Agrochemical Pollution of Water Resources

Proceedings of a Conference held on 16–18 February 2000 at Hat Yai, Thailand

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Preface

THE GREAT BENEFITS of fertilisers and pesticides do not come without cost. One such cost is water pollution. Hence the implicit research question underlying each paper in these Proceedings was: how can sustainable intensive agriculture be at its most productive, without polluting water resources? The main focus was on the need for uncontaminated water to be freely available for drinking.

This volume records the main research findings of ACIAR Project LWR1/1994/054 as presented to a conference held in Thailand on 16–18 February 2000. The aim of the project was to identify and evaluate promising technologies and management options to minimise the contamination of water resources by agrochemicals. It focused on agricultural systems that depend on chemical inputs such as fertilisers and pesticides (herbicides, insecticides, and fungicides).

The purpose of the project was to better understand the principles by which agrochemicals contaminate surface water and groundwater under these conditions. The research program was developed to evaluate and use predictive modelling using system parameters, and to devise and evaluate management practices to minimise pollution. The research was conducted by three organisations: the Malaysian Agricultural Research and Development Institute (MARDI); the Faculty of Natural Resources, Prince of Songkla University, Thailand (PSU); and the Commonwealth Scientific and Industrial Research Organisation, Land and Water Division, Australia (CSIRO). The project was conducted at three contrasting sites in Malaysia, Thailand, and Australia.

In Malaysia, surface water monitoring involved small plots, small sub-catchments, catchments, and major rivers in the Cameron Highlands. Flow was measured in all sites in order to estimate pesticide loads. MARDI conducted specialised experiments evaluating transport of pollutants in surface and groundwater, field and laboratory characterisation of system parameters, long-term monitoring of experimental sites, and application and evaluation of modelling techniques.

In Thailand, groundwater monitoring was conducted in three different geomorphological areas within Rataphum Watershed: uplands (fruit orchards); slopes (rubber); and flats (vegetables). PSU investigated groundwater pollution problems through field surveys, experimentation and common technology. It evaluated the application of models and the impact of modifying management practices.

In Western Australia, CSIRO conducted detailed field experiments to investigate groundwater pollution problems in the Gnangara Mound aquifer below the Swan Coastal Plain. Monitoring of water quality with respect to selected pesticides was conducted at three different levels: small-scale (column and undisturbed cores) in the laboratory; medium-scale field experiments; and large-scale monitoring in agricultural areas.

The Australian team also coordinated the various techniques, analytical methods and modelling used in various CSIRO pesticide projects, and transferred the technology to its counterparts in Malaysia and Thailand.

Thanks are due to MARDI, PSU and CSIRO for their generous support of the project activities in their respective countries and to the landholders who provided land or access for the field work. Thanks are also due to all the scientists and support staff for their contributions to both the project and the conference.

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Summary of Findings

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THE PROJECT'S APPROACH was to make an initial assessment of the extent and spread of contamination of surface and ground waters in the Cameron Highlands and the Rataphum watershed. This included, in each of the main cropping systems, assessment of farmers' practices that may lead to contamination of groundwater and runoff water, or to excessive losses of eroded soil.

The initial assessment was complemented by detailed plot work and the application of leaching and pesticide degradation models. Some laboratory work was required to obtain information on the sorption and degradation behaviour of pesticides used in the areas. Some of these data were applied to models to describe the leaching of nitrate and the leaching and degradation of pesticides in intensive tropical agriculture. More emphasis was given to surface runoff and soil erosion in the steep areas of the Cameron Highlands.

Recommendations for reducing nutrient and pesticide contamination of water resources were developed. Also, for those sites where the major concern is groundwater contamination, the project devised a means of assessing groundwater contamination by nitrate and pesticides on a regional scale.

