wind tunnel was used on farm tracks and a cotton field to determine the threshold wind speed that erosion commenced and sediment flux rate for each surface. Samples for particle-size and endosulfan analyses were taken at 0.3 m height in the wind tunnel. The methods are fully described for the dust and endosulfan emission in Leys et al. (1998). In brief, dust profiles between 0.3 and 3.0 m were collected with high volume filtration system mounted on a vehicle which followed behind the dust emission source in the configuration as shown in Figure 6.1. Samples for particle-size and endosulfan analyses were taken at 0.6 m height.

The methods are fully described for the dust and endosulfan deposition in Larney et al. (1998). In brief, dust deposition was measured with dry deposition (DD) traps and endosulfan deposition with foil covered with polybutene (PB), a sticky substance to catch the dust, mounted at 2 m height. The traps were arranged in transects away from a busy road and a field that was sprayed with endosulfan. A second set of traps were located at four sites along the Namoi river to measure dust and endosulfan deposition rates to the riverine environment. These traps were downloaded weekly and as such collected total deposition of endosulfan via the aerial pathway.

Dust emission

A portable wind tunnel was used to determine the threshold friction velocities, sediment flux rates and the pesticide source strength for an unsealed farm road and a cultivated field (Leys, Larney and McTainsh 1998).

Figure 6.1. Dust emission sampling configuration for dust and endosulfan sampling.



The study demonstrates that road surfaces represent an important source of wind erosion on cotton farms. The wind erosion potential, as measured by sediment flux in a portable field wind tunnel, of an unsealed road was 53 times greater than that of an adjacent cultivated cotton field in northern New South Wales, whereas endosulfan emissions were 1.6 times greater for the cotton field than the road because the endosulfan concentrations on the road dust were only 1 % that of the field dust. The threshold wind velocity necessary to initiate erosion (U_t), friction velocity (u_*), threshold friction velocity (u_{*t}) and the aerodynamic roughness length (z_0) of the road surface were all significantly lower than the field surface.

These finding suggest that dust emissions were greatest from roads compared to the adjacent cotton fields, but the endosulfan emission, nine days after application, were higher from the field because of the higher source strength of endosulfan on the field soil. If roads are accidentally over-sprayed or have chemical drift deposited on them, they could then become a significant source of endosulfan emission.

Having identified that the roads are major sources for wind erosion, the next step was to verify if anthropogenic activities, such as vehicle movement and cultivation, were major sources of dust and endosulfan emissions (Leys et al. 1998). A vehicle travelling at 80 km/h on an unsealed road was a greater source of TSP emission (3.7 g/m travelled) than an 8 m wide inter-row cultivator travelling at 8 km/h (1.7 g/m) (Photo 6.1.).

However, the particle size distribution of the TSP from inter-row cultivation was finer (mode of 19-22 μm) than that from vehicular traffic on unsealed roads (mode of 32 μm) and hence may be transported further.

Endosulfan source strength from inter-row cultivation was 3.6 μg/m of travel (or 0.45 μg/m^2) which was only 6.0×10^{-4} % of that applied, 4 days after endosulfan application. This was slightly higher than the endosulfan source strength from vehicular traffic on an unsealed road (3.1 μg/m of travel), only two days after spraying.

On unsealed roads, particle-associated endosulfan mass fractions declined rapidly with time due to volatilisation and photodegradation and a decrease in endosulfan-enriched source sediment due to removal by repeated vehicle passes. These findings suggest that anthropogenic activities are a regular source of dust on-farm during dry weather. Endosulfan source strength will be highest shortly after spraying because the levels of endosulfan decline rapidly over the following days. If emissions should occur, the next question to be answered is what levels are being deposited off-farm.

Dust deposition

The objectives of the dust deposition project (Larney et al. 1998) were to examine: (1) dust deposition from vehicular traffic on an unsealed road on a cotton farm, and around a cotton field in the 11-65 hr period after endosulfan application; (2) endosulfan deposition in the 11-65 hr period after endosulfan application, and over a three-month period at on-farm and off-farm (non-target) locations in the cotton-growing region of northern New South Wales. Dust deposition rates from vehicular traffic varied from 0.013 g/m^2/vehicle at 1 m, and 0.002 g/m^2/vehicle at 100 m from an unsealed road.

Dust deposition, which was caused by vehicle movement on unsealed farm roads around the sprayed field, in the 11-65 hr period after endosulfan spraying varied from 0.30 g/m^2 at 10 m to 0.14 g/m^2 at 1000 m from the field.

Photo 6.1. Dust emissions from inter-row cultivation.

The highest endosulfan deposition values in this post-spraying period were 95 $\mu g/m^2$ at 5 m, 35 $\mu g/m^2$ at 100 m and 13 $\mu g/m^2$ at 1000 m from the field, measured with polybutene traps.

However, we believe that these endosulfan deposition rates include both vapour and dust associated endosulfan, because the polybutene traps absorb endosulfan vapour as well as collected airborne particles. Caution must also be exercised in using the endosulfan deposition data reported here because the absorption / release rate of endosulfan from the polybutene traps is not known at this stage.

Separating the dust and vapour contributions is not possible from the current study but we believe that dust contributions are 1-10 % of the total endosulfan deposition. In the absence of any other data, and acknowledging the above mentioned limitations in the methodology, it is possible to calculate the endosulfan concentration in a 1 m deep, non-flowing river at 100 m from the field: giving a concentration 0.035 µg/L, which is above the ANZECC guideline of 0.01 µg/L but below the river concentration of 0.06 mg/L measured during the study period (Cooper 1996).

Over a 3-month monitoring period (December 1996-March 1997), the average daily deposition rate (which could include drift+dust+vapour) of endosulfan was 0.16 $\mu g/m^2$/day for the off-farm sites compared with 0.35 $\mu g/m^2$/day for the on-farm site. Acknowledging the above mentioned limitations in the methodology, calculation of the off-farm endosulfan deposition rate into a 1 m deep non flowing river, results in a concentration of 1.6×10^{-4} µg/L which is well below the ANZECC guideline of 0.01 µg/L and that of the measured levels of endosulfan in rivers of the study area in 1995/96 (Cooper 1996). This highlights the danger of using time averaged data that does not truly indicate the peaks of exposure that could occur if unfavourable meteorological and dust emission conditions occur.

Implications of results and mitigation methods for dust and endosulfan movement

The mitigation methods discussed below can be viewed as part of the best management practice to reduce dust emissions. If however, pesticide spray drift is reduced to roads, the major source of dust, then endosulfan emissions are further reduced and the need for dust emission control becomes less of an issue. However, the following recommendations would reduce the risk of endosulfan emissions to negligible levels.

Wind erosion of fields and unsealed roads

Fields with self-mulching clay soils, such as those at Auscott Narrabri, do not pose an erosion problem as long as they are not over cultivated.

Best management practices employed for good soil structure will ensure erosion is minimised. However, the implementation of stubble retention, as required for water erosion, will reduce erosion risk to negligible levels.

Unsealed roads do pose a dust source. However roads more than 100 m away from sensitive areas pose less of a problem for off-site removal of endosulfan as > 85 % of dust had deposited under low wind conditions (2.3 m/s). For roads close to sensitive sites, emissions are related to the loose erodible mass (LEM) of particles on the road < 0.85 mm in diameter. When LEM is > 4.8 kg/m^2, wind erosion rates exceed an erosion control target of 5 g/m/s. Methods of controlling wind erosion from roads include watering, adhesive application, grading or ripping.

Dust emission from anthropogenic activities

Vehicle movement and cultivation are greater causes of dust emission than wind erosion. Dust emissions for cultivation can be reduced by adoption of best management practice for soil structure: minimise cultivations, cultivate at correct soil moisture contents and reduce cultivation speed.

Dust emissions from roads can be reduced by driving slower and using them less often. To minimise endosulfan emissions, cultivation of sprayed fields or use of roads adjacent to sprayed fields, should be avoided for up to three days after endosulfan application if the emitted dust is blowing off farm, ie roads and fields within 100 m of sensitive areas.

In summary:

1. Avoid spraying to edges of fields adjacent to roads, thereby avoiding pesticide contamination of road surfaces.

2. Avoid cultivation of fields and vehicle movement on roads within 100 m of sensitive areas when wind direction is off-farm.

If recommendation 2 is not feasible, then

3. Locate unsealed roads greater than 100 m away from sensitive areas.

4. Reduce vehicle speeds on sprayed roads and cultivate when soil is moist.

5. Reduce the loose erodible material on unsealed roads by watering, grading or use of adhesives.

Finally:

6. Interception barriers, such as wind breaks, may be an option for filtering dust from the air upwind of sensitive sites, and is worthy of further investigation.

Conclusions

The levels of dust and endosulfan emission associated with dust appears to be small compared with volatilisation. However, these findings do identify that dust is a pathway off farm. The reduction of spray drift to roads and the reduction of cultivation and vehicle movement within 100 m up-wind of sensitive areas should minimise deposition in average weather conditions (ie. wind speeds less than 5 m/s). The use of wind breaks could provide additional protection to sensitive areas.

These studies indicated the importance of dust movement off-farm and indicate that there is generally minimal impact on the environment from dust associated endosulfan emission from agricultural activities. However, when unfavourable meteorological and dust emission conditions occur close to rivers, then environmental impact is plausible. The research indicates that land managers can mitigate the impact of dust emissions by implementing best management practices which can minimise the movement of dust and pesticides. The adoption of best management practices is currently under way in the study area (Williams 1997).

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7. Movement and fate of endosulfan on-farm (New South Wales)

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Abstract

From a comprehensive study of the fate of endosulfan, following its application in cotton production systems, it is now possible to quantitatively define the mechanisms by which it dissipates and by which its residues are transported off-field. Dissipation of endosulfan in the field occurs mainly through volatilisation in the first 2-3 weeks after application, a process with a half life of a few days. Endosulfan absorbed by the foliage of cotton plants is quickly degraded, with a half-life of three-four days.

Degradation in soil takes much longer, partly because of the formation of endosulfan sulphate, a biological oxidation product with a typical 'half-life' in soil of about 110 days. This extends the period of potential risk from endosulfan in the riverine environment, by allowing significant transport of endosulfan residues in irrigation tail waters and particularly in runoff from major rainfall events. The implications of these findings for management of cotton farms to protect the riverine environment are discussed.

Introduction

In the development of farming practices to minimise the extent of contamination of produce and the environment with chemical pesticides, knowledge of the environmental fate of particular chemicals following application is essential. The objectives of this project were to measure the rate of degradation of endosulfan on cotton fields following aerial application and to determine the potential for movement of endosulfan and endosulfan sulphate, paying attention to the concentration on cotton fields and in related tail drains.

The study was also to describe the relationship between pesticide movement and the hydrograph of runoff during irrigation and storm events. By measuring the rate of degradation and the residence time of endosulfan on foliage, in soil and in runoff water, a chemical balance for inputs and outputs of endosulfan could be prepared.

From the results of these studies, practical measures to reduce the environmental impacts of endosulfan and other pesticides as part of a farm management plan were to be recommended.

Methods

Full details of the experimental methods used in this study will be published elsewhere (see Kennedy et al., 1997b for a preliminary report). However, for illustrative purposes, the following details are supplied.

Cotton fields on farms owned by Auscott at Narrabri and Warren in the Namoi and Macquarie river valleys of New South Wales were chosen for the three consecutive years of this study. In some cases in this study, research was integrated with aerial transport by drift (N. Woods, University of Queensland, Gatton), volatilisation (V. Edge and N. Ahmad, NSW Agriculture) and transport on dust (J. Leys, NSW Land & Water Conservation). The studies included hydrological measurement of flows off the field, measuring all relevant parameters related to meteorology, soil, sediment and water properties. In initial trials, stratified block designs for convenience of large-scale sampling of soil and plant material, and to allow analysis with respect to sampling intensity and to determine any spatial or temporal variability in soil residues, were employed.

To estimate the amounts of pesticide falling on both soil and canopy immediately after spraying, a set of filter paper strips on wooden slats and another set on aluminium plates 1 metre above the canopy were placed in the field, as well as foliage samples. Plant cover of soil by the foliage of cotton plants was calculated using a shadow technique to measure horizontal cover near noon, also measuring the height and width of plants on 1 metre long sections of 10 furrows. Soil sampling was done in accordance with the standard sampling protocols (Kennedy et al., 1998).

Foliage was sampled on each occasion as nine whole plants, allowing the calculation of a pesticide load per plant and a chemical balance for the whole field. As the season proceeded and the size of cotton plants increased, plants were separated for analysis into outer and inner leaves, stems and bolls.

Water runoff samples were taken in 1 L amber glass bottles closed with Teflon seals during irrigation or storm events. Information on the total runoff via the return drain exiting from fields through a 'drop-box' was obtained using stage height indicators recording on data loggers, and also by equipment installed by the NSW Department of Land and Water Conservation.

In the second year of the study, three storms produced sufficient discharge to take runoff samples, one being of very large volume)less than 1 in 25 years probability).

A project on quality assurance involving analysis of selected field samples in two or more analytical laboratories participating in the joint program was conducted (Kennedy et al., 1998). This involved generation of gas-liquid chromatography (GLC) data following solvent extraction of water and soil samples (Kennedy et al., 1997b). Analytical work by three different laboratories (the Biological and Chemical Research Institute at Rydalmere, the NSW Department of Land and Water Conservation at Arncliffe and Department of Natural Resources at Indooroopilly in Queensland) assessed the accuracy of the analytical results obtained during this program. A validation of immunoassays (ELISAs) for soil and water samples using CSIRO immunoassay kits for endosulfan (Lee, Skerrit and Kennedy 1995, Lee et al 1995, Lee et al 1997) was also conducted. Immunoassays allow the analysis of a much larger number of field samples than possible by GLC.

Results and discussion

Analytical methods and quality assurance

The project on quality assurance conducted in this program has shown that the three main analytical centres involved in this research program produced gas-liquid chromatography (GLC) data following solvent extraction of water and soil samples within acceptable limits of quality assurance (Kennedy et al., 1998). Analytical work by three different laboratories proved that confidence in the accuracy of the range of analytical results obtained during this program was justified.

Validation of the use of immunoassays (ELISAs) for endosulfan in soil and water samples using CSIRO field test kits has been a great advantage (Lee et al., 1997), allowing many more field samples to be analysed for pesticide residues. The compromise is some loss of specificity (all cyclodienes yield positives) and inability to distinguish between the toxic isomers of endosulfan and endosulfan sulphate.

However, non-toxic products such as endosulfan diol are not detected at the sensitivity of detection in soil of about 0.1 mg/kg (ppm) and a range for analysis of 0.2-50 µg/L (ppb) in water were ideally suited to the needs of this study. Agreement between the results obtained by gas chromatography and immunoassay for soil and runoff water was excellent ($r^2 = 0.9$), using at least 10 g of well-mixed soil for reliable analyses with extraction in 90 % methanol.

Degradation rates on cotton fields

The following research findings focussing on endosulfan have provided outcomes that can now be applied to a range of pesticides:

1. The initial dissipation of endosulfan (70 % α-isomer, 30 % β-isomer) on cotton fields occurs mainly through volatilisation of the α-isomer in the first 2-3 weeks after application (70 %), with an apparent half-life of only 2-3 days. Such volatilisation is temperature-dependent and applications made near sun-down are likely to be more effective, reducing the need for future applications and environmental dissipation to the atmosphere. Other rapid dissipation of endosulfan occurs in run-off water, either by volatilisation, or hydrolysis, particularly if the pH value is above 8.

2. Unfortunately, persistence of endosulfan in the field occurs because of the formation of endosulfan sulphate in soil - a toxic oxidation product - with a 'half-life' in soil of about three months, and some remaining β-endosulfan which is more firmly bound to soil organic matter, of shorter half-life (Figure 7.1.). However, by the start of the new growing season only 1-2 % of the endosulfan applied remains on field as endosulfan sulphate, so there is little or no long-term accumulation.

3. Endosulfan in cotton plants, including the sulphate, is quickly broken down, with half-lives of 3-4 days. In two weeks only 2-3 % of the amount applied in one spraying remains in the foliage (Figure 7.2.). By contrast, a similar study on chlorfluazuron (Helix) conducted using similar methods indicated only a low degree of dissipation of this insect growth regulator during the same period of measurement.

4. Despite its rapid dissipation from plants, small amounts of endosulfan remain in cotton plant tissues even after harvesting, with concentrations of up to 0.5 mg/kg (dry matter) six months after spraying. The current general prohibition on feeding gin trash to stock is obviously a wise precaution, but the risk with particular pesticides is dependent on the rate of breakdown in plants.

Fate of endosulfan in soil: half-life

Baseline data obtained from soil sampled on cotton fields invariably showed a low residual concentration of endosulfan at the commencement of each cotton season (less than 0.08 mg/kg, equivalent to 60 g/ha).

The maximum concentration observed in a cotton field soil averaged to 5 cm depth was 0.86 mg/kg (440 g/ha) when plant cover was 25%, immediately after a second spraying.

Another spraying 16 days later showed a lower peak of 0.68 mg/kg (345 g/ha) when the plant cover was more than 50 %. It is apparent that there is a two-phase dissipation of endosulfan from soil. In the first phase the parent isomers present in the formulation (α- and β-endosulfan) disappear mainly by volatilisation while endosulfan sulphate is formed in soil, reaching a maximum of about 0.2 mg/kg about two weeks after the final spraying.

Figure 7.1. Typical rate of dissipation of total endosulfan from soil on cotton fields (cumulative data) at Auscott Warren, field 7 (1995-96). Endosulfan sulphate, probably mainly formed by fungi in soil, is the most persistent residue.

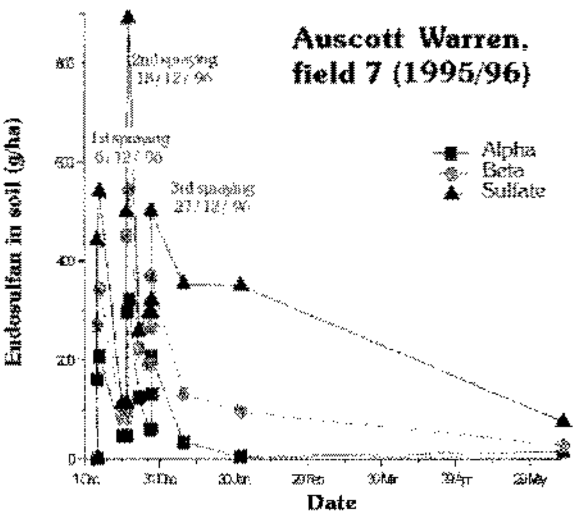
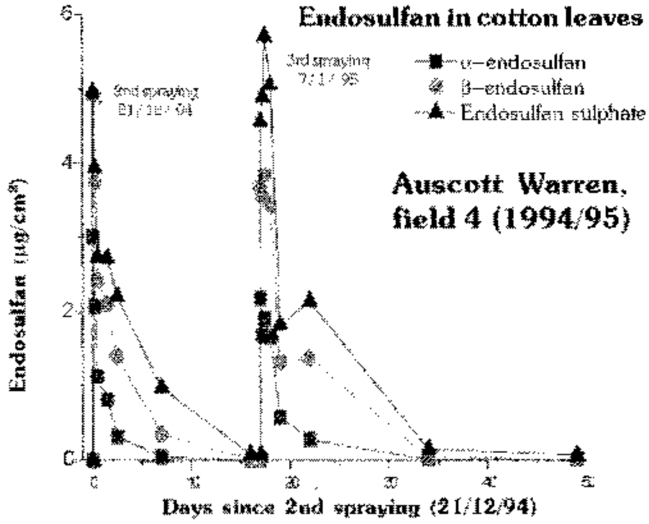


Figure 7.2. Rapid decline of total endosulfan residues (cumulative data) in cotton foliage at Auscott Warren, field 7 (1994-95). Even endosulfan sulphate, a metabolic product of endosulfan, particularly the α-isomer, is degraded rapidly.



Apparent half-lives for each of these two phases have been estimated from a large number of data points (Table 7.1.), with mean values of about 4 days and 138 days for the two phases. The half-life in soil varied from field to field as the environmental conditions (time of day, temperature, wind speed, etc.) differed for each spraying. In general, the decline in α-endosulfan concentration in soil by volatilisation was much faster than that for β-endosulfan, whilst endosulfan sulphate was formed quickly as α-endosulfan disappeared. On one field, the peak quantity of endosulfan sulphate represented about one-fifth the total endosulfan applied in the three aerial sprayings.

Statistical analysis (ANOVA) of the data for the stratified design by rows and columns (Kennedy et al., 1998) indicated that there was no significant difference in concentrations of endosulfan residues between different strata on the field. Thus, aerial application provides an even spread of pesticide, and the rate of conversion to endosulfan sulphate also seems to occur evenly across the field at least during the first weeks.

Later in the season the distribution of total endosulfan in soil becomes uneven, due probably to a combination of factors such as variable runoff losses between furrows, concentration of stubble and microorganisms in certain parts of the field.

Movement through soil layers

On field 21 at Narrabri, a special set of four cores from the field, tail-drain slope, tail-drain scow, and return drain was taken for analysis of endosulfan residues in soil layers of different depth. Most of the endosulfan was present in the top surface layer, its concentration declining with depth and being negligible beyond 8-10 cm. Given the low solubility of endosulfan and its high affinity for organic matter, leaching seems improbable; rather, any presence of endosulfan below surface layers may be explained by soil and contaminated dust falling into the wide and deep cracks that often appear in this type of soil.

Endosulfan in runoff water

There was significant pesticide contamination of all irrigated runoff water after the first spray application. The residues found were generally in the range 1-30 mg/L in runoff at the drop-box, depending on the number of days from the previous aerial application. Values declined to about 2 mg/L one month after spraying, corresponding with the decline in on-field soil residue concentration (see Figure 7.3.). There was evidence suggestive of much higher concentration of residues in runoff water for the first two hours of the runoff event, declining to about half this value in later runoff, but this was correlated with the sediment load.

Table 7.1. Estimated half-life in days of endosulfan in soil of cotton growing areas

Year	Field	Phase	α-endosulfan	β-endosulfan	E. sulphate	Total Endosulfan
1993/94	21	1	5.5	6.8	-	4
		2	10.5	103	120	180
1994/95	4	1	1.8	4.1	-	2
		2	65	86	152	105
1995/96	20	1	5.7	-	-	6
		2	35.7	40.2	63	129
1995/96	7	1	3.7	4	-	5.2
		2	7.8	119	105	137
average		1	4.2±1.8	4.9±1.6	-	4.3±1.7
		2	29.7±26.6	87±34	110±36.9	137.7±31.3

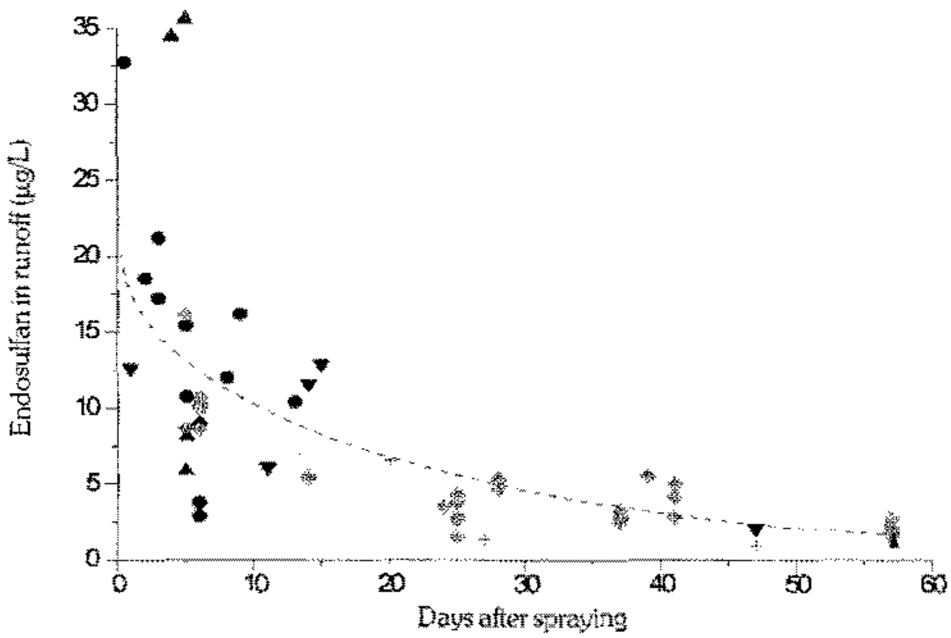
Table 7.2. Transport of endosulfan residues in run-off water

(Field 4, Auscott Warren, 1994/95)

Event	Date	Days since last spraying	Discharge (ML ha^{-1})	Endosulfan in water ($\mu g\ L^{-1}$)	Endosulfan removed (g/ha)	% endosulfan on-field moved
Irrigation 1	8/12/94	8	0.97	7.65	7.42	4.3
Irrigation 2	28/12/94	7	0.84	6.98	5.86	2.9
Storm 1	5/1/95	15	0.037	6.11	0.23	0.1
Irrigation 3	13/1/95	6	0.69	6.96	4.8	2.7
Storm 2	19/1/95	12	2.35	8.85	20.8	9.9
Storm 3	28/1/95	21	0.022	6.09	0.13	0.07
Irrigation 4	6/2/95	30	1.03	1.62	1.67	0.9
Irrigation 5	20/2/95	44	0.73	0.75	0.55	0.3
Irrigation 6	4/3/95	56	0.75	0.15	0.11	0.08
TOTAL			**7.42**		**41.57**	

The irrigation events indicated in the table involve an abnormally large runoff, partly as a result of a mixed soil type including a red soil more difficult to wet than the more typical Vertisol, but also for atypical operational reasons. More typical irrigation events observed involved less than 0.3 ML ha^{-1}.

Figure 7.3. Endosulfan residues in runoff from cotton fields (19 fields Auscott at Warren 1995/96). The decline in residue concentration in irrigation runoff in several return drains is well correlated with the declining concentration in soil (see Figure 7.1). Different symbols indicate various degrees of field canopy cover at the time of application: circles=20%; squares=30%; triangles=40%; diamonds=55%; cross=60%.



It is important to realise that pesticide residues in irrigation runoff from cotton fields are recirculated within the farm boundary. There has been a high degree of compliance with the guideline that runoff water be retained on-farm.

In Table 7.2. calculated amounts of endosulfan residues for different levels of measured runoff are shown. This data indicates that 0.1-0.4% of the residues on-field are typically washed off for each 0.1 ML of runoff in an irrigation event, with up to 10 % leaving the field through the drop-box during an unusually major storm, although most thunderstorms cause much less movement.

Implications of results, uptake and adoption

These results on the fate of endosulfan have significant implications regarding environmental care in cotton farming.

Although the dissipation of endosulfan by volatilisation and degradation on foliage is relatively rapid, sufficient residues remain in plant material to pose a risk if plant residues are taken off-farm.

It is preferable to allow foliage to degrade on cotton fields, ensuring pesticide breakdown on-farm.

The decision of the cotton industry to prohibit the feeding of cotton trash to livestock since this program began (mainly as an outcome of the experience with Helix) is therefore very soundly based.

The study has shown that an important factor in the extent of environmental risk is the degree of soil exposure during pesticide applications. Thus, high cover from the cotton canopy can mitigate against high concentrations of pesticide in soil and the pesticide load in runoff. The advent of transgenic Ingard cotton, not requiring early applications of endosulfan when soil is highly exposed, is therefore most welcome.

The fate of endosulfan in soil, rapidly forming significant concentrations of equally toxic endosulfan sulphate which persists for several months, means that a cotton field can act as a strong source of pesticide residues in runoff water for several months after applications (see Figure 7.3.). Even the largest storms only remove a small fraction of the total pesticide bound to soil.

Consequently, as far as possible irrigation and storm runoff must be retained on-farm by proper management of water including the provision of the maximum water storages. Unfortunately, endosulfan sulphate on sediments degrades too slowly, even in ponded water, to allow deliberate release of untreated water from farms, although endosulfan isomers do dissipate strongly from water quarantined in this way. Other pesticides may degrade more rapidly under such conditions.

The results of this study focussed on endosulfan have already found application in the development of best practices by the cotton industry. In addition, the experience gained in this project has been utilised in pre-registration trials conducted in the last two-three years for new chemicals being promoted by chemical companies. The protocols developed for endosulfan provide methods that can often be directly applied to test these new chemicals under commercial conditions for cotton production.

Conclusions

Despite the rapid dissipation of most of the endosulfan applied to cotton fields in the first few weeks after application, the remaining residues require careful management if significant contamination off-farm is to be prevented.

The results of the project have shown that, in very large storm events, it may be impossible to prevent movement of endosulfan residues off-farm to nearby wetlands and rivers. Since storms occur in most seasons, the possibility of some contamination of rivers from transport of endosulfan in surface waters must be accepted.

However, by using better water management on farms and techniques such as band spraying to reduce the extent of soil contamination, significant reductions in the risks to the off-farm environment can be made.

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8. Pesticide behaviour on-farm: persistence and off-site transport (Queensland)

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Abstract

A field study was conducted on a typical cotton production system in the Emerald Irrigation Area (EIA) of Central Queensland to provide an understanding of the processes involved in off-site movement of pesticides under current practices. The persistence of the major insecticide endosulfan and the key herbicides trifluralin, diuron, prometryn and fluometuron was measured on-farm in the soil throughout the cotton season. Pesticide residues in runoff at plot-scale, tail-drain and main drain were measured following irrigations and rainfall events.

The results showed that maintaining soil and sediment on farm via improved soil erosion strategies offered significant reduction in off-site movement of those pesticides with higher K_{oc} values such as trifluralin and endosulfan. Better water management to minimise runoff, combined with careful timing of irrigation and pesticide application would be required for minimising losses of the more water soluble pesticides such as prometryn.

Introduction

The Emerald Irrigation Area (EIA) located in Central Queensland, is one of Queensland's most productive cotton growing areas. Constant high temperature and other favourable conditions during the season result in high pest pressure, particularly from heliothis. Regular applications of endosulfan in the earlier part of the season have proven to be highly effective in controlling heliothis. Endosulfan is normally applied at 3L/ha ultra-low volume (ULV) as aerial application, with up to ten (10) sprays per year when high insect pressures exist. These applications combined with additional applications of other insecticides and herbicides, increase the potential for environmental contamination.

With increasing regulatory pressures and increased community concerns regarding the impact of pesticides on the riverine environment, the cotton industry is frequently targeted as being responsible for environmental damage, particularly fish kills.

To address such concerns, the cotton industry in Australia required sound scientific data on the persistence and behaviour of endosulfan and other cotton pesticides within the cotton production system. Such information was seen as a key pre-requisite to introducing any changed management practices for minimising off-site movement of pesticides.

Whilst the world literature has significant information on the behaviour of pesticides within the farming system, including the off-site movement in irrigation or stormwater runoff, there was a real need to provide information on the processes involved in Australian conditions of extreme temperatures, different soil types and farming conditions. Such a scientific study required a multidisciplinary approach with expertise in cotton production, pesticide chemistry, soil science, hydrology and soil erosion.

Methods

A 'typical' irrigated cotton farming system (on brown cracking clay) was selected and instrumented at plot scale (6 rows x 250 m) with flumes, bed-load traps, runoff height recorders, loggers and samplers. Taildrain outlets on two blocks (approx. 80 hectares) were fitted with weirs, height recorders and samplers. Detailed recordings were kept of farm practices, crop growth, pesticide inputs, meteorological data (collected on farm) and irrigation details.

Photo 8.1. Instrumentation installed at plot-scale for measuring and sampling runoff

Photo 8.2. Taildrain outlet during irrigation event

Samples of soil, sediment and runoff were taken throughout the crop cycle and analysed for pesticide residues to determine both the persistence of the pesticide on-farm (potential for runoff) and the concentration in the runoff. Hydrological data, collected for all runoff events, was used to calculate the total load of pesticide leaving the farm. The effect of cotton stubble retention and added wheat straw on pesticide movement was included in the second season. In the third season, an additional site was added to study the effect of a more extreme treatment of a pre-cotton wheat crop on pesticide retention.

Regular sampling of a major drainage channel throughout the project provided data on the pesticide residues in runoff from multiple farms. In the final year, some targeted sampling between the farm site and the Nogoa River, combined with flow data (drains and river), enabled estimates to be made on the potential impact of the EIA cotton growing on the pesticide concentrations downstream in the river.

Key results

Soils

In the high-clay (65%) soils of the Emerald Irrigation Area (EIA), there was no evidence of build-up of pesticide residues in the soil from season to season — either in the surface layer (0-5 cm) or down the profile (approx. 1 metre). Compounds measured included endosulfan (α, β and sulphate), trifluralin, prometryn, fluometuron, diuron and methyl parathion. DDE, the persistent breakdown product of the previously used insecticide DDT, was also determined in all samples analysed.

Figure 8.1. shows seasonal build-up and decline of the applied pesticides measured in the surface layer (0-2.5 cm) during the 1993-94 growing season. A similar pattern was measured in the following year, showing consistency from season to season with similar applications and conditions.

Figure 8.1. Pesticide residues in soil Emerald - (1993/94 season)

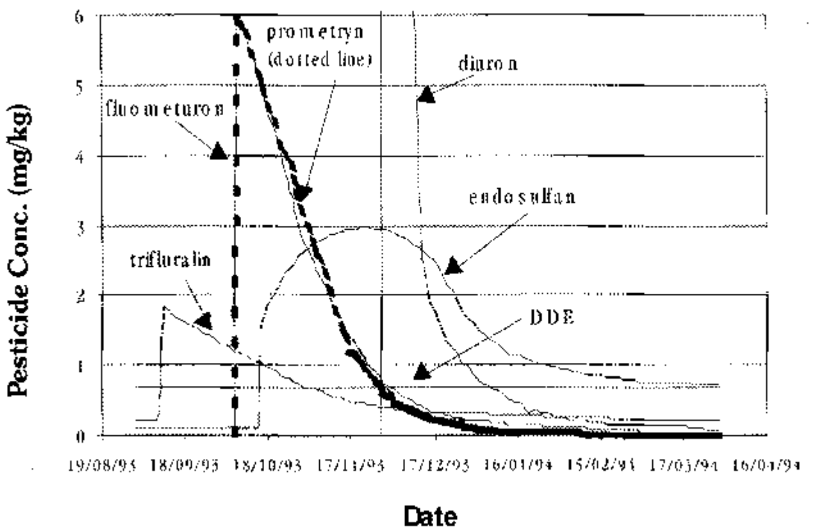


Figure 8.2. Total endosulfan in soil 'measured' and 'estimated'

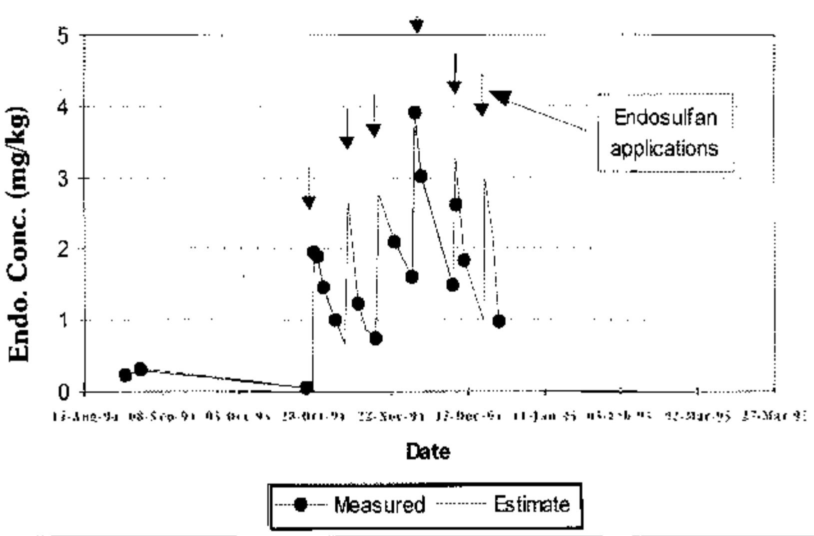
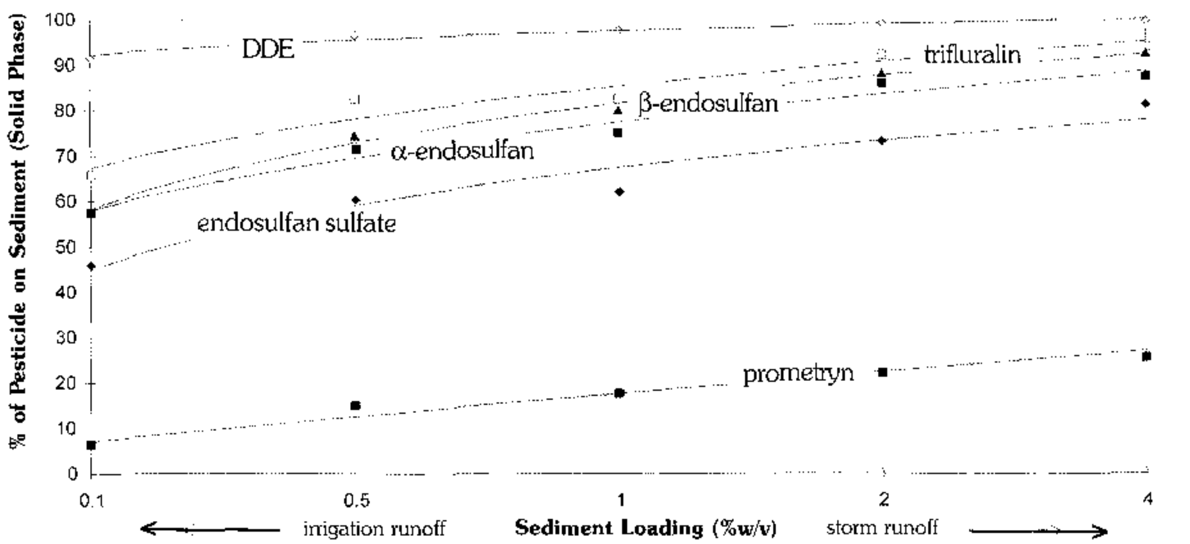


Figure 8.3. Sediment/water distribution of pesticides: [on cotton soil (brown cracking clay)]



Following the first endosulfan application, residues in the surface soil (0-2.5 cm) rose to approximately 2 mg/kg (application of 3 L/ha ULV aerially applied) and showed reasonably rapid decay (half life of approximately one week for total endosulfan), a process where both the original α and β isomers are reduced by a number of mechanisms, including conversion to endosulfan sulfate. Multiple applications of endosulfan (up to 10 per season in the EIA in 1993-94) resulted in slow build-up (because of on-going breakdown) to approximately 4 mg/kg in the surface (0-2.5 cm) layer (see Figure 8.2.).

