

HERBICIDE DISSIPATION AND RUN-OFF FROM SOILS UNDER SUGARCANE IN MAURITIUS

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Abstract

Increasing concern about the potential pollution of surface and groundwaters by herbicides used in sugarcane cultivation in Mauritius is calling for a need to identify agricultural practices that would minimise the movement of herbicides to our water resources. In this context, the off-farm transport by surface run-off of atrazine, diuron, hexazinone and acetochlor were monitored on a plot scale (500 m²) as well as on a 40 hectare catchment at a site (Valetta) receiving an annual rainfall of about 3500 mm. The results showed that rapid dissipation of herbicide occurred in the top 0-2,5 cm layer of the soil and little herbicide was transported down the soil profile to below 30 cm depth. There was no evidence of on-farm build-up of herbicide residues. Mean herbicide concentrations in run-off waters were low and did not exceed existing drinking water guidelines. The total mass of herbicide lost by run-off from the 40 hectare catchment over one growing season represented not more than 0,02% atrazine, 0,32% hexazinone, 0,07% diuron and 0,19% acetochlor with respect to the amount normally applied. Although at plot scale herbicide losses occurred mainly as sediment-bound residues, at the 40 hectare catchment, 70-95% of herbicide lost occurred as dissolved residues. Based on visual observation of crystal clear watercourses becoming loaded with mud during and after a heavy rainfall event, the perception of the general public is that quantities of herbicides representing a hazard to human health are being moved during soil erosion. The data obtained therefore showed that this perception is unfounded.

Introduction

Sugarcane cultivation in Mauritius relies heavily on the use of herbicides. Each year the 78 000 ha of land under cane receives approximately 460 tons active ingredient (a.i.) of herbicides. Although benefits from the use of herbicides are well recognised, the impact of these chemicals on the environment, particularly the contamination of surface and ground waters and the marine ecosystems, has become a major issue. The presence of low levels of herbicide residues in surface and ground waters of Mauritius has been demonstrated by Ng Kee Kwong *et al.* (1998) who also inferred that no freshwater source in Mauritius is completely exempt from possible contamination by herbicides used in sugarcane cultivation. Moreover, in view of the generally undulating topography of the island and with the fact that up to 70% of

the yearly rainfall occurs as high intensity events between January and April, the potential for off-farm movement of herbicides by surface run-off and subsurface drainage is high.

While numerous studies on off-farm transport of pesticides have been done in the USA and Europe (Gaynor *et al.*, 1995; Lennartz *et al.*, 1997; Mathiessen *et al.*, 1972), there remains a general lack of information on this issue under tropical conditions. Yet this information is vital in the development of best management practices to minimise the environmental impact of herbicide usage. This study was therefore initiated with the objectives of (i) measuring the persistence of herbicide in soils and in surface run-off from a defined sugarcane catchment and (ii) to assess the impact of this movement on herbicide residue concentration in surface water.

Materials and methods

This study was initiated in 1997 as part of a large scale project aimed at measuring and predicting the movement of agrochemicals in tropical sugar production. The experiment site was located at Valetta in a superhumid zone of Mauritius receiving 3500 mm rain annually. The soil was a Humic Ferruginous Latosol (Humic Acrisol according to the FAO/UNESCO classification) with a silty clay loam texture and with an organic C content of 30 g/kg. The site was instrumented at four levels, namely 500 m² plot, 4, 10 and 40 ha catchments to measure surface run-off and soil loss.

Herbicide treatment and experimental set-up

At the plot scale of 500 m², with ratoon sugarcane and trash arranged in alternate interrows, atrazine, diuron, hexazinone and acetochlor were applied at 2,7, 2,7, 0,4 and 1,3 kg a.i./ha, respectively.

Sugarcane within the 40 ha catchment received the following herbicides: diuron (4 kg a.i./ha), hexazinone (0,8 kg a.i./ha), acetochlor (2 kg a.i./ha) and ioxynil+2,4-D (2,5 kg a.i./ha). All fields within the 40 ha catchment including the 500 m² plot also received 800 kg of the complex fertiliser 17:8:25 per hectare.