Malaysia

Erosion of surface soil in the Cameron Highlands is of serious concern. Soil loss can be expected to be very large during construction of terraces and flattening of hilltops. After establishment of intensive vegetable farms, soil losses remain high – in the region of 83 t/ha/yr. Erosion rates are generally high during crop establishment, and decrease during the growing season as surface coverage increases. In furrow and bed systems used for vegetables, initial erosion is due to raindrop detachment of soil from the beds. Some of the detached soil accumulates into the compacted furrows. Rapid soil loss occurs in overland flow down the furrows during heavy rainstorms. Erosion rates of soil used for flower production under plastic shelters are very much less (about one t/ha/yr) because the soil is not subjected to natural rainfall. Erosion from tea plantations occurs in empty rows and landslip-scarred areas and is generally low.

Analyses of suspended sediment and the original soil showed that transported materials were enriched in nutrients. The finest particles were the most enriched; they were also likely to be transported furthest, and to ultimately reach reservoirs and other surface-water bodies.

Under cabbage about three per cent of applied nitrogen was lost in runoff. The loss was most rapid soon after application of the fertilisers and decreased during the growing season. The findings suggest that erosion-mitigation measures are required in vegetable-growing areas. Shelters used in high-value flower production effectively control erosion, but their high cost restricts their use to this specialised industry. Losses of nitrogen by leaching in cabbage farms were about eight per cent of the nitrogen applied. Losses of nutrients from the soil were small in comparison with the amounts applied in organic and inorganic fertilisers. Such losses were insignificant in terms of crop production; however, they may be a significant source of nitrogen in surface-water bodies.

Endosulfan and methamidophos insecticides, and their degradation products, were detected in trace quantities in surface runoff water and in water that drained into lysimeters. Residues were also detected in the soil. Methamidophos, although more mobile than endosulfan in Cameron Highland soils, was degraded rapidly by microbial activity (half-life of 5–8 days), whereas endosulfan was more persistent (half-life of 433–495 days). Therefore endosulfan has greater potential as a contaminant than methamidophos.

Thailand

In the Rataphum watershed of southern Thailand, a general assessment of risks of agrochemical contamination identified intensive vegetable production on alluvial soils with shallow watertables as most at risk. During the course of the study, misuse of pesticides and poor practices, such as over-application of homemade mixtures, were observed. Contamination risks from rubber plantations were rated as 'low' and restricted to the relatively small areas (5–10 per cent) being re-established at any one time. Tree fruit production is still a smallholder activity and not subject to large inputs of fertiliser or pesticide.

Modelling studies for a wide range of pesticides showed that there was little potential for leaching or for contamination of groundwater. However, all such studies assume homogenous porous media where water and solute flow are uniform; also the input data on pesticide properties are from other countries and known to not relate well to local soils. Therefore conclusions reached from modelling studies must be regarded as, at best, preliminary. The studies also showed that maintaining organic matter concentrations of the surface soil and reducing irrigation water applications would be effective in reducing the leaching potential of pesticides. Potential for nitrate leaching was greater than that of pesticides.

On-farm evaluations of bio-insecticides, entomopathogenic bacteria (*Bacillus thuringiensis*), and nematodes (*Stienernema carpocapsae*) showed that they were not as effective as synthetic insecticides in controlling insect pests on chaisim vegetables. The higher costs and lower yields of plots treated with the bio-insecticides and reduced inputs of synthetic insecticides make this means of pest control unattractive to farmers.

The shallow groundwater is utilised for drinking water supplies and a survey was made of coliform bacteria in wells in the rubber, fruit tree and vegetable-growing areas. Excessive numbers of coliform bacteria, in terms of drinking-water standards, were found in all areas and were greatest in shallow wells in vegetable-growing areas. Protection from contamination and boiling of water intended for human consumption are recommended.

Australia

In Western Australia, a detailed study of the soils of part of the Swan Coastal Plain was made to assess their susceptibility to leaching of pesticides and nutrients.