The herbicide trifluralin, which is applied pre-planting (incorporated to 10 cm) was found to be relatively persistent in the soil and slowly declined throughout the season. Prometryn and fluometuron (applied to hills [plant rows] at planting) declined moderately (half-life of approximately one month) and diuron (applied to furrows at last cultivation) declined rapidly, particularly when furrow irrigation (or runoff from rain) was applied immediately after application

This information on pesticide levels in the soil, clearly shows that the major potential risk for off-site movement of these pesticides from the cotton field is limited to the early part of the season when soil residues are the highest. The highest risk periods for the more water soluble herbicides eg prometryn, fluometuron and diuron are more defined to the period 4-6 weeks after application.

The endosulfan 'loading' on the soil, and thus the potential for off-site movement, is reduced by approximately half, for each week after application. Repeated applications of endosulfan will result in a short-term build-up of residues, the extent of the build-up depending on the time interval between applications. Such repeated applications extend the risk period for endosulfan losses and help explain why endosulfan residues can be detected in runoff waters over a large part of the cotton season.

Mechanisms/processes for off-site movement of pesticides

Off-site movement of pesticides to the riverine environment occurs mainly via soil movement (erosion), in suspended sediment (also erosion) and dissolved in water. All pesticides studied moved off-site via these three mechanisms. Because of the different physical and chemical properties of each pesticide, the dominant mechanism for off-site transport for each pesticide varied.

The relative amounts in the solid (soil and suspended sediment) and the water phases depends on the intensity of the erosion (soil/water combination) as well as the chemical and physical properties of each pesticide. Figure 8.3. shows measured distribution (laboratory studies) between pesticide on suspended sediment and dissolved in water for a number of the pesticides studied using soil from the study site (65 % clay).

Figure 8.4. Effect of surface treatment on bedload moved - (250 m furrows, 0.15ha)

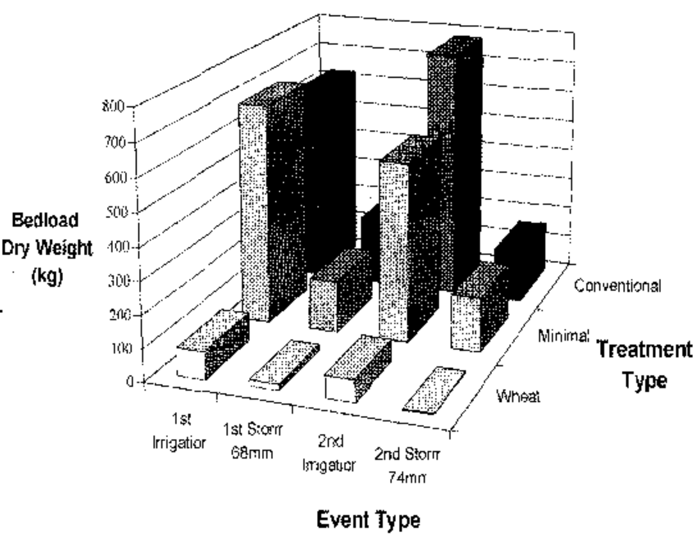


Table 8.1. Effect of pre-cotton wheat planting on endosulfan export (first irrigation)

Fraction Measured	Conventional Tillage	Reduced Tillage	Wheat Planted	Reduction (in wheat treatment) % of Conventional
Bedload Moved (kg/Ha)	4160	4573	566	**13.6**
Runoff ('000 L/Ha)	1160	910	450	**38.8**
Suspended Sediment (g/L)	2.2	1.5	0.6	**24.7**
Total Endosulfan in Bedload (mg/Kg)	0.62	0.52	0.28	**45.2**
Total Endosulfan in Runoff (μg/L)	3.3	3.7	3.4	**103**
Endosulfan Exported -				
Bedload (g/Ha)	2.58	2.38	0.16	**6.1**
Runoff (g/Ha)	3.78	3.33	1.54	**40.7**
TOTAL (g/Ha)	6.36	5.71	1.70	**26.7**
% Total Endosulfan Exported wrt Conventional Tillage	**100**	**89.8**	**26.7**	

The results highlight the potential reduction in off-site movement of these pesticides if all sediment could be retained on-site.

Field trials in 1994/95 comparing three surface treatments [rake and burn (current practice); cotton stubble retention; and wheat straw added (2-3 tonne/ha)] showed no significant effect on soil loss, bedload or suspended sediment and thus pesticide loss. The cotton stubble and added straw treatments may have been effective in reducing pesticide losses for an initial rainfall runoff event (had there been one resulting in runoff) but there was visual evidence that the stubble was quick to break down, thus any potential effect would be short-lived.

Because of little rainfall, most significant runoff events during this trial were from irrigation. Higher furrow slopes produced higher bedload and suspended sediment for all three plot-scale treatments.

Field trials in 1995/96 comparing conventional tillage, reduced tillage and pre-cotton wheat planting (wheat plants killed prior to cotton planting into wheat stubble) demonstrated that the wheat 'treatment' significantly reduced bedload (see Figure 8.4.) and suspended sediment, particularly in the early to mid-season. For a 'heavy' irrigation, only three (3) days after the first endosulfan application (2.1 L/ha), the wheat treatment produced only 30 % of endosulfan loss compared with conventional tillage. Endosulfan in runoff was reduced to 40 % and endosulfan loss via bedload reduced to only 6 % (see Table 8.1.). Reduced tillage resulted in only a 10 % reduction in endosulfan loss for the same event.

Whilst the amount of pesticide leaving the taildrain after a typical furrow irrigation was calculated to be in the order of 0.5 to 1.5 % of the pesticide present in the soil at the time, concentrations of pesticide in the runoff at this point may be well over current environmental guideline values set for environmental waters (rivers).

The difference in the slope of the furrows from 1.2 % to 0.8 % in two separate blocks (similar inputs) resulted in a significant (90 %) reduction in the amount of trifluralin being exported, resulting from reduced sediment and runoff leaving the block.

The study clearly showed that the adoption of conventional soil conservation practices such as reduced slope in furrows and tail-drains or the incorporation of effective stubble retention, can significantly reduce pesticide losses. This is particularly relevant for those pesticides that moderately or strongly adsorb to soil or suspended sediment particles (Figure 8.3.).

For the more mobile pesticides such as prometryn, fluometuron or diuron, sediment retention will be less effective and improved water management combined with improved timing of irrigations and pesticide applications is therefore required. Management changes that reduce both soil and sediment losses as well as reducing the quantity of runoff are necessary if real reductions in all pesticide losses are to be achieved.

Farm-to-river transport

In the Emerald Irrigation Area, the engineering design of drainage channels provides potential for significant quantities of cotton chemicals to be carried to the Nogoa River during major runoff events. Irrigation runoff may have little direct impact on the river, but sediment deposited (with pesticide residues) in drains can be remobilised during major flows.

During significant rainfall/storm events, high runoff in cotton-growing catchments will result in high volumes eg 1200 ML/day of runoff (calculated 1,440 tonnes sediment) entering the river via one of the main drains. The runoff hydrograph (Figure 8.5.) shows peak flow measured in the drain equal to approximately 2600 ML/day or 110 ML/hour for a storm runoff event in January 1996.

Figure 8.5. Storm runoff (LN1 main drain) January 9-10, 1996

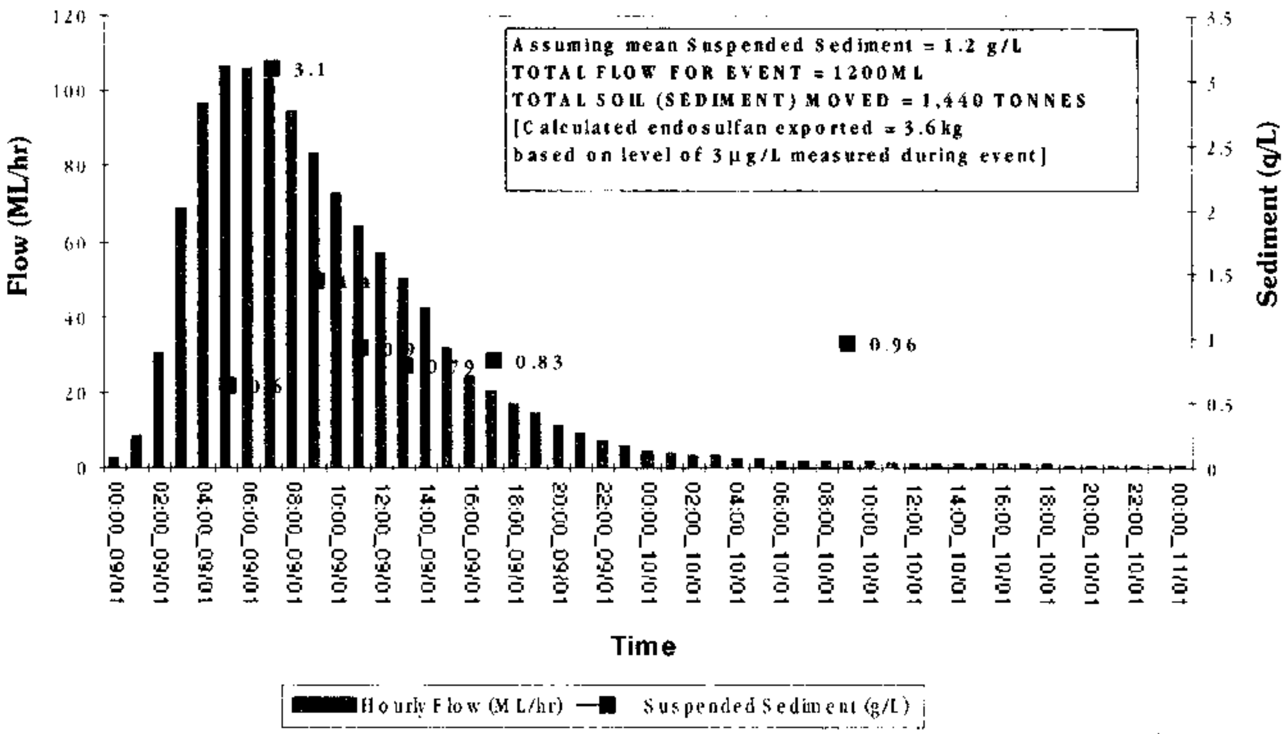
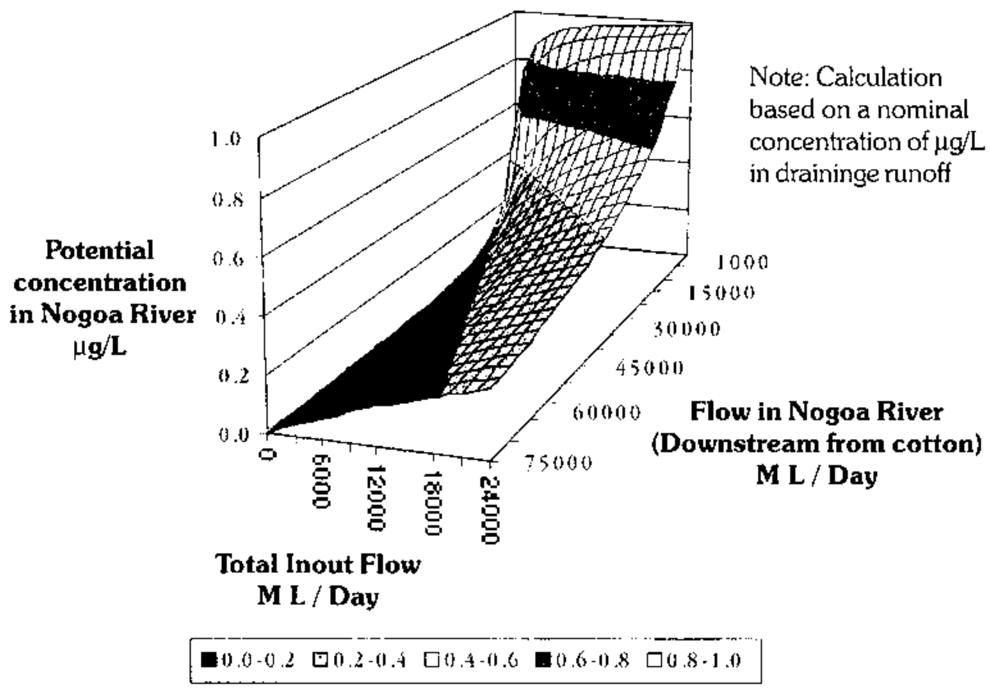


Figure 8.6. A model of potential endosulfan increase in Nogoa River



Endosulfan exported in this event was calculated (based on measured concentrations in the drain at the time of the event) at 3.6 kg active endosulfan. Measured endosulfan concentration in the river downstream of the drain entry to the river was 0.5 µg/L.

Figure 8.6. shows that whilst elevated levels will be observed following major runoff events, these levels will rapidly decline once runoff from the actual cotton area ceases. Those involved in measuring and assessing data from monitoring programs should ensure that supporting information is obtained on the conditions at the time of sampling. Failure to take account of such information can lead to misleading interpretation on trends and thus fail to effectively evaluate the impact of changed land use practices or potential for environmental impacts.

Rapidly changing input flows, combined with rapidly changing river flows can result in significant short-term variations in pesticide residue concentrations close to the drain's discharge point in the river over a 24 hour period. Using measured and calculated flows during a major runoff event in January 1996, the total impact (Figure 8.6.) on endosulfan concentration in the Nogoa River downstream from the cotton area was calculated.

This event was towards the end of the season. Had the event occurred earlier in the season where pesticide residues in the soil were at their highest, and soil was less compacted with cotton canopy cover less developed, residues in the river would be expected to be considerably higher.

Acknowledgement

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9. Regional level monitoring of pesticides and their behaviour in rivers

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Abstract

The Department of Land and Water Conservation, NSW, conducts one of the largest water quality monitoring programs in Australia which deals with water quality issues arising from intensive irrigated agriculture. Surface water monitoring within the central and north-west regions of NSW has recorded long term water quality trends within these areas since 1991. Considerable contamination of inland waterways of NSW by pesticides has been demonstrated as a result of pesticide use on irrigated and broadacre farming. Changes that have taken place within the industry during the 1990s, and variations in production between seasons due to rainfall, have been monitored through this program.

Introduction

Concerns about the potential adverse effects of agricultural chemicals on the environment and human health have led to extensive research into their environmental behaviour and fate in the USA and Europe. During the late 1980s in Australia, there was a growing concern about the impact of irrigated agriculture on the environment. Investigation into this issue has been carried out in part by the Central and North West Regions Water Quality Program (CNWRWQP) which is a joint initiative of the Department of Land and Water Conservation, NSW (DLWC) and the water users of the Macintyre, Gwydir, Namoi and Macquarie valleys of NSW.

Recently, extensive research has been performed into the transport pathways of pesticides into the off farm environment. However, significant gaps still exist in the understanding of the impact of pesticide contamination on the biological processes occurring within the surface water environment.

Over the last decade there have been many important developments in the Australian cotton industry including the geographical expansion of cotton production into large areas of northern NSW and southern QLD. The transgenic cotton, Ingard), was introduced as a commercial crop during the 1996/97 growing season. As Ingard) cotton requires less sprays for heliothis control, a reduction in the amount of pesticides reaching off farm environments, such as waterways, would be reduced when Ingard) is planted in ecologically sensitive areas.

Perhaps the most significant landmark has been the introduction of the Australian Cotton Industry's Best Management Practices (BMPs). This process has prompted much discussion on a range of issues related to cotton farming, the environment and the community. The implementation of the BMP guidelines over the next few seasons are expected to reduce the occurrence of pesticides in the off-farm environment and any effect on local communities.

The National Registration Authority's (NRA) Review of Existing Chemicals process may prove to be one of the most important recent events to affect the industry. Inter-agency and industry collaboration are required to meet the monitoring requirements set by the NRA for the use of endosulfan.

The large temporal and spatial scale of the surface water monitoring program gives an indication of the areas most impacted by chemicals. However, surface water monitoring does not allow for any conclusions to be made about environmental damage. An integrated biological monitoring program has also been undertaken to monitor long term environmental health of these systems.

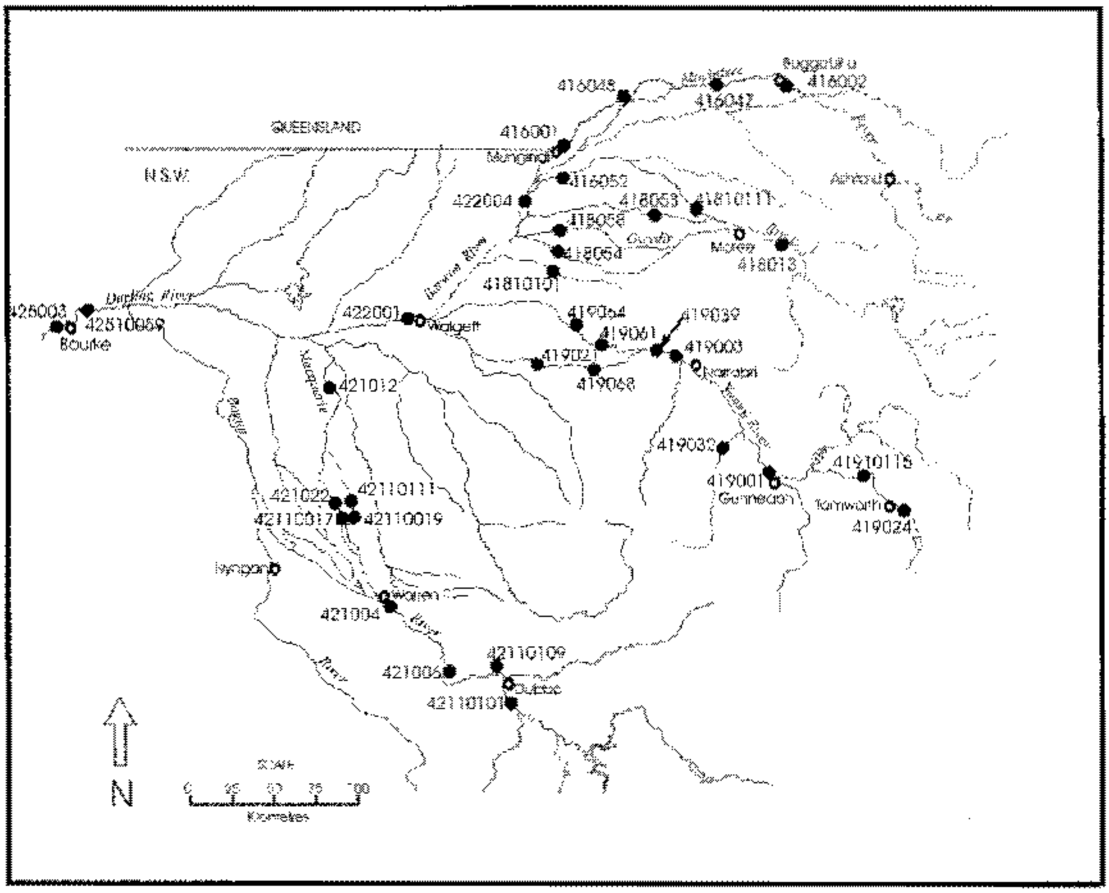
Biological river health assessment has taken place in the form of a macroinvertebrate monitoring program, integrated with the pesticide monitoring and supplemented by mesocosm studies. Discussion of these results are presented in another paper presented at this conference, 'Biological Monitoring - Central and North West Regions Water Quality Program' by A. Brooks.

Methods

Pesticide monitoring in surface waters was designed around the Insect Resistance Management Strategy to mimic the seasonality of cotton related agrochemicals, particularly endosulfan. Samples are taken weekly over the summer, monthly over the winter and fortnightly on the shoulders of the summer season. Sampling was performed using standard 'grab sample' techniques, supplemented by *in situ* integrated sampling using continuous sampler bags and riverine sediment analysis.

The spatial scale of this program is large. Twenty-eight sites across the Macintyre, Gwydir, Namoi and Macquarie River basins of NSW and the Darling River at Bourke (Figure 9.1.) are routinely sampled. Within each basin there are sample sites located upstream of

Figure 9.1. Water quality sampling sites in the central and north-west regions of NSW.



irrigated agriculture and sites within areas of irrigated agriculture. This distribution of sites ensures that performance can be reported on a basin level. Comparisons between impacted and non impacted sites can also be made.

The location of the current sampling sites are shown as solid symbols in Figure 9.1. Thirty agrochemicals and metabolites are sampled as part of the routine program, as well as physical water quality parameters and total nitrogen and total phosphate concentrations.

The majority of sites are located at hydrographic gauge stations for the collection of flow data. Three locations have been sampled for pesticides in surface waters using the continuous sampler bags method - Carole Creek in the Gwydir basin, Brageen Crossing on the Gwydir River and the Namoi River at Gunnedah.

Laboratory analysis was performed at the DLWC's Water Environment Laboratory at Arncliffe, Sydney. For the manual grab samples, a liquid/liquid extraction was used to preconcentrate the organochlorine, organophosphorus, pyrethroid insecticides, the triazines and other organonitrogen herbicides. The method is based on USEPA Method 3510, 'Separatory Funnel Liquid/Liquid Extraction'.

For herbicides such as phenylureas, as well as atrazine and its metabolites, a solid phase extraction procedure was used to pre-concentrate the analytes. Samples with high suspended solids were clarified by centrifugation or filtration. An aliquot of the sample was passed through a pre-treated C18 cartridge. After air drying the cartridge, the herbicides were eluted with a small volume of methanol or acetonitrile.

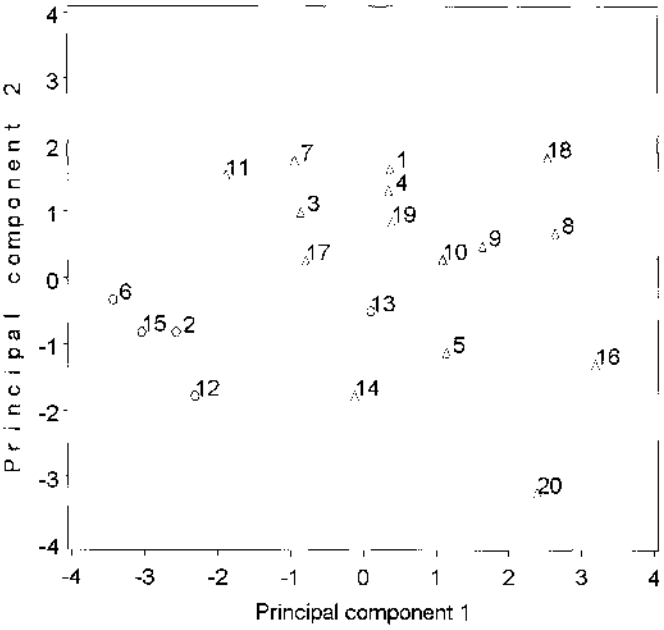
Both the solvent from the continuous sampler bags, and the manual grab samples, were analysed by gas chromatography. Urea herbicides and atrazine metabolites were determined by high performance liquid chromatography.

Results and discussion

A principal components analysis was performed on the 1996/97 pesticide data to investigate whether the classification of sites upstream of irrigated agriculture were truly representative of 'reference' sites. An ordination of this analysis clearly shows the separation between these upstream sites and those sites within areas of agriculture (Figure 9.2.).

Water quality results of 1996/97 have shown that the lower reaches of the Macintyre, Gwydir and Namoi catchments are contaminated by pesticides to a greater degree than the upper reaches of these catchments (Figure 9.3). This was demonstrated by performing cluster analysis of all sites within the sampling program using data collected during the summer spray season for endosulfan, atrazine, prometryn, fluometuron, diuron and metolachlor. Sites that were typified by generally low pesticide occurrences, most commonly atrazine, were in the upper reaches of all catchments (Cluster 1). Sites typified by medium ranges of endosulfan and atrazine and low levels of diuron,

Figure 9.2. Principal components plot of sites upstream (circles) and within (triangles) areas of irrigated agriculture using in-season data.



Site legend for Figure 9.2.

1, 416001: 2, 416002; 3, 416047; 4, 416048; 5, 416052; 6, 418013; 7, 418053; 8, 418054; 9, 418058; 10, 41810101; 11, 41810111; 12, 419001; 13, 419003; 14, 419021; 15, 419024; 16, 419032; 17, 419061; 18, 419064; 19, 419068; 20, 425003.

fluometuron, metolachlor and prometryn were in the middle reaches of each catchment (Cluster 2).

Irrigated agriculture is common in these areas. Sites that were typified by a high occurrence of pesticides, of which endosulfan sulfate and endosulfan isomers were common, as well as by high detections of atrazine, diuron, fluometuron, metolachlor and prometryn were found at the bottom of each catchment (Cluster 3). Two sites had relatively high incidences of endosulfan sulfate, alpha and beta endosulfan, atrazine, fluometuron, prometryn and metolachlor (Cluster 4).

Long term trends of water quality data are expressed simply in graphic form (Figure 9.4.). The centre line in each box represents the median concentration. The length of the box represents fifty percent of the results.

In 1991/92, endosulfan contamination of the riverine environment was the worst recorded throughout this monitoring program. Endosulfan concentrations found in surface waters have since decreased. The low cotton production year of 1994/95 due to drought conditions, was reflected by the lowest levels of endosulfan detected in all rivers.

Since then, the Border Rivers and Darling River at Bourke have shown a rising trend of endosulfan contamination, stabilising over the last year. The Macquarie River catchment has maintained low levels of contamination throughout the monitoring program.

Endosulfan contamination in the Gwydir and Namoi River catchments rose to pre-drought levels in 1995/96, but decreased in the 1996/97 and 1997/98 seasons, despite these seasons being the highest cotton production years since water quality monitoring commenced.

It is hoped that this reflects the beginning of a declining trend of endosulfan contamination in these two catchments brought about by the awareness of BMPs, including the planting of Ingard) cotton in sensitive areas. Future monitoring will evaluate whether this trend will hold as BMPs are further implemented.

Figure 9.3. Contamination levels across catchments.

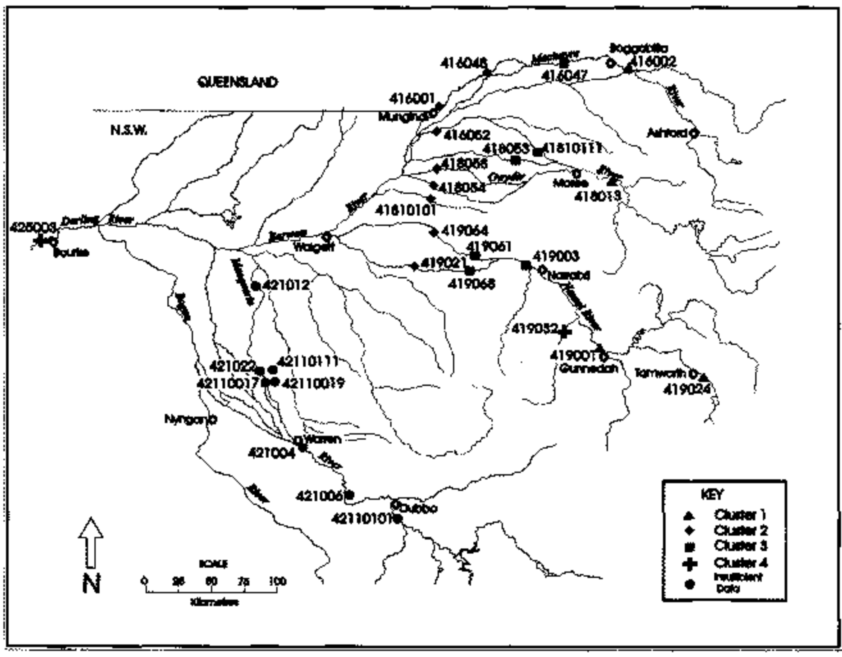
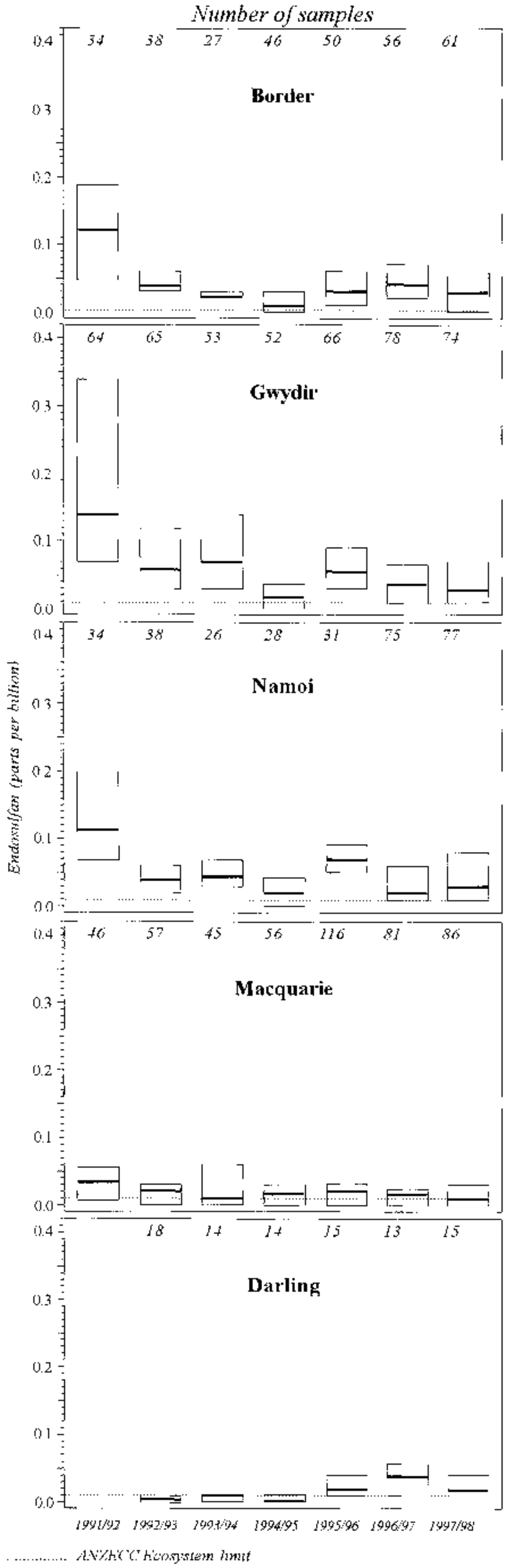


Figure 9.4. Graphs of total endosulfan by river basin (irrigated cotton area data only) 1991/92 to 1997/98.



Each box represents the middle 50% of the data collected for the November to March period allowing a consistent way of comparing results. The largest and smallest quarters of data have not been displayed. The thick line represents the median (or 50th percentile) value which is most useful when assessing water quality data.

However, during the last three seasons, the percentage of samples which exceed the ANZECC protection of aquatic ecosystems guidelines (0.01 µg/L), remains within the range of sixty five to seventy percent.

This result raises several questions. Can the main body of samples which fall within the concentration levels of 0.01 to 0.08 µg/L be significantly reduced more than they already have during good production years? Since the commencement of the monitoring program, BMPs have caused a reduction in extremely high contamination levels; therefore is the majority of riverine contamination of endosulfan in these catchments due to such processes as volatilisation which can not, to a large extent, be any better managed?

Monitoring over the next few seasons will determine whether the implementation of BMPs will actually have the effect of reducing the percentage of samples exceeding the guideline value.

There is a growing concern that the impact of contaminated river sediments on riverine ecology is not fully understood. Sediments were collected and analysed from sites across the central and north west catchments of NSW during January, February and May of 1998. Of the 15 sites monitored, five sites were contaminated by endosulfan.

These sites were the Mehi River at Bronte, Thalaba Creek at Merrywinebone, the Namoi River at Bugilbone, Pian Creek at Rossmore and Gunidgera Creek near Warren. Cox's Creek at Boggabri recorded sediment contamination of the herbicide metolachlor.

The Gwydir River at Brageen Crossing was monitored at regular intervals over the summer of 1997/98, however no endosulfan was recorded in the sediment despite endosulfan being recorded in the surface water.
The carbon content and particulate size of sediment appears to affect whether endosulfan will be more or less likely to bind to the sediment. Monitoring of sediments will continue during 1997/98 to provide further information regarding the extent and degree of contamination in these catchments.

Surface water contamination can result from various instantaneous events which may occur between the dates set for routine monitoring. A new technique of continuously sampling surface waters using passive sampling bags was used to augment standard manual sampling techniques. These bags are a low density polyethylene membrane, filled with a solvent which attracts and binds pesticides inside the bag. These bags remain in the water for days or weeks at a time, continuously accumulating pesticides which pass down the river. This method of sampling has two major advantages; firstly they are able to detect contamination events which may occur outside the routine weekly sampling occasions, and secondly they are able to accumulate chronic low levels of pesticides to concentration levels detectable by analytical methods, which may otherwise go unrecorded by the monitoring program.

The bags have been trialed for 1996/97 and 1997/98. Carole Creek in the Gwydir catchment was chosen as a location to investigate whether the bags were able to distinguish between locations as greater or lesser contaminated, as well as whether the bags were able to detect chemicals which may have been missed through routine sampling.

One site was chosen upstream of an area of irrigated agriculture and another site downstream of this area. Within the bags, amitraz and pendimethalin were detected only at the downstream site. The bags also detected that endosulfan, profenofos and propargite levels were significantly higher at the downstream site. Weekly routine surface water sampling at these two sites during the period of this trial only detected endosulfan, which was also at significantly higher levels at the downstream site.

Whilst this method can not be quantitative because the importance of such variables as flow, temperature and surface water concentrations are unknown, we were confident with using this method to compare two sites which have undergone the same hydrological fluctuations and where the bags were deployed for exactly the same time periods.

During trials of this technique on the Namoi River at Gunnedah and the Gwydir River at Brageen Crossing, the bags detected the agrochemicals amitraz, chlorpyrifos, profenofos, pendimethalin and propargite that the routine weekly surface water sampling did not detect. The continuous passive sampling bag technique will be incorporated into the future monitoring program in areas which are environmentally sensitive, and where access during high rainfall events is not possible.

Rainfall runoff can be a major source of contamination for agrochemicals reaching receiving waters. They represent acute phases where the environment is exposed to high levels of agrochemicals. Storm patterns depend on catchment characteristics, the intensity of the storm and the localised nature of the storm. A storm event on the Gwydir River which was monitored at Brageen Crossing in February 1997 is shown in Figure 9.5.

The first half of the hydrograph represents runoff from localised areas around the sampling site. The larger peak in the second half of the hydrograph represents the storm waters coming down from the upper catchment.

Figure 9.5. Flow and endosulfan data for storm event.

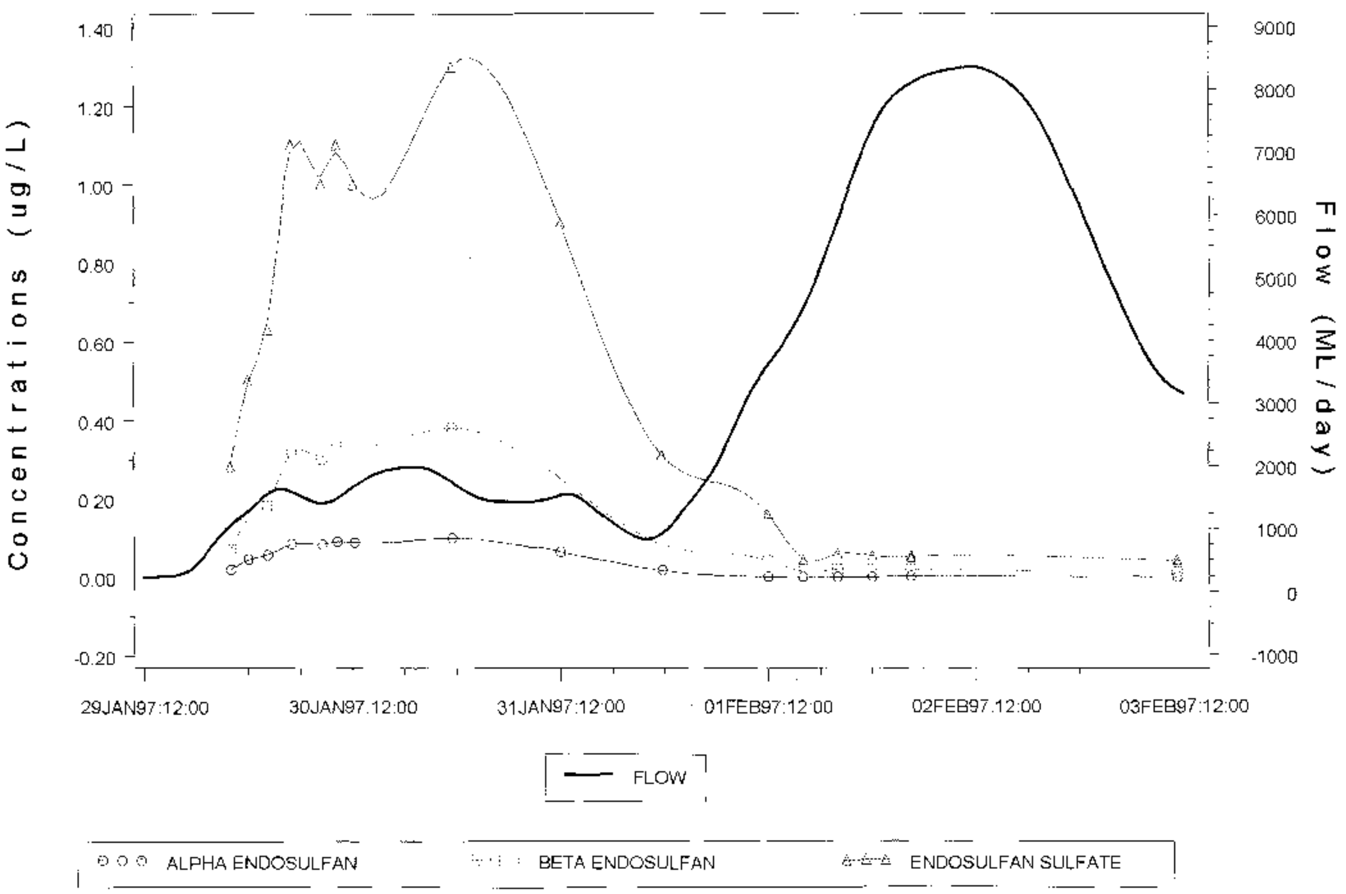
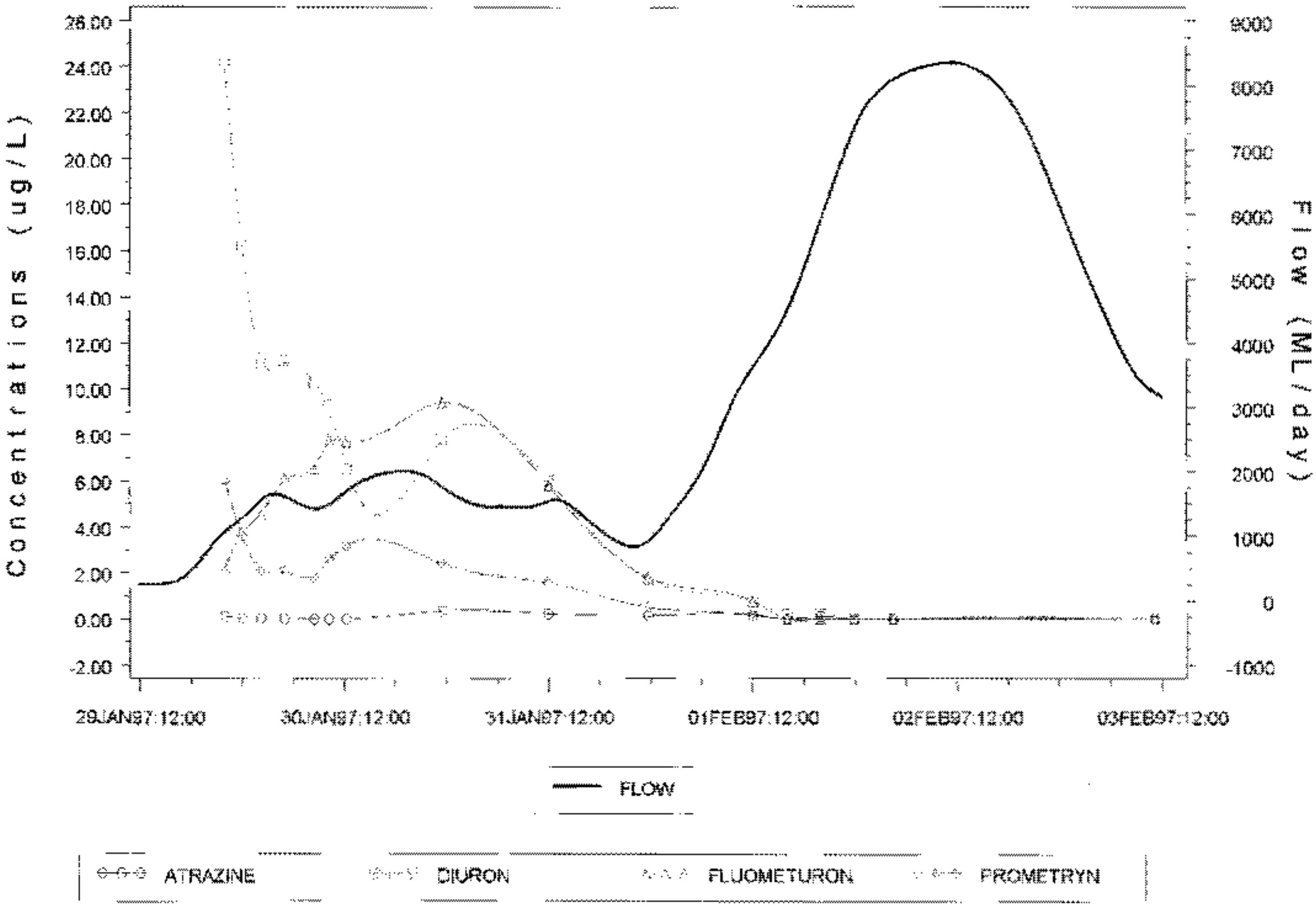


Figure 9.6. Flow and diuron, prometryn, fluometuron and atrazine data for storm event.