The 500 m² plot was equipped with a run-off collection system consisting of a metal trough laid downslope of the plot and tipping buckets (16 L) connected to dataloggers for measuring and recording run-off volumes and rainfall. Run-off samples were taken at each tip using a splitter (split ratio

1:160) and pumped into 5 L bottles refrigerated at 4°C. The plot was isolated from the adjacent field by means of trenches (75-80 cm deep) and soil mounds that intercepted flows from outside the experimental plots.

At the 4 and 10 ha catchment scales, measurement and sampling of run-off was done by means of San Dimas flumes. At each flume, run-off hydrographs were recorded by means of a Greenspan pressure transducer linked to a Campbell datalogger. During major rainfall events, surface run-off was sampled by means of an ISCO automatic sampler preset to collect samples throughout the hydrograph and triggered by the datalogger. Water samples were collected in glass bottles maintained at 4°C.

Run-off from the 40 ha catchment was measured and sampled at a bridge that was reconstructed so as to serve as a San Dimas flume and was equipped with a pressure transducer, datalogger and an ISCO autosampler as at the 4 and 10 ha catchments.

Soil sampling

The background herbicide residues were determined in 19 soil profiles representing the five major soil groups existing in Mauritius. Soil depths sampled were 0-2.5, 2.5-5, 5-10, 10-20, 20-30, 30-60, and 60-90 cm.

Following herbicide application to the experiment site at Valetta, soil samples were collected 1, 3, 7, 10 and 15 days after application. Thereafter soil sampling was carried out at monthly intervals. Soil depths sampled were 0-2.5, 2.5-5, 5-10, 10-20 cm during the first 10 days after application; thereafter, additional layers (20-30, 30-45 cm) were also sampled. All soil samples were frozen until analysis.

Herbicides analyses

For the determination of atrazine, diuron, hexazinone and acetochlor in soils, a 20 g soil sample was shaken for one hour in a methanol/water mixture (80% v/v methanol). The resulting extract was cleaned up by partitioning with a dichloromethane/hexane mixture (50% v/v). After evaporation of the solvent mixture under vacuum, the residue was reconstituted in acetonitrile/water (1:4 v/v) or in hexane.

Quantitation of diuron, atrazine and hexazinone was done by high performance liquid chromatography (HPLC) with a diode array detector (DAD), while acetochlor was quantified by gas chromatography (GC) with a thermionic specific detector (TSD) using an external standard method of calibration. For the determination of 2,4-D residues in soil, a 20 g portion was refluxed in acidified acetone, and the extract cleaned up by partitioning in ethyl acetate. The ethyl acetate extract was esterified and the esterified residues quantified by GC with electron capture detector (ECD) using an external standard method of calibration.

In low sediment water samples the herbicide residues were extracted with dichloromethane and hexane. The solvent extracts were combined and, after evaporation under vacuum, were reconstituted in acetonitrile/water or hexane for quantitation on HPLC or GC as for soil samples.

High sediment water samples were filtered. Atrazine, diuron, hexazinone and acetochlor were extracted from the sediment by boiling with a mixture of dichloromethane and acetone (50% v/v). The extracts were evaporated, taken in bidistilled water and then partitioned with dichloromethane and hexane. After evaporation of the organic phase the residues were determined as described for soil samples. The water fractions were treated in the same way as described for low sediment water samples.

Results and discussion

Background herbicide concentrations in soil profiles

Figure 1 shows the frequency of background herbicide detections in the top 90 cm soil layer of the five major soil groups existing in Mauritius. Of the five herbicides analysed, diuron was most frequently detected (71% samples) followed by acetochlor (35% samples), atrazine (35% samples) and hexazinone (29% samples). Although 2,4-D was applied at some of the sites during the 1996-1997 crop season, residues of this herbicide could not be detected. This was to be expected as 2,4-D is known to be rapidly degraded in soils (Umrit and Ng Kee Kwong, 1996).