The soils were described in terms of their sand and organic carbon contents, soil water retention, hydraulic conductivity and bulk density. Detailed soil maps were compared to GIS-produced hydrogeomorphic maps. It was found that the hydrogeomorphic maps could be used to classify catchments in terms of their susceptibility to leaching in the absence of detailed soil maps. The sorption properties of the soils for a range of pesticides and metabolites were determined in the laboratory. There was a general trend for increasing sorption with increasing organic carbon concentration. The metabolites of atrazine and fenamiphos had much lower affinities for soil than their parent compounds, and may therefore be vulnerable to leaching to the groundwater. The sorption capacity of subsoils low in organic carbon was very low; so once a pesticide or metabolite leached below the surface soils, it moved easily. However even in field experiments where pesticide residues were detected at trace levels in the soils, they were not detected in groundwater samples taken by a range of techniques.

Modelling studies of various irrigation vs. organic carbon scenarios in surface soils indicated that the risk of pesticides leaching below one metre is low, although the potential for leaching varied between soil-types. Given the high permeability of soils in the Swan Coastal Plain, careful choice of pesticide, keeping pesticide application frequency low, and improving irrigation practices are recommended to prevent leaching. Nitrogen, as ammonium as well as nitrate, leached rapidly through these soils when used for intensive horticulture (strawberry and turf production). Reducing irrigation water applications to that required for crop growth can reduce the leaching. Regional maps of the vulnerability of groundwater to nitrate accessions were also produced. Nitrate leaching was predicted in the range 16–400 kg N/ha. The amount leached increased with the rate of fertiliser application and the quantity of irrigation water. As with pesticides, optimising fertiliser and irrigation inputs reduces the transfer of nitrate to the groundwater.

Conclusions

The first requirement in any effort to reduce pollution in agricultural systems is to identify the practices and land, soil and water systems that are the most likely sources. At each study site of the project, the agricultural systems responsible for contamination of water resources were identified.

In the Cameron Highlands, loss of nitrogen to surface runoff and then to surface water bodies, and leaching of nitrate to groundwater, during intensive (unsheltered) vegetable production were the main sources of contaminants. Loss of soil by water erosion was also serious during the construction of terraces, but could be stabilised at an acceptable level by soil conservation practices once cropping was established. Soil conservation practices are essential for horticultural production in the Cameron Highlands. The use of rain-shelters greatly reduced losses in runoff and erosion, but these are only feasible for very high-value crops such as cut flowers.

Intensive horticultural activities were also the cause of pollution in the Rataphum watershed and the Gnangara Mound area. At these two sites, the main concern was the leaching of nitrate to the groundwater. Although none of the tested pesticides was detected in groundwater, it is likely that some residues, too low to detect experimentally, would reach the groundwater especially in the irrigated shallow-watertable areas.

At all project sites used for perennial trees (tropical fruits and rubber in Thailand, tea plantations and jungle in Malaysia, and pine plantations and disturbed bushland in Western Australia) there was very little potential for pollution because of the small rates of application of pesticides and fertilisers and the lack of irrigation.

At all sites used for intensive production it was shown that reduction in the pollution of groundwater can be achieved by limiting:

- fertiliser applications to that required for production,
- pesticide inputs to the recommended rates, and
- irrigation water applications to that required for crop growth.

In light-textured soils that receive pesticides it is also recommended that organic carbon concentrations in the surface soil be maintained or increased. The non-point nature of the pollution considered in the agricultural systems of this project can only be reduced by changes in farmers' practices. It is unlikely that legislation or regulation would be effective in achieving this, other than by deregistering persistent pesticides.

Implementation of the project's results requires educational activities to show farmers how to change their practices to reduce pollution. This may be achieved by incorporating environmental objectives with extension activities primarily aimed at improving crop production and farmers' incomes. Another approach, which has been successful in other countries, would be to link promotion of non-polluting practices with external support for improving water supplies in rural areas. It seems more likely that rural folk will adopt practices that reduce contamination of water if they understand the direct link between health and improved water supply and quality.

These results are being transferred to existing programs examining pesticide use and residues.