The highest concentrations of alpha and beta endosulfan and endosulfan sulphate were during the first smaller flow peak, indicating that the source of these agrochemicals came from areas close to the sampling site.

Total endosulfan levels reached 1.75 µg/L. As the ANZECC guideline for the protection of aquatic ecosystems is 0.01 µg/L, this event was a major acute contamination event. The high values of the less stable parent products of alpha and beta endosulfan in the surface water indicate that spraying in neighbouring areas probably occurred within a week of this storm.

Four other agrochemicals were detected during this storm event (Figure 9.6.). They were the herbicides fluometuron, diuron, atrazine and prometryn. Diuron and prometryn levels were highest with the first water sample taken, then decreased, showing how important the initial runoff can be as a source of high concentration levels.

The similar pattern of these two chemicals infer that they were most likely from the same source, and possibly a different source to that of endosulfan and fluometuron. Atrazine levels were low, this was to be expected as it is not used in irrigated agriculture in this region, and was most likely sourced from other more diffuse landuses.

Implications of results, uptake and adoption

Community and industry are placing an increasing value on water quality information. Community consultation through the river management committees that are driven by the Water Reforms process are consistently placing environmental health values as important objectives for the future. The review of endosulfan by the NRA is placing pressure on the cotton irrigation industries such as cotton, to implement BMPs.

Likewise the review of atrazine will require the broadacre agriculture industry to meet environmental guidelines. These processes will require the community and industry to be able to assess and report on the meeting of water quality objectives. The CNWRWQP is the major vehicle through which large scale water quality and biological monitoring is performed. It is vital therefore that collaboration between industry bodies and the DLWC be optimised.

Conclusions

The CNWRWQP continues to make a substantial and significant contribution towards a better understanding of environmental pesticide contamination in the riverine environment. The program has helped identify locations where pesticide contaminations of surface waters are relatively high.

This information has assisted industry groups to develop Best Management Practices and will provide further assistance by monitoring the outcomes of the implementation of these practices.

Further development of the risk assessment model will continue over several years, along with continued research into the environmental impact of pesticides on river ecology.

Acknowledgments

The CNWRWQP is jointly funded by the DLWC and the water users of the Macintyre, Gwydir, Namoi and Macquarie Valleys whose ongoing concern, contributions and support are greatly acknowledged. The support of regional staff of the DLWC is acknowledged for their assistance with sample collection, and John Brayan, Senior Chemist at the DLWC is thanked for his assistance with chemical analysis and advice.

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10. Integrative assessment of endosulfan transport from farm to river by multiple pathways

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Abstract

To reduce endosulfan contamination in rivers and waterways, it is important to know the relative significances of airborne transport pathways (including spray drift, vapour transport and dust transport) and waterborne transport pathways (including overland and stream runoff). This work uses an integrated modelling approach to assess the absolute and relative contributions of these pathways to riverine endosulfan concentrations. The modelling framework involves two parts: a set of simple models for each transport pathway, and a model for the physical and chemical processes acting on endosulfan in river water. The results show that spray drift, vapour transport and runoff are all significant pathways.

Spray drift and vapour transport both contribute low-level but nearly continuous inputs to the riverine endosulfan load during the spray season in a large cotton-growing area, whereas runoff provides very occasional but higher inputs. These findings are confirmed with observational evidence in two ways: first, good general agreement is found between model predictions and observed typical riverine endosulfan concentrations in the Namoi River and Pian Creek. Second, a new analysis of observed riverine endosulfan concentrations is used to distinguish events due to airborne and waterborne transport, providing clear evidence that both airborne and waterborne transport are important. Management implications are drawn from the outcomes of the work.

Introduction

This paper provides a summary of a series of model-based investigations of endosulfan transport from cotton farms to the riverine environment. Four potential transport pathways are considered: spray drift, vapour transport and dust transport (aerial pathways) and runoff (a waterborne pathway). The overall aims of the work are (1) to assess the relative importance of each pathway, using process-based models and data interpretation; and (2) to elucidate management implications by predicting the responses of endosulfan concentrations to possible management practices aimed at reducing the riverine endosulfan load.

The work reported here has taken place in several stages as part of the Research Program 'Minimising the Impact of Pesticides on the Riverine Environment' jointly funded by the Land and Water Resources Research and Development Corporation, the Cotton Research and Development Corporation and the Murray-Darling Basin Commission. The various stages of the work are described in detail in four technical and consultancy reports (Raupach et al. 1996, Raupach and Briggs 1996, Briggs et al. 1998, Raupach and Briggs 1998) and the overall results are presented in three journal papers (Raupach and Briggs 1999a, 1999b, Briggs et al. 1999). These publications contain full details of models and data which can only be described indicatively here.

Section 2 of this paper summarises the modelling framework. Section 3 presents model results for Pian Creek and the Namoi River in the Narrabri region. Section 4 describes a new analysis of observed riverine endosulfan concentrations which distinguish events due to airborne and waterborne transport. Management implications and conclusions are given in Section 5.

Overview of modelling framework

To provide an integrated assessment of endosulfan transport by the spray, vapour, dust and runoff pathways, it is necessary to combine two kinds of model: transport models to describe the *spread* of endosulfan from farm to river by each of these pathways, and a model of the physical and chemical processes contributing to the *fate* of the endosulfan in the river water. Both kinds of model are crucial, as the overall endosulfan concentration in a riverine water column is a result of the balance between input by transport through the various pathways, and removal by chemical degradation.

This balance is expressed by the mass conservation equation for endosulfan, which represents the rate of change of the endosulfan concentration $C(X,t)$ (at a downstream location X and time t) as the sum of terms describing three kinds of process: advection (inflow of water with a different concentration to that at X), fluxes through the boundaries of the water body arising from the various transport pathways, and sources or sinks due to chemical and physical transformations within the water body.

Advection is computed as the equation is solved, but the transformation and flux terms must each be specified separately.

Transformation terms

Terms are determined by the chemical degradation pathways and exchange processes for endosulfan in the environment. Endosulfan ($C_9H_6O_3Cl_6S$) exists as α and β isomers, occurring in the ratio 2:1 in the 'technical endosulfan' applied to cotton crops in spray form. Once in the natural environment, endosulfan is subject to several chemical and physical transformations: first, both the α and β isomers oxidise to endosulfan sulphate in the presence of biotic material, over a time scale which is highly variable but is typically several days if sufficient biotic material is present.

The α, β and sulphate forms are all of comparable toxicity. Second, the α and β isomers hydrolyse in water to endosulfan diol, which is much less toxic and can be regarded as a sink for endosulfan from the standpoint of toxicity. Third, endosulfan in aqueous solution is adsorbed onto and desorbed from sediment particles in a rapid, effectively instantaneous two-way physical process. Finally, endosulfan in aqueous solution is exchanged with the atmosphere, in another two-way physical process with a time scale of hours to days, depending on the water depth.

Flux terms arise from the four transport pathways under consideration.

1. *Spray Drift:* During a spraying operation, some spray drifts off-target and lands on downwind surfaces. The deposition can be expressed as a 'drift deposition fraction' f_{drift} of the intended deposition or dose over the target area. The fraction f_{drift} depends on the dispersive droplet motions, and thence on the meteorological conditions (wind speed and atmospheric stability) and the geometry of the spray (release height and area sprayed). It may be found using a model of spray dispersion and droplet deposition. The model used here is described fully in Raupach and Briggs (1996, 1999a). Typically, f_{drift} is around 0.03 at a distance of 500 m downwind of the sprayed field. At a typical spray dose of 0.72 kg-endosulfan ha $^{-1}$, this implies a total endosulfan deposition into the river from a single spray drift event of 2.18 x 10^{6} kg m^{-2}.

2. *Vapour Transport:* Volatilisation of endosulfan from the crop is a continuous process which eventually removes up to 70 % of the total endosulfan deposited during a spray. This vapour is dispersed by wind and may be deposited on downwind surfaces, including rivers. The deposition process is driven by the difference between the concentrations in air and water (weighted by the water-air partition coefficient A^s) and is therefore a bidirectional process: endosulfan dissolves from air into water when the air concentration (C_a) is high and revolatilises from water back to air when C_a is low. The period of downward air-to-water flux typically extends for a day or two after spraying.

We have modelled vapour transport with a physical model incorporating post-spray volatilisation of endosulfan from the crop, the dispersion of vapour by wind and turbulence, and the deposition of vapour to water surfaces; see Raupach et al. (1996) and Raupach and Briggs (1999a).

3. *Dust Transport:* The dust transport pathway operates by the windblown movement of endosulfan-bearing dust from a cotton farm into the riverine environment. Potential mechanisms for on-farm dust generation include dust uplift during wind erosion events, uplift by vehicular traffic on unpaved roads, and uplift by agricultural operations. The input of endosulfan to a river (or other downwind surface) from a single dust transport event is determined by the dust deposition and the mass fraction of endosulfan on the dust. Using measurements of these quantities by Leys et al. (1998), we have shown that dust transport is a negligible pathway, being two to three orders of magnitude less important than spray drift or vapour transport: see Raupach and Briggs (1996, 1999a) for details.

4. *Runoff:* The runoff pathway involves transport of endosulfan in water by overland or stream flow, either in dissolved or particle-bound forms. The behaviour of the runoff pathway is controlled by three major factors: runoff amount, runoff frequency and the concentrations of endosulfan in runoff water. The *amount* of local runoff is influenced by on-farm retention of water and local topography. Retention systems to recycle water from irrigation and rainfall are used on many NSW cotton farms. Overflows into local rivers occur only when runoff exceeds the capacity of on-farm storage. O'Brien (1996) estimated that 31 % of Upper Namoi growers and 3 % of Lower Namoi growers cannot contain 25 mm of rain on-farm. Local topography also causes a substantial fraction of runoff to flow away from the river on the Lower Namoi floodplain and similar systems, because of silt accumulation on floodplains over geological time periods.

To examine the *frequency* (as well as the amount) of runoff, a simple soil water balance model for a cotton field has been constructed using available daily rainfall and pan evaporation data. This shows that mean annual runoff is around 100 mm/yr in the lower Namoi Valley, occurring in only a few events per year (3 to 10 events, depending on the amount of on-farm water storage). Endosulfan *concentrations* can be as high as 50 mg L^{-1} in tailwater dams (M. Silburn and R. Connelly, personal communication), but values around 2 to 10 mg L^{-1} are more typical of concentrations measured during flood events in off-farm waterways and small creeks (Cooper 1996, Muschal and Cooper 1998).

The difference between these figures implies an attrition of endosulfan in overland flow, caused both by the affinity of dissolved endosulfan for soil particles as contaminated water flows over uncontaminated soil, and also by sedimentation of particulate loads lifted from cotton fields by water erosion.

A simple model for the runoff pathway can be developed from mass balance considerations, the parameters being the runoff dilution factor and the concentration in the flow entering the river (Raupach and Briggs 1998, 1999a, b).

Because of the infrequency of runoff, it is necessary to consider discrete runoff events, but unfortunately, it is not possible to determine the dilution factor and runoff concentrations predictively for individual events because of the diversity of flows in different events and the variable attrition of endosulfan concentrations in overland flows.

Instead, we choose illustrative parameter values for typical events which are compatible with available evidence. This is not a major problem because the main model outcomes for the runoff pathway concern the event *timing*. These outcomes are independent of the above parameters, which affect only the predicted event *magnitude*.

Model results

The modelling framework has been used to simulate the spatial and temporal behaviour of riverine endosulfan concentrations in two actual riverine environments where irrigated cotton is a major land use: Pian Creek and the Namoi River in the Lower Namoi Valley near Narrabri, NSW. The simulations are based on the following realistic (though somewhat simplified) representations of the environments and the transport pathways:

1. The model was set up to simulate a stretch of each river up to 100 km in length, over a period of 40 days in the spraying season (November to January).

2. On the basis of survey data from Peasley (1996), it is assumed that cotton is grown on 50 % of land in a strip extending 5 km on either side of each river, except in a buffer strip of width 500 m on either side of the river.

3. The airborne fluxes into the river from the spray, vapour and dust pathways are assumed to be a 'steady drizzle' which is continuous both in time and with distance X along the river. This assumption is based on the fact that airborne fluxes arise from numerous, frequent individual sources on either side of the river.

4. Fluxes for the spray, vapour, dust and runoff pathways are determined with the models outlined above.

5. The river is assumed to be clean at the start of the simulation, and to be clean upstream. Full details of the model and the parameter choices are given in Raupach and Briggs (1998, 1999a, b).

Figures 10.1. and 10.2. show (for the Namoi River and Pian Creek respectively) the variation of endosulfan concentration C with time t, at three downstream distances X (measured from the upstream end of the simulated region): X = 10 km, 40 km and 100 km. The large, sharp peak in C induced by the runoff event is evident at both X = 40 km (just downstream of the runoff entry point) and at X = 100 km.

The time delay between the two peaks is the time needed for the slug of contaminated water injected by the runoff event to travel the 60 km between the two points. The peak concentration is reduced during this journey by volatilisation and chemical sinks (mainly hydrolysis). The flow speed of the river is such that the contaminated water introduced by runoff flows out of the region within a short time, even for the slow-flowing Pian Creek.

The steady background concentrations in Figures 10.1. and 10.2. are the result of airborne transport pathways, which cause C to rise within a few days to an

Figure 10.1. Namoi River. Modelled variation over time of total riverine endosulfan concentration (solid) and $\alpha + \beta$ as a fraction of the total (dashed), integrating all transport pathways (spray + vapour + dust + runoff). Time traces are given for X = 10, 40, and 100 km downstream A major runoff input occurs on days 8 and 9 at X = 35km.

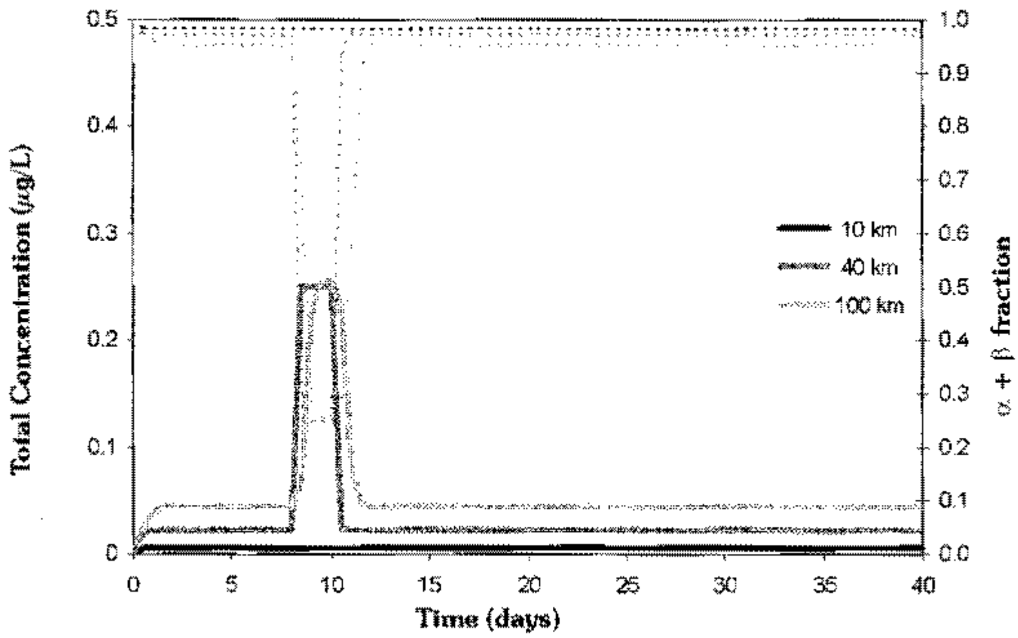
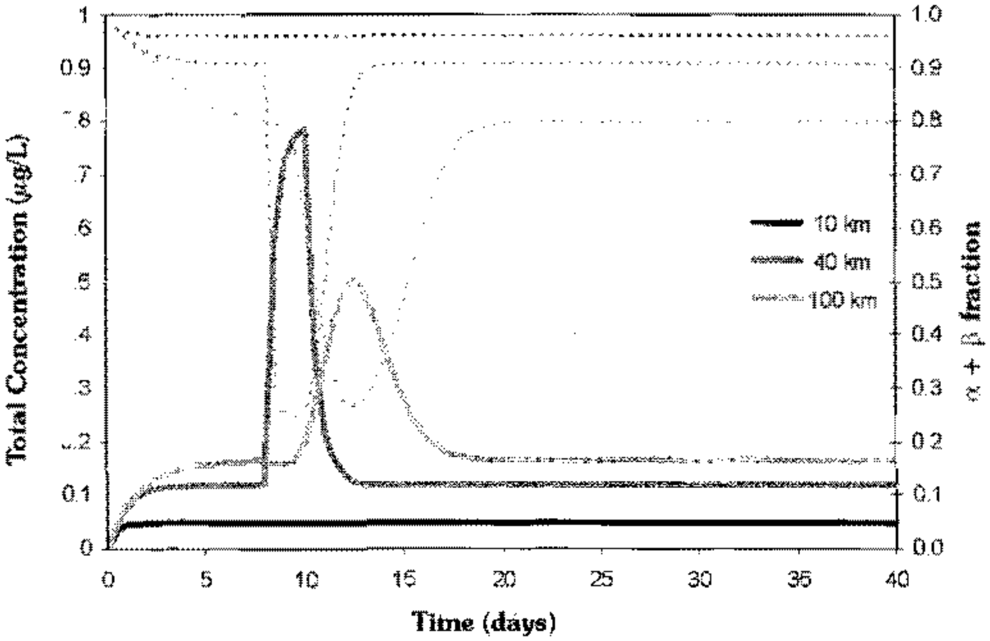


Figure 10.2. Pian Creek. Modelled variation over time of total riverine endosulfan concentration (solid) and $\alpha + \beta$ as a fraction of the total (dashed), integrating all transport pathways (spray + vapour + dust + runoff). Time traces are given for X = 10, 40, and 100 km downstream. A major runoff input occurs on days 8 and 9 at X = 35 km.



equilibrium level at which the inputs from airborne transport pathways are balanced by losses, mainly from volatilisation, hydrolysis and advection (downstream transport in the river).

The roles of different transport pathways are shown in Figures 10.3. and 10.4., respectively for the Namoi River and Pian Creek. These figures break the total concentration C (at X = 50 km) into contributions from spray drift, vapour transport, dust transport and runoff.

Figures 10.3.a (Namoi River) and 10.4.a (Pian Creek) show the breakdown at t = 10 days, just after the end of the runoff event; Figures 10.3.b and 10.4.b show the corresponding breakdown at t = 40 days, when the runoff event has long been flushed out of the domain and the only contributions to C are those from airborne transport routes.

It is evident that runoff is the dominant transport pathway on those infrequent occasions when a significant runoff event occurs. However, most of the time the situation is more like Figures 10.3.b and 10.4.b, where the entire riverine concentration is due to airborne transport. Of the three airborne pathways, dust transport is entirely negligible: its contribution is about three orders of magnitude smaller than the other pathways (as foreshadowed in the previous section). However, vapour transport and spray drift are *of the same order of magnitude*. The fact that spray drift is somewhat higher than vapour transport in these simulations is an accidental consequence of the particular parameters chosen for each pathway.

The important conclusion is that each is a significant contributor to riverine concentrations. Riverine endosulfan concentration data have been recorded by the NSW Department of Land and Water Conservation (NSW-DLWC) under its Central and North West Regions Water Quality Program (CNWRWQP); see Cooper (1996) and Muschal and Cooper (1998). The data for the Namoi River at Bugilbone and Pian Creek at Rossmore (stations representative of the conditions for present simulations) are consistent with the model predictions in two important respects.

First, the overall levels during the spraying season are observed to be about 0.05 μg L^{-1} (Namoi) and 0.1 μg L^{-1} (Pian Creek), values similar to the concentrations predicted in Figures 10.3. and 10.4. to arise from *airborne* fluxes.

Second, the observed concentrations have a regular, steady character through the spraying season (with some variability) rather than a spiky, intermittent character, consistent with airborne rather than waterborne transport being the major contributor to riverine endosulfan levels except when infrequent runoff events occur. When such events do occur, they are flushed from the local region within a few days.

Distinguishing airborne and waterborne transport events in data

To seek additional evidence concerning the relative contributions of airborne and waterborne transport to observed riverine endosulfan concentrations, we have undertaken a statistical analysis of the observations which is independent of the above modelling investigations. This analysis, reported in detail in Briggs et al. (1998, 1999), had two stages.

In the first, we identified concentration 'signatures', or typical patterns of concentration change following a transport event, for the various airborne and waterborne transport pathways.

Figure 10.3. For the Namoi River, modelled contributions to the total riverine endosulfan concentration at X = 50 km by each contributing transport pathway at (a) t = 10 days and (b) t = 40 days. Note that the contribution of dust transport is negligible.

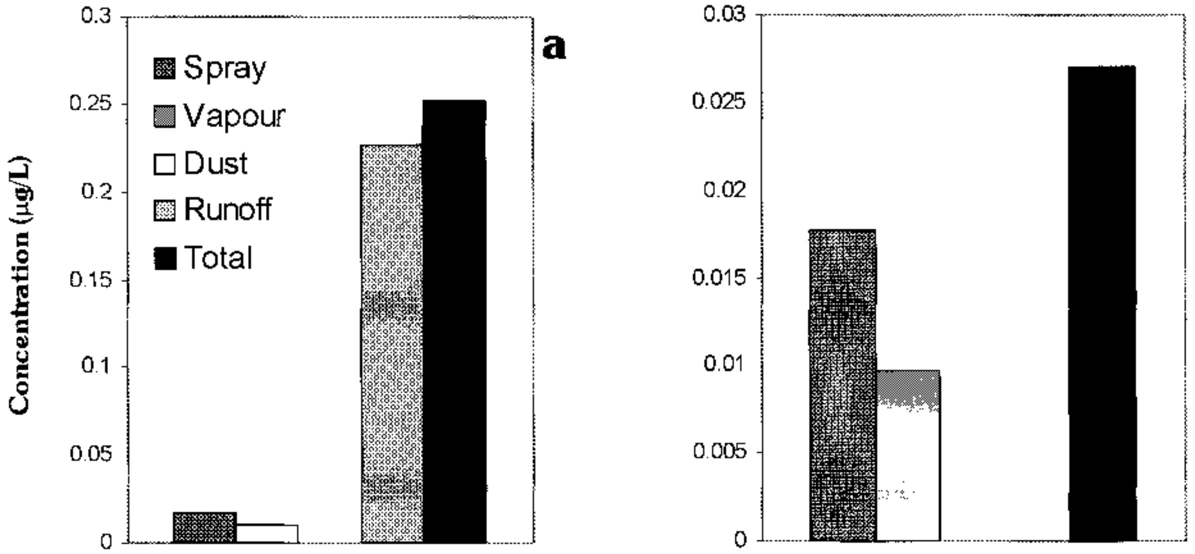
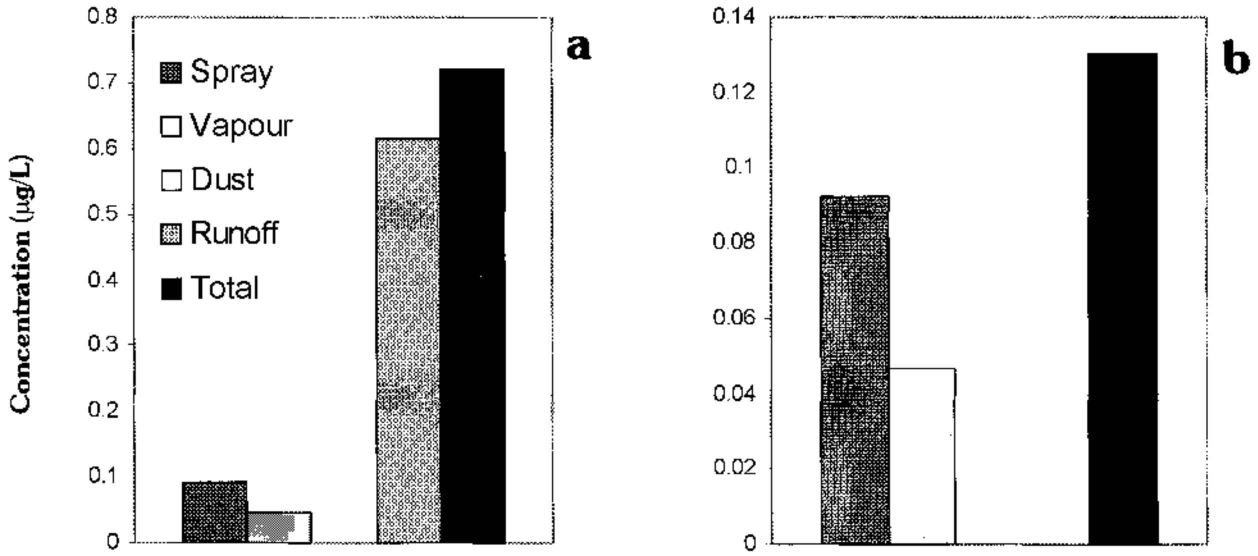


Figure 10.4. For Pian Creek, modelled contributions to the total riverine endosulfan concentration at X = 50 km by each contributing transport pathway at (a) t = 10 days and (b) t = 40 days. Note that the contribution of dust transport is negligible.



Properties of the concentration signatures were determined through physical reasoning, modelling and appeal to measurement. The most important of these properties are:

1. *species mix* (airborne pathways carry endosulfan α and β exclusively whereas waterborne pathways carry mainly, though not only, endosulfan sulphate); and

2. *timing* (waterborne transport can only occur after antecedent rainfall).

The second stage of the analysis was to devise and apply a method for associating observed riverine concentrations with transport pathways.

This was done by the following procedure:

1. Concentration peaks were identified in the CNWRWQP data for seven stations in the Namoi Valley, including Namoi River at Bugilbone and Pian Creek at Rossmore.

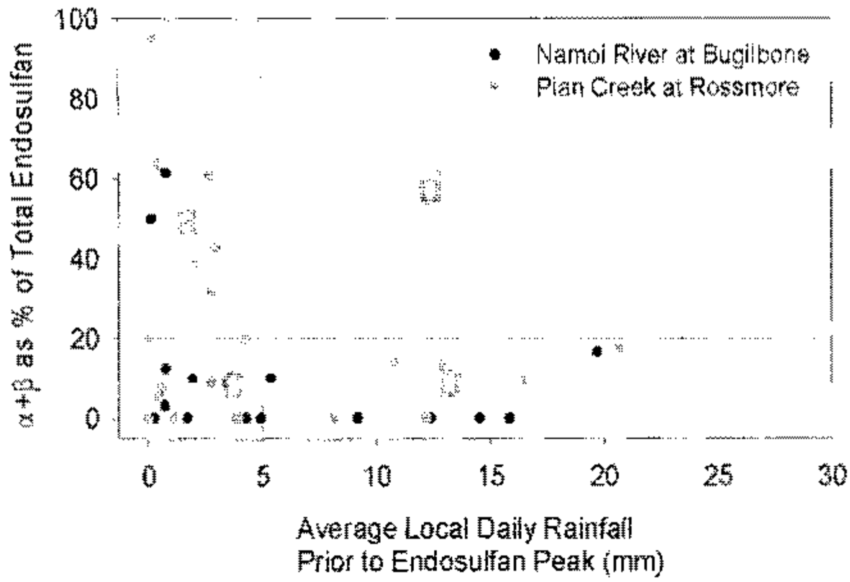
2. The fraction of endosulfan α and β in each peak concentration was identified.

3. For each peak, we determined the local antecedent rainfall in the period between the peak and the prior concentration measurement (usually one or two weeks), using Bureau of Meteorology rainfall records.

4. Using these properties, each peak was plotted on a plane in which the vertical axis is the fraction of endosulfan α and β in the peak concentration, and the horizontal axis is a measure of antecedent rainfall (either the mean or the maximum daily rainfall in the prior one to two weeks, depending on the concentration sampling interval). Figure 10.5. shows the resulting plot for the Namoi River at Bugilbone and Pian Creek at Rossmore.

The position of a point (corresponding to an observed concentration peak) on this plot provides two independent tests of its origin as an airborne or

Figure 10.5. For peak in-season endosulfan measurements, the fraction of $\alpha + \beta$ in the total riverine endosulfan plotted against the average antecedent rainfall over the interval (typically 7 or 14 days) prior to the peak. Regions suggesting probable transport mechanisms are shown in grey: (a) likely airborne transport; (b) likely waterborne transport; (c) indeterminate; (d) rare due to dominance of sulphate in waterborne transport.



waterborne transport event: the fraction of endosulfan α and β (a significant fraction is likely to be associated with a significant level of airborne transport) and amount of antecedent rainfall (a significant amount provides necessary conditions for waterborne transport).

It is observed in Figure 10.5. that points fall into two distinct regions: (a) events with high fractions of endosulfan α and β and little antecedent rainfall, and (b) events with low α and β fractions and high antecedent rainfall. Events in region (a) can be attributed primarily to airborne transport, and those in region (b) primarily to waterborne transport.

Some events occur in a third region (c) with low α and β fractions and low antecedent rainfall, arising from the continued presence of endosulfan sulphate with a long riverine residence time (such retention may be the result of entrapment in sediments or other slow-moving reservoirs, a feature not included in the model described above).

No events are observed in the fourth region (high α and β fractions and high antecedent rainfall). Studies of the magnitudes of the events in Figure 10.5. show that events in region (a) tend to be in the range 0.05 to 0.1 $\mu g\ L^{-1}$, which the model predicts to be typical for airborne transport.

Events in regions (b) and (c) tend to be smaller except for a few large peaks in region (b), a pattern consistent with the above findings for waterborne transport.

Conclusions and management implications

This work leads to four major conclusions about the relative roles of airborne pathways (spray, vapour and dust) and waterborne pathways (runoff) in transporting endosulfan from cotton farms to the riverine environment:

1. Runoff-pathway events are large and infrequent.

2. Airborne-pathway events are smaller in magnitude than runoff events but act quasi-continuously, resembling a 'steady drizzle'.

3. Of the airborne pathways, spray drift and vapour transport are of similar magnitude, but dust transport is negligible.

4. Most of the observed riverine endosulfan is transported by airborne routes, as the large but infrequent runoff-pathway events are flushed away rapidly.

These findings have significant implications for efforts to limit the transport of endosulfan into the riverine environment. First, and not surprisingly, they provide support for efforts to reduce spray drift and rain-induced runoff as laid down in current guidelines for Best Management Practice.

Secondly, and more controversially, they suggest that there is an irreducible minimum level of riverine contamination associated with vapour transport, of order 0.02 to 0.04 mg m^{-3} (depending on the size of the river and its proximity to sources). This cannot be significantly reduced with buffer strips or other practices used to reduce spray drift.

The only means of significantly reducing the component of endosulfan which reaches the river by vapour transport is to reduce the source, by reducing the use of sprays through techniques such as integrated pest management and the selective use of genetically modified cotton resistant to insect attack.

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11. Soil factors in the transport of pesticides from cotton farms: overview paper

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Introduction

Basic understanding of the processes involved is the key to the development of sound management practices for controlling the various mechanisms by which pesticides used in cotton production may be transported off-site from cotton farms and thus pose a hazard to the health of the surrounding ecosystem.

While off-farm movement of pesticides such as endosulfan through spray drift during application (Woods, 1998) and subsequent volatilization from plant leaves, water reservoirs etc. is generally amenable to rigorous control and attention to conditions at the time of application (Edge, 1998), the pesticide residues which find their way into the soil profile are subject to a wide range of varying physical, chemical and biological processes which can significantly complicate the management procedures necessary.

By sorption onto soil components, principally clay minerals and organic matter, and in some cases the production of toxic daughter compounds (eg. endosulfan sulphate), the persistence (half-lives) of the pesticides can be greatly enhanced and increase the potential for off-site movement.

Such movement can include wind erosion in the form of dust or run-off, either in solution or through water erosion of mobile sediments. More strongly adsorbed pesticides such as endosulfan and trifluralin generally pose little hazard in terms of their potential for leaching to groundwater but the mobility in the soil profile of the numerous other herbicides used in cotton production should not be overlooked. Because of the different physical and chemical properties of each pesticide and variable soil properties, the dominant mechanism for off-site transport can be expected to vary significantly.

Dust erosion appears to be a minor concern, largely limited to that from unsealed roads and should be relatively easily countered (Edge, 1998; Leys, 1998). However it is clear from other presentations at this conference (Silburn et al., 1998; Simpson et al., 1998 and Kennedy et al., 1998) that run-off and consequent soil loss can be substantial and will require careful ongoing research and remedial attention to reduce this source of off-farm contamination. Two critical factors in controlling water run-off and the extent of associated sediment transport, are the infiltration capacity of the soil profile relative to precipitation or irrigation rates, and the inherent erodibility of the soil surface.

Infiltration

Run-off will occur when the ability of the soil profile to absorb incident water(ie. the soil water storage capacity), is exceeded and this can occur under conditions described by hydrologists as either:

1. *Infiltration excess* - the rate of infiltration generally asymptotes to the saturated hydraulic conductivity of the soil with time due largely to the decreasing matric water potential gradient between the surface and the wetting front moving downwards. If the surface horizon has the lowest hydraulic conductivity, this will determine the maximum infiltration rate and when run-off occurs.
2. *Saturation excess* - if the sub-surface soil has a lower hydraulic conductivity the maximum infiltration will be determined by the storage capacity of the surface horizon.

Infiltration rate is not an intrinsic property for any given soil and can change significantly depending on surface condition (roughness, sealing etc.), plant coverage and soil management practices. It is subject to considerable spatial and temporal variability and seasonal conditions. Understanding the site specific hydrological characteristics of the whole soil profile is thus an essential prerequisite to the planning of irrigation strategies and successful water management on the farm.

Erodibility

Erodibility has been defined in terms of what is known as the *Universal Soil Loss Equation* (Wischmeier and Smith, 1978) written in the form:

$$A = R.K.LS.P.C$$

where R is a *Rainfall Erosion Index* related to the intensity and length of precipitation events; K is the *Soil Erodibility Factor* depending primarily on the texture, organic matter content, structural stability and hydraulic conductivity of the soil; L and S are respectively the *Slope Length* and *Gradient Factors* ; C is the *Crop Management Factor* identifying the effects of specific cropping practices on the susceptibility of the soil to erode and P the *Erosion Control Practice Factor*, indicates the fractional amount of erosion that occurs with special conservation practices (eg. contour tillage) as compared to what it would be without them (ie. worst case). See also the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1983) incorporating recent improvements.