Diuron and acetochlor were detected in nearly 90% of the

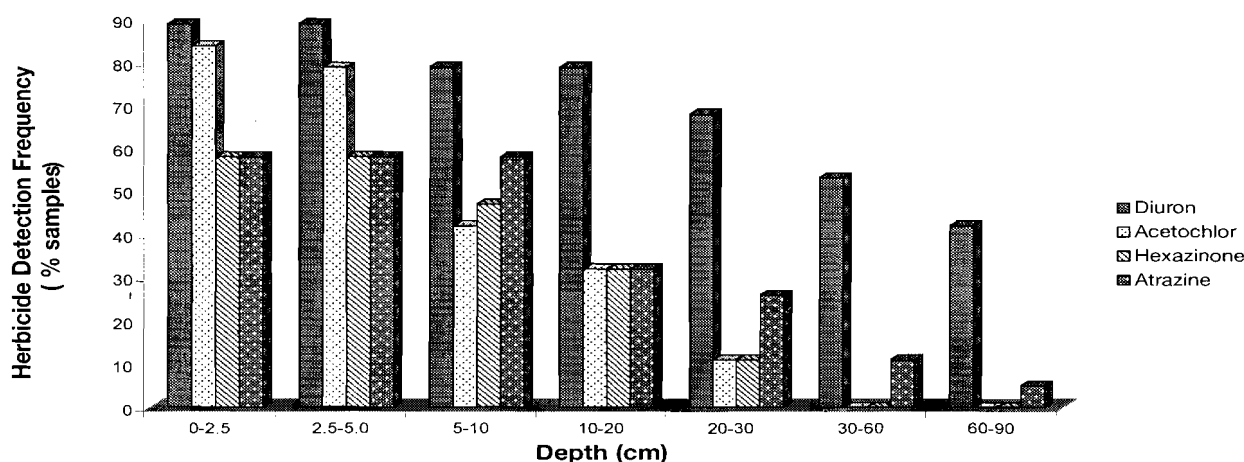


Figure 1. Detection frequency of diuron, acetochlor, atrazine and hexazinone with depth in soil profiles from 19 sites in Mauritius.

samples collected from the top 5 cm layer of the profile. Diuron appeared to be the most mobile with 40% of the samples analysed containing this compound to a depth of 90 cm. Only 10% of the samples taken below the 30 cm depth contained atrazine, while acetochlor and hexazinone were found to be restricted to the 0-30 cm soil layer. Approximately 60% of the samples contained atrazine and hexazinone in the top 2,5 cm layer, the number of detections decreasing to about 30% in the 10-20 cm soil increment.

The highest masses of diuron measured (approximately 1,2 kg/ha in the top 2,5 cm layer and 2,2 kg/ha for the 0-90 cm depth) were at two sites receiving multiple applications of diuron within one growing season. In general, however, diuron concentrations were less than 0,35 kg/ha in the top 2,5 cm layer and less than 1,0 kg/ha for the entire 90 cm layer. Most of the diuron residues were distributed in the upper 10 cm layer which on average had an organic carbon content of 3%, thereby suggesting that diuron residues were adsorbed by organic matter. Increased adsorption of diuron in soil with increasing organic carbon had been demonstrated elsewhere (Adhikari and Mandal, 1994; Gonzalez-Pradus *et al.*, 1992).

Atrazine and hexazinone concentrations in the surface 0-2.5 cm layer were generally less than 0,04 kg/ha, whereas for the whole profile the maximum amounts found were 0,41 kg/ha atrazine and 0,11 kg/ha hexazinone. The low levels of hexazinone observed may be attributed to low application rates (e.g. 0,6 kg/ha) rather than lower persistence. Small concentrations of acetochlor, up to 0,08 kg/ha in the 0-2,5 cm layer and 0,14 kg/ha in the whole profile, were also detected.

The presence of low concentrations of diuron and atrazine, up to 0,05 and 0,07 kg/ha at the 60-90 cm depth, at some sites signifies that these compounds can migrate below the root zone and leach to groundwaters. This is supported by the fact that low levels of diuron and atrazine residues had indeed been detected in the groundwaters of Mauritius (Ng Kee Kwong *et al.*, 1998). The generally low background lev-

els of herbicide residues in soil profiles nevertheless suggest that there is little on-farm build-up of residue as a result of current herbicide usage for the control of weeds in sugarcane fields of Mauritius.