Soil losses reported for some farms are clearly substantial and unacceptable (Silburn et al., 1998) leading to unwanted consequences such as pesticide export and the need for frequent de-silting of drains. Addressing the above variables can substantially reduce the susceptibility of the surface soil to removal by the action of wind and water. For example, reducing the slope of irrigation furrows from 1.2 % to 0.8 % was observed to reduce the export of the pesticides triflurin by up to 90 % (Simpson et al., 1998) and soil protection under cover of plant residues and improved soil structural stability under minimum tillage or by artificial means, could be expected to significantly reduce sediment loads (Silburn et al., 1998).

Soil structure

Of fundamental importance to both infiltration and erodibility are the structural status and stability of the surface soil. This in turn will be determined by a range of factors including its composition and management history. Good soil structure is most generally provided by soils containing appreciable amounts of fine particles (ie. high surface area clays) combined into small crumbs or aggregates which are stable to wetting and drying processes. Stability is usually derived from a combination of favourable surface properties (exchangeable cations) and binding by organic matter or cementing materials such as iron and aluminium oxides. Soil degradation and susceptibility to erosion occurs as a result of mechanical trauma (tillage and traffic) and the disruptive forces associated with wetting. Structural breakdown almost inevitably leads to problems of poor permeability and hard-setting behaviour.

The disruption of structure which occurs on wetting arises from two mechanisms: (1) dispersion - caused by double layer swelling forces (Quirk, 1994) and characterized by the detachment of clay-sized particles; and (2) slaking or non-dispersive failure where larger compound particles are broken down by rapid wetting but clay dispersion does not necessarily occur (Cochrane and Aylmore, 1991).

Numerous methods have been proposed for assessing the dispersive and slaking behaviour of soils. The most widely adopted quantitative tests measure clay dispersion in soil/water suspension and water-stable aggregation by wet sieving with many variants being suggested for each method (Williams et al., 1966; Rengasamy et al., 1984). Where such behaviour is evident remedial practices aimed at modifying the surface physicochemical characteristics of the soil clay particles are required.

Non-dispersive failure on the other hand results from a combination of differential swelling forces and explosive compression of entrapped air (surface tension forces) associated with rapid wetting. Since this can occur in the absence of dispersion alternative methods are required for quantitative assessment of its significance and control particularly in hard-setting and apedal soils (Aylmore and Sills, 1982; Cochrane and Aylmore, 1991). The relative roles played by these mechanisms influence the choice of management strategy best suited to reducing soil structural instability.

The susceptibility of the soil to the previous forces can vary dramatically between different soil types depending on the surface physicochemical characteristics of the soil components and their interdependence. Consequently management practices need to be tailored to the particular structure forming characteristics of individual soils. It is equally important to recognise the contribution of the structural properties of the total soil profile since these can greatly influence soil water infiltration, redistribution and storage.

Mineralogy

Identification of the mineralogical composition of the soil provides an immediate clue to its likely physical behaviour. The presence of smectite, a high specific surface area, finely divided layer-lattice aluminosilicate clay mineral common to Vertisol soils, may indicate a potentially high swelling soil particularly prone to dispersion under specific conditions. Depending on the prevailing surface physicochemical characteristics such clays can exhibit either desirable attributes such as self-mulching or undesirable features such as poor permeability.

Red brown earths on the other hand, dominated by illitic and kaolinitic clay minerals are less strongly hydrated and generally more stable than the grey and black cracking clays common on many cotton farms. All clay soils are however potentially dispersive under favourable conditions associated with their surface physico-chemical characteristics (evidenced by hard-setting of some red-brown soils) and it is important for farmers to recognize the specific features of their soil.

Exchangeable cations and total dissolved salts

Basic determinants of the physicochemical behaviour of a soil are the magnitude of the cation exchange capacity balacing the negative charge on the crystalline clay minerals (derived from isomorphous substitution of ions within the clay lattice), the nature of the exchangeable cations themselves (whether monovalent or polyvalent) and the electrolyte (solute) concentration in the soil solution. If the exchange complex contains a significant proportion of monovalent cations such as sodium and the soil solution is relatively dilute (ie. high quality water with low total dissolved salts) strong osmotic imbibition of water can occur leading to swelling, the disruption of any aggregate structure and ultimately dispersion. Sodic soils are variously defined as soils with exchangeable sodium percentage (ESP) greater than 15 (USA; Richards, 1954) or 6 (Australia; Northcote and Skene, 1972) depending largely on the quality of the irrigation water. Susceptibility to structural failure on wetting can occur even at lower ESPs and may require ameliorative procedures.

While the use of artificial soil stabilizers such as polyacrylamide (PAM) or PVA can effectively prevent these consequences, application can be expensive and these chemicals may themselves pose health hazards. The traditional agricultural use of gypsum (hydrated calcium sulphate) added to the soil or irrigation water (Davidson and Quirk, 1961) to improve the physical structure and hence productivity, warrants attention in relation to potential sediment and associated pesticide transport even on non-sodic soils. Gypsum is only sparingly soluble (<2 g/L) but the electrolyte effect is sufficient to compress the ionic distribution associated with the clay surfaces (diffuse double layer) thus reducing swelling and dispersion. The long-term stabilisation of the surface soil is best achieved by combining gypsum treatment with management practices designed to enhance the soil organic matter content (ie. reduced or zero tillage).

Crop residues

The susceptibility of farm soils to soil loss is demonstrably greatest early in the season with bare soils exposed to erosive forces. The benefits of stubble retention to protect the soil surface from wind erosion, raindrop impact and water erosion are self evident. One or two tonnes per hectare of crop residue can usually reduce the erosion of even highly erosive soils to a negligible or at least acceptable factor.

While cotton cropping generally results in insufficient residue to provide adequate cover for erosion control (Simpson et al., 1998) rotation with wheat crops appears a profitable and effective approach. To be most effective plant residue cover should remain anchored to the soil since root systems can both help to bind the soil and to enhance infiltration.

Leaching to groundwater

The pesticide of major interest in the recent program has been the insecticide endosulfan which because of its strong retention by the soil can generally be considered essentially immobile in the soil profile. However the possibility, in vulnerable circumstances, of leaching to groundwater of other potentially more mobile pesticides used such as the herbicides fluometuron, diuron, prometryn and trifluralin should not be overlooked. Whether a pesticide persists for a long time or is rapidly degraded or transformed in soil is a major determinant of the extent to which it can pose a pollution hazard.

Organic matter provides not only a major substrate for pesticide retention but determines the degree of microbial activity and hence the degradation rate. Literature values for the sorption coefficients (k_{oc}) and half-lives ($t_{1/2}$) for most pesticides commonly vary substantially between various authors indicating that not only the content but also the nature of the organic matter present is important (Singh et al., 1989). In addition other factors such as the presence of competition for sorption sites by other chemicals present, preferred flow paths derived from plant root channels, clay cracking or soil water repellency, and passenger transport of pesticides on soluble organic and other colloidal materials may require evaluation in terms of their influence on mobility.

Modelling

The literature contains a multiplicity of predictive models for chemical and particulate transport varying greatly in terms of their complexity and claimed applicability. Such models are best used in combination with experimental data to identify the relative contributions of the different pathways for off-farm transport (eg. Raupach, 1998). However the complexity attendant on the multiplicity of factors operating in the field is likely to make the more comprehensive mechanistic models somewhat cumbersome and restrictive in user-friendly terms.

As such their use is principally of value to researchers in providing insights into the relative effectiveness of individual management procedures eg. GLEAMS (Connolly, 1998). Farmers themselves are likely to be more comfortable with, and in daily practice, make use of simpler assessment models such as PIRI (Kookana, 1998) or scaling models directed to individual aspects of the potential transport processes and requiring only limited data input eg. PESTCSRN (Aylmore and Di, 1998).

There is a need to define the degree of complexity with which fundamental processes need to be treated in such models and the extent of characterization of the range of physical, chemical and biological mechanisms required to avoid problems of site specificity and to provide a satisfactory data base for predictive modelling.

Conclusions

The outcomes from the present extensive program of policy and research, presented at this meeting, has provided a sound basis for defining Best Management Practice for cotton farming. However ongoing research is necessary for continued development and refinement of the template provided.

The basic principles of successful soil and water conservation are now very well defined (see for example the recent *Soil Guide - A handbook for understanding and managing agricultural soils* Ed. Geoff Moore, Agriculture Western Australia) but evaluation of site specific parameters remains an essential prerequisite to their successful implementation.

Continued collaboration between scientists, policy makers, regulators, extension workers and individual farmers, as demonstrated at this workshop, in the evaluation of soil characteristics and their management requirements, will help to ensure the continued sustainability of the cotton industry and community confidence in its environmental safety.

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12. Laboratory ecotoxicology studies and implications for key pesticides

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Abstract

Laboratory toxicity data are presented on the pesticides endosulfan and profenofos and discussed, in the light of current field data, to give a clearer picture of the potential impact of these chemicals on the riverine environment. Laboratory studies indicate that turbid waters do not significantly ameliorate the toxicity of endosulfan. High temperatures may increase the short-term acute toxicity of endosulfan to fish by around twofold. Toxicity of endosulfan (24 h) to silver perch **Bidyanus bidyanus** ***caged in ponds sprayed with endosulfan was similar to that found in the laboratory. Plant material and, to a lesser extent, higher pH, increased the degradation rate of endosulfan.***

Levels of profenofos in some lagoons and creeks in the cotton growing areas around Wee Waa during the spraying season were sufficient to inhibit acetylcholinesterase (AChE) enzyme activity in fish and may be toxic to invertebrates. Recovery of AChE is slow and reduced AChE levels over prolonged periods may inhibit long-term survival of some populations. This may become more significant if use of organophosphorus pesticides increases. More data are required on profenofos to derive water quality guidelines.

Introduction

Laboratory ecotoxicology data, despite their limitations, form an important basis for determining the potential effects of chemicals on the environment. Some of the values of laboratory testing include: deriving and assessing water quality criteria; screening and ranking of the toxicity of chemicals; predicting hazard or risk of chemicals to the environment; establishing overall biological response to complex mixtures; determining cause - effect relationships; and establishing and 'calibrating' field bioindicators (Chapman 1995).

The LWRRDC/CRDC/MDBC program focussed on three pesticides, endosulfan, pyrethroids and profenofos, representing the major groups of chemicals in the pest management strategy. This paper will focus on endosulfan and profenofos. The program included laboratory studies to support concurrent field studies and provide a clearer picture of the potential impact of these chemicals on the riverine environment.

Methods

Most of the data reported in this paper have been, or are being, published elsewhere. Fish toxicity data were derived according to Sunderam et al. (1992) and cladoceran figures, according to Sunderam et al. (1994). Data on effects of temperature on toxicity were derived according to Patra et al. (1995a-c; 1996). Profenofos data were derived according to Abdullah et al. (1994) and Kumar (1995).

Results and discussion

Laboratory toxicity of endosulfan

Toxicity of endosulfan to Australian native fish was within the high toxicity range reported for overseas species (Sunderam et al. 1992). The most sensitive native species was bony bream *Nematolosa erebi* (96h LC50 of 0.2 µg/L) and these data contributed to the previous ANZECC (1992) guideline figures for endosulfan. Patra et al. (1996) repeated previous nominal tests on the Australian cladoceran *Ceriodaphnia dubia* at 20°C and found that the nominal 48-h LC50 figure (254 µg/L) significantly underestimated the measured toxicity (44 µg/L).

Similarly, the measured No-observed effect concentration (NOEC; 3.3 µg/L) and Lowest-observed effect concentration (LOEC; 15.9 µg/L) figures for chronic reproductive impairment of *C. dubia* over seven to ten days were two to three times lower than nominal at 20°C. However, measured acute-to-chronic ratios were lower (3-11) than the ratio (50) derived by Sunderam et al. (1994) from nominal figures.

Few fish chronic data on endosulfan are reported in the literature, preventing calculation of water quality guidelines using chronic data. Sub-lethal tests on early life-stages of Australian gudgeons *Mogurnda adspersa* and rainbowfish *Melanotaenia duboulayi* are currently being standardised using reference toxicants. Preliminary tests had indicated effects on survival, growth and spinal deformities in the ng/L range (Kumar & Chapman 1997a).

However, repeated tests produced values much closer to the toxicity levels obtained with juveniles. The 72-h LC50 values for two and four-week-old rainbowfish were between 0.1 and 1 µg/L, while the NOEC figure for one-week-old gudgeons was 5 µg/L (Hyne, pers. comm).

Laboratory toxicity of the organophosphorus pesticide, profenofos

At the start of this project there were no Australian data on profenofos; 96-h LC50 values to three overseas fish varied from 80 to 300 µg/L (Tomlin 1994). Organophosphorus (OP) pesticides inhibit the activity of the acetylcholinesterase (AChE) enzyme, which may eventually result in death. Measurement of AChE inhibition compared to controls is used as a biochemical indicator of exposure to OPs.

The rainbowfish *M. duboulayi* was an order of magnitude less sensitive to profenofos than crucian carp *Carassius carassius*. Exposure to 0.9 mg/L for 96-h (around the LC50) corresponded with an 83 % reduction in AChE activity in survivors.

Rainbowfish exposed to acutely toxic concentrations of profenofos showed higher lethal body burdens, but lesser AChE inhibition, than those immobilised by longer, normally sublethal, exposures. This is consistent with profenofos being slowly biotransformed to a more toxic metabolite. Profenofos rapidly accumulated in rainbowfish exposed to 50 µg/L, reaching 9.6 mg/kg after 96 hours, corresponding with 56 % AChE inhibition.

Residues in fish reduced rapidly (half-life of 70-h) after fish were transferred to clean water. However, the AChE activity recovered only slowly and sporadically, and was still inhibited by 39 % after seven days. Sublethal exposure to profenofos caused similar AChE inhibition and a similar pattern of AChE recovery in carp *Cyprinus carpio* (Kumar 1995) and freshwater shrimp *Paratya australiensis* (Abdullah et al. 1994), although shrimp were much more sensitive. In general, the recovery of all species from profenofos exposure was dependent on the duration of exposure, residues in fish tissues, amount of AChE depression and frequency of repeat pulses.

The question remains, what is the biological significance of these reduced AChE levels? Rainbowfish exposed to 10 mg/L for ten days accumulated profenofos residues of 5.3 mg/kg, associated with a 70 % reduction in AChE activity. Food intake, food conversion efficiency and growth significantly decreased at 10 d, and fish had lost weight at 21 d. These effects were associated with markedly increased swimming activity and response to light. A clear relationship was demonstrated between the depression of AChE activity and these behavioural responses observed in fish (Kumar & Chapman 1998).

Similarly, a 75 % reduction in feeding rate of carp resulted from 28 d exposure to 5 µg/L, associated with AChE inhibition by up to 71 % and 3.2 mg/kg residues in liver. Recovery for 7 d allowed rapid elimination of profenofos from residues but, again, AChE activity (53 % inhibition) and feeding rate remained low (Kumar 1995). AChE inhibition of only 28 % in *Paratya* corresponded with a significant inhibition of chemoreceptor behaviour, an indicator of ability to capture prey, after only 24-h exposure to 50 µg/L (Kumar & Chapman 1997b).

Exposing carp to three successive pulses (24-h duration) of profenofos (50 µg/L) at 7-d intervals simulated potential worst-case field conditions. The effect was partly cumulative with increased AChE depression, by 37 %, 51 % and 71 %, after each successive pulse, and only partial recovery in between. AChE activity was still inhibited by 30 % after 21-d recovery (Kumar 1995). The concentrations that caused similar effects in *Paratya* were much lower.

When *Paratya* were exposed to three pulses (24-h duration) of 0.1 µg/L at 7-d and 0.5 µg/L at 4-d intervals, the pattern of inhibition and recovery was very similar (Abdullah *et al.*1994). Some shrimp died by the third pulse at the higher exposure. Frequent OP exposure affects the ability of organisms to recover their AChE activity due to incomplete elimination of residues from their bodies. The fish exposure levels would not normally be encountered in the field but concentrations similar to those affecting shrimp have been measured (see below).

Derivation of Australian water quality guidelines for profenofos requires a minimum data set, preferably chronic data with at least five species from different taxonomic groups (Warne 1997). These data are being gathered for profenofos but are currently incomplete. Profenofos was only moderately toxic to the alga *Selenastrum capricornutum* with a 72-h EC50 for growth of 2.9 mg/L (Stauber et al. 1996). Initial fish ELS tests (Kumar and Chapman 1997b) showed growth and survival effects in the low µg/L range. However, repeated tests under standardised conditions, produced a 14-d LC50 value of approximately 200 mg/L for gudgeons *Mogurnda adspersa* (Patra, pers. comm). Fish are less sensitive to profenofos than invertebrates and more invertebrate data are needed to derive guidelines.

Effects of water quality paramaters on toxicity

Arguably, two of the most significant water quality parameters that could affect pesticide toxicity are temperature and suspended solids. Water temperatures in some parts of the north west region can reach 35°C while turbidity in the inland rivers is usually high. Laboratory studies under controlled conditions enable the effects of these parameters on chemical toxicity to be evaluated. It is not always possible, even under controlled conditions, to clearly distinguish the effects of these parameters on fate and transport of the chemical from effects on the intrinsic toxicity to the organism.

Increases in temperature caused little change in endosulfan toxicity to silver perch *Bidyanus bidyanus* over 96 hours but there was two-fold increase in short-term (24-h) toxicity as temperature increased from 15°C to 35°C (Patra et al. 1995a). Most of this increase in toxicity occurred between 25 and 30°C. Critical thermal maximum (CTM) tests supported these conclusions; after exposure of four fish species to sublethal concentrations of endosulfan (0.3-1 μg/L) for 15 days, their CTM temperatures were significantly reduced by around 3°C, compared to controls (Patra et al. 1995b).

Increased test temperatures markedly increased the toxicity of endosulfan to the cladoceran *C. dubia* (Patra et al. 1996); the measured LC50 value decreased from 166 μg/L at 15°C (nominal, 353 μg/L) to 2.4 μg/L at 30°C (nominal, 33 μg/L), a 70-fold increase in toxicity. The increase in measured acute toxicity was 18-fold from 20 to 30°C and 12-fold from 25 to 30°C. The temperature effects on *Paratya* were less marked; the 96-h LC50 at 20°C (13.3 μg/L) decreased by only 25 % at 30°C (Sunderam 1990). Chronic toxicity (reproductive impairment) of endosulfan to *C. dubia* also increased with an increase in temperature. At 30°C the measured NOEC was 0.1 μg/L (30-fold lower than at 20°C and ten-fold from 25°C) and LOEC was 0.6 μg/L (26-fold lower than at 20°C and three-fold from 25°C) (Patra et al. 1996).

Although suspended clay particles reduced the toxicity of endosulfan to fish in the laboratory (Sunderam 1990), there was no difference in toxicity of endosulfan to three species in turbid Mehi River water from that in Sydney mains water (Sunderam et al. 1992). Leigh et al. (1997) found that suspended sediment did not ameliorate endosulfan toxicity to rainbowfish *M. duboulayi* at normal turbidities (1.4 g/L). Toxicity was only reduced (by around 75 %) when the sediment load was very high (52 g/L), leading to suspended and bottom sediment.

Laboratory toxicity tests of endosulfan-spiked sediment with nymphs of the mayfly *Jappa kutera* gave a NOEC of 42 ppb and a LOEC of 76 ppb (wet weight) (Leonard et al. in preparation). The NOEC is around the highest field sediment concentration that they measured, so direct toxicity from sediments is not likely in rivers.

However, the sediment may be acting as a source of endosulfan in the water column. During the 10-d sediment toxicity test, sediment concentrations of α-endosulfan declined and concentrations of the sulfate increased. At ten days, there were significant linear regressions of total endosulfan in the bottom sediment with concentrations of both total endosulfan and sulfate in the water column.

The sediment NOEC and LOEC values corresponded to total endosulfan concentrations in the water column of 0.13 ppb and 0.18 ppb, respectively. Pulse water-only exposures of *J. kutera* separately to technical grade endosulfan, the a-isomer and endosulfan sulfate in Namoi River water gave similar 96-hour LOEC values of 0.3 ppb, while ß-endosulfan gave a LOEC value of 0.9 ppb. Changes in the composition of endosulfan compounds measured in sediments and *in situ* passive samplers placed in the Namoi River adjacent to cotton fields indicated that a-endosulfan and the sulfate were the most mobile endosulfan compounds during field run-off events.

There are no data on the effect of temperature and turbidity on profenofos toxicity. It is probable that temperature-toxicity relationships determined for chlorpyrifos (Patra et al. 1995a, b; 1996) are similar. There was a 3.7-fold increase in acute toxicity of chlorpyrifos to silver perch *B. bidyanus* between 15°C and 35°C, although the biggest change (2-fold) was between 15°C and 20°C. Similar results were found for *C. dubia*. The difference in chronic toxicity (reproductive impairment) for *C. dubia* between 20°C and 30°C was greater, between 3 and 30-fold, depending on the endpoint.

Relationship of laboratory results to field effects
Bowmer et al. (1995) outlined some of the reasons why laboratory data that indicated high endosulfan toxicity did not always seem to accord with some field observations. These included biological factors in field (eg. avoidance) or laboratory (eg. differences in acclimation, species and test conditions), exposure factors, sampling and design factors as well as the problems of unsupported observations in the field.

An additional exposure factor may arise from comparing results of 96-h tests with short-term pulse exposures in the field while some species of field organisms found in tailwater drains may have developed levels of resistance to endosulfan not encountered in rivers.

Endosulfan effects under field conditions

Hyne et al. (1998) reported that the main predictor of changes in abundances of selected benthic mayfly and caddisfly taxa in the Namoi River was endosulfan that entered the river, predominantly from field run-off during storms. This is consistent with earlier findings that endosulfan residues found in the livers of in three species of fish caught from waterways in the cotton area increased during a wetter summer (1988; Nowak and Julli 1991). However, despite some low residues being found in winter, endosulfan was not being bioaccumulated from one season to the next.

Four large earth ponds in Narrandera were sprayed with endosulfan in January 1994 and responses of caged silver perch *Bidyanus bidyanus* (cages changed every 24 hours) were compared with those in two control ponds (Patra et al. 1995c). High endosulfan concentrations in the first six hours (11-27 μg/L measured) rapidly declined to 1.5 - 2.5 μg/L by 96 h in three ponds. In the fourth pond (#18) which had lower pH and less aquatic plant life, endosulfan levels remained at 7 μg/L at 96 h and took 14 days to drop below 2 μg/L.

There was no clear relationship of endosulfan degradation to turbidity. Furthermore, degradation rates in the ponds were much faster than those calculated on the basis of pH-mediated hydrolysis (from Peterson & Batley 1991). Endosulfan levels after filtration through 0.45 μm filters remained at around 50-75 % (range 36-89 %) of the unfiltered figures, with no noticeable decrease in percentage with time.

All fish died in the treated ponds within six hours and mortality in three ponds remained at 100 % by 48 hours (only 10 % in one pond #19). By 96-h, mortality (over 24-h) in three ponds was around 4 % and reached zero at 6 d. In the fourth pond (#18) mortality remained at 100 % until the tenth day, then it decreased slowly to 13 % by d-14 and zero by d-17.

The slower reduction in fish mortalities in pond #18 was consistent with the slower dissipation of endosulfan in this pond. Pond LC50 values (24-h) for endosulfan to silver perch were between 3.2 and 4.4 μg/L for unfiltered water and 1.9 - 3.8 μg/L for filtered water. Unfiltered values were similar to the 24 h figure of 2.7 $\pm$ 0.4 μg/L determined in the laboratory under flow-through conditions. Zero mortality (24 h NOEC) was generally achieved when the unfiltered endosulfan levels declined to around 1.5 - 1.8 μg/L.

Profenofos residues and AChE effects in wild fish from the cotton growing area

Carp (*C. carpio*), bony bream (*Nematolosa erebi*) and mosquitofish (*Gambusia holbrooki*) were collected from lagoons and creeks in the cotton growing areas around Wee Waa (Kumar 1995). Profenofos concentrations in water, sediment and fish tissue were generally correlated, and reflected its general level of use.

Water concentrations in March 1994 (1.1 - 3.7 μg/L) were significantly higher than in 1993 and generally decreased in May, six weeks after cessation of spraying. Up to 5.4 μg/L was found in Myall Vale canal after overnight spraying of nearby fields. By May, profenofos could not be detected in lagoons and Galathera Creek, but in Kerribee Lagoon and Gunidgera Creek (1.1 - 1.2 μg/L) were 30-42 % of March levels.

The lagoon was in close vicinity to cotton fields and received tailwater and the creek had ceased flowing due to drought. This persistence did not accord with the expected hydrolytic degradation. Profenofos may be binding to soil and sediments, to be subsequently released to the water column and in turn, to fish. Profenofos levels in sediment were higher in March (0.4 - 0.7 mg/kg in most sites) than in May (0.02 - 0.3 mg/kg).

During the spraying season, elevated residues of profenofos in many of the fish from lagoons and creeks confirmed that they were exposed to high sublethal levels of this pesticide.

The liver was the main target organ, related to its high lipid content. Residues in bony bream from Kerribee Lagoon in March 1994 were high, around 3.0 mg/kg in liver. At most sites in May, residues had reduced to ≤50 % of those in March. In contrast, profenofos persisted in the livers of bony bream from Kerribee Lagoon and were 83 % of levels in March. Mosquitofish from lagoons and canals contained the highest residues; up to 10.7 mg/kg in gravid females in March and 7.6 mg/kg in May.

AChE activity was significantly depressed in all fish species collected from the exposed sites in comparison to the fish from reference sites. For instance, AChE levels in fish from the more exposed Kerribee Lagoon were only 45 % of those from the reference site in March and even lower in May. The degree of recovery of AChE activity varied at each site but, at 5/6 sites, remained below the levels at reference sites six weeks after spraying. Bony bream and gravid female mosquitofish recovered AChE levels more slowly than carp or non-gravid mosquitofish. AChE inhibition was a useful indicator of profenofos exposure within a season, if linked with residue measurements.

Conclusions

Laboratory data provided useful information on the potential effects of the pesticides endosulfan and profenofos on the environment, particularly in conjunction with field data. Endosulfan was highly toxic to Australian fish (96-h LC50, 0.2-2.5 μg/L), but this was within the range reported for overseas fish. Early life-stages (ELS) of rainbowfish *Melanotaenia duboulayi* were only a little more sensitive than juveniles but ELS of gudgeons *Mogurnda adspersa* were less sensitive than juveniles of most other species. Hence it is likely that chronic toxicity of endosulfan to fish occur at concentrations only slightly lower than those that cause acute toxicity.

Cladocerans were less sensitive to endosulfan than fish but previous nominal figures significantly underestimated the measured toxicities to Australian *C. dubia* and over estimated the acute-to-chronic ratios, which are often used to derive water quality criteria. There are still insufficient chronic data to derive water quality guidelines for endosulfan using an Australian chronic data set.

If water quality guidelines are to be modified to account for site-specific factors in rivers in the north-west, the main water quality parameters that could conceivably affect toxicity are turbidity and temperature. Laboratory tests indicated that normal levels of suspended sediment did not ameliorate the acute toxicity of endosulfan to *M. duboulayi*. Endosulfan adsorbed to sediments appeared to readily desorb and become bioavailable.

Furthermore, turbidity did not seem to modify endosulfan toxicity in ponds. Pond LC50 figures were similar to the 24-h laboratory LC50 figures.

Endosulfan generally degraded more rapidly in the ponds containing water with higher pH and containing more plant material. Higher temperatures, however, were significant in increasing short-term acute toxicity to fish by a factor of 2 between 15 and 35°C and acute toxicity to cladocerans by up to 18-fold over a smaller range (20-30°C).

The toxicity data on profenofos are the first on Australian species. Rainbowfish *M. duboulayi* were an order of magnitude less sensitive than some overseas species to profenofos but the shrimp *Paratya australiensis* was affected at low μg/L levels which were commonly measured in the field. Sublethal exposure of fish to profenofos for long term periods resulted in greater AChE inhibition than short-term acute exposures, even though the acute exposures resulted in higher residues.

When fish were transferred to clean water, AChE levels recovered more slowly than expected from the rate of loss of residues. Hence AChE inhibition was a useful indicator of profenofos exposure if linked with evidence of exposure. The recovery of all species was dependent on the duration of exposure, profenofos residues in fish tissues, degree of AChE inhibition and frequency of repeat pulses. Good correlations were found between residues and AChE levels in laboratory tests and also in wild bony bream collected after exposure in the field.

AChE inhibition of around 70 % resulted in behavioural effects in fish that would be expected to be ecologically significant. However, the exposures required to produce these levels of inhibition would not be expected in the field. Levels of inhibition in shrimp as low as 28 % appeared to significantly affect chemoreceptor behaviour, an indication of the ability to capture prey.

More work is required to confirm the ecological significance of different degrees of AChE depression. Concentrations of profenofos that significantly affected shrimp in the laboratory have been measured in the field in the spraying season and for up to six weeks afterwards. Repeat spraying with any OP may have partially cumulative effects, particularly given the slow recovery of AChE. Again, more chronic data are needed to allow derivation of water quality guidelines for profenofos.

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13. Relationship between endosulfan concentrations and macroinvertebrate densities in the Namoi river over two cotton growing seasons

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Abstract

The toxicity of the pesticide, endosulfan, in the presence of suspended and bottom sediment, was investigated in a field and laboratory study. The field survey investigated the relationship of changes in the population densities of six dominant macroinvertebrate taxa (ephemeropteran nymphs **Jappa kutera, Atalophlebia australis, Tasmanocoenis sp., Baetis** ***sp. and the trichopteran larvae*** **Cheumatopsyche** ***sp. and*** **Ecnomus** ***sp.) to endosulfan concentrations in the Namoi River. The survey was conducted before, during and after (October to March) the spraying of endosulfan on cotton crops in 1995/96 and 1997/98 seasons.***

Eight sites in 1995/96 and seventeen sites in 1997/98 were surveyed in riffle-pool habitats upstream and downstream of the cotton-growing areas in the Namoi River. In November 1995 and November 1997 before pesticide spraying commenced, the population densities of the study taxa were similar at all sites. Throughout both seasons, the monthly mean total endosulfan concentrations at the reference sites were less than 50 ppb in solvent-filled polyethylene bags.

Population densities of the study taxa at the reference sites increased 6-15 fold in January/ February 1996 and 1-13 fold in February/March 1998. In contrast, densities of these taxa at sites with exposure to 10-25 fold higher concentrations of total endosulfan remained static or decreased throughout the surveys and were between one and two orders of magnitude lower than densities at the reference sites in February 1996 and March 1998, respectively.

Univariate analysis and multivariate Principal Response Curve analysis indicate that endosulfan concentrations were a significant correlate with the relative reductions in population densities of the study taxa, compared to those at the reference sites.

Laboratory 48 hour LC50 values of technical endosulfan in river water were 0.6, 1.0 and 0.4 ppb for early instar nymphs of **A. australis, J. kutera** ***and larvae of*** **Cheumatopsyche** ***sp., respectively.***

These values are within the range of concentrations measured in river water during land run-off following storm events. As endosulfan sulfate formed a large proportion of the total endosulfan concentrations measured from in situ solvent-filled polyethylene bags its source is possibly from land run-off events.

Introduction

Storm runoff events in cotton growing areas are thought to contribute to large fish kills (Napier et al., 1998). In contrast to this, fish have been observed to survive in high concentrations of endosulfan in turbid waters of drainage canals (Napier et al., 1998). Endosulfan is a hydrophobic compound sorbing to soil and particulate material in land run-off following storm events.

The alpha and beta isomers of endosulfan have a half-life of only a few days in water, but the toxic biological metabolite endosulfan sulfate has an aqueous half-life of several weeks (Peterson and Batley, 1993). Both toxic isomers and the sulfate metabolite of endosulfan are more persistent when sorbed to soil and sediment.

The persistence of endosulfan in soil suggests that field run-off during storm events may be a major source of endosulfan which may possibly contribute to fish kills. Suspended or bottom sediments, however, have a protective role in ameliorating endosulfan toxicity. The contradiction in roles of suspended and bottom sediments, poses a dilemma in setting water quality guidelines and for risk assessment of this chemical.

This study examined the use of benthic macroinvertebrates as biomonitors of endosulfan contamination in the Namoi River. We investigated the relationship between changes in densities of six dominant macroinvertebrate taxa in the Namoi River and environmental factors, particularly total endosulfan concentrations measured in the solvent-filled polyethylene bags placed in the river.

The study taxa occur in high abundance in the riffle-pool communities at all study sites and their sedentary behaviour facilitated changes in their population densities to be quantified.

Methods

Field study design

Changes in the population densities of the study taxa were both temporal and spatial and were examined with a BACI type design (Underwood, 1991). Sampling occurred before, during and after the pesticide-spraying season for cotton from November 1995 to February 1996. Eight sites were selected along the Namoi River (Figure 13.1.) to represent reference sites (sites 1 and 2 upstream of the cotton growing areas), a site with low pesticide exposure (site 3), and sites with high pesticide exposure (sites 4 to 8).

In 1997/98 the eight sites were re-sampled but supplemented with additional sites to give a spatial design consisting of 17 sites at least 5 km apart within the region of sites 1-7 of the previous study (Figure 13.1.). Based on the 1995/96 data, these 17 sites may potentially consist of six reference sites (A,B,1,C,2,D), six low-exposure sites (E,F,G,H,3,I) and five high-exposure sites (4,5,J,6,7). The 17 sites were sampled for population densities of macroinvertebrates, particularly mayfly nymphs and caddisfly larvae in November and December 1997 and February and March 1998.

Pesticide concentrations

Pesticide sampling was carried out using two approaches. The initial choice was analysis of surficial bottom sediment. The sediment samples were extracted using the USA-EPA 3550B methodology (US EPA, 1996) and analysed by gas chromatography for organochlorines and organophosphates. However, the data from this procedure was considered unreliable, as variances were very high between replicates.

The second approach for pesticide sampling, used *in situ* passive samplers constructed of polyethylene bags containing trimethylpentane (Peterson et al., 1995) placed in the water column of the river (Leonard et al., 1998). The passive samplers were replaced monthly and the recovery of the trimethylpentane was over 90 %. The solvent containing the pesticides was analysed directly by GC-ECD and they were confirmed using GC-mass spectrometry (Leonard et al., 1998).

Densities of selected macroinvertebrate taxa

One month was the chosen sampling interval, as it is the minimum emergence time reported for closely related taxa. The study taxa were the ephemeropteran nymphs *Jappa kutera*, *Atalophlebia australis*, *Tasmanocoenis* sp., *Baetis* sp. and the trichopteran larvae, *Cheumatopsyche* sp. and *Ecnomus* sp.

A stratified random sampling design was implemented for the collection of macroinvertebrate samples. At each site six samples were collected monthly with a Surber sampler (0.16 m^2) in riffle-pool habitats with a rocky substrate. The samples collected at each site on each sampling time were pooled and quantified. Abiotic variables measured at each site in both studies included pesticide concentrations in solvent-filled polyethylene bags, mean measurements of river discharge, rainfall, river channel width, distance downstream, substrate type, water quality parameters (temperature, pH, conductivity and DO) and amount of riparian vegetation.

Mean measurements of river discharge between sampling times were calculated from data recorded daily at six hydrological gauging stations (New South Wales Department of Land and Water Conservation) located in the vicinity of the sampling sites.

Laboratory assessment of the toxicity of endosulfan to study taxa

Mayfly nymphs and caddisfly larvae were collected at unpolluted site 1 or 100 km upstream of site 1 at Lowry Ford, near Manilla, NSW. The size range used for sediment testing was set at 3 to 6 mm body length. The mayfly nymphs and caddisfly larvae were transported and acclimated to laboratory conditions as described by

Figure 13.1. The Namoi River and positions of the sampling sites (1 - 7, A - J), the major town (□) and cotton growing areas. These areas are categorised by non-irrigated (░) and groundwater-irrigated cotton (▓).

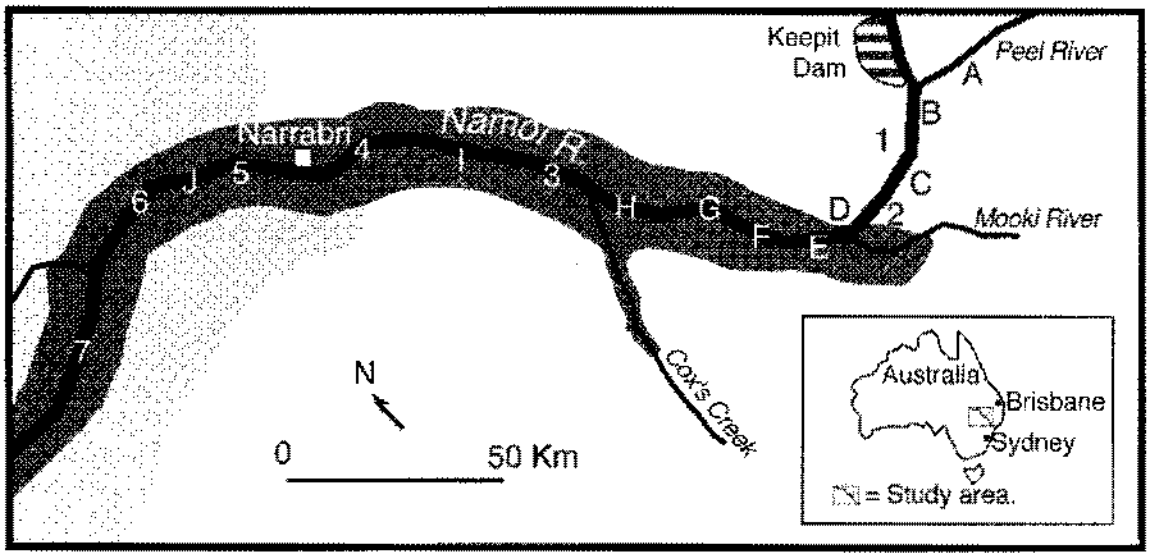
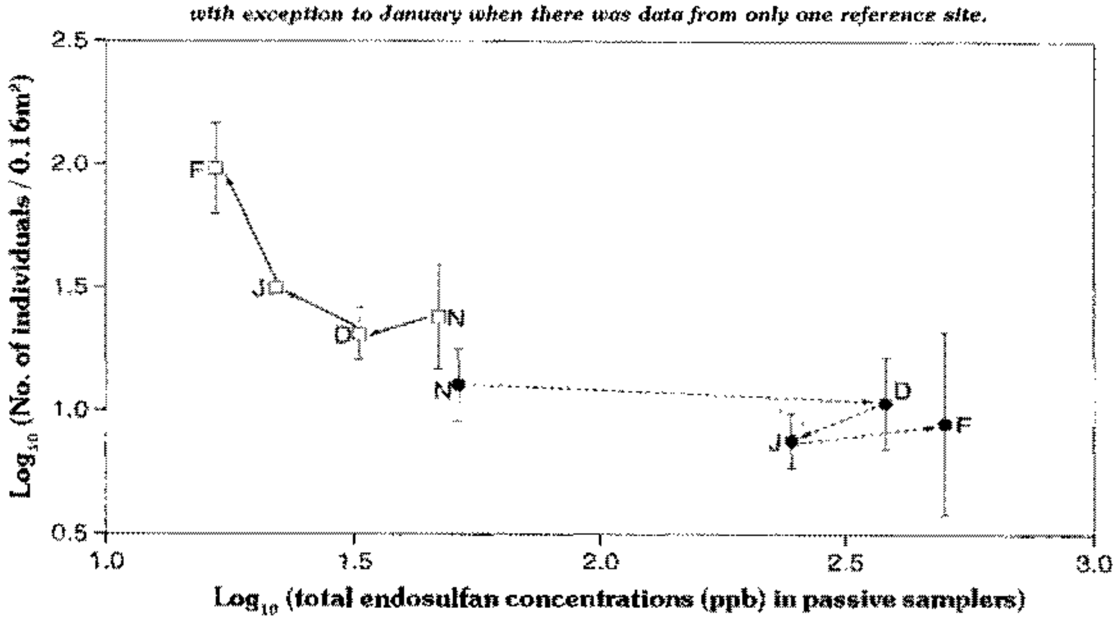


Figure 13.2. Densities of dominant mayfly nymphs and caddisfly larvae in the Namoi River between November 1995 and February 1996, and changes in total endosulfan concentrates in passive samplers placed in the water column at reference (◻) and exposed sites (●). There were five exposed and two reference sites, selected on the basis of the total endosulfan concentrations which were the sum of concentrations of alpha endosulfan, beta endosulfan and endosulfan sulfate. The different sampling times are indicated by N=November; D=December; J=January and F=February. The error bars for exposed sites are 95 % confidence intervals while the error bars for the two reference sites are based on minimum and maximum values. This is with exception to January when there was data from only one reference site.



Leonard et al., (1998). The toxicity of technical grade endosulfan to macroinvertebrates was determined under static test conditions in Namoi River water transported back to the laboratory. 'Alive' and 'immobilised' were defined as locomotory positive (crawling) and no movement in response to gentle prodding, respectively. Gill movement was not considered as a locomotory response.

Statistical analysis

Significant differences in the taxa population densities or pesticides concentrations between sites was tested by ANOVA using a post-hoc Tukey's HSD test for unequal sample size (Statsoft, Inc., 1997). The assumptions of homogeneity of variance were tested using a combination of Cochran's, Hartley's and Bartlett's tests and the normality of the distribution was assessed using a normal probability plot of residuals from the Statistica for windows package (Statsoft, Inc., 1997).

If the assumptions were violated, the non-parametric Mann-Whitney U test was used. Due to the small sample sizes the exact probabilities were determined using a cummulative one-sided probability of the U statistic (Statsoft, Inc., 1997). The assumptions of the regressions were tested from the Statistica for windows package (Statsoft, Inc., 1997).

Results and discussion

River conditions during field survey

During the field survey, hydrological conditions of the Namoi River catchment in the 1995/96 season were characterised by wet conditions with summer rains from November 1995 to February 1996 resulting in extensive land run-off. Two major flood events occurred in late December 1995 and late January 1996. Discharge was higher at sites 1 to 5 with sites 6 to 8 receiving less water due to water extraction for irrigation.

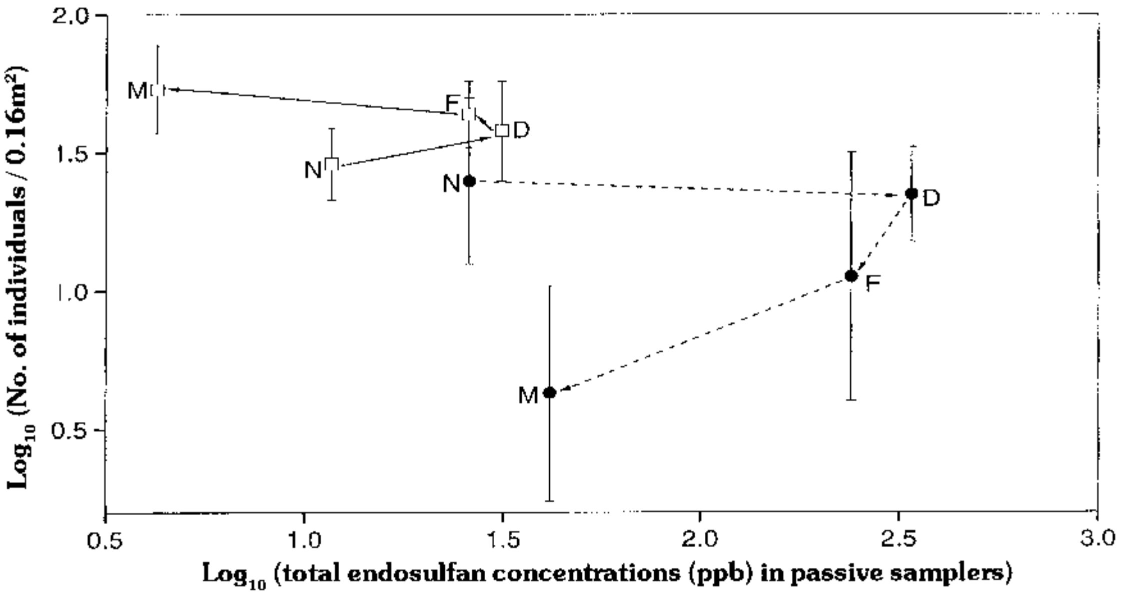
The 1997/98 season in the Namoi River catchment was characterised by dry conditions with some isolated storms in December 1997 and more extensive storm events throughout the catchment in February 1998. These climatic conditions led to reduced land run-off water entering the river compared to the 1995/96 season. From late December 1997 to mid-February 1998 sampling could not be carried out, as the river level was high due to the release of water from Lake Keepit.

Pesticide concentrations

High concentrations of some pesticides were detected in the solvent-filled polyethylene bags, particularly total endosulfan (the sum total of the alpha and beta isomers, plus endosulfan sulfate). Pesticides have a much higher affinity for the solvent than water, so they are continuously absorbed to give a time-integrated measure of pesticide exposure in the water column. In the 1995/96 study, the only other chemical that had concentrations close to these was the herbicide prometryn, which is not likely to be toxic to aquatic fauna (Tomlin, 1994). The organophosphates, chlorpyrifos, profenofos and sulprofos were found in low concentrations.

Thus, endosulfan was the pesticide most likely to have a toxic impact on the aquatic fauna. In contrast, total endosulfan concentrations in the bottom sediment were very low. There was a significant regression ($r^2 = 0.426$, $P<0.001$) between total endosulfan concentrations in the bottom sediment and corresponding concentrations in the solvent-filled polyethylene bags. In November

Figure 13.3. Densities of dominant mayfly nymphs and caddisfly larvae in the Namoi River between November 1997 and March 1998, and changes in total endosulfan concentrates in passive samplers positioned in the water column at reference (□) and exposed sites (●). There were five exposed and twelve reference sites, selected on the basis of the total endosulfan concentrations which were the sum of concentrations of alpha endosulfan, beta endosulfan and endosulfan sulfate. The different sampling times are indicated by N=November; D=December; F=February and M=March. The error bars are 95 % confidence intervals.



1997, before pesticide spraying commenced, there was no significant difference (P>0.05) in the total endosulfan concentrations between the reference and the exposed sites (Figures 13.2. and 13.3.).

Throughout both studies, the mean total endosulfan concentrations at the reference sites were less than 50 ppb in the solvent-filled polyethylene bags. However, from December 1995 to February 1996 and December 1997 to March 1998 the total endosulfan concentrations in the exposed sites increased. In February 1996 and February 1998, the endosulfan levels in the exposed sites were approximately 10-25 times higher than those in the reference sites (Figures 13.2 and 13.3.). In addition in February of both 1996 and 1998, over 80 % of the endosulfan was in the form of endosulfan sulfate.

Population densities of selected macroinvertebrate taxa

The six study taxa represented more than 80 % of the macroinvertebrate community abundance at all the study sites.

The same riffle-pool habitats were sampled in both studies.

In the summer months between December 1995 and February 1996, the populations of the six study taxa in the Namoi River were expected to continue to increase from the lower winter densities at all sites due to increased flow rate and temperature stimulating recruitment and growth. Cohort analyses (between October 1995 and February 1996) indicate at least two generations should have recruited to each site over the survey period.

Between December 1995 to February 1996 there was a continuous increase in population densities of all study taxa at reference sites 1 and 2, but no increase of *J. kutera*, *A. australis*, *Tasmanocoenis* sp. and the two caddisfly species (*Cheumatopsyche* sp. and *Ecnomus* sp.) at exposed sites 3 to 8 (Figure 13.2.).

Baetis sp. did increase at these sites. Therefore, we suggest that a perturbation(s) present at sites 3 to 8 restricted the increase in density of all taxa except *Baetis* sp. By February the density of the study taxa at the two reference sites were an order of magnitude higher than the mean density at the five high-exposure sites (Figure 13.2.).

In the 1997/98 study in the Namoi River, there was also a continuous increase in population densities of the six study taxa at the six reference sites (A,B,1,C,2,D) and the six 'low-exposure sites' (E,F,G,H,3,I), but no increase at the five high-exposure sites (4,5,J,6,7). Since there was no significant difference (P>0.05) in the population densities of the six study taxa at the six reference sites and the six 'low-exposure sites' they were combined to form a single group of 12 sites to compare with the population densities at the five high-exposure sites (Figure 13.3.).

In February and March 1998, the mean density of the six study taxa at the twelve reference sites were significantly higher (P<0.05) than the mean density at the five high-exposure sites (Figure 13.3.). By March the density of the six study taxa at the twelve reference sites were an order of magnitude higher than the mean density at the five high-exposure sites (Figure 13.3.).

Similar patterns were detected in changes in population densities using univariate analyses (Leonard et al., 1998) and the multivariate Principal Response Curve analysis developed by van den Brink and ter Braak (1998).

The overall indication is that the densities of the study taxa were significantly decreased at sites exposed to high concentrations of total endosulfan in the solvent-filled polyethylene bags in February 1996 and March 1998.When endosulfan concentrations were low in both November 1995 and November 1997, distance downstream was not significantly correlated ($P>0.05$) with population densities. Therefore, unless an important variable correlated to distance downstream has not been measured, endosulfan in the riverine environment is the most likely factor explaining these trends in decreasing macroinvertebrate densities relative to those of the reference sites.

Toxicity of endosulfan to the study taxa

In the field study, significant relationships were found between abundances of the selected insect nymphs and larvae and endosulfan concentrations in the solvent-filled polyethylene bags. Laboratory toxicity tests were conducted to determine the sensitivity of the study taxa to a single pulse exposure of endosulfan. Laboratory 48 hour LC50 values of technical endosulfan in Namoi River water were 0.6, 1.0 and 0.4 ppb for early instar nymphs of *A. australis*, *J. kutera* and larvae of *Cheumatopsyche* sp., respectively (Leonard et al. 1998). These 48 hour LC50 values are within the range of total endosulfan concentrations, and duration of exposure, measured in river water during land run-off following storm events (Cooper, 1996).

Conclusions

1. During the 1995/96 and 1997/98 cotton-growing seasons there was an inverse correlation between the population densities of dominant benthic macroinvertebrates and concentrations of endosulfan in the Namoi River.

2. The dominant toxic component of endosulfan in riverine samples was the metabolite endosulfan sulfate.

3. Throughout both cotton-growing seasons, the mean total endosulfan concentrations in solvent-filled polyethylene bags at the high-exposure sites were 10-25 times those at the reference sites.

4. Pesticide concentrations in solvent-filled polyethylene bags placed in the water column can possibly be used as a regulatory tool to audit the impact of Best Management Practice in the Cotton Industry on the riverine environment.

Acknowledgements

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14. Biological monitoring – Central and North-West Regions Water Quality Program

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Abstract

Biological monitoring has taken place as part of the Central and North-West Regions Water Quality Program since 1992. The program is jointly funded by the NSW Department of Land and Water Conservation (DLWC) and the water users of the Macquarie, Namoi, Gwydir and Macintyre River valleys. The monitoring program has found changes in macroinvertebrate communities through time at putatively impacted sites (within irrigated agriculture) with no corresponding changes at reference sites (upstream of irrigated agriculture) in some growing seasons.

The causal mechanisms of these changes are unknown, but are not experienced by macroinvertebrate communities at upstream sites. The results of other complementary investigations are also discussed. Field experiments and ecological risk assessment are discussed as additional approaches to field monitoring to enable the effect of endosulfan on macroinvertebrate communities to be more comprehensively assessed.

Introduction

The Central and North West Regions Water Quality Program (CNWRWQP) is a broad spatial and temporal water quality monitoring program that focuses on the central and north western areas of NSW (Figure 14.1.). The program is jointly funded by the DLWC and the water users of the Macquarie, Namoi, Gwydir and Macintyre River valleys.

Biological monitoring was first undertaken as part of the CNWRWQP during 1991/92, as a pilot project by the Murray-Darling Freshwater Research Centre (Hillman 1992, Bales and Smalls 1993). The pilot program was instigated in response to community concerns over the impacts of pesticides from irrigated agriculture on water bodies in the region.

Because of the widespread presence of endosulfan in rivers of north-west NSW at concentrations that frequently exceed ANZECC environmental guidelines (Muschal 1997), this chemical has been determined to be the agent with the most potential to cause environmental effects and is the focus of the biological monitoring program. This pilot study sampled six sites in the Gwydir River system on two occasions during May and July 1992. Compared with other sites, those within the area used for irrigation had fewer individuals, fewer taxa and different community structure, indicating possible impacts on macroinvertebrate communities associated with irrigated agriculture. Subsequently, the DLWC (then NSW Department of Water Resources) commissioned an on-going biological monitoring program as part of the CNWRWQP and has been carried out in various forms since that time.

Methods

In the 1992/93 biological monitoring program, samples were taken at 17 river sites throughout the Macquarie, Namoi, Gwydir and Macintyre basins (Royal and Bales 1994). The sites were sampled using artificial substrata on five occasions during the year.

The site network was expanded for 1993/1994 to 39 sites, covering cotton-growing and associated areas (Royal and Bales 1994). Sampling changed from the use of artificial substrata to sampling of natural habitats. This occurred because habitat sampling collects macroinvertebrates that naturally exist at a site, not macroinvertebrates present because of their adventitious use of artificial substrata.

In 1994/95 the 34 sites were studied (Royal and Brooks 1995). Samples were collected and processed using the methods outlined in the River Bioassessment Manual for the Monitoring River Health Initiative (1994). In 1995/96 24 sites were sampled with a greater focus on the Macquarie River sites (Brooks and Cole 1996). Study sites were increased to 28 in 1996/97 (Moroney et al. 1998). For the past two seasons, sites corresponded to those used for monitoring pesticides in the water.

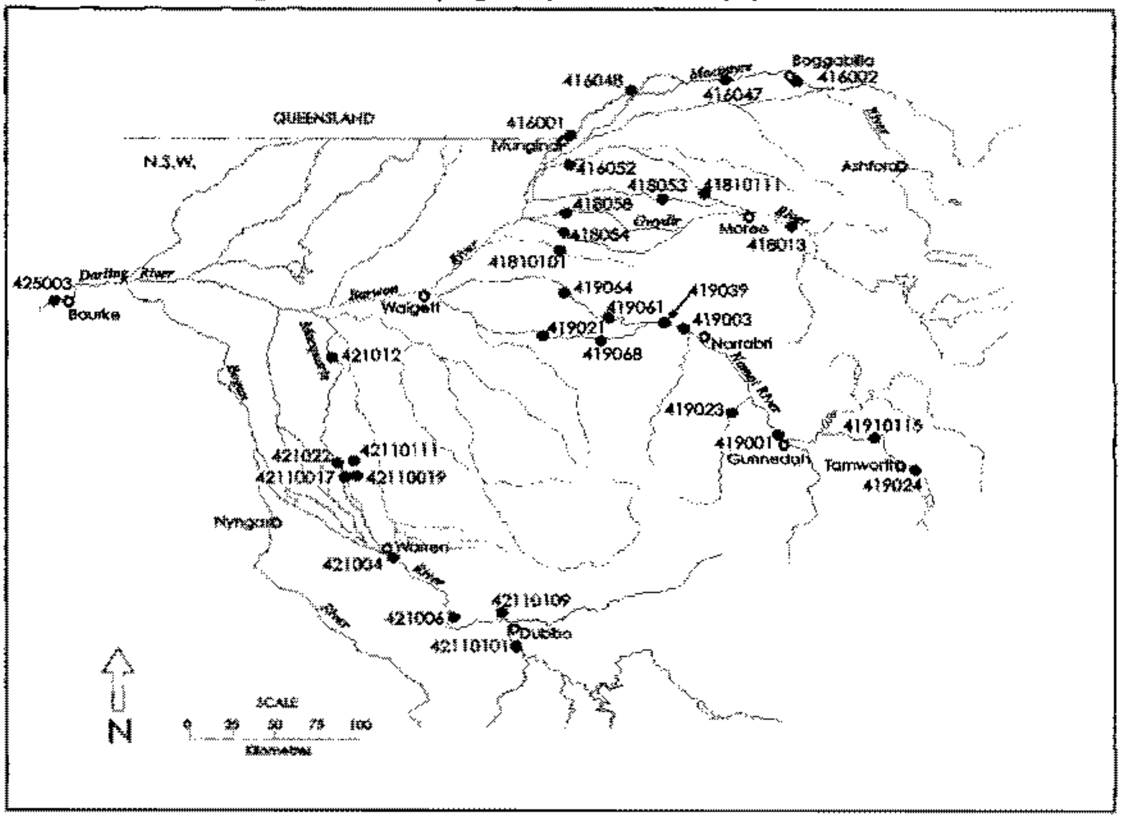
In general, sites were sampled once before the pesticide spray season begins, once during and once afterwards. Sites were situated both upstream, within and downstream of irrigated agriculture.

Results and discussion

The monitoring program has found statistical differences in macroinvertebrate community structure between samples collected before, during and after pesticide spraying at putatively impacted sites (within irrigated agriculture) with no corresponding changes at reference sites (upstream of irrigated agriculture) in 1995/95 and 1996/97 (Brooks and Cole 1996, Moroney et al. 1998).

Communities at sites within irrigated areas were presumably affected by a variety of environmental factors not experienced by macroinvertebrate communities at upstream sites. The causal mechanism of these changes is

Figure 14.1. Sampling sites for the CNWRWQP for 1996/97



unknown, but is particular to areas of irrigated agriculture. It should also be noted that during years where no statistical differences were detected, the power of the monitoring program may have been very low and real changes were undetected.

To address the concern that effects may occur at smaller temporal and spatial scales than the broad monitoring program, DLWC and the Land and Water Resources Research and Development Corporation (LWRRDC) conducted a joint project in 1994/95 investigating possible impacts on aquatic biota adjacent to an isolated cotton farm along the Macquarie River.

The results were equivocal in regards to the effects of endosulfan, as there were no detections of this pesticide in the water over the season. Studies of macroinvertebrates in irrigation channels of the adjacent cotton farm showed significant correlations between endosulfan water concentrations and aquatic macroinvertebrate abundances and number of taxa (Brooks 1995). However, the levels of endosulfan were much higher than generally found in river systems.

Effects at individual river basin scale corresponding to pesticide use have been reported by DLWC and other agencies. In the Macquarie River basin in 1995/96, significantly lower aquatic macroinvertebrate diversity in areas of irrigated agriculture than in areas upstream of irrigated agriculture were detected during the pesticide spray season (Brooks and Cole 1996).

The current biological monitoring program has shown changes in macroinvertebrate communities associated with irrigated agriculture, although not consistently. Clearly establishing endosulfan (or any other factor) as the cause has not yet been be made. A long-term monitoring program will determine if the trends continue, but not endosulfan's role in these changes.

Implications of results

Overseas there have been similar inconsistencies in the results of field studies assessing the impacts of pesticides on aquatic organisms (Russell-Smith and Ruckert 1981, Muirhead-Thompson 1987 Ch. 8, Ernst et al. 1991, van Urk 1993). Often the difficulty in attributing cause in some of these studies was because of a number of confounding factors during endosulfan application and field sampling such as rain and flooding.

Because of the observational/correlative nature of the field monitoring program, the specific causal factors (pesticides, nutrients and/or other physical and chemical variables) in any observed changes can only be inferred. More importantly, reference sites in the river systems of north-western NSW are usually restricted to areas upstream of the point/region of suspected impact, and the comparison between pesticide-exposed and non-exposed sites is confounded by the fact that the two groups of sites are in different geographic regions.

The stated objectives of the current biological monitoring program are:

1. Assess the impact of irrigated agriculture on macroinvertebrate community structure with particular reference to pesticides, nutrients and other physical and chemical variables over a large area; and

2. Monitor the diversity of macroinvertebrates occurring in inland rivers and streams in the north-west region of NSW.

To completely meet these objectives it is necessary to clearly define in some manner the extent and likelihood of endosulfan's role in any observed biological changes. To achieve this, additional approaches to field monitoring are being employed.

Keough and Mapstone (1995) have discussed three ways to approach the task of estimating human impacts:

- Infer impacts from empirical evidence collected during the occurrence of (potentially) impacting activities;
- Experimentally investigate impacts of specified activities; and
- Predict impacts from prior knowledge or experience.

A combination of all three approaches is being used to provide a better overview for determining the impacts, if any, from endosulfan and other pesticides associated with irrigated agriculture.

Infer impacts from empirical evidence collected during the occurrence of (potentially) impacting activities

The current biological monitoring program will continue with some modifications. Patterns emerging from the monitoring program can be related to the results of experimental work. Other changes to the program are:

1. Develop a predictive model for the rivers of central and north west regions similarly to the First National Assessment of River Health to more appropriately determine health of river systems.

    * *Predictive model for north-western regions of NSW needs to be fully developed to allow more accurate assessments.*

2. Investigate feasibility and applicability of monitoring another ecological relevant component of ecosystem.

    * *Fish biomarkers specific to stress caused by pesticides*
    * *Monitor fish assemblages, individual populations*

3. Investigate feasibility and applicability of undertaking specific field monitoring around a known area of pesticide contamination at smaller spatial and temporal scales (kilometres and months).

    * *Monitor a small area of pesticide input, such as a single or cluster of irrigated agricultural farms, with no pesticide input upstream using a BACIP or similar design, over a number of pesticide spray seasons.*

Experimentally investigate impacts of specified activities

Determining the toxicity of endosulfan to aquatic fauna under controlled conditions provides information with which to compare the observations recorded in the field monitoring program. The most common experimental work with endosulfan in Australia involves single species laboratory based toxicity testing. These studies are commonly used to identify taxa sensitive to endosulfan or other pesticides and help identify possible faunal changes in natural systems.

Artificial ponds or streams (mesocosms) are also used to overcome the limitations in field monitoring studies. This is because they resemble natural freshwater ecosystems and enable the investigator to establish direct and indirect cause-and-effect relationships between contaminants and aquatic organisms (Caquet et al. 1996). Mesocosms are considered an intermediate level of study between the laboratory and the field, bridging gaps between large-scale uncontrolled field studies (eg. CNWRWQP Biomonitoring) and highly replicated but often unrealistic laboratory conditions (Rodgers et al. 1996). Mesocosms also allow simultaneous studies on the fate and behaviour of contaminants under near-natural conditions.

DLWC and LWRRDC identified the need for experimental field studies and have conducted a joint research project on the impacts of endosulfan using artificial ponds (Brooks 1998). The 20 artificial ponds were created from a disused irrigation channel on the farm 'Milchengowrie', which borders the Namoi River, near Boggabri, NSW. Static systems were used to simulate the lentic conditions that often occur in the river systems of north-western NSW during summer, the season of maximum pesticide use.

Multivariate analysis found clear differences in macroinvertebrate communities between the control and nominal 10 μg/L treatments after 72 hours. At the individual organism level, *Hydraena* sp. and *Triplectides* sp. were significantly affected by endosulfan. *Hydraena* sp. was significantly impacted at all treatment levels and the impact increased with higher endosulfan contamination. *Triplectides* sp. did not consistently differ between the control and endosulfan treatment but did show a significant increased impact as the level of endosulfan increased.

The results from this study indicate that although occurring infrequently, the highest levels recorded in the rivers of north-western NSW would be sufficient to have an acute impact on macroinvertebrate communities, whilst the more frequent levels of approximately 0.01 μg/L would have impacts on individual species.

The combination of both high and low endosulfan exposure throughout the summer pesticide spray season would consequently affect aquatic macroinvertebrate's role as the major primary and secondary consumers in the river systems of these areas. Field experiments with endosulfan using artificial ponds or streams are crucial in providing information on whether the macroinvertebrate community changes observed in the monitoring studies are attributable to pesticides.

Table 14.1. Likelihood of endosulfan causing chronic effects to aquatic fauna in irrigated agricultural areas during the pesticide spray season from 1991 to 1997.

Toxicity data information	Acute endosulfan toxicity (µg/L)	% samples equal to or exceeding stated toxicity level	Calculated endosulfan chronic toxicity (µg/L)	% samples equal to or exceeding stated toxicity level
Laboratory derived 96 hour LC_{50}				
Bony Bream - *Nematolosa erebi*	0.2[a]	8.3	0.02	74.0
Golden Perch - *Macquaria ambigua*	0.3[d]	4.8	0.03	62.6
Silver Perch - *Bidyanus bidyanus*	2.4[a]	0.2	0.24	6.4
Eastern Rainbow fish - *Melanotaenia duboulayi*	2.4[a]	0.2	0.24	6.4
Firetail gudgeon - *Hypseleotris gallii*	2.2[b]	0.2	0.22	7.1
Laboratory derived 48 hour EC_{50}				
Mayfly nymphs - *Jappa kutera*	1.1[c]	1.2	0.11	18.7
- *Atalophlebia australis*	0.6[c]	2.2	0.06	37.7
Caddisfly larvae - *Cheumatopsche* sp.	0.4[c]	2.9	0.04	51.8
Notonecta sp. (probably *Ethinares* sp.)	0.1[d]	20.8	0.01	84.2
Artificial pond experiment (72 hours) lowest concentration causing detectable effect				
Adult water beetle - *Hydraena* sp.	0.02[e]	74.0	0.002	84.2
Caddisfly larvae - *Triplectides* sp.	0.02[e]	74.0	0.002	84.2
Changed aquatic macroinvertebrate community structure	2.9[e]	0.1	0.29	4.9

a. Sunderam et al. (1992) b. Mowbray (1978) c. Sunderam (1990) d. Hyne (unpublished data) e. Brooks (1998)

Predicting impacts

There is a large amount of existing information on pesticide sources, pathways of contamination and levels of water contamination collected through the CNWRWQP and LWRRDC program 'Minimising the impact of pesticides on the riverine environment using the cotton industry as a model'. However, there is limited information on the ecological impact of recorded levels of endosulfan contamination. Of the information that is available on aquatic impacts, most studies have involved laboratory based acute and chronic toxicity and bioaccumulation tests (eg. Muirhead-Thompson 1973, Naqvi et al. 1987, Sunderam et al. 1992). Although more recently DLWC and NSW EPA have conducted joint projects with LWRRDC assessing the effects of endosulfan on aquatic macroinvertebrate communities in artificial ponds and streams respectively.

Using this existing chemical and biological monitoring, ecotoxicology and transport modelling data, an ecological risk assessment for endosulfan can be undertaken. The ecological risk assessment is a process for organising and analysing data, information, assumptions, and uncertainties to evaluate the likelihood of adverse ecological effects caused by endosulfan. The assessment will also identify gaps in information, which then can be targeted through specific data collection studies in the CNWRWQP biological monitoring program.

A preliminary assessment of pesticide data from 1991 to 1998 (not including storm event data) shows that the period of greatest risk to the aquatic environment from endosulfan is in the irrigated agricultural areas during this pesticide's spray period. Comparison of endosulfan levels from these areas and periods with existing laboratory acute toxicity data indicate that the likelihood of 50 % mortality or impairment of native fish and particular mayfly nymphs and caddis fly larvae is very small (Table 14.1.). The backswimmer, *Notonecta* sp. appears to be at moderate risk in all river systems, as 20.8 % of samples exceed the 48 hour EC_{50}. It should be noted it is likely this invertebrate is probably *Ethirnores* sp., as *Notonecta* sp. is not found in NSW.

Field experiments indicate that the water beetle, *Hydraena* sp., and caddisfly larvae, *Triplectides* sp. are at very high risk of acute impairment from endosulfan in all river systems (Brooks 1998). Acute effects on overall community structure would be unlikely to occur based on this study.

An assessment of ecological risk of chronic effects was made by dividing by ten the reported LC_{50} and lowest observed No-effect-concentrations as used by Sydney Water (1995). The risk of chronic effects is obviously much greater than acute impacts (Table 14.1.). Almost all aquatic macroinvertebrates assessed were at high risk of chronic impacts caused by endosulfan. Bony bream, golden perch and firetail gudgeon were assessed to be at very high risk, with silver perch and eastern rainbow fish at low risk. This preliminary assessment of toxicity information highlights a number of issues which need to be addressed in future studies.

1. The information available generally records 50 % impairment or mortality of selected taxa. (50 % impairment/mortality information may not be an appropriate measure of risk as chronic effects are of higher likelihood. The applicability of ten as a safety factor is unknown.)

2. There is a limited amount of toxicity data on Australian aquatic macroinvertebrate taxa, and of the data that is available, almost all is laboratory based acute toxicity information. (Further field experiments are required to provide a link between field monitoring and acute toxicity laboratory data.)

3. There is a high percentage of water samples with endosulfan levels ranging between 0.01 μg/L and 0.1 μg/L in all river systems during the pesticide spray season. (Information on the effects of endosulfan on individual taxa and communities at these low levels of contamination over longer periods of time (months) are needed.)

DLWC plans to conduct field experiments with continued endosulfan exposure over a number of months. Experiments over these time scales will allow more accurate extrapolation of results to the river systems of central and north west NSW.

Conclusions

The current biological program will continue to assess the 'health' of aquatic macroinvertebrate communities in the central and north west rivers of NSW. Significant changes corresponding to irrigated agriculture have been found during some growing seasons, but the specific role endosulfan plays in these changes, if any, cannot be established by field monitoring alone.

An ecological risk assessment for endosulfan will provide a more comprehensive assessment of this pesticide's likely impacts on aquatic fauna. As part of the ecological risk assessment, laboratory and field experiments will be conducted to provide direct cause-and-effect information with which to interpret the findings of the field biological and water quality monitoring programs.

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15. Session commentary: understanding the impact of pesticides in the riverine environment

P.E. Davies

Freshwater Systems

One of the central but unstated, questions of this workshop session is:

Is the observed endosulfan contamination of river water and sediment having a deleterious impact on riverine ecosystems and associated fauna?

While the work presented here went some way towards providing data on aspects relating to this central question, they do not provide compelling evidence for or against such an environmental impact.

Toxicological studies

This work provides measures of lethal, sublethal and behavioural responses to endosulfan contamination in a laboratory setting under a range of conditions, and some indication of the concentration ranges at which such effects occur.

Field survey study

This field survey showed a negative correlation between macroinvertebrate densities and endosulfan concentrations over two seasons in the Namoi River. The design incorporated sampling at a number of locations down the Namoi River, with control sites upstream and contaminated sites downstream.

Unfortunately, this design results in endosulfan contamination levels increasing downstream and hence confounding of endosulfan contamination with other changes associated with the passage of the Namoi through agricultural land.

The lower river experiences changes in flow regimes, sediment regimes, riparian vegetation conditions and other water quality changes, all of which to a degree 'compound' downstream. None of these were examined in the work presented, and thus the potential for confounding is substantial. Correlation does not imply causality, especially in as complex an environment as the Namoi catchment.

Limitations imposed by the use of a single river in a control-impact paired design include a lack of truly independent spatial replication of the treatment (endosulfan contamination), as well as the lack of uncontaminated control river systems with similar site layout. These limitations have been well described by Underwood (1994) and others, and present a significant problem for the interpretation of the Namoi study data.

Finally, the survey work relies heavily on using solvent-filled bags for assessing endosulfan concentration. This method has not been calibrated to date and hence its validity in estimating magnitudes and trends in endosulfan concentrations in the water column is not fully proven. The study pointed out the need for a detailed assessment of sampling needs for assessing sediment contamination.

Mesocosm study

The work on artificial pond macroinvertebrate community responses to endosulfan exposure is perhaps the best procedural advance made to date in the question of endosulfan impacts on the aquatic environment. To be truly useful in addressing the central question, this work needs further expansion to include:

1. Longer exposure periods;
2. A wider range of endosulfan concentrations and environmental conditions;
3. A range of 'natural' habitats sampled, rather than artificial substrates.
4. Assessment of water column and sediment contamination using a variety of methods;
5. Assessment of responses of target macroinvertebrates known to show strong spatial patterns in the field (eg. *Jappa kutera*).

In addition, it needs integration into the field survey work so that endpoints are comparable for both macroinvertebrate responses and assessment of endosulfan concentrations.

Recommendations

A key issue is integration. Tight integration of the toxicity and field evaluations is needed, with mesocosm trials providing major insights.

To date we have toxicological, field and mesocosm responses all shown for differing taxa under a range of different conditions, and with design limitations. This has limited the ability of the parts to make a compelling whole.

While this work provides some initial insights, a final, effective blow can be struck by tightly integrating all three aspects, combined with a well defined series of endpoints.

A major issue raised by all aspects of the work presented in this session, is that of 'what constitutes a significant ecological impact?' The magnitude of the effect, as well as the magnitude of the Type I and II errors to be accepted in survey or experimental studies of endosulfan impacts must be agreed on up-front, and explicitly stated.

Selection of the levels of Type I and II errors (and hence the alpha and beta levels in statistical tests) is largely a social issue and not a technical one i.e. how much damage does society deem acceptable? While it can be informed by technical knowledge, arguments as to whether a 5 % or a 25 % decrease in the abundance of species x is 'significant' cannot be answered in a purely technical environment. This point is discussed at length in the current drafts of the revised ANZECC national water quality guidelines.

In my view, the following activities would aid greatly in pulling together the threads with regard to the extent of impacts from endosulfan on the aquatic environment in north-western NSW:

1. A study to validate/calibrate the solvent-filled bag method for assessing magnitudes and/or trends in endosulfan concentrations in river waters;

2. A larger scale river survey study with true control rivers with a similar site layout to that of the current Namoi River study – i.e. moving from the simplistic BACI re-design to a 'beyond-BACI' approach (see works by Underwood) – possibly integrating with the DLWC NW water quality survey or any best practice related biomonitoring programs;

3. A further, carefully designed mesocosm study, with endpoints integrated with both the field surveys and laboratory toxicity testing; and

4. A formal process for developing threshold 'effects sizes' and agreeing on the magnitude of Type I and II error levels for all field, mesocosm and laboratory study components.

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16. Assessing risk at catchment or regional level through a Pesticide Impact Ranking Index (PIRI)

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Abstract

A Pesticide Impact Ranking Index (PIRI) has been developed to (i) rank pesticides in terms of their relative pollution potential to groundwater or surface water, and (ii) to compare different landuses in a catchment or at a regional scale in terms of their relative impact on water quality.

PIRI is based on three components, namely the value of the asset (water resources threatened); the source(s) of threat to the asset (pesticides use); the pathway through which the threat is released to the asset. Each component is quantified using pesticide characteristics (toxicity, amount used, sorption and persistence) and soil and other site conditions (water input, erodibility and vulnerability to soil loss, recharge rate, depth of watertable etc.). The paper describes PIRI with example applications.

Introduction

Systematic methods which allow a relative assessment of pesticide impact are of great value to both pesticide users and regulators in choosing the pesticides and practices with the least detrimental impact (Levitan et al. 1995). A simple systematic method, namely Pesticide Impact Ranking Index (PIRI) has been developed under a current Land and Water Resources Research and Development Corporation (LWRRDC) project.

PIRI can be a useful tool in designing pesticide monitoring programs and in setting the research and developmental priorities to minimise the off-site impact of pesticides. The objective of this paper is to provide a brief description of PIRI and show examples of PIRI application for ranking pesticides in terms of their potential impact on surface and groundwater quality.

The approach used in PIRI

PIRI is based on a quantitative risk assessment approach (Correll and Dillon,1993). For the risk to be quantified, it is essential to identify:

1. The value of the asset (water resources threatened);

2. The source(s) of threat to the asset (pesticides use); and

3. How the threat will be released to the asset.

Estimation of the detriment

The detriment is calculated as the product of the three components, ie.

$$\text{Detriment} = VLT \qquad (1)$$

where V is the asset score, L the pesticide load and T the transport function. Since the transport function for the pesticides depends on their sorption (K_{oc}) and persistence in the environment (half-life), so the load on the water body has to be considered separately for each pesticide. For comparison of detriment from various land uses, the sum of the individual contributions for all pesticides is used.

Quantifying water resources as an asset

The value of each aquifer and body of surface water would depend on the size of the water body, water quality (ranging from potable and good quality drinking water to very saline water), aesthetic and/or ecological importance, number of people and industries dependent on the water supply, and alternative sources.

Given the lack of data needed for such an assessment, a score system ranging from 1 to 100 is used in PIRI. The water resource used for drinking or of high ecological value has the highest value (100) and saline water with minimum ecological significance the lowest (one but not zero). It is noteworthy that the value parameter is only needed when PIRI is used to assess relative risk assessment among different sites or land uses associated with different water bodies.

Pesticide load

The calculation of pesticide load requires knowledge of how much of each pesticide is used under each landuse in a catchment. The amount of pesticide applied in an area or catchment is determined from the total area of the crop (Area), the proportion of the crop that uses that pesticide (*p*), the frequency of application (*f*), the dosage (*d*) of active ingredient:

$$Load = Area \sum_{pesticides} fdp \qquad (2)$$

The dosage and frequency of application is rarely known for each farm. Surrogates for these can be used on the basis of the recommendations from manufacturers and other agencies.

Not only the amount of pesticides but their nature is equally important in determining the impact on a water resource. Therefore, a range of parameters of each pesticide considered in the assessment, including the toxicity of each pesticide (measured by LC_{50} or health advisory level (HAL)), its sorption and half-life. In PIRI, LC_{50} for rainbow trout is used as a measure of toxicity.