Herbicide dissipation in soil

Following application, herbicide residues in the surface 2.5cm layer declined rapidly (Figure 2). Dissipation rates were estimated from their concentrations in soil by using a first order reaction model which commonly describes herbicide dissipation kinetics in soil (Hamaker, 1972) and which is given by the expression $C = C_0 e^{-kt}$, where C is the measured herbicide concentration in soil at time t, C₀ is the concentration at time of application and k is the first order rate coefficient. Estimated half-lives (time to 50% dissipation) of the four herbicides in the surface soil varied between 10 and 17 days (Table 1).

Table 1. Estimated first order rate coefficients (K) and dissipation half-lives ($t_{1/2}$) of atrazine, diuron, hexazinone and acetochlor in the surface 2,5 cm soil under sugarcane at Valetta, Mauritius.

Compound	K, (d ⁻¹)	$t_{1/2}$, (d)	r ²
Atrazine	0,071	10	0,859
Diuron	0,048	14	0,666
Hexazinone	0,042	17	0,778
Acetochlor	0,069	10	0,816

In an earlier study using the same soil type under laboratory conditions, half-life values within the range of 42-70 days for atrazine and 35-50 days for hexazinone were observed (Umrit and Ng Kee Kwong, 1996). Hornsby *et al.* (1996), in a review of pesticide properties in soil, reported a mean half-life of 90 days for diuron. The data obtained therefore indicate that herbicide dissipation in the field was more rapid than dissipation under controlled laboratory conditions. Similar dissipation rates in surface soil under field conditions have been reported by Keller and Weber (1995) for atrazine and by Lennartz *et al.* (1997) for diuron.

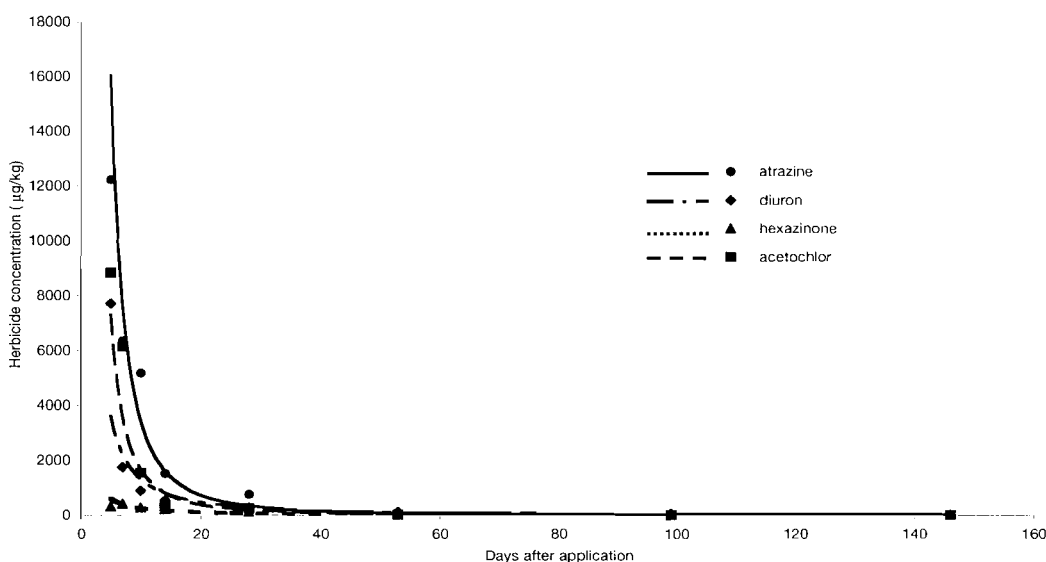


Figure 2. Dissipation of atrazine, diuron, hexazinone and acetochlor in the surface 2.5 cm soil of Valetta cropped with sugar cane during the 1997- 1998 growing season.