Toxicity values are moderated within an upper and a lower bound, as for very high or very low toxicity values the impact assessed by PIRI is not likely to be proportional to the numerical values. To account for the individual pesticide toxicity and persistence in soil, the toxic load can be calculated for surface water as

$$Load = Area \sum_{pesticides} \frac{t_{1/2}}{LC_{50}} fdp \quad (2.a.)$$

and for groundwater as

$$Load = Area \sum_{pesticides} \frac{fdp}{LC_{50}} \quad (2.b.)$$

For groundwater assessment the half-life ($t_{1/2}$) of pesticide is taken into consideration during the calculation of transport factor for each pesticide.

Pesticide transport

Transport to groundwater

The movement of pesticides through soil is retarded (ie. slower than water) due to the sorption of pesticides to soil organic matter, K_{oc} – the higher the K_{oc}, the greater the retardation. The retardation factor, RF, can be measured from K_{oc} and other soil properties by:

$$RF = \left[1 + \frac{\rho \ f_{oc} \ K_{oc}}{\theta_{FC}} \right] \quad (3)$$

where ρ is the bulk density of soil (kg/m^3), f_{oc} is the organic carbon content (kg/kg soil), and θ_{FC} is the volumetric moisture content at field capacity. RF is in effect the reciprocal of the fraction of the pesticide that is in the water phase.

The rate of water movement in the soil profile can be represented by the quotient of the recharge rate, q, and the water content, θ_{FC}. If q metres per year of water is input into a volume of soil containing moisture content θ_{FC}, the time required for water to pass through a soil profile of depth D is D/velocity = $D\theta_{FC}/q$.

Thus the residence time t of the pesticide in the soil profile of known depth D is

$$t = \frac{D\theta_{FC} RF}{q} \quad (4)$$

Loss of a pesticide through degradation will depend on the residence time in the soil. Generally, the values of the recharge rates q are not readily available. In such cases q can be assumed to be simply proportional to the difference between water input and evapo-transpiration for the crop-growing season in question.

As mentioned above, the degradation rate for PIRI is assumed to be constant across sites. The degradation of a pesticide during its transport through the soil profile can be represented in the form of attenuation factor AF for the groundwater, given by Rao et al. (1985), as follows.

$$AF_{GW} = \exp\left[\frac{-0.693 D RF \theta_{FC}}{q t_{1/2}}\right] = \exp\left[\frac{\log(1/2)t}{t_{1/2}}\right] \quad (5)$$

Here $t_{1/2}$ is the half life of the pesticide. In the case of groundwater, the transport function, T, is

$$AF_{GW}$$

The AF for each pesticide is different due to its sorption (K_{oc}) and degradation rate (as measured by $t_{1/2}$) and needs to be calculated individually. Therefore the load (L, defined in equation 2) and the transport (T, defined from equation 5) components need to be multiplied to give the pollution potential (PP) for the assessment of impact on groundwater.

The relative pollution potential to the groundwater of each pesticide applied to the area can be obtained by ranking the pollution potential of each. The total toxic load likely to reach ground water at a site can be calculated from the following relation:

$$TL_{GW} = \text{Area} \sum_{\text{pesticides}} LAF_{GW} = \sum_{\text{pesticides}} \text{PP} \quad (6)$$

Transport to surface water

The pathways of transport of pesticides from farms to surface water bodies are more complex and site specific. The transport to surface water is partitioned between runoff water, erosion of soils, and drift of sprays out of the target area. These are quite separate pathways, although there will be a high correlation between the surface runoff pathway and the soil erosion pathway. In contrast, spray drift is an unrelated pathway and must be considered separately.

Transport due to soil erosion

Pesticide transported with the soil particles through erosion will depend on soil loss. The prediction of soil loss through simple equations like the Universal Soil Loss Equation (USLE) is common and has been found very useful (Wischmeier and Smith, 1978). At this stage these equations have not been adapted for use in PIRI. While this limits the use of PIRI for comparisons among sites, it does not affect its usefulness for ranking pesticides within a site, or between comparable sites.

The amount of pesticide that will be associated with the soil particles will depend on the sorption of pesticide represented by the product of K_{oc} and f_{oc}, that is K_p. The loss of pesticide through soil erosion requires a function that is initially zero and then asymptotes to the proportion of the pesticide that is lost in this manner. A suitable function is

$$T_{\text{Erosion}} = \frac{0.1(\text{Soil Loss}) / \max(\text{Soil Loss})}{1 + \dfrac{1}{b K_{oc} f_{oc}}} \tag{7}$$

Ideally the function should asymptote to 0.1, the maximum fraction of pesticide that is likely to be lost due to erosion (Leonard, 1990) and *b* is a constant that was taken as 0.015. At this stage *b* has not been formally estimated.

Direct runoff

The amount of pesticide in runoff water must depend on the runoff characteristics.

A pesticide with a low K_{oc} that has been deposited on a plant or soil surface can be washed off by subsequent rain or irrigation. Available data (Leonard, 1990) would indicate that up to 5 % of the applied pesticide could be lost in this manner. This amount would decline rapidly with increasing K_{oc}.

A simple function with these properties is

$$T_{\text{direct runoff}} = \frac{0.05\,\text{Min}(K_{oc})R}{K_{oc}} \tag{8}$$

where *R* is the fraction of rainfall + irrigation that runs off the site, and $\text{Min}(K_{oc})$ was taken as 10. As with the soil loss factor, *R* is only important when comparisons are being made among sites. The total surface transport factor for each pesticide is therefore:

$$T = T_{\text{erosion}} + T_{\text{direct runoff}} \tag{9}$$

Atmospheric transport

The atmospheric pathway of pesticide transport is difficult to quantify. There are also two components, droplets and vapour, and perhaps a combination of both.

Each component is a function of many environmental and management variables and requires detailed knowledge of the method of application (including such details as the spraying pressure) and local wind and humidity conditions.

Movement of pesticides via droplets can be a significant pathway of pesticides to surface water, depending on the method of application, the size of the droplet, formulation, the proximity to and the size of the water body. This multitude of factors affecting atmospheric transport and the complexity of the processes involved preclude the inclusion of atmospheric transport component without sacrificing the simplicity of PIRI.

However, one can enhance the transport component of those insecticides which are applied aerially to target pests on foliage by a certain factor ie. 1.5 - 2 in calculations by PIRI.

Validation and application of PIRI

PIRI can be used for two purposes, namely (i) to rank pesticides in terms of their relative pollution potential to surface or ground water, and (ii) to compare different land uses in a catchment or different management practices in terms of their relative impact on water quality.

Ranking pesticides at a site

To rank pesticides that are used in a particular cropping system in terms of their relative pollution potential, only two component of PIRI ie. loading (*L*) and transport (*T*) for pesticides, are required. The value (*V*) component and the total area under a cropping system being assessed is not needed. Nor does the soil loss factor need to be evaluated. However, all pesticides need to be individually assessed on the basis of their chemical nature in terms of sorption, persistence and toxicity.

Surface water

Different pesticides are applied at different rates and also their frequency of use varies. Therefore the amount of pesticide applied per unit area per unit time is needed. Reliable information on pesticide use is often lacking. Some efforts in this direction have been made either at catchment scale (eg. Rayment and Simpson, 1993) or for the entire agro-industry (eg. Hamilton et al. 1996 for sugarcane in Queensland). Without reliable information any assessment is not likely to be valid.

The complementary LWRRDC project led by Mr Bruce Simpson (Department of Natural Resources, Queensland) is currently carrying out a pesticide audit at a catchment scale in the Murrumbidgee Irrigation Area (MIA). For validation of PIRI, not only the pesticide usage need to be known but also data from the pesticide monitoring studies.

The surface water quality program run by NSW Department of Land and Water Conservation (Cooper 1996) is the most comprehensive pesticide monitoring program for cotton growing area. However, the pesticide input data for the entire cotton growing area in Australia was not readily available for use in PIRI. Data for irrigated cotton in the Namoi Valley has been obtained from Cotton Consultants Australia (CCA) in 1996. The following example was based on the data from the above sources.

In Table 16.1, an example for several pesticides used in cotton production systems in the Namoi Valley is used to show the application of PIRI and the validation of some modules of PIRI. Data on toxicity (LC_{50}) sorption (K_{oc}) and persistence (half-life) have been taken from a US database (Hornsby et al. 1996) and are considered to calculate the surface transport factor of pesticides which is then converted into a score. The scores are used to categorise pesticides in terms of their potential risk to surface water quality. For example, in this particular case, three pesticides were given a high risk rating.

Of these three pesticides, endosulfan and profenofos were both detected while no analysis was available for phorate (Cooper 1996). At the other extreme, PIRI indicated that three pesticides present a very low risk and two of these were not detectable. The exception was parathion methyl, which was used in exceptionally large quantities in that year. Of the six pesticides considered as a low risk in Table 16.1, three were not detected while no assays were made for the other three.

It is noteworthy that from purely transport potential point of view the toxicity does not matter, however, from the standpoint of risk of impact on water quality, it is obviously very important. Therefore toxicity is part of the ranking system in PIRI. For example, the high LC_{50} of parathion methyl would have decreased its risk ranking in PIRI, which partially explains the apparent anomaly observed above.

Groundwater

Application of PIRI for assessing groundwater contamination potential of pesticides is shown in Table 16.2. In this case the data are based on the pesticides registered for vegetable production systems. Recommended rates of pesticides have been supplied to PIRI and so the results do not reflect the real use.

Nevertheless the relative ranking score between pesticides for a given site is a true representation of their properties under a constant set of soil and environmental conditions. The PIRI predictions show that fenamiphos has a high potential to contaminate groundwater – this was caused by its low LC_{50} (0.072mg/kg), a long half life (50 days), a high application rate (24 kg/ha) and a low K_{oc} (100).

Metham had the second highest rank, which was brought about by its very low K_{oc} (10) and its very high rate of application (790 L/ha), but its half life is short (10 days). By contrast, chlorthal, although it has a high application rate (15 kg/ha), presents little risk to the groundwater as it has a high K_{oc} (5000) and a moderate LC_{50} (4.7 mg/kg). Another interesting example is trichlorfon which, despite its low K_{oc} (10) presents only a small potential risk because of its short half life (10 days).

Ranking pesticides in different landuses at a catchment scale

For ranking different land uses in a catchment in terms of their impact, all three components of PIRI (*V*,*L* and *T*) need evaluation. In addition parameters such as soil loss estimates and area of crop, are also needed. Given the lack of input data, only a limited attempt has been made here, without an assessment of differential potential soil losses under different cropping systems.

We use the data from Bowmer et al. (1998) for ranking pesticides in different landuses in terms of their risk potential. Table 16.3. shows the predictions from PIRI using the pesticide use data under three different land uses in the Murrumbidgee Irrigation Area (MIA), based on a report by Bowmer et al. (1998). For rice, molinate was predicted to have high risk potential. This prediction is consistent with the frequent detection of this pesticide in the surface water in the MIA. PIRI also ranked thiobencarb and malathion as presenting a moderate-high risk - both of these pesticides also have been detected in the surface water.

In the case of citrus, the pesticides which were predicted to have the highest potential are diuron and bromacil. Both of these herbicides have been detected in surface water monitoring studies carried out by CSIRO (Bowmer et al. 1998), diuron being among the most frequently detected pesticides. In the case of maize/sorghum, among the pesticides used in 1994-95, those ranked to have very high potential were endosulfan, atrazine and metalochlor, all of which have been detected in surface waters of MIA.

For winter cereals none of the pesticides used in 1994-95 (Bowmer et al. 1998) fell in the category of highest risk. However, diclofop methyl was predicted to have high potential, followed by chlorpyriphos and fenvalerate in the moderate category.

Water samples from the MIA have been tested only for chlorpyriphos (Bowmer et al. 1998), and this pesticide has been detected on some occasions. The above

Table 16.1. An example of PIRI application in ranking pesticides used in cotton grown in the Namoi Valley for their potential impact on surface water quality. Input data on pesticide were taken from CCA (1996). The monitoring data has been taken from Cooper (1996).

(Assume f_{oc} = 0.01)

Pesticide	LC50 (fish)	LC50 mod(*)	Half life days	K_{oc}	Dosage (kg/ha)	a.i. (#)	frequency per season	fdp	PErosion	PRunoff	Total SW transport	100 x SW loading	Score	Loading risk ranking	Detection reported
Aldicarb	0.88	0.88	30	30	0.552	0.15	0.5	0.0414	0.0048	0.0017	0.0064	0.9073	3	medium	
Amitraz	0.74	0.74	2	1000	0.485	0.2	0.92	0.08924	0.0001	0.0001	0.0002	0.0048	1	very low	no
Chlorpyriphos EC	0.003	0.1	30	6070	0.9	0.5	1	0.45	0.0000	0.0000	0.0000	0.4447	3	medium	yes
Deltamethrin	0.0009	0.1	25	100000	0.8	0.1	9	0.72	0.0000	0.0000	0.0000	0.0360	2	low	no
Demeton-methyl	6.4	6.4	50	22	0.003	0.25	1	0.00075	0.0064	0.0023	0.0087	0.0051	1	very low	no
Dicofol	0.12	0.12	45	5000	0.154	0.24	1	0.03696	0.0000	0.0000	0.0000	0.0554	2	low	no
Dimethoate	6.2	6.2	7	20	0.786	0.4	1	0.3144	0.0070	0.0025	0.0095	0.3364	3	medium	no
Endosulfan EC+ULV	0.002	0.1	50	12400	3.356	0.475	2	3.1882	0.0000	0.0000	0.0000	2.5709	4	high	yes
Methomyl EC+LV	3.4	3.4	30	72	0.03	0.25	0.92	0.0069	0.0020	0.0007	0.0027	0.0167	2	low	
Monocrotophos	12	12	30	1	0.003	0.4	1	0.0012	0.0600	0.0500	0.1100	0.0330	2	low	
Omethoate	9.1	9.1	7	50	0.081	0.8	1	0.0648	0.0029	0.0010	0.0039	0.0195	2	low	no
Parathion methyl	2.7	2.7	14	5000	0.851	0.5	0.26	0.11063	0.0000	0.0000	0.0000	0.0023	1	very low	yes
Phorate	0.013	0.1	60	1000	0.617	0.2	1	0.1234	0.0001	0.0001	0.0002	1.4791	4	high	
Profenofos EC+LV	0.08	0.1	8	2000	5.24	0.25	1.6	2.096	0.0001	0.0000	0.0001	1.6759	4	high	yes
Thiodicarb	2.55	2.55	7	350	0.901	0.375	1.84	0.62169	0.0004	0.0001	0.0006	0.0972	2	low	

(*) moderated

(#) active ingredient

Table 16.2. An example work sheet for calculating relative contributions of different pesticides used in vegetable production in terms of their impact on groundwater quality. Use rates are recommended rates rather than actual rates.

(*Assume*: $\rho = 1.4\ g/cm^3$, $\theta_{FC} = 0.4\ cm^3/cm^3$, $f_{oc} = 0.0052$, $q = 1m/yr$, D (uniform) = 1m, f = 1, p = 1, Area = 50)

Pesticide	LC50 (fish)	Half life (days)	K_{oc}	Dosage (kg/ha)	a.i. (#)	Amount (dfap)	RF	AF	GW PP	Score
Benomyl	0.17	67	1900	1	0.5	0.5	36	0.00000	0.000	0
Chlorpyrifos	0.003	30	6070	2	0.5	1.0	112	0.00000	0.000	0
Chlorthal	4.7	100	5000	15	0.75	11.25	93	0.00000	0.000	0
Chlorthalonil	49	30	1680	3.5	0.72	2.52	32	0.00000	0.000	0
Demeton-methyl	6.4	50	22	1.1	0.25	0.275	1.40	0.05834	0.125	2
Dimethoate	6.2	7	20	0.7	0.4	0.28	1.37	0.00000	0.000	0
Endosulfan	0.002	50	12400	2.1	0.35	0.735	228	0.00000	0.000	0
Fenamiphos	0.072	50	100	24	0.4	9.6	2.83	0.00323	21.517	4
Fluazifop butyl	1.37	15	5700	1	0.21	0.212	105	0.00000	0.000	0
Iprodione	4.1	14	700	2	0.2	0.4	14	0.00000	0.000	0
Linuron	3.15	30	400	4.5	0.45	2.025	8.3	0.00000	0.000	0
Mancozeb	2.2	70	2000	2.2	0.75	1.65	38	0.00000	0.000	0
Metalaxyl	100	70	50	2.5	0.08	0.2	1.92	0.06257	0.006	0
Metham	0.079	10	10	790	0.42	334.17	1.18	0.00001	1.324	3
Metiram	1.1	20	500000	2.2	0.8	1.76	9158	0.00000	0.000	0
Metribuzin	64	40	60	1.5	0.48	0.72	2.10	0.00492	0.003	0
Parathion	1.5	14	5000	0.7	0.5	0.35	93	0.00000	0.000	0
Permethrin	0.003	38	100000	0.2	0.5	0.1	1832	0.00000	0.000	0
Prometryne	2.5	60	400	2.2	0.5	1.1	8.3	0.00000	0.000	0
Propachlor	1.4	6	80	18	0.21	3.852	2.47	0.00000	0.000	0
Propyzamide	4.7	60	800	4.5	0.5	2.25	16	0.00000	0.000	0
Sethoxydim	38	5	100	1.6	0.12	0.192	2.83	0.00000	0.000	0
Trichlorfon	0.7	10	10	1.7	0.5	0.85	1.18	0.00001	0.000	0
Trifluralin	0.01	60	8000	2.8	0.4	1.12	148	0.00000	0.000	0
Vinclozolin	22	20	10000	1	0.5	0.5	184	0.00000	0.000	0

(#) active ingredient

Table 16.3. An example risk ranking of pesticides by PIRI under different land uses in MIA (based on input data from a report by Bowmer et al. 1998)

Potential Risk Category	Rice	Citrus	Maize/sorghum	Winter cereals
Very High	Molinate, Trichlorfon	Diuron, Bromacil	Endosulfan, Metalochlor, Atrazine	- (none)
High	Thiobencarb	Methidathion	Methomyl, Chlorpyriphos, Terbufos	Diclofop methyl
Moderate	Malathion, Propanil, Chlorpyriphos	Copper oxychloride, Copper sulfate	Cypermethrin, Deltamethrin	Chlorpyriphos, Fenvalerate
Low	MCPA, Glyphosate, Diquat	Glyphosate	None (only eight pesticides assessed)	MCPA, Fenoxaprop

examples showing a good agreement between the pesticides ranked to have very high potential of surface water contamination and their frequency of detection from MIA for various land uses demonstrate that the results from PIRI are reliable.

Strengths and weaknesses of PIRI

PIRI is a simple index and not a simulation model and therefore not designed to predict concentrations of pesticide likely to reach surface or ground water but merely assesses an indicative risk factor with individual pesticides or cropping systems. It is therefore very important to understand the strengths and weakness of PIRI, which are briefly described below.

1. PIRI is a simple model and does not require modelling skills needed to run a simulation model.

2. PIRI is based on realistic transport processes, such as leaching, transport in runoff water and sediments. These processes are used in a manner that the results are as quantitative as possible.

3. PIRI takes the pesticide use and toxicity into account, which are important parameters but often ignored.

4. The input data needed in PIRI is easily available or can be computed through simple calculations. Most of the data, such as pesticide properties and typical soil properties, are built in PIRI. These data however, can be modified if more reliable data are available.

5. The limited validation of PIRI suggests that the predictions are consistent with observations, as described in the sections above. However, PIRI has not yet been comprehensively tested for a realistic situation or thoroughly validated, mainly due to the lack of pesticide use data.

6. Probably the most important limitation of PIRI is the requirement of specific pesticide input data at a given site or cropping systems, which is currently lacking. This is being addressed in a complementary LWRRDC project for selected catchments.

7. PIRI is not a simulation model but an index based on simplifications of the processes and 'thumb rules'. Therefore the outputs do not represent the absolute risk but a relative risk factor among pesticides or land uses in a catchment.

8. PIRI does not take any pesticide interactions or degradation beyond the point of its entry in waterways, ie. it provides the 'edge of field' scenario.

9. Pesticide properties such as half-life and sorption coefficients (K_d) used in PIRI are based on overseas data. Little local data exist on these parameters. However, as the data become available, these can easily be incorporated in PIRI.

Future R&D requirements

Most effort has so far gone into development and improvement of PIRI. Limited validation of predictions from PIRI indicates that the results from PIRI are reliable. However, a thorough and rigorous evaluation of PIRI is needed.

This is only possible with some reliable data on pesticide use and their off-site migration pattern. This is partly being addressed through the pesticide audits being carried out under a complementary LWRRDC project.

However, for a thorough validation of PIRI a comparison between the predictions from a simulation model and those from PIRI needs to be carried out for some selected locations. Once validated, PIRI should be applied to selected catchments to (i) identify the practices which are likely to result in a greater potential of pesticide impact on water quality and (ii) evaluate management options in terms of their contributions in minimising pesticide impact in riverine environment.

Acknowledgment

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17. Practices for minimising spray drift and dust

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Summary

Adopting a range of integrated strategies can reduce the off-target, downwind transport of endosulfan by means of spray drift and dust movement. Field experiments have shown that by selecting appropriate wind vectors, adopting large droplet placement (LDP) application techniques and creating in-crop buffer distances on the downwind sides of sprayed areas, the off-target droplet movement of sprays can be reduced. Such technologies benefit from being incorporated into holistic best management practices that encourage risk assessment and the selection of the most appropriate case specific mitigating strategies.

Introduction

A comprehensive series of studies undertaken over the last five years has established that the normal application of ultra low volume (ULV) pesticides has the potential to contribute to endosulfan loads in the riverine environment. With ULV application, approximately 14 % of the applied dose † was found to move across the downwind edge of a field (LWRRDC Project UQL 13, 1998).

† figure is a percentage of that applied to a 500 m wide field

This paper outlines mechanisms and management strategies that can be undertaken by cotton growers and applicators to reduce these levels and retain greater proportions of pesticides within the intended target area.

The objective of the study was to develop effective drift management strategies to reduce off-target spray drift by droplet manipulation and the use of buffer distances, both within and external to the crop.

Methods

Computer modelling

When a pesticide spray is released over a crop the droplets disperse over the canopy dependent upon their droplet size and the characteristics of the local airflow. Using Gaussian plume dispersal algorithms, spray deposits from the single pass of a sprayer can be sequentially overlapped to demonstrate how a ULV spray pattern is built up over a field, (Figure 17.1.).

Such an analysis shows that the resultant dose deposited within a crop canopy is formed by the overlap of numerous swaths. If spraying is conducted strictly between the boundaries of a field, the upwind edge of the crop is likely to receive less than the required dose.

Figure 17.1. A diagrammatic representation of ULV application showing the sequential build up of deposit across a field and downwind deposition profile.

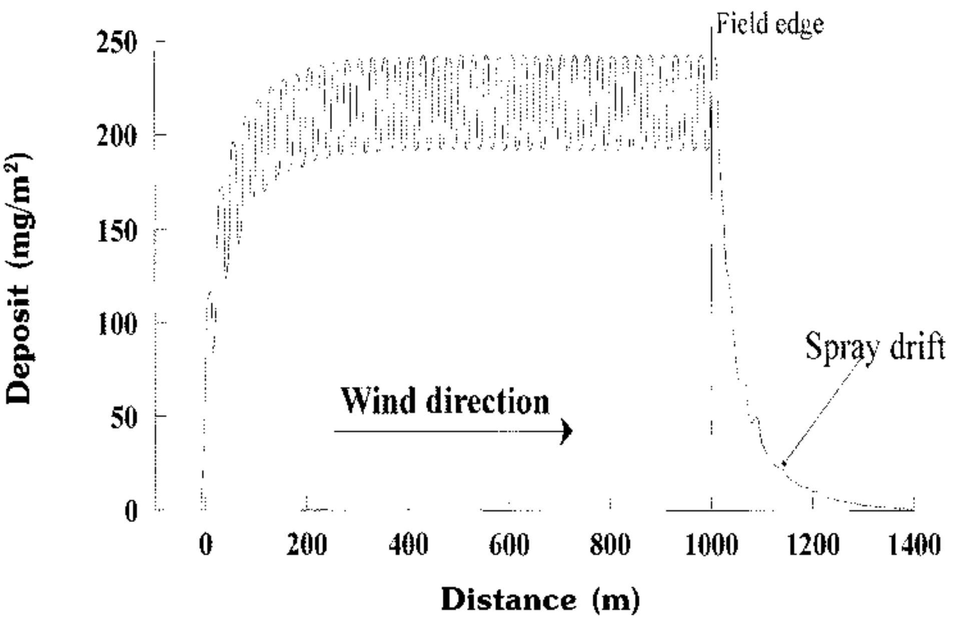
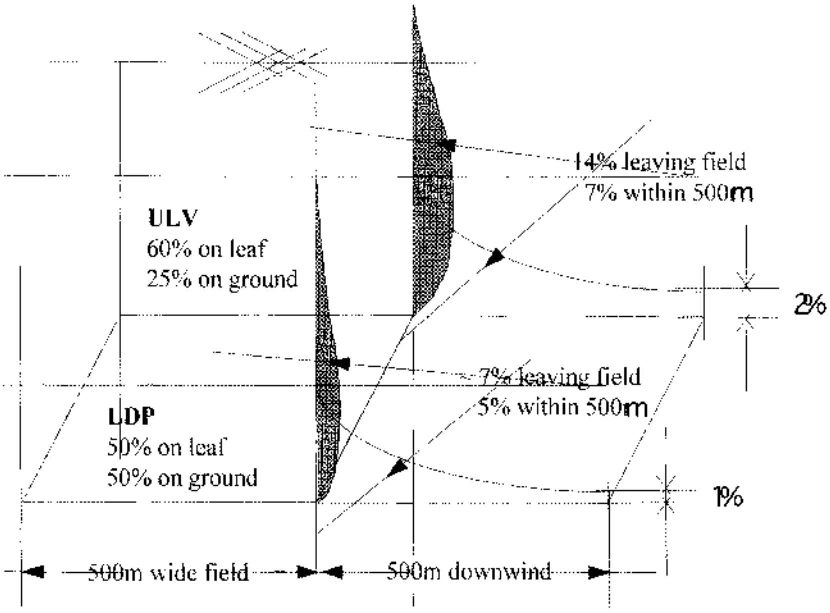


Figure 17.2. Summary of endosulfan transport characteristics



Conversely a downwind tail extending beyond the edge of the downwind field boundary can be expected to form.

Field measurements

A comprehensive monitoring program undertaken to quantify this 'tail' showed that both airborne fractions of endosulfan and downwind deposit levels could be reduced by increasing droplet size and using large droplet placement (LDP) application techniques (Woods et al 1998). This technique however, also caused a higher fraction of the spray to be deposited at soil level beneath the crop canopy, (Figure 17.2.).

Laser droplet sizing

Larger droplet sizes can be obtained by changing Micronair settings to lower cage rotational speeds. Figure 17.3. shows the decrease in droplet size resulting from operating a Micronair AU5000 nozzle at increasing rotational speeds and demonstrates the importance of operating such equipment at correct settings. This graph also shows that droplet sizes, (Volume Median Diameters (VMD)) much above 200 µm were not generated with this nozzle using endosulfan formulations. Of great importance the data shows that both water-based emulsifiable concentrate (EC) and oil based ULV formulations generated similar VMD values.

Significantly greater droplet sizes (VMD) can be obtained by using some large orifice hydraulic nozzles. Work conducted in conjunction with Spraysearch Victoria, showed that VMD values greater than 200 µm can be obtained, particularly when slower aircraft are used (Figure 17.4.).

To obtain larger droplets, nozzles must be angled back at 180 degrees to the flight direction. When larger droplets are generated, higher volumes of carrier (usually 30 L/ha+) should normally be used to ensure that sufficient coverage of targets is maintained.

Figure 17.3. Droplet size (Volume Median Diameter) generated by a Micronair AU5000 applying two formulations of endosulfan (ULV and EC) at two airspeeds (100 and 130 knots)

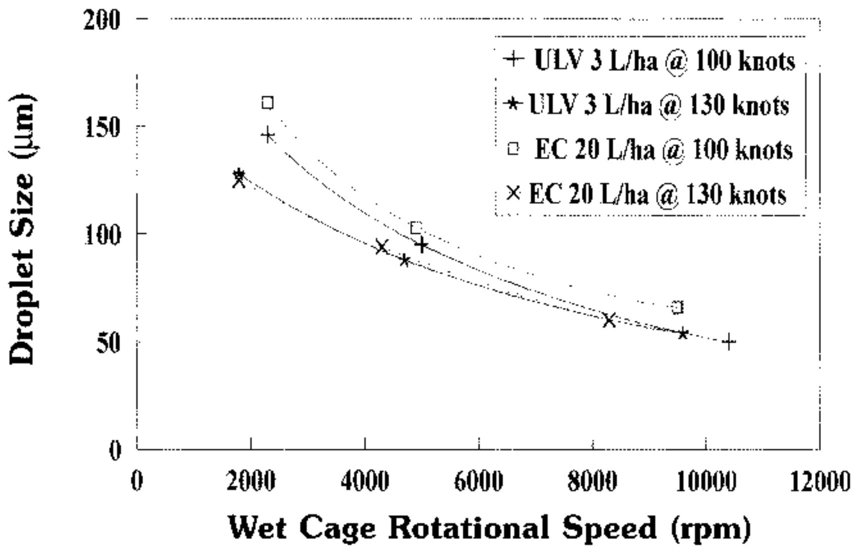


Figure 17.4. Hydraulic nozzle droplet size data. Measurements were made using a Malvern 2600 laser diffraction analyser in a 100 knot airstream

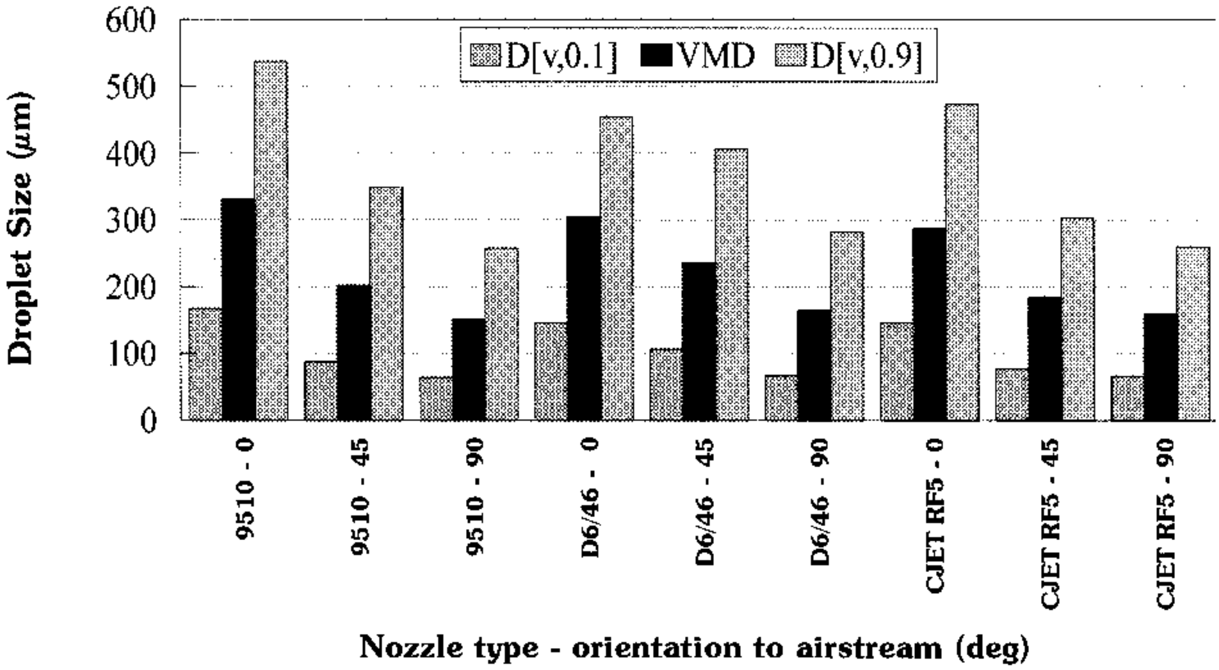
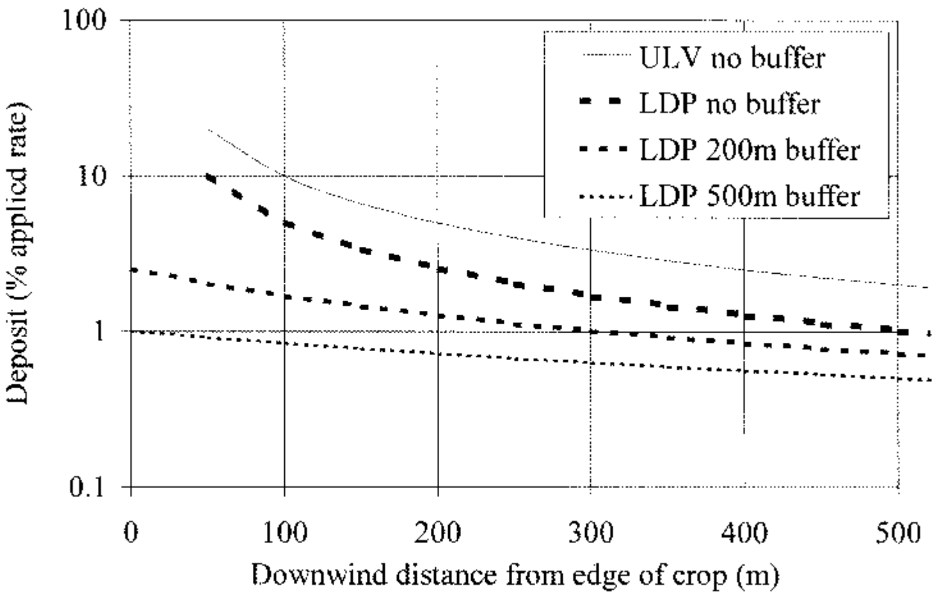


Figure 17.5. Predictions of combined effect of using a LDP spraying technique and an in-crop buffer distance.



Drift mitigation

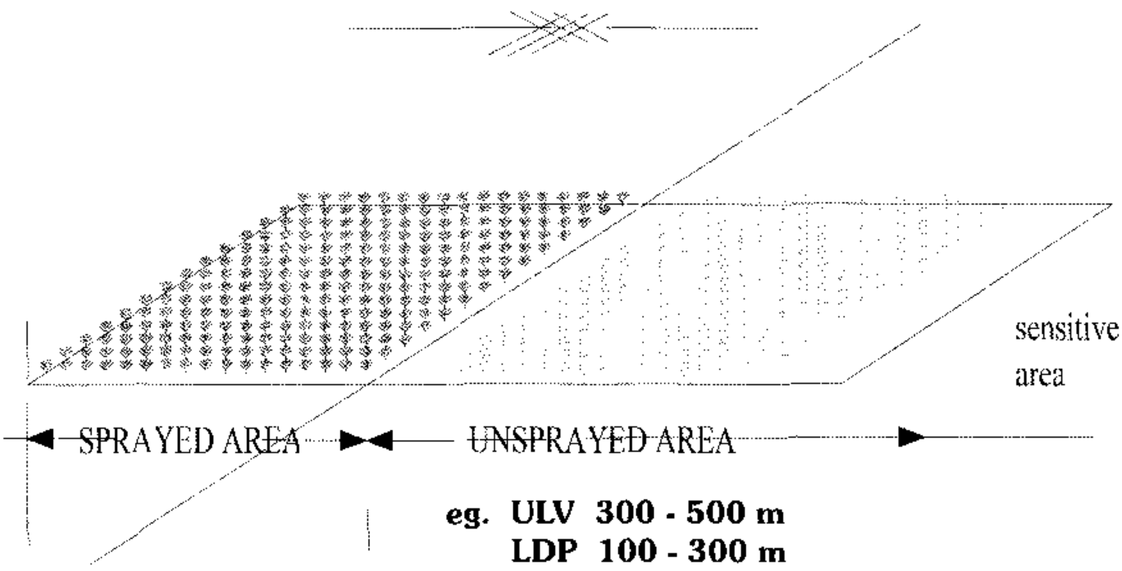
Since downwind deposit curves decay with distance, reductions in down wind deposit levels can be maximised by creating an in crop buffer distance and off-setting the last runs of an agricultural aircraft on the downwind side of a field. By extrapolating the data using a simple empirical model, predictions of the combined affect of adopting an LDP and in crop buffer distance can be made (Figure 17.5.). For example, by using LDP spraying technology coupled with an in-crop buffer distance of 500 m, off target deposition 100 metres downwind of a sprayed field can be reduced by approximately 10 times compared to ULV application without a buffer.

Downwind buffer distances can be designed according to the characteristics of a particular pesticide and the local environment. A typical scenario is illustrated in Figure 17.6.

Discussion

Large droplets and in-crop downwind offset buffer zones can reduce both airborne and deposit drift values. However such strategies should always be used in conjunction with other techniques. The use of single strategies may not be sufficient on their own to have a significant effect on pesticide drift management.

Figure 17.6. Possible buffer zone design.



To supplement the adoption of LDP techniques and the use of in-crop offset buffer distances, some important supporting drift mitigation procedures are summarised as follows.

Planning and pre-spray

1. Identify all areas around an area to be sprayed that could be susceptible to spray drift damage.
2. Communicate on a regular basis with neighbours regarding proposed spray schedules and activities.
3. Maintain copies of relevant material safety data sheets (MSDS).
4. Read, understand and heed the pesticide product label prior to spraying.

Meteorology

1. Observe and record wind direction, wind speed, temperature and humidity prior and during application.
2. Avoid spraying when wind is blowing towards susceptible areas
3. Spraying should not be undertaken if the wind is light and variable in strength or direction
4. Spraying of water-based sprays should be undertaken when temperatures are the lowest, (in a 24 hr cycle)
5. Spraying of water-based sprays should not take place under conditions of high temperature and low humidity
6. Spraying should ideally take place when atmospheric conditions are neutral
7. Spraying should not take place during highly unstable conditions
8. Spraying should not take place during highly stable conditions or when surface temperature inversion exists.

Application techniques

1. Where appropriate, spraying should be undertaken on the upwind section of a field, such that the unsprayed downwind section is used to retain spray drift (field splitting)
2. Spraying should, where possible, be carried out with a crosswind, and progress upwind
3. Sprays should be applied when aircraft are straight and level above a crop
4. Smoking devices should be used to monitor changes in wind direction and stability
5. Ensure aircraft are correctly calibrated and optimum flight lane separations are used

Dust mitigation

1. Locate unsealed roads greater than 100 metres from sensitive areas
2. Prevent cultivation and if necessary close roads for three days after spraying where areas are located less that 100 metres upwind of sensitive areas
3. Reduce road speeds and cultivation speeds on sprayed areas
4. Where necessary, reduce wind erosion on unsealed roads by watering, grading and ripping and adhesive application (Leys et al 1998)

Conclusions

Analysis has shown that the off target downwind deposition falls to approximately 1 to 2 % of the applied dose within 500 metres for ULV spraying, and about 250 metres for LDP spraying.

By adopting LDP techniques and using a correctly calibrated aircraft to apply large droplets (and by necessity, higher volumes of carrier and water-based formulations), airborne and deposit drift fractions can be reduced.

The concept of variable in-crop buffer zones on the downwind sides of sprayed areas should be adopted in conjunction with other recognised strategies to successfully manage pesticide drift.

Further research

1. Data from this project has implied that spray drift from ULV and LDP application may not be significantly different at distances beyond 500 metres. Work is required to measure and monitor drift levels present from 500 metres to about 3 km downwind and to establish control mechanisms.

2. This study has shown that although spray drift can be reduced, elimination is not possible using existing nozzle technology. The cotton industry needs a nozzle that can generate droplets approximately 250 µm in diameter (VMD) without the production of significant fines (droplets less than 100 µm). If this could be achieved, LDP application could be optimised and the off target movement of insecticides significantly reduced.

Acknowledgements

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18. Exploring farm design and management options with modelling

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Summary

We used the GLEAMS model to evaluate the effectiveness of a range of farm design and management options aimed at reducing the amount of endosulfan in runoff. Stubble retained was the most effective field management scenario for reducing endosulfan transport off-field. Improved irrigation practice, no irrigation and reduced sprays each reduced transport compared to conventional practice, but field management alone still allowed some endosulfan transport in runoff from the field. Most transport from the field could be captured with a 30 to 50 mm capacity storage when water was held for three days. Less storage capacity was required when runoff was minimised by good field management. The rainfall environment influenced runoff, with more intense daily rainfall leading to larger runoff events and more endosulfan runoff.

Introduction

This paper presents results of the program project QPI22 'Application of models to estimate transport of pesticides from cotton production systems'.

The objectives of this project were:

1. To develop a capacity to predict the major interactions between climate, crops, soil and pesticides on the mass of endosulfan transported from cotton systems.

2. To link data from field and laboratory studies of soil, water and endosulfan movement to allow a more complete analysis of these experimental analyses.

3. To simulate the relative effectiveness of various management practices in reducing transport of endosulfan from cotton systems, and evaluate the risk of endosulfan transport over periods of 50 to 100 years.

To address objectives 1 and 2, a simulation framework was developed and tested. We used the GLEAMS model (Leonard et al., 1987) and parameterised and tested it for Australian conditions. Measured data from rainfall simulator and field studies were used to parameterise and test the model. Experimental data was taken from the following program projects: QPI21, 'Rainulator studies of pesticide movement from agricultural production systems', QPI23, 'Pesticide transport from cotton production systems — Queensland site', and USY3, 'Transport and fate of pesticides in cotton production systems — NSW field site'.

Once GLEAMS was set-up and tested, the effects of a range of management treatments on endosulfan transport from cotton farms in Queensland and New South Wales was simulated. The simulations were made for periods much longer than could be measured experimentally, a key benefit of this modelling study.

In this paper, we concentrate on presenting results of the modelling. We particularly stress the usefulness of the model results for evaluating the relative effectiveness of various farm design and management options aimed at reducing transport of pesticide in runoff.

Methods

GLEAMS was parameterised and validated using measured data from rainfall simulator plots and field studies at sites in Queensland (Hopsons, Field 5) and New South Wales (Auscott Warren, Field 4). The ability of GLEAMS to represent time variation in soil endosulfan concentration, soil water, crop growth, runoff, sediment and endosulfan transport was tested. Data for parameterising and validating GLEAMS was available from rainfall simulator plots and field studies at both sites.

Model accuracy was tested by comparing measured observations with predictions. In general, the model was capable of representing the important processes operating at the farm scale, and accounting for the influence of change in management on runoff and pesticide transport. Once validated, GLEAMS was used to simulate effects of management at the field scale on runoff and endosulfan transport. A simple on-farm storage system was also simulated to evaluate the effectiveness of storage in reducing endosulfan movement off-farm.

The scenarios simulated for the Queensland and New South Wales sites were:

1. *Conventional* — cotton stubble raked and burned after picking, and tillage used to control weeds and prepare hills for planting.

2. *Stubble retained* — maintaining about 40 % stubble cover throughout the cotton growing season, either by retaining cotton stubble from the previous season or from a winter cover crop.

3. *Improved irrigation* — an irrigation strategy that applied irrigation without tailwater.

4. *Dryland* — no irrigation.

5. *Reduced sprays* — reducing the number of endosulfan sprays from ten to five for the Queensland site, and three to one for the New South Wales site.

On-farm storage was represented by storing runoff, pumped at a specified daily rate, until the storage capacity was full. Stored water was released after a specified duration with no additions to the storage, at a specified release rate. Endosulfan concentration was assumed to have declined sufficiently during storage to allow safe release.

To evaluate the effect of climate on runoff, the conventional scenario at the New South Wales site was simulated using the Queensland site's rainfall and irrigation. All other characteristics of the New South Wales site (such as other aspects of climate and soil type, agronomic and spray operations) were held constant.

Figure 18.1. ***Typical endosulfan concentrations on soil at the Queensland and New South Wales sites for the 'conventional', 'stubble retained' and 'reduced sprays' scenarios.***

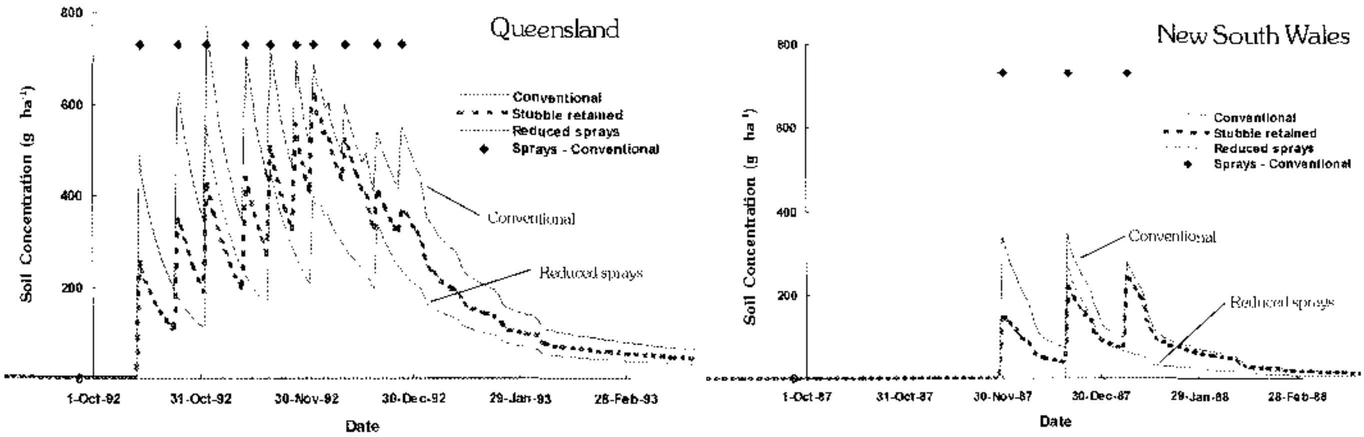


Figure 18.2. ***Average annual runoff and endosulfan transport from the field at the Queensland site***

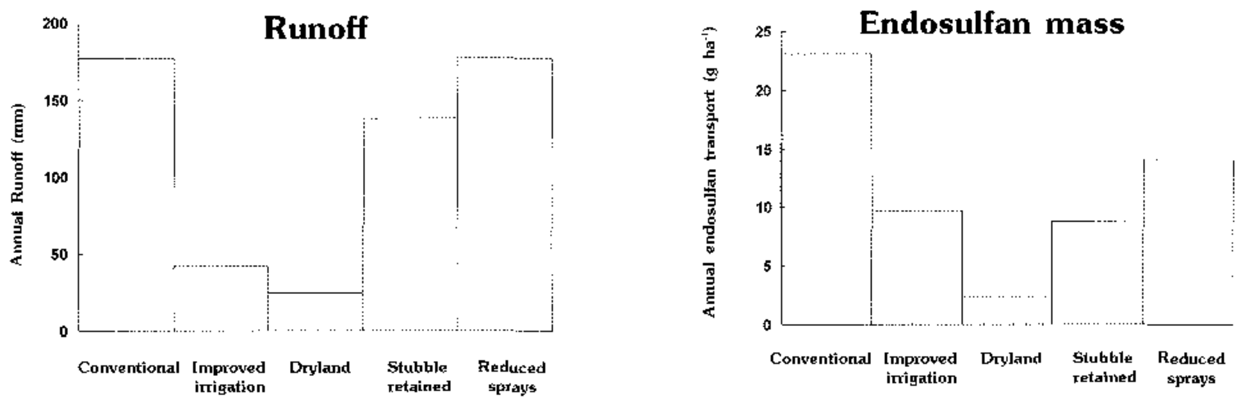


Figure 18.3. ***Average annual runoff and endosulfan transport from the field at the New South Wales site.***

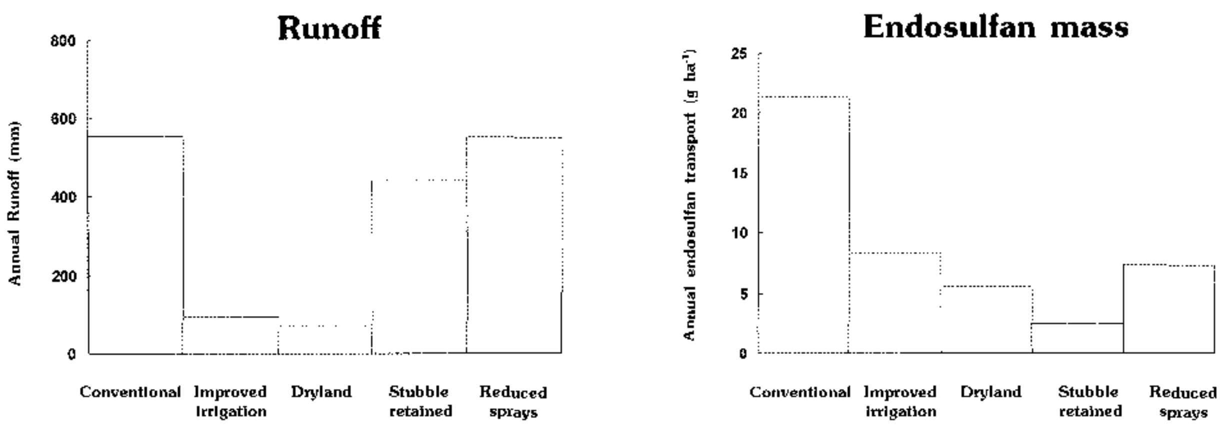


Figure 18.4. Daily endosulfan mass and concentration likely in runoff from large events at the Queensland site. Top and bottom of the thin bars are the 1:30 and 1:1 year probabilities, top and bottom of the thick bars are the 1:10 and 4:5 year probabilities.

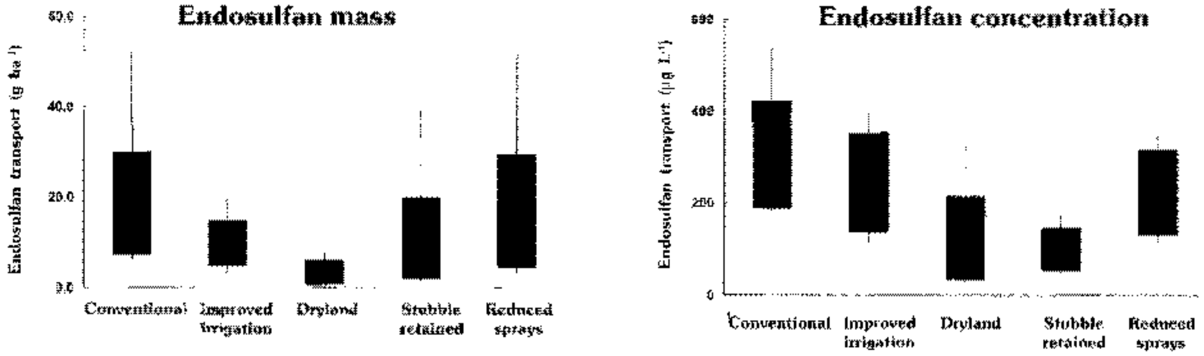
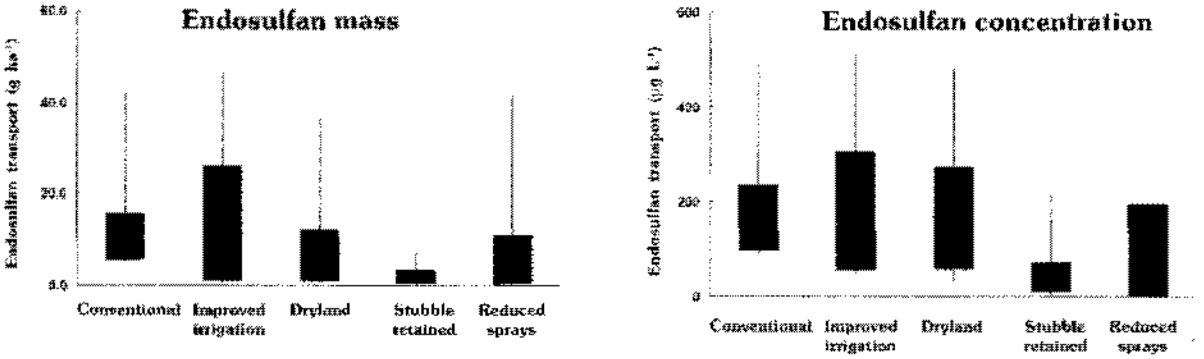


Figure 18.5. Daily endosulfan mass and concentration likely in runoff from large events at the New South Wales site. Top and bottom of the thin bars are the 1:30 and 1:1 year probabilities, top and bottom of the thick bars are the 1:10 and 4:5 year probabilities.



Results and discussion

Annual runoff and endosulfan transport off-field

In general, the simulations showed that the New South Wales site produced more runoff than the Queensland site (Figures 18.2. and 18.3.). This increased runoff was due to a combination of greater irrigation amounts and lower soil infiltration capacity. Between 0.3 % (Conventional) and 0.1% (Dryland) of endosulfan applied at the Queensland site each year was transported off the field. Between 1 % (Conventional) and 0.1 % (Stubble retained) of applied endosulfan was transported off-field each year at the New South Wales site.

The Improved irrigation scenario was effective in reducing runoff and endosulfan transport, mainly by reducing the amount of excess irrigation. However, the reduction in endosulfan transport did not fall in proportion to the reduction in runoff. Even though excess irrigation was reduced, runoff from rainfall still accounted for a significant proportion of endosulfan transport. Runoff from rainfall events, particularly large events, tended to contain high endosulfan loads (see Figures 18.4. and 18.5.).

The Stubble retained scenario was the most effective scenario for reducing endosulfan transport. Cover reduced runoff volumes in most events by increasing infiltration. Stubble retention increases the tortuosity of water flow, thus reducing detachment and transport of sediment. In addition, the amount of endosulfan available on the soil for transport in water was less than scenarios with relatively bare soil surfaces because endosulfan was assumed to contact the soil and vegetative matter in proportion to the vegetative cover.

Reduced sprays at the New South Wales site reduced endosulfan transport in proportion to the spray reduction, that is: two thirds. This indicates soil concentration limited the amount of endosulfan transport at this site. A 50 % spray reduction at the Queensland site only led to a 30 % reduction in endosulfan transport, suggesting movement in this environment was limited by transport potential of runoff rather than soil concentration.

Runoff and endosulfan transport off-field with large daily events

Figures 18.4. and 18.5. present a summary of a partial series analysis of daily endosulfan transport and endosulfan concentration in runoff from the 30 largest events in the 30 year simulation. The amount of endosulfan transported in large runoff events at both Queensland and New South Wales was very high. Conventional scenarios had the greatest rates of endosulfan transport. An event with a 3 % chance of exceedence with conventional management (1:30 year) could transport 40 g ha^{-1} in a single day, more than the annual average, with a concentration in runoff exceeding 500 µg L^{-1}.

Even in a 1:1 year event, daily endosulfan masses of 5 g ha^{-1} and concentrations of 100-200 µg L^{-1} were predicted for the Conventional scenario. The partial series analysis used here only considered the 30 largest events, so small events are not included in Figures 18.4. and 18.5. Many small events, particularly those resulting from irrigation, would have concentrations much less than 100 µg L^{-1}

Management scenarios that reduced irrigation amounts (Improved irrigation and Dryland) were effective in reducing endosulfan transport at the Queensland site, even for large runoff events.

At the New South Wales site though, reduced amounts of irrigation did not reduce endosulfan transport in large events because of this soils very high runoff potential (curve number = 90). In the case of the Improved irrigation scenario at the New South Wales site, the magnitude of large events increased; irrigation was applied more frequently with the Improved irrigation scenario, consequentially runoff potential was even higher than with the other scenarios.

The magnitude of small events was reduced with irrigation management at both sites, resulting in lower average annual runoff. The Stubble retained scenario reduced endosulfan mass and concentration in runoff from both sites for all size events. This was consistent with reduced soil endosulfan available for transport and lower soil transport capacity of runoff. High amounts of endosulfan were transported in the largest events with the Reduced sprays scenario, indicating that, in the long term, large storm events will most likely occur close to a spray operation, regardless of how many sprays there are. Transport in the more frequently occurring events (4:5 years) was reduced when number of sprays was reduced because of generally lower soil concentrations.

Impact of on-farm storage on endosulfan transport off-farm

Figures 18.6. and 18.7. show average annual runoff and endosulfan transport with increasing storage capacities when water was retained for three days prior to release. On-farm storage was particularly effective for management scenarios that reduced field runoff, such as the Improved irrigation scenario. Scenarios with less runoff generally left the storage with more capacity available to capture large runoff events.

Figure 18.6. Effect of on-farm storage size on average annual runoff and endosulfan transport from the Queensland site. Runoff from 'conventional'. 'Reduced spray' is identical to 'conventional', and is not shown. Storage duration was three days.

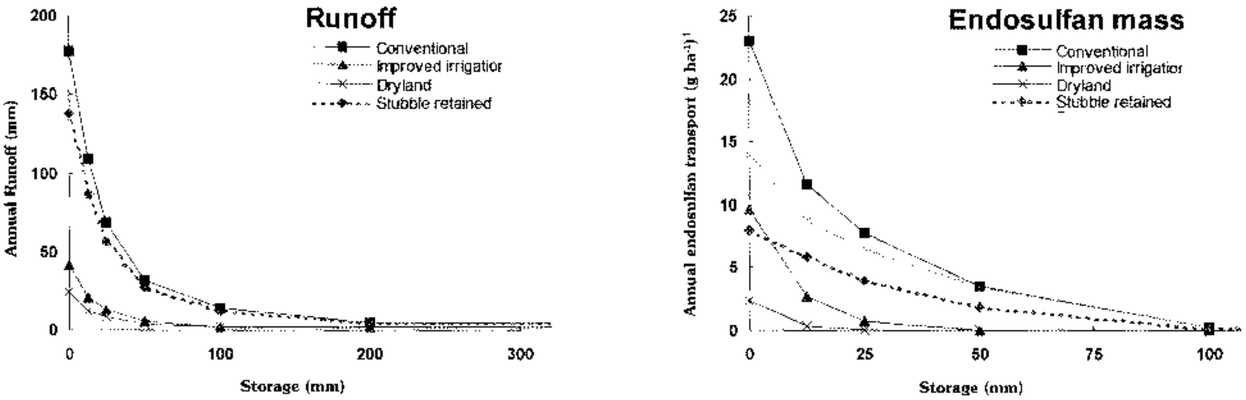
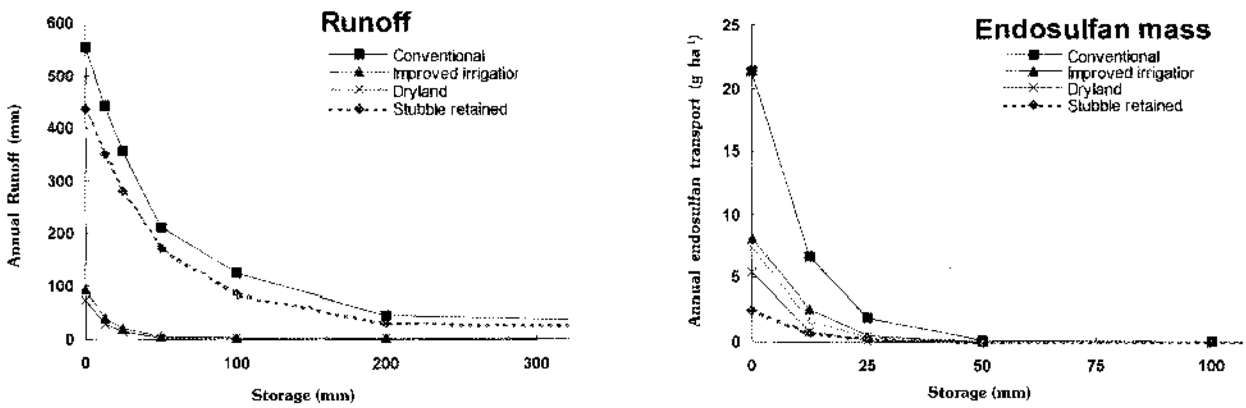


Figure 18.7. Effect of on-farm storage size on average annual runoff and endosulfan transport from the New South Wales site. Runoff from 'Conventional'. 'Reduced spray' is identical to 'conventional', and is not shown. Storage duration was three days.



An impractically large storage was needed to eliminate runoff from all scenarios (more than 1000 mm), though endosulfan transport was almost eliminated with 100 mm storage (three day storage duration). At the Queensland site, a similar amount of storage was required for the Reduced sprays scenario as the Conventional scenario because soil endosulfan concentrations were still high (Figure 18.1.) and runoff was not reduced.

Impact of rainfall environment on runoff and endosulfan transport

To illustrate the effect of rainfall environment on runoff and endosulfan transport, runoff from the New South Wales site was simulated using rainfall and irrigations from the Queensland site (Table 18.1.). Both sites had similar average annual rainfall, but Queensland has more intense rainfall than New South Wales, and less irrigation is applied.

The more intense Queensland rainfall at the New South Wales site markedly increased the magnitude of large runoff events. Even though average annual runoff at the News South Wales site decreased with Queensland's rainfall+irrigations, average annual endosulfan transport increased, consistent with a reduced amount of irrigation but more intense rainfall.

Conclusions

Endosulfan transport off-field and off-farm could be reduced with improved farm management. Retaining cover on the soil surface (increases infiltration and reduces the amount of endosulfan available for transport in runoff) was the most effective strategy for reducing endosulfan transport off-field. However, field management alone was not sufficient to eliminate endosulfan transport off-field, particularly in large runoff events.

On-farm storage had the potential to capture most of the endosulfan transported in runoff from the field, particularly when runoff from the field was minimised with good management. On-farm storage could not realistically eliminate runoff though, as the storage invariably overtopped during periods with extreme runoff. The rainfall environment influenced runoff, suggesting interactions between climate and site characteristics should be considered when evaluating management strategies that minimise agricultural chemical movement in runoff.

Acknowledgements

Funding for this work from the Land and Water Resources Research and Development Corporation, the Cotton Research and Development Corporation and the Murray-Darling Basin Commission in projects QPI21, QPI22, QPI23 and USY3 is gratefully acknowledged. Evan Thomas, Brett Kuskopf, Bob Noble, Chris Carroll, Steve Kimber and Francisco Sanchez-Bayo are thanked for their assistance with data analysis.

Reference

Leonard, R.A., Knisel, W.G., and Still, D.A., 1987. GLEAMS: Groundwater loading effects of agricultural management systems. *Trans. of the ASAE.*, **30**: pp. 1403-1418.

Table 18.1. Effect of the Queensland site's rainfall and irrigations on runoff from the New South Wales site. The Conventional management scenario was simulated.

Site	Annual Average			1 : 10 year	
	Rain and irrigation (mm)	Runoff (mm)	Endosulfan transport (g ha^{-1})	Runoff (mm)	Endosulfan transport (g ha^{-1})
New South Wales	625	24	0.7	21	2.1
New South Wales with Queensland's rainfall	605	43	1.6	42	3.5

19. Techniques for stabilising soil erosion on cotton farms

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Summary

Recent studies of runoff and soil loss from irrigated cotton in Australia are reviewed, with particular reference to techniques for controlling soil erosion by water. Soil loss rates from irrigated cotton in the Emerald irrigation area are typically 4-8 t/ha per year. The only other data available, for the Macquarie Valley NSW, suggest higher soil loss rates (eg. 10 t/ha/yr), due to different soils and/or irrigation practices, even though slopes are much lower. Reasonably large amounts of runoff are typical, 100 - 200 mm/yr in Emerald studies and 75 - 750 mm/yr in NSW studies, with a large contribution from irrigation tailwater, indicating there is considerable scope for improved water management. High tailwater volumes are presumably associated with soils with low infiltration rates and/or long durations of inflow.

Soil loss rates can be substantially reduced by reducing tailwater from irrigation, retaining anchored crop stubble under cotton and/or use of polymers in irrigation water. Recent on-farm trials in the Emerald irrigation area have shown that these practices can be incorporated into profitable irrigated cotton systems at commercial farm scale and provide the expected benefits in reduced soil losses and pesticide transport. Off-field practices, involving trapping sediment in tail-drains and silt traps, also reduce sediment movement off the farm. Further research and, in particular, development is required in irrigation management, integration of stubble retention into cotton farming systems and the concept of 'zonal' farming.

Introduction

In this paper, we review techniques for controlling runoff and soil erosion from cotton furrows and fields, based on research from the LWRRDC/CRDC/MDBC pesticide program (this proceedings). Considerable data on pesticide transport was also collected during these studies, but will not be reviewed here. In summary, management techniques that reduce runoff and sediment transport produce equal or greater reductions in transport of more soluble and more sorbed pesticides, respectively (Silburn and Connolly 1998).

Results are presented for (a) management practices for use within cotton fields, including preliminary results for two recent studies; (b) evaluating practical and innovative management practices to reduce off-farm movement of sediment and chemicals at the commercial farm scale (Waters, 1997); and (c) evaluating off-field options to reduce siltation of drains in the Emerald Irrigation Area (EIA) (Connolly et al. in prep.).

Impacts of soil erosion

Soil erosion can potentially influence natural resources and production through:

1. On-site loss of soil productivity (eg. loss of soil depth, quality and nutrients);

2. Off-site movement of sediment and associated nutrients and pesticides to streams and water bodies; and

3. Siltation of on-farm and downstream drainage systems and infrastructure.

Cotton is often grown on low slopes, deep soils and with high fertiliser inputs. On low slopes (< 1 %) erosion rates are expected to be low and not expected to reduce on-site productivity except on shallow, infertile soils. The general perception has been that erosion is not a major problem in the cotton industry (Yule 1997).

However, actual erosion rates measured from irrigated cotton, only available in recent years, are not as low as may have been expected (see next section), although it is difficult to assess effects on productivity. Given the perception of low erosion rates, there has been little adoption of soil conservative farming practices such as stubble retention. In any case, cotton crops may not provide enough useful stubble (trash) on which to base a stubble retention system for erosion control.

Even though erosion may not be perceived as a major concern, de-silting of eroded soil deposited in drains is frequently required, both on-farm and off-farm in public drains. De-silting public drains in the EIA costs about $200,000 per year. On-farm erosion prevention would greatly reduce this cost (Connolly et al. in prep.). Also silt cleaned from drains may contain pesticides and require special care in disposal. Most importantly, changes in community environmental standards and expansion of cotton during the last decade, including large areas of dryland cotton, mean that better management of erosion and off-site impacts is needed. Increased cost and competition for water will reinforce this, as conservation of water and soil are highly related. In response to these pressures, many irrigated cotton farms capture runoff and irrigation tailwater for re-use, approaching a closed system. However, on many dryland cotton areas runoff from storms drains directly off-site.

How much runoff and soil erosion occurs?

Runoff and soil loss data for irrigated cotton in Australia are reviewed by Silburn (1995) and Silburn et al. (1997) — a summary is given here. The majority of data are from the Emerald Irrigation Area (EIA) on black cracking clays, with studies over the last 12 years (Carroll et al. 1991, Simpson 1997, Waters 1997). Runoff was typically 100-200 mm per year, with a large, but variable component from irrigation tailwater. In dry years all runoff was tailwater, eg. soil loss of 8 t/ha in 94/95. Thus tailwater can make a considerable contribution to soil erosion.

During six years of monitoring, *soil loss from furrows was 4-8 t/ha each year* on slopes of 1-1.5 %, and 5-10 times less on 0.5 % slope. Runoff and soil losses from tail-drain outlets were similar to those from furrows, giving considerable export of sediment into EIA drains. About 60 % of soil lost from furrows was suspended (fine) sediment, which will settle slowly in water and travel long distances in runoff.

Studies in the Macquarie Valley NSW found soil losses from furrows of 10-12 t/ha in a season (data from two fields, for one year; grey cracking clay (Holden 1995), hard-setting red-brown soil (Kennedy 1997). Slopes were 1:1500 or 0.07 %. That is, *soil losses were greater than on the steeper slopes in the EIA*. The reasons for this are not clear, especially when there is a strong response to slope within the Emerald studies. Differences in soil properties (erodibility) and in irrigation practices (flow rate and duration) are likely causes.

Certainly, the large amount of irrigation water used in the case of the hard-setting red-brown soil counteracts this soil's inherent high strength and assumed low erodibility, resulting in total soil losses similar to cracking clays. Silburn et al. (1997) ranked the soils from highest to lowest erodibility - grey cracking clay > red-brown > black cracking clay, based on mean sediment concentrations per unit slope (and very limited data).

Unfortunately, without long term studies of erosion from cotton fields a more realistic assessment of erodibilities, and long term erosion rates, is difficult. The best approach is probably that of Connolly (1997) — combining a reasonably sophisticated model (eg. GLEAMS) and process data from rainfall simulator studies, with short term field data as a 'reality check'.

A wide range in runoff amounts were measured in these studies (70-700 mm/yr), indicating there is considerable latitude to reduce soil erosion by reducing the amount of runoff. Erosion rates are higher than may have been previously expected given the low slope, ie. compared to our experience in dryland cropping.

This is due to the direct contribution of erosion by tailwater, some increased rainfall runoff as the soil is kept wetter by irrigation, and the soil surface being bare. Also at the hill-furrow scale much of the field is actually steep (eg. 50 % slope) although overall the field may be almost level. Under rain a large amount of sediment is generated on these steep slopes. While much of this is deposited in the furrows, the finer sediment will leave the field in runoff.

Review: Techniques for controlling soil erosion

Techniques for controlling soil erosion on cotton farms were evaluated during the LWRRDC/CRDC/MDBC program - 'Minimising the impacts of pesticides on the riverine environment using the cotton industry as a model' (Connolly 1997, Silburn 1997, Simpson 1997) using:

1. Rainfall simulator and furrow scale studies, which provided controlled comparison of a range of practices;

2. On-farm (commercial scale) trials, demonstrating both efficacy and difficulties of a few selected practices when integrated into 'real world' cotton farming systems; and

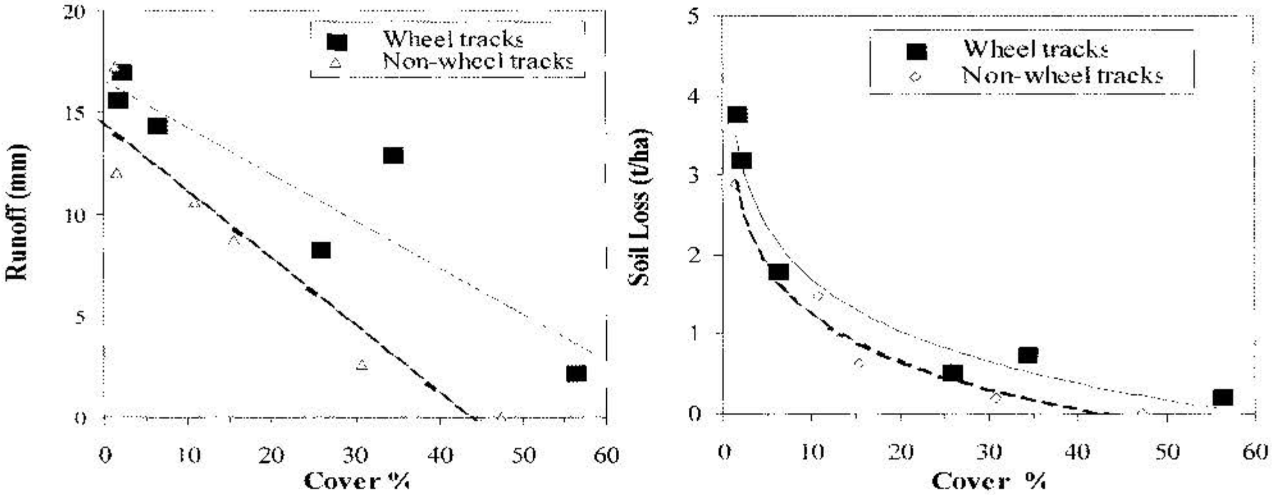
3. Simulation modelling, which has allowed a wide range of combinations of locations and practices, including off-field practices, to be evaluated for much longer periods.

Erosion control techniques involve either preventing erosion at its source within the field or removing eroded sediment from runoff at the edge of, or off, the field, or containing all or part of the runoff.

Table 19.1. Effectiveness of stubble retention on runoff and soil loss from cotton furrows under a storm (40 min at 100 mm/hr) at Warren (Auscott) NSW, on grey/brown clays. Cotton in wheat stubble/cotton sown with minimal disturbance after a wheat crop. Data are means for four-eight furrows.

Treatment	Cover (%)	Runoff (mm)	Soil loss (t/ha)	Sediment Concentration
Bare	< 5	29.4	4.6	15
Cotton trash in furrow	35	15.8	1.1	7
Cotton in wheat stubble	50 - 60	5.4	0.1	3

Figure 19.1. Runoff and soil loss, from 40 min of storm rain, as affected by cover and wheel traffic, under a large rainfall simulator. Black Earth, Emerald, Qld. (Source: Silburn et al. 1995).



(A) Management practices within the cotton field

Soil erosion by water can be controlled by :

1. Managing the amount of runoff. Runoff is reduced by maintaining a soil water deficit (ie. dry soil) so soil has capacity to store rainfall. In dryland cropping, the optimal approach is opportunity cropping or following the rule 'soil water - use it or lose it'. In furrow irrigation, reducing flow rate, cutting back or earlier cut-off of irrigation, thus reducing tailwater volume, will reduce soil loss. Drip and sprinkler irrigation, with no tailwater, will reduce erosion compared to furrow irrigation. Retaining cover on the soil surface and controlled traffic also reduce runoff (Figure 19.1., Table 19.1.).

2. Reducing the concentration of sediment in runoff. Retaining cover on the soil surface is very effective in reducing soil loss (Silburn 1997, Silburn et al. 1995) (Figure 19.1. and Table 19.1.). For furrow irrigation or large runoff rates during storms, cover in the furrows is effective so long as it is anchored (Simpson 1997, Waters 1997).

Use of flocculants, eg. polyacrylamide (PAM), in irrigation water considerably reduces sediment loads, eg. 75 % reduction (Hugo, pers. comm.), but gives variable effects on infiltration and runoff and has little effect during subsequent storms (Hugo and Silburn, unpub. data). Reduced or no tillage alone (ie. without stubble retention) has variable effects on soil loss, depending on soil type, eg. reducing soil loss by 50 % (Holden 1995) to only 12 % (Simpson 1997).

While retaining cover has been shown to be effective in reducing soil erosion, the problem in cotton farming is where to get the cover from. Firstly, it is helpful to make a clear distinction between types of crop residues, in particular between those of cotton and of other crops (Silburn et al. 1997). Cotton trash is dense, woody, generally of insufficient quantity and cover to prevent soil erosion, and must be broken down to allow further cropping operations.

Suitable cover is provided by stubble of other crops, particularly cereals grown prior to cotton. As approximately 50 % of growers now grow cotton in rotation with other crops (John Marshall, pers comm), there is a potential source of useful stubble in some years. Secondly, to be useful in erosion control, cover must be on the soil surface, ie. not buried. To control erosion during irrigation, anchored cover is needed in the furrow; tillage must be avoided, at least in the furrow (see zonal-tillage below).

(B) New results from on-farm erosion control trials

Many practical issues in using these in-field practices are being investigated, and overcome, in on-farm trials. Simpson (1997) found when cotton and wheat cover treatments were tilled twice soil loss was reduced by only 50 %, as there was too little stubble and the unanchored stubble was removed by irrigation.

Photo 19.1.(a). 'Conventional' cotton - no cover, Emerald

Photo 19.1.(b). Cotton in wheat stubble, Emerald

Photo 19.1.(c). Wheat planted with spreader & hills 'chained'

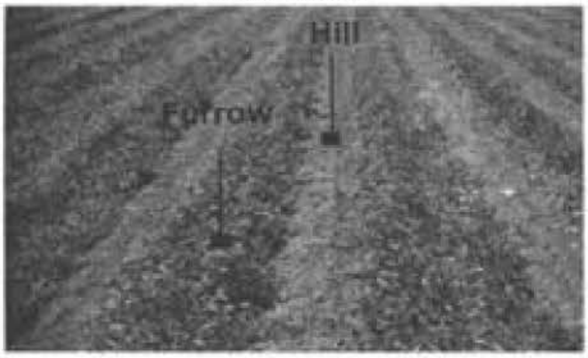


Photo 19.1.(d). PAM applicator in irrigation head-ditch, Emerald

When cotton was planted into wheat stubble without disturbance, soil loss was greatly reduced, eg. during the first irrigation, soil loss was 6.8 t/ha without cover and 0.84 t/ha with wheat cover.

Field trials to evaluate and demonstrate management of erosion and pesticide runoff are now under way on commercial farms (Waters 1997). Irrigation and rainfall runoff, soil loss, nutrient and pesticide samples are collected at tail-drain outlets (30 ha), for wheat stubble/cotton double crop vs conventional cotton (Photo 19.1.(a), (b), (c)). Polyacrylamide (PAM) applied to irrigation water vs conventional cotton (Photo 19.1.(d)).