As a result of their high dissipation rates, very little herbicide residues should be available for off-farm transport through run-off. The results obtained also showed that little herbicide was transported below the 30 cm depth during the first three months following application, as exemplified by the minor increases in atrazine and acetochlor concentration below this depth (Figure 3). The observed rapid dissipation of herbicides illustrated in Figure 2 was therefore primarily due to degradation (or bound residue formation) which left very low quantities for potential loss by leaching.

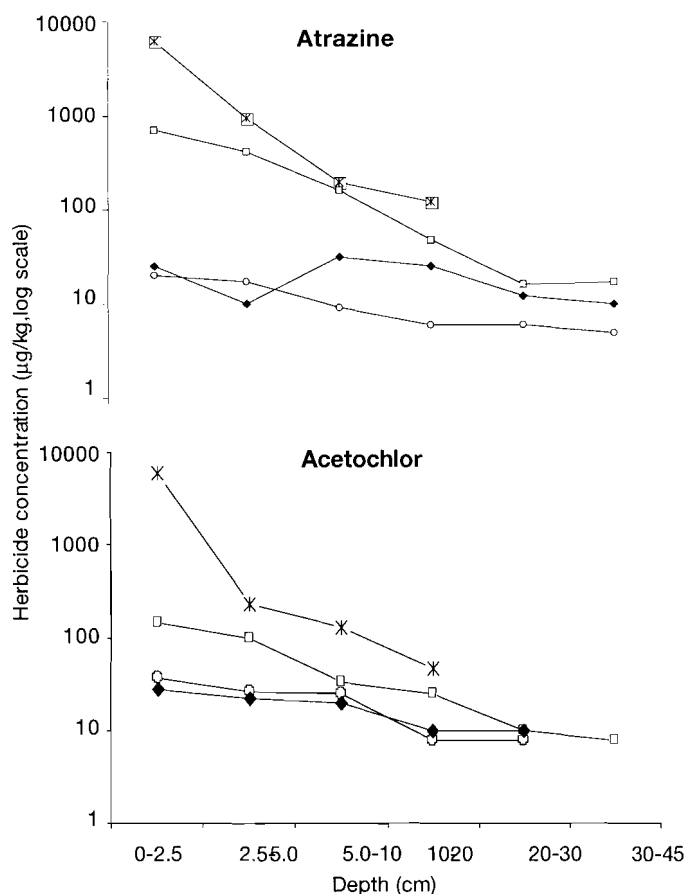


Figure 3. Atrazine and acetochlor concentrations ($\mu\text{g}/\text{kg}$) within the soil profile of Valetta at different times after application. (—○— Day 0, —X— Day 7, —□— Day 28, —◆— Day 99)

Following herbicide application on 1 December 1997, the first rainfall event resulting in significant run-off occurred on 31 December 1997. For this event, herbicide levels (averaged over the entire event) in run-off from the small catchment (4 ha) were 0,58 $\mu\text{g}/\text{L}$ atrazine, 5,7 $\mu\text{g}/\text{L}$ hexazinone, 16,8 $\mu\text{g}/\text{L}$ diuron and 17,3 $\mu\text{g}/\text{L}$ acetochlor. As shown in Figure 4, herbicide residue concentrations generally declined during subsequent run-off events, falling to 0,21, 1,0, 1,6 and 1,6 $\mu\text{g}/\text{L}$ atrazine, hexazinone, diuron and acetochlor respectively, during the event of 12 February 1998. Over the 40 ha catchment the first run-off water samples were only available on 8 January 1998. Herbicide levels in run-off water for this event were 0,37 $\mu\text{g}/\text{L}$ atrazine, 1,79 $\mu\text{g}/\text{L}$ hexazinone, 3,9 $\mu\text{g}/\text{L}$ acetochlor and 4,63 $\mu\text{g}/\text{L}$ diuron. These levels grad-

ually declined to less than 1 $\mu\text{g}/\text{L}$ during a later event occurring on 19 February 1998. A generally similar pattern of herbicide concentration was observed at the 500m² plot (Figure 4). The low levels of herbicide residue (maximum 2,2 $\mu\text{g}/\text{L}$) observed in the first run-off from the plot was to be expected on account of the large lag period (75 days) between the time of application and the first run-off event occurring on 14 February 1998.

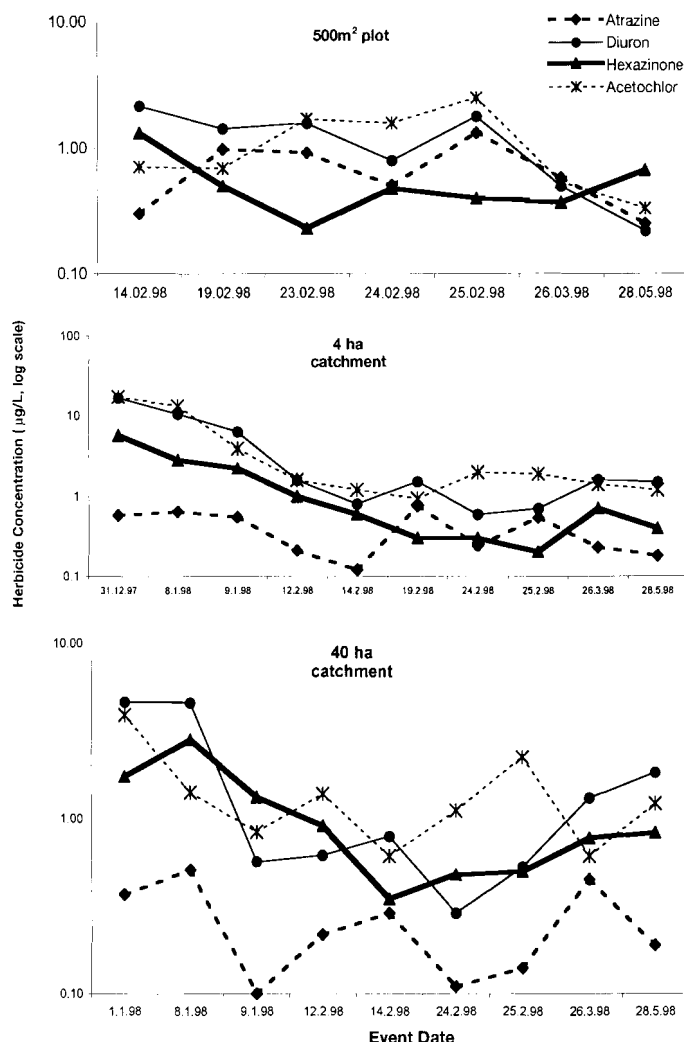


Figure 4. Atrazine, diuron, hexazinone and acetochlor concentrations in runoff water from Valetta during the 1997-1998 sugarcane crop season.

The results confirmed that the first run-off event following the application of herbicides generally resulted in the highest measured herbicide concentration in the run-off water (Figure 4). Moreover, the level of herbicide in run-off was also shown to be influenced by the intensity of the run-off, as evidenced by the observed increases in herbicide concentration in the run-off water sampled during the event of 25 February 1998 when a run-off intensity of more than 100 mm/hr was recorded. Measured concentration of herbicide in run-off generally did not exceed the maximum contaminant level (MCL) of 3 $\mu\text{g}/\text{L}$ atrazine, 14 $\mu\text{g}/\text{L}$ diuron and 210

$\mu\text{g/L}$ hexazinone (as laid down in the Environmental Protection Act 1991 of Mauritius or the United States Environmental Protection Agency). On one occasion, however, the MCL of 14 $\mu\text{g/L}$ for diuron was exceeded.