Wheat/cotton double crop

Wheat stubble/cotton double cropping was successful in the EIA in the 97/98 season. The number of growers planting wheat increased from two to five for the coming season, with potential to double the following season.

Figure 19.2. Soil loss (t/ha) - wheat stubble/cotton and conventional cotton for six irrigations, 1997/98

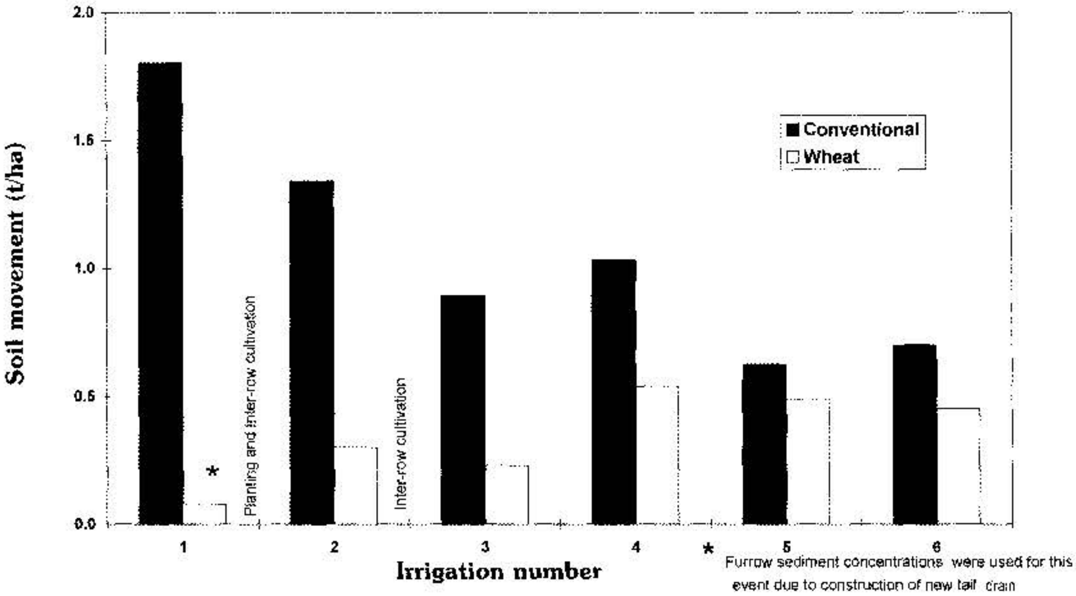
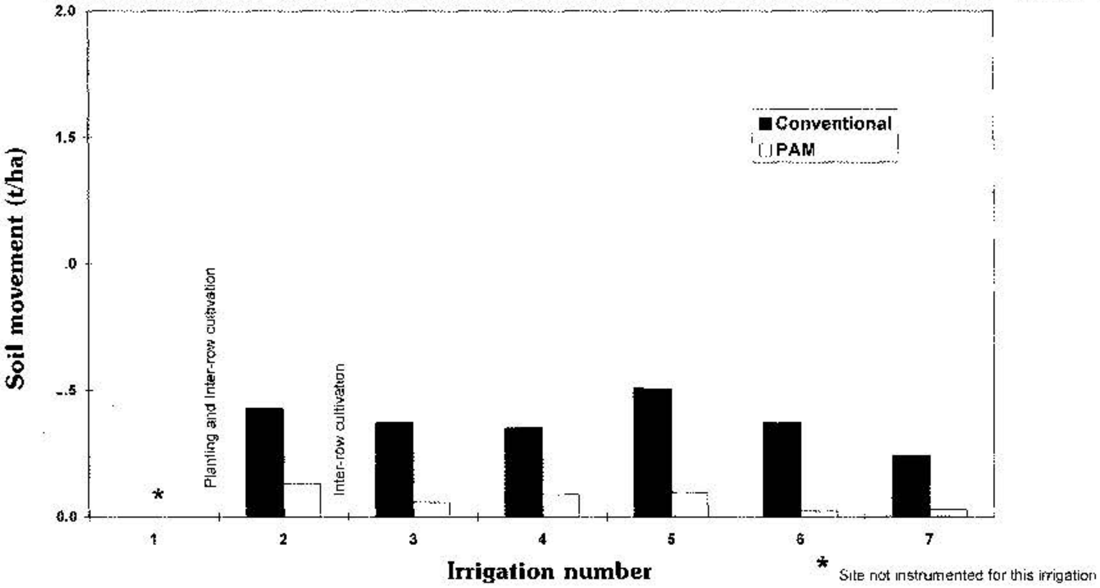


Figure 19.3. Soil loss (t/ha) - Polyacrylamide (PAM) and conventional cotton, six irrigations - 1997/98



Endosulfan sprays were reduced by three on wheat stubble/ cotton compared to conventional, using the usual insect thresholds, ie. insect pressure was lower and predator numbers greater on the wheat treatment. Soil loss from the wheat/cotton treatment was approximately 70 % lower over the season (Figure 19.2.). A similar reduction in pesticide moving off-site on sediment is expected, on top of the reduction due to less endosulfan use.

Polyacrylamide (PAM)

Addition of polyacrylamide (PAM) to irrigation water (Photo 19.1.(d)) reduced soil movement by 70 % over six irrigations relative to conventional (Figure 19.3.).

Soil losses for conventional cotton at the PAM trial were lower than for conventional at the wheat trial (Figure 19.2.), largely due to earlier cut-off of irrigation. The cost of PAM was about half of the cost (saved) of de-silting silt traps. By 1998 there were seven growers using PAM in the EIA. Further development of application techniques and rates is needed.

(C) Off-field storage, trapping and settling

Practices for managing runoff off-field before it leaves the farm, include tail-drain management, use of silt-traps and on-farm storage dams. (Silburn and Connolly 1998, Connolly et al. in prep).

1. Tail-drain management

Changing the hydraulic characteristics of tail-drains can substantially alter movement of sediment. Beneficial changes include reducing tail-drain slope (overall or towards the outlet) or increasing hydraulic roughness by increasing cover.

Steep sections in tail-drains, particularly toward the outlet, can substantially increase sediment movement from the tail-drain. These practices reduce transport of larger sediment sizes and pesticide attached to these particles.

Figure 19.4. (simulated with the GLEAMS model) is an example of effects of cover in the tail-drain compared with conventional (bare field and tail-drain) and other in-field practices.

Sediment movement off-farm was reduced by about half with cover in the tail-drain, for all in-field practices. Cover over the entire field had a large effect as it reduced erosion at its source. Drip irrigation (instead of furrow) gave the least soil loss as it produced no tail-water runoff and reduced storm runoff.

2. Silt-traps and on-farm storages

Sediment transport off-farm (simulated with GLEAMS) was reduced by about 40 % with a silt-trap (Figure 19.4.), for all in-field practices. Silt traps capture larger sediment while fine sediments move through the trap.

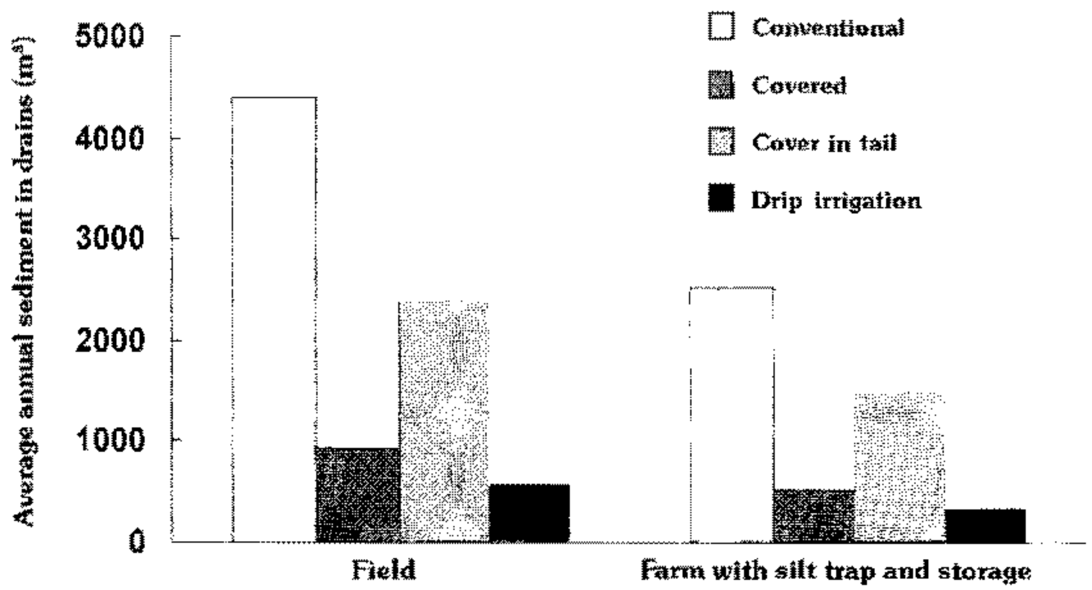
In-field practices that reduce runoff or erosion make the silt-trap more effective and reduce the need for de-silting. On-farm water storages can be used to capture contaminated runoff and hold water for a specified time.

Their use in reducing off-farm losses of endosulfan was evaluated by Connolly (1997) and Connolly *et al.* (this proceedings). Storages for this purpose should be kept empty as much as possible to maximize their potential to capture runoff. Increasing storage size reduced runoff and endosulfan transport off-farm, but very large storages were required to capture most runoff. Thus good in-field management is critical.

Adoption of new practices

Implementing stubble retention in irrigated cotton requires considerable adaptation of technology and solving new problems in irrigation, weed and insect management. Continuous cotton cropping will

Figure 19.4. Effects of in-field and tail-drain management on average annual sediment transport off-farm into LN1 drain (EIA), with and without farm silt-traps. Simulated with GLEAMS (Connolly et al. in prep.)



probably not provide adequate cover for erosion control, as cotton provides a low volume of trash.

However, some 50 % of growers now grow cotton in rotation with other crops (John Marshall, pers comm), providing a potential source of stubble in some years.

Wheat/cotton double cropping used in the EIA on-farm studies are less practical in southern cotton regions, as wheat is harvested later and would delay cotton planting - other options need to be developed.

Ideas that may overcome perceived conflicts between competing requirements are (Silburn et al. 1997).

1. Separating operations according to their different *timing* in the growing sequence, eg. the critical time for erosion control is early in the crop and during irrigation, whereas pupae control is required after picking;

2. Zonal tillage/farming or strip tillage (Marshall et al. 1996a) where different zones of the hill/furrow system are managed for different purposes (Photo 19.1.c.), eg. seedbed, wheel traffic and irrigation/runoff zone (furrow) requiring anchored stubble, and bed side-slope, requiring stubble cover; and

3. Considering the different roles of cotton trash (ie. generally a problem) and stubble (very useful, but where do you get it from). As little crop residue is available for retention after a cotton crop there is no real conflict between stubble retention and pupae busting, which requires reasonably complete tillage after picking Marshall et al. (1996b).

Further R&D required

Development and adoption of practices that are productive and conserve resources need to continue. As shown by the lower insect pressures, higher predator numbers and less insecticide sprays on cotton grown in wheat stubble in the Emerald trials, *there are many unforseen potential benefits.*

Similarly, use of stubble in furrows may improve irrigation, particularly on soils with poorer infiltration and slow 'subbing-up', and reduce evaporation and water use, but this requires further research and development.

In general, our knowledge of erosion rates and erodibilities of cotton soils, and of effects on erosion of furrow slope, length and in particular irrigation flow rates, is poor and limits our ability to optimise management. While irrigated cotton farms are heading towards being closed (runoff) systems, dryland cotton production is practiced over a large area, presumably using similar amounts of pesticides per hectare as irrigated cotton, with little runoff control.

Further research, and particularly development, is required into zonal farming systems and practical systems that provide cover during the early part of the cotton season, for both dryland and irrigated cotton, including double cropping, cover crops and longer rotations from winter cereals (eg. wheat) into cotton.

Conclusions

Soil loss rates from irrigated cotton in the Emerald irrigation area are typically 4-8 t/ha per year. The only other data available, for the Macquarie Valley NSW, suggest higher soil loss rates (eg. 10 t/ha/yr), due to different soils and/or irrigation practices, even though slopes are much lower. Reasonably large amounts of runoff are typical, 100 - 200 mm/yr in Emerald studies and 75 - 750 mm/yr in NSW studies, with a large contribution from irrigation tailwater, indicating there is considerable scope for improved water management.

High tailwater volumes are presumably associated with soils with low infiltration rates and/or long durations of inflow. Soil loss rates can be substantially reduced by reducing tailwater from irrigation, retaining anchored crop stubble under cotton and/or use of polymers in irrigation water. Recent on-farm trials in the Emerald irrigation area have shown that these practices can be incorporated into profitable irrigated cotton systems at commercial farm scale and provide the expected benefits in reduced soils losses and pesticide transport. Off-field practices, involving trapping sediment in tail-drains and silt traps, also reduce sediment movement off the farm.

Further research and, in particular, development is required in irrigation management, integration of stubble retention into cotton farming systems and the concept of 'zonal' farming.

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20. Science, best practice, legislation and environmental performance

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Summary

Modern industries recognise that improvements in environmental performance can be achieved with contributions from science, the adoption of best practice and compliance with the environmental legislation. The Environment Protection Authority (EPA) of New South Wales encourages industries to identify where improvements in environmental performance can be made, and take on the challenge of making those improvements. The cotton industry is an example of an agricultural industry seeking to improve its environmental performance by focussing on each of these important factors.

Introduction

The EPA of New South Wales recognises the need to develop new approaches to environment protection, as well as improving traditional approaches to meet the community's expectations of clean water, clean air and sustainable industry (EPA 1997a).

Modern industries are employing a combination of scientific research and advances in technology, best practice, and compliance with the legislation to achieve improved environmental performance.

The Australian Manufacturing Council (1992) maintains that:

> *"Environmental excellence, which will incorporate changes in management practices, employee participation, adoption of new cleaner technologies, and emphasis on recycling, reuse and recovery, is the means by which industry will move toward sustainability."*

Much attention has been given to the environmental performance, and modern trends such as the move to cleaner production of secondary and extractive industries (EPA 1997b).

Environmental improvements through well-founded industry initiatives are also being made in agricultural industries such as the cotton industry in NSW and Queensland. This paper cites programs involving the cotton industry from a NSW perspective.

Science and industry

Knowledge can come from experience or from the systematic development of knowledge through science (Cullen 1996).

Put simply, the application of scientific research provides a foundation for establishing reliable facts and for identifying and testing the reliability of important trends and relationships.

Industries that have improved and prospered by adopting a strong research and development approach realise the value of utilising science to provide direction and drive improvement in environmental performance.

For example the Australian cotton industry, since its early development in the Namoi Valley of NSW in the 1960s, has used science to improve plant genetics and boost crop production (McHugh 1996).

The science of cotton growing has benefited from significant contributions from the Commonwealth Scientific and Industrial Research Organisation (CSIRO), NSW Agriculture, the Australian Cotton Growers Research Association (ACGRA) and the Cotton Research and Development Corporation (CRDC).

In meeting the challenges of the 1990s to improve environmental performance, the cotton industry has relied on its previous experience with scientific research.

One example is its support for the research program 'Minimising the Impact of Pesticides on the Riverine Environment Using the Cotton Industry as a Model'. This program seeks to guide improvements in the cotton industry in relation to the implementation of best practices procedures and legislative compliance.

The program, jointly conducted by the Land and Water Resources Research and Development Corporation (LWRRDC), the Murray-Darling Basin Commission (MDBC) and the CRDC, aims to provide a scientific basis for achieving these outcomes.

Best practice and industry

The Australian Manufacturing Council (1992) maintains that while best practice is not amenable to simple definition, it is a strategy for organisational change, which represents the application of technology to all manner of environmental issues in order to achieve optimum outcomes by balancing continuous improvement and cost.

As many industries move towards the adoption of best practice the cost to industry becomes more important. Industries committing funds for environmental protection want to know that the dollars spent will achieve the outcome sought. In NSW the EPA is working towards the best environmental outcomes at the least cost to society by taking an integrated view of all resources (EPA 1997a).

Best practice, along with compliance with the environmental legislation, allows industries to reach the expectations of the community that has arisen since the 1980s. Over 90 percent of respondents in a survey of NSW industries agreed that the general public in NSW expects industry to continue to improve its environmental performance (EPA 1997b).

Environmental guidelines providing information about good operational design and management is not a new idea and represents an earlier version of the concept of Best Practice. The State Pollution Control Commission's 'Environmental Guidelines for Intensive Piggeries' published in 1979 is an early example of guidelines for an agricultural industry to assist in adopting the Best Practice of the day.

The beef feedlot industry is an intensive agricultural industry which has a history of working towards meeting environmental guidelines and Best Practice (NSW Agriculture et al. 1995). In the case of the feedlot industry, accreditation is a part of its application of Best Practice for all parts of the industry.

The Best Management Practice Manual for the cotton industry which has resulted from the LWRRDC/MDBC/CRDC program is an indication that agricultural cropping industries can progress in a similar manner.

Legislation and industry

Industry is required to operate within an environmental legislative framework. However, the relationship between a legally compliant operation and benefits from good environmental performance is only now being understood.

A recent industry survey found that legal requirements was the dominant reason for making environmental improvements offered by primary and secondary industry (EPA 1997b). Interestingly, the same survey respondents rated financial benefits, enhanced public image, improved staff morale, and better products and competitive edge, above avoiding fines or penalties as the significant advantages gained from improving environmental performance. There is little doubt that good environmental management is good business.

Whereas industry initially believed meeting legal requirements was the goal, it is apparent that the real advantages can be more expansive. In the case of the cotton industry, the experience of others may point the way towards achieving broader goals, such as improving the community perception of the industry and improving the industry's market image.

Legislation too is changing in line with changing community expectations and changing industry performance.

Recent changes in legislation relate strongly to performance based regulation. Typically, performance based regulation specifies an outcome, but the means or process to achieve the outcome is not prescribed, allowing industry to develop the means to achieve the end or select from methods already available.

Load Based Licensing within the framework of the new Protection of the Environment Operations Act 1997, and the principles of cleaner production, is a recent initiative whereby industries are being encouraged to provide the solutions to their industry specific challenges.

Performance based regulation is most appropriate where:

1. A range of acceptable solutions is possible;

2. It is possible to explicitly state the desired outcomes/ objectives;

3. Prescription would stifle innovation; and

4. There are clear assessment criteria and efficient methods of demonstrating compliance.

Performance based regulation has similarities with Best Practice in that both seek to achieve the best environmental outcome which is economically achievable. The factors listed above for performance based regulation also have applicability for Best Practice.

The relationship between best practice and legislation

The successful application of best practice should enable an industry to comply with the environmental legislation under which it operates. In NSW the adoption of best practice does not provide a person or commercial entity with protection from prosecution should the legislation be breached. However, the adherence to best practice may be relevant in mitigation in any court proceedings and most likely avoid breaches in the first place.

Achieving environmental improvement

Industries keen to make environmental improvements need to be aware of the advantages of pursuing best practice, and depending on the industry, complying with performance based regulation and the environmental legislation of NSW.

Additionally, the role of scientific research and technological improvements, where applicable, should also be strongly considered.

In the 1990s the Australian cotton industry has responded to concerns about its use of chemicals and potential impacts on the environment and community, by embarking on scientific research, adopting best practice and seeking to comply with the relevant environmental legislation.

In the case of the cotton industry, the best practice approach has been chosen for implementation. The principles, however, are not dissimilar to performance based regulation, in that desirable environmental outcomes are the goal.

If best practice is successfully implemented and audited, the cotton industry could expect to achieve improved environmental performance. In order to reach this goal the industry will need to ensure that best practice is adopted by all cotton growers, and that the initiative involves the poor performers as well as those growers already motivated to seek improvements.

Conclusion

Environmental improvement by industry depends on the industry's capacity for change and willingness to meet new challenges. In NSW the community has a high expectation of industry in achieving improved environmental performance. In the case of the NSW cotton industry, compliance with the State's environmental legislation is a requirement, and the use of scientific research findings and best practice, to do better from an environmental perspective, is the challenge.

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21. The Australian cotton industry's Best Management Practices Manual

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Introduction

Two years ago, the first draft of the Best Management Practices Manual for Minimising the Impact of Pesticides ('Manual') had just been released. It was a booklet of some 70 pages, which listed a number of practices (with some details explaining the reasoning behind the practice), under four major headings.

Apart from comments on some of the technical issues contained in the draft, and queries over the use of 'mandatory' language in the best practice statements, there were three issues which were raised consistently. These were:

1. How do we use it? How do we prevent it from being filed away as yet more information?

2. What about the parts that don't apply to my farm? – if a particular practice was not seen as relevant, then given there was (initially) no mechanism to account for that, there was potential for the credibility of the entire document to suffer.

3. How is compliance going to be checked? How is the industry going to know that the practices are actually being adopted?

It was therefore clear that the structure of the Manual needed to be improved so that these issues could be addressed. It is essential that any best management practices manual really is a manual, that is something that is used (not just read), as the word manual implies. A collection of statements, no matter how accurate or sound need to exist in some sort of framework whereby they can be used by a farmer on his farm.

Structure of Manual

The solution was to adapt a successful concept developed in the United States, and utilised extremely effectively in Ontario, Canada. The core of the expanded manual is a series of self-assessment worksheets, which enable farmers to assess and document their own operation, based on the best practice guidelines and against a series of risk rated examples.

These worksheets then lead to the development of action plans designed to minimise the risk in areas highlighted as being of high risk during the self-assessment process. However, self assessment sheets can't hope to be comprehensive, and aim to only highlight the most critical issues. For farmers who want to take the development of best practices further, there is a process of hazard analysis described, which allows farmers to identify in detail issues for their own farm.

Self-assessment worksheets

The initial stage of the Manual leads the farmer through a series of self-assessment worksheets, which are grouped under four main headings: farm design and management, pesticide application, integrated pest management and pesticide storage and handling. Issues relevant to each heading and relating to the risks associated with the use of pesticides are highlighted on the self-assessment worksheets (see Appendix 1 for a worded example).

Each of these self-assessment worksheets is designed to allow the cotton farmer to assess and rank the potential risks on their farm relating to the use of pesticides. These risk-rankings are then used to identify high priority areas for the development of action plans that will help minimise that risk.

The self-assessment worksheets are based on the self-assessment concept developed by Farm*A*Syst, Madison, Wisconsin. Their help and support is gratefully acknowledged.

The rankings go from low to moderate to high to extreme (from 1 to 4), and designed to provide an indication of the relative risk that may result from an activity in the given circumstances. Thus a ranking of 1 for a particular issue means that that issue poses a relatively low risk; rank 2 could be a moderate risk; rank 3 a high risk and rank 4 a more extreme risk.

Rankings of 3 to 4 mean a higher level of risk, and any issue which attracts these rankings are prioritised for the development of action plans to reduce the degree of risk.

Hazard analysis

Although the self-assessment worksheets address a number of important issues relating to pesticide use in the cotton industry, they are by no means complete or exhaustive due to the broad complexity of the farms, operating conditions and practices existing in an industry as diverse and sophisticated as cotton.

Thus a framework which will assist cotton farmers to identify all the critical issues they face on their own farm, leading to the development of a more comprehensive farm plan (in effect a farm specific set of best management practices) has also been included in the Manual. This framework takes the form of hazard identification and analysis (see Appendix 2 for a worked example), and is designed to break down the task of establishing farm specific best practices into a series of steps which are manageable.

The starting point is to list the activities which occur on a cotton farm and then identify the hazards associated with these activities and for which best management practices will be developed and applied. Rather than provide a prescriptive set of practices users are guided to develop their own best management practices and check these against some standard issues (included in the Manual). This process alerts people to the key issues and the potential problems while allowing them to develop a set of practices with accompanying monitoring systems which suit their specific circumstances and operations.

Planning

The key to success in using the Manual is in developing action plans (see Appendix 3 for a worked example) for those areas or issues identified as posing a significant risk. Once the self assessment sheets (and the hazard analysis if applicable) have been completed, those areas requiring attention have been identified and ranked. The solutions chosen for the identified risk areas are documented, as are the monitoring and review processes implemented to evaluate the effectiveness of the plans, together with the person responsible for seeing the plan is implemented.

Supporting documentation, which provides some guidelines or management options for the development of action plans, is included in the form of 'Best Practice' booklets. Further resources to assist cotton farmers in their planning process are also listed under each self-assessment heading, including other published material and relevant legislation.

The Manual provides a flexible framework for cotton farmers. It recognises that cotton farming takes place under a wide range of environmental, commercial and social conditions. These varying conditions may place differing constraints on a cotton farmer. By using a planning framework, cotton farmers are able to identify any particular constraints that they may be operating under, and then plan the most appropriate method for them of overcoming that constraint. By using the Manual, cotton farmers will be developing practical farm plans which minimise any impacts of cotton farming on the environment, as well as demonstrating their commitment to responsible resource management.

The Manual therefore has two distinct components, one addressing the best management practice guidelines, while the second is directed at providing cotton farmers with a framework they can use to document and plan the environmental aspects of their farming operation. In fact, BMP could just as easily stand for best management planning as for best managment practice.

This planning framework aims to provide a flexible process that will address the need to manage the natural resource base, and also meet producer's needs (and thus addressing the first two issues raised by the first drafts, how is it used, and how are non-applicable practices catered for). It enables the user to:

1. Objectively assess their current situation;

2. Document decisions made to improve situations identified as being a potential risk; and

3. Monitor the effectiveness of those decisions. This in turn provides a framework for checking adoption of the practices on-farm, thus addressing the third issue raised by the first drafts.

A generic document will always have limitations - if there are say 1200 cotton farms, then there are probably well over 1000 variations to be taken into account regarding how to manage that operation environmentally. By focusing on farmer developed action plans based on a process which highlights the critical issues to be addressed, solutions are founded on a combination of common sense, sound science, economics and site specific management.

Accordingly, the adoption of best practices is substantially improved. The critical lesson to be learned from this move to an expanded format is that there are two aspects of a best management practices approach to improving resouce management-there are the actual practices themselves, as well the delivery method used to maximise adoption of those practices.

Implementation

Implementation of the Manual is being organised through the local cotton grower associations, (the active involvement of growers at a local level is essential for the success of the Manual) who will be responsible, together with the local Cotton Australia regional manager and/or extension officer, for distributing the manuals, maintaining the record of recipients and organising the training meetings that cotton farmers will attend to be shown how to use the Manual.

Centralised coordination and support for these activities is also provided. The brief description of the process is as follows:

1. Cotton farmers are made aware that the Manual is available. This is being done through the various industry publications and communications streams from the local grower association, as well as relevant media publications (eg. the *Australian Cotton Grower*).

2. Generally, an introductory meeting is held, where copies of the Manual are distributed (together with a short 'How to Use' guide, which contains worked examples), and a brief introduction to its development and content is given.

3. Once farmers have received the manual, a training day is organised where they are shown how to complete the Manual. The trainers will be primarily Cotton Australia field staff, supported by cotton industry extension and development officers.

4. Once the cotton farmer has completed the Manual, a follow up meeting is organised with the farmer to ensure he has completed the relevant parts of the Manual.

A BMP working group has been established to oversee the development of the implementation process, as well as being responsible for ensuring that the day-to-day work is being performed. The BMP working group has representatives from the Australian Cotton Growers Research Association, Cotton Australia, Cotton Research & Development Corporation and the CRC for Sustainable Cotton Production.

Key benefits

Resource management in North America is headed down this path in a number of areas because of the limitations in the traditional agency controlled planning system, which tends to limit implementation to only those actions specifically required; stifles innovation; and relies on 'cookie cutter' solutions and does not allow for site specific solutions.

It is generally accepted that when farmers develop plans on their own initiative (aided by technical input from both public and private sources), they will implement many more actions to maintain and enhance natural resources than they would with other policy mechanisms such as regulation or public-sector controlled planning. This has been one of the core philosophies of the approach in Ontario: 'self directed initiatives are more likely to work than command and control mechanisms of change'.

This approach also recognises that any environmental strategy must recognise that specific needs vary markedly from farm to farm. The local, voluntary approach to solving (environmental) problems related to agriculture may progress more slowly than many in the environmental community deem acceptable. However, it should be understood that change occurs somewhat slowly in agriculture due to the extremely risky nature of farming. Allowing the users of agricultural chemicals to (in a sense) self regulate their activities provides an innovative and acceptable method of solving a problem that is very difficult for the state to effectively regulate (Waskon and Walker).

The creation and adoption of a best management practice approach by the cotton industry to the use of pesticides is one way of ensuring that the impacts of cotton growing on the environment are minimised. The approach has a number of definite advantages, including the ability to cope with a range of conditions, through the potential ability to develop local best practices-it is a flexible, on-going system that can be adapted as circumstances and levels of knowledge change, based on site-specific planning.

The Manual fits very well in the current trend of environmental legislation, which focuses on a general environmental duty of care and the need for due diligence requirements, and which requires that risks be assessed, planned for and managed (for example Queensland's Environment Code of Practice for Agriculture and the recommendations from the Industry Commission's Inquiry into Ecologically Sustainable Land Management, September 1997).

The Manual also provides a mechanism whereby cotton farmers can maintain a degree of say in the environmental management of their operations, thus capturing the benefits that self-regulation is able to provide. At the same time, the Manual has had input from relevant government agencies, and seeks to have their endorsement. As it also provides a mechanism whereby levels of adoption can be accurately gauged, it can also capture the benefits of regulation (for further discussion of the advantages and disadvantages of self-regulation and external regulation, see Doak, 1998).

The format of the Manual, which leads cotton farmers down a planning pathway, is a very powerful method of having R&D outcomes adopted, as the critical issues that the research focuses on can be highlighted in the self-assessment worksheets. A strong link can be made between the reason or need for adopting a practice and the practice itself. Solutions to those issues are then identified on an as needs basis ie. the research outcomes can be focused very specifically on the needs of the individual farmer - the farmer only needs to investigate those areas where a risk has been identified in the self-assessment process.

Future developments

Of course, if the cotton industry is serious about demonstrating that it is capable of planning its own environmental agenda, there are some responsibilities, the first of which is the need for the documented analysis and planning approach exemplified by the Manual. Another likely issue for the industry (and agriculture in general) will be certification. The cotton industry's strategy and ultimate goal is to have the regulatory bodies, ie. the decision makers on issues which directly affect cotton farming, endorse the Manual. While the cotton industry currently has their strong support, endorsement is likely to require evidence that the Manual is actually being used, being used properly, and having a positive impact. This evidence will most likely require some type of audit process, for example ISO 14000.

Conclusion

In summary, there are a number of advantages for the cotton industry, regulators and researchers in proceeding down the BMP pathway:

1. It provides the opportunity for farmers to look at their farming operation from a slightly different perspective and will help them to improve their management of pesticides.

2. If cotton farmers want to retain some control over the environmental management of their farming operations, then it is essential that a significant proportion of them undertake the BMP program.

3. Building up the industry's involvement in BMP will enable flexibility to be built into the process of environmental management (ie cotton farmers can develop their own site specific plans at their own pace and can deal with issues in ways that best suit them).

4. A number of European countries are discussing using pesticides an a non-tariff trade barrier (particularly with respect to organochlorines, of which endosulfan is one). If the Australian cotton industry wishes to maintain its markets against this type of barrier and also continue to use such pesticides, then a demonstrated management system is essential.

5. Adoption of BMP may be the only way cotton growers will be able to have access to products such as endosulfan in the future. It may also be the only way the industry gains access to some of the newer pesticides eg. Intreped.

6. The flexible, site specific and farmer driven nature of the process helps to improve the adoption of best practices.

7. The Manual provides a mechanism for extending and promoting research.

The Manual seeks to be a flexible, useable framework for cotton farmers. It is recognised that cotton farming takes place under a wide range of environmental, commercial and social conditions. By using a planning framework, cotton farmers are able to identify any particular constraints that they may be operating under, and then plan the most appropriate method for them of overcoming that constraint. The cotton industry has recognised the importance of the Manual and has enthusiastically endorsed it.

By using the Manual, cotton farmers will be developing practical farm plans which minimise any impacts of cotton farming on the environment, as well as demonstrating their commitment to responsible resource management.

Acknowledgments

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PESTICIDE STORAGE AND HANDLING WORKSHEET 7		Growing season: 1997/98		Date completed: 31/12/97	
ISSUE	Rank 1	Rank 2	Rank 3	Rank 4	Site Reference
11. Handling system	Closed transfer system used for pesticide handling.	Most pesticides are transferred with a closed system; filling point on spray tank is easy to reach.	Pesticides are poured by hand and filling point of spray tank is easy to reach.	Pesticides are poured by hand and filling point is difficult to reach. (ie splashes are highly likely to occur).	"Homeville"
Ranking: 4	Comments: Spray tank and rig are farm built, and due for replacement at end of season. Other Documents: Budget				
12. Spray tank cleaning and rinsate disposal	Containers triple rinsed and rinsate added to spray tank for immediate use. Unused rinsate is collected in a sump or soak-away pit.			*Rinsate dumped.*	"Homeville"
Ranking: 1	Comments: Containers are triple rinsed (with rinsate added to spray tank) and returned to supplier. Other Documents:				

Appendix 1

ACTIVITY HAZARD ASSESSMENT WORKSHEET

Operation: Ground rig applications

Date: 31/12/97

Activity: Pouring of insecticide into tank

Activity	Level of Risk: Extreme	High	Moderate	Low	Comments
Location of mixing site			X		Mixing site in paddock well away from river (at least 500 metres)
Location of filling point on tank		X			Filling point is difficult to reach
Operator safety		X			Appropriate Personal Protective Equipment requirements need to be determined-label and MSDS to be used.

PLANNING AND ACTION SUMMARY WORKSHEET

Date: 15/1/98

Issue to be addressed: Pouring of insecticides

When: By 30 June 1998

Site reference: Whole farm, all employees (as relevant)

Responsibility: J Foreman

Monitoring:

Review: Progress to be checked in June 1998

1. MSDSheets to be obtained for all chemicals used on farm; appropriate PPE obtained as indicated.

2. Staff to be trained in proper and safe handling methods

3. Ladder to be provided on water tanker to improve access to fill point on spray tank (until new tank and rig purchased)

4. When spray tank is replaced (planned for 98/99 season), attention to be paid to ease of access for filling tank

Appendix 3

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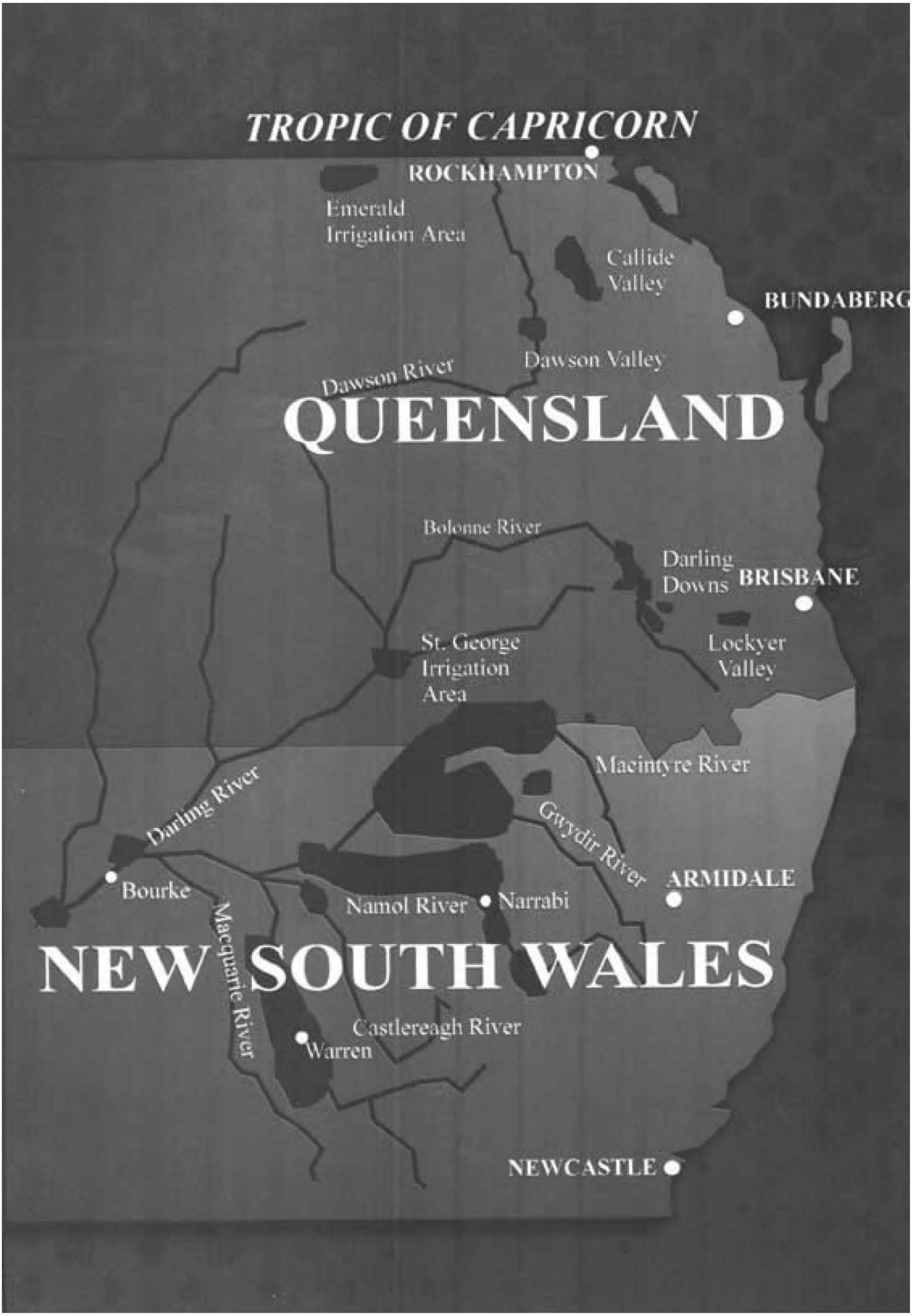
TROPIC OF CAPRICORN
ROCKHAMPTON
Emerald
Irrigation Area
Callide
Valley
BUNDABERG
Dawson Valley
Dawson River
QUEENSLAND
Bolonne River
Darling
Downs
BRISBANE
St. George
Irrigation
Area
Lockyer
Valley
Macintyre River
Darling River
Gwydir River
ARMIDALE
Bourke
Namol River
Narrabi
Macquarie River
NEW SOUTH WALES
Castlereagh River
Warren
NEWCASTLE