Herbicide losses in run-off water

Based on measurements of run-off volumes and herbicide concentrations, the total loss of herbicide over the 1997-98 sugarcane growing season at the plot scale of 500 m² was estimated to be 1380 mg/ha atrazine, 1850 mg/ha diuron, 730 mg/ha hexazinone and 2495 mg/ha acetochlor. This represented approximately 0,05, 0,07, 0,18 and 0,19% respectively of the amount of atrazine, diuron, hexazinone and acetochlor applied (Table 2). These measured values were much lower than the loss percentage of 0,19-0,28% reported elsewhere for atrazine (Ma and Spalding, 1997), 0,68-1,71% for diuron (Lennartz *et al.*, 1997) and 0,33% for hexazinone (Lavy *et al.*, 1989). The lower loss of herbicide observed in this study was likely to be due to the long period of time (>75 days) between herbicide application and run-off events, as well as to the rapid dissipation rates of the herbicides in the soils (Table 1). Estimates of herbicide loss due to run-off on the 4 ha and 40 ha catchments yielded only slightly different values, except for hexazinone (Table 2). The lower loss of atrazine (0,02%) was to be expected because most of the sugarcane fields in the 40 ha catchment did not receive any atrazine during the 1997-98 growing season. The measured loss of 0,02% atrazine was, therefore, mostly from the atrazine applied the previous year. Hexazinone loss was estimated to be 0,09% at the small catchment (4 ha) but as high as 0,32% for the 40 ha catchment. Acetochlor loss was lower (0,11 %) when estimated from the 4 ha catchment data.

Most of the herbicide losses from the 500 m² plot occurred during an event occurring on 25 February 1998 and with a run-off intensity of 117 mm/hr. Despite the time lag of 86 days between herbicide application and this event, it accounted for 81-85% of the herbicides exported (46% for hexazinone) from the 500 m² plot. Similarly, at the 4 ha catchment, more than 50% of the herbicide losses (81% for atrazine) was exported from the experiment field during the events of 25 February and 28 May 1998. Similar impact of

large run-off events on total losses has also been observed elsewhere by Brown *et al.* (1995) and Gaynor *et al.* (1995).

The relative amounts of herbicide in the dissolved and sediment-bound fractions varied from one run-off event to another and were related to the type of herbicide as well as to the size of catchment over which overland flow occurred (Table 2). As acetochlor was the least adsorbed on the sediment, 77-85% of its total loss in run-off occurred in the dissolved phase. At the 500 m² plot, between 45 and 52% of the atrazine, diuron and hexazinone in run-off waters were moved during the 1997-98 growing season by the suspended sediments, as compared with 38, 29 and 66% diuron, hexazinone and atrazine, respectively, in the 4 ha catchment. In contrast, the percentage of sediment-bound herbicide carried in run-off water from the 40 ha catchment was 20% atrazine and diuron and only 3% hexazinone.

Conclusion

This study has demonstrated that there is little or no on-farm build-up of herbicide residues arising from current herbicide usage in sugarcane fields in Mauritius. As a result of high dissipation rates of herbicides in surface soil only a small part, between 0,03% and 0,32% of the amount applied to sugarcane is transported from fields to water courses by run-off. Most of the herbicide in run-off leaves the farm during very high intensity rainfall events both in suspended sediments and in solution. However, by the time the run-off water reaches the end of a catchment, the herbicide residues are transported mainly in the solution phase. Measured concentrations of herbicides in run-off water in a stream draining a 40 ha catchment under sugarcane were generally below the maximum allowable concentration for drinking water. Although current usage of herbicides in sugarcane cultivation does discharge residues into surface water, the concentrations are too low to have a detrimental effect on human health. Therefore, the current public perception that water courses loaded with suspended sediments following a rainfall event could be discharging levels of herbicide residues harmful to human health, is unfounded.

Table 2. Residues of atrazine, diuron, hexazinone and acetochlor lost (mg/ha) in run-off water over the 1997-98 growing season at Valetta, Mauritius.

	atrazine (mg/ha)	diuron (mg/ha)	hexazinone (mg/ha)	acetochlor (mg/ha)
500 m ² plot				
Dissolved phase	657	995	404	2 034
Sediment phase	723	854	327	460
% of applied	0,05	0,07	0,18	0,19
4 ha catchment				
Dissolved phase	223	1 087	491	1 685
Sediment phase	445	678	198	502
% of applied	0,02	0,05	0,09	0,11
40 ha catchment				
Dissolved phase	488	2 063	2 460	3 058
Sediment phase	120	528	70	523
% of applied	0,02	0,06	0,32	0,18

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WEATHER BASED DECISION SUPPORT THROUGH THE INTERNET FOR AGRONOMIC MANAGEMENT OF SUGARCANE

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Introduction

Optimal management of natural and other resources is essential for successful sugarcane production in a globally competitive market. Sound management decision making requires timely, relevant and accurate information on the continually changing state of the sugarcane system as it is affected by environmental and management factors. Computer models, expert systems and databases (such as on-line weather data) are increasingly used to generate this information.

Adoption of existing decision support systems such as CANESIM (formerly called IRRICANE by Singels *et al.*, 1998) by farmers and extension officers has been slow. Potential users find the modelling and communications software complicated and difficult to use (T Culverwell and B Swart, Extension Department, Sasex, personal communication). Software developers also have difficulties in maintaining and supporting software installed on remote computers.

A possible solution to these problems is to capture and process data at a central site and provide access to decision support through the Internet (see e.g. Pan *et al.*, 1998). Reported here is the initial development of a system 1) to capture and process weather data from selected stations at a central computer, and 2) to provide access to these data and a crop model through the Internet, thereby facilitating interactive decision support for agronomic management of sugarcane. The use of this system is also demonstrated by applying it to estimate cane yields for selected scenarios.

Methods

Figure 1 shows the flow of data from automatic weather stations (AWS) to the SASEX computing centre for agronomic advice (CCAA), onto a Web server and then onto computers of Web users.

The different stages of data flow and data processing are now described.

Data capture and transfer from the AWS to CCAA

Hourly and daily values of radiation, wind speed, dry and wet bulb temperature and total rainfall are recorded on Campbell Scientific data loggers. Currently 10 AWS's are accessed (for a list see <http://www.sasa.org.za/sasex/irricane/tables/index.htm>). Data are transferred either daily through Siemens cell phone

modems directly onto a personal computer connected to the SASEX local area network (LAN), or monthly through serial link onto a laptop and then copied to the SASEX LAN. Intermittent disruptions of communication occurred early on in the project. These were due to weak signal amplitude, operator mistakes, cellular network errors, remote and local power interruptions and telephone cable theft. Most of these problems have subsequently been eliminated.

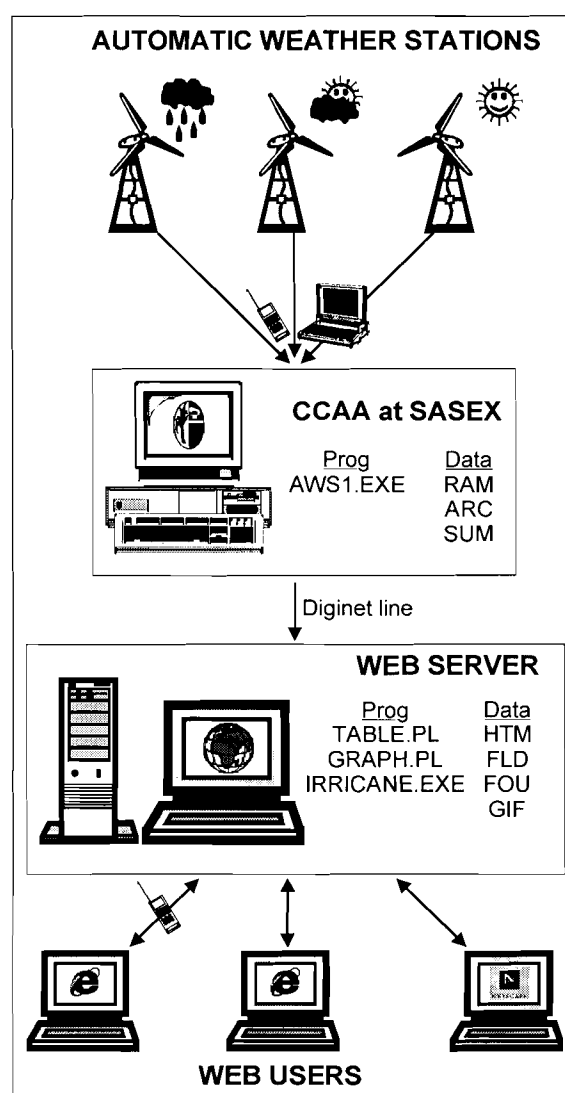


Figure 1. Data flow and processing.