Carbofuran Presence in Soil Leachate, Groundwater, and Surface Water in the Potato Growing Area in Carchi, Ecuador

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Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) is a toxic insecticide widely used on potato (*Solanum tuberosum* L.) crops in Carchi Province, Ecuador. Carbofuran can leach to groundwater and become a threat for both human health and the environment. To determine the extent of carbofuran presence in the area, we sampled soil leachate, groundwater, and surface water from within 14 hydrologic units (each 2.5–20 ha) where potato was being grown from September to November 1999. Carbofuran was found in all hydrologic units except one, at concentrations that were inversely proportional to the organic matter content of the predominant soil type. A simulation study showed that the Leaching Estimation and Chemistry Model (LEACHM) could be a valuable tool for evaluating carbofuran fate, because it was shown to correctly identify soil types with the greatest risk for leaching.

The mountainous area of Carchi in the northern Andes of Ecuador has an intensive, market-oriented potato production system with high levels of pesticide use. The single most widely used insecticide is carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate), which is applied by growers to control the Andean potato weevil (*Premnotrypes vorax* (Hustache)) (Crissman et al., 1998b). A potential contaminant of water supplies, carbofuran can enter groundwater by leaching and surface water by runoff from treated fields. At sufficiently high carbofuran concentrations, the human health effects due to long-term exposure include damage to the nervous and reproductive systems (EPA, 1998).

Concerns about the adverse effects of carbofuran on human health and the environment led to an analysis of farmer practices and pesticide use in two Carchi watersheds during the early 1990s (Crissman et al., 1998a). This analysis showed that most of the negative impacts of pesticide use on human health were due to pesticide exposure following unsafe storage, handling, and application. Although the fate of carbofuran in the environment was not measured and monitored directly, modeling studies indicated that leaching of carbofuran would be minimal because of the high organic matter (OM) content of soils in the region; sorption of the pesticide increases with increasing OM content (Ducrot et al., 1998). These results, however, do not suggest that carbofuran poses no adverse environmental risks in the potato-growing areas of Carchi. Rather, they have provided the impetus for several more

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detailed studies intended to better document the environmental fate of carbofuran through both measurement and simulation.

In this paper, we present the results of one such study designed to measure the concentration of carbofuran in soil leachate, groundwater, and surface water in 14 small catchments or hydrologic units located near the town of San Gabriel in Carchi. These measurements were taken during a short period of time, but over a wide area to determine the possible extent of carbofuran contamination. The study also assessed the feasibility of using the LEACHM (Leaching Estimation and Chemistry Model) (Hutson and Wagenet, 1992) simulation model to predict carbofuran movement in the predominant soil of each hydrologic unit.

Materials and Methods

Carbofuran measurements

Soil leachate, groundwater, and surface water samples were taken from 14 hydrologic units in the potato-growing area around San Gabriel between September and November 1999 (Table 1). The size of the hydrologic units varied from 2.5 to 20 ha. Each hydrologic unit contained sloping potato fields that were being cultivated during the sampling period. Carbofuran was applied to potato fields in all but two units. The predominant soil type in each hydrologic unit was either a Duriudoll–Eutrandept (Cf), Dystrandept (Dp), or Eutrandept-Argiudoll (Hf). These types are distinguished mainly by differences in soil OM content, which is known to influence pesticide degradation (Ducrot et al., 1998).

Within each hydrologic unit, sloping potato fields for which we had information on the date and amount of carbofuran application were selected to take leachate and water samples at the positions illustrated in Figure 1. Soil leachate was collected from the unsaturated soil below the potato crop at sites near the top, middle, and bottom portions of the field using a suction probe (Rhizon Sampler from Eijkelkamp Agrisearch Equipment, http://www.eijkelkamp.com). The suction probes were installed horizontally in pits dug between the potato furrows, usually at

Table 1. General description of the selected hydrologic units showing altitude, predominant soil type, average soil organic matter (OM) content, total area cropped to potato, and amount of the insecticide carbofuran applied to potato fields.

Hydrologic unit number	Altitude (m)	Soil type[1]	OM content (%)	Total area (ha)	Potato area (ha)	Carbofuran applied[2] (l/ha)
1	3070	Cf	8	7.0	2.0	2.00
2	3200	Dp	10	7.0	6.0	2.00
3	3100	Dp	10	5.0	2.2	0.00
4	3100	Dp	10	20.0	4.0	2.00
5	3000	Dp	10	10.0	4.0	4.00
6	3100	Dp	10	12.0	5.0	2.00
7	3100	Dp	10	2.5	1.5	0.00
8	3200	Dp	10	6.0	1.2	2.30
9	2900	Cf	8	10.0	5.0	2.00
10	3100	Dp	10	8.0	7.0	2.00
11	2770	Hf	6	3.0	3.0	0.25
12	2900	Hf	6	7.0	6.5	1.60
13	2800	Hf	6	4.5	4.0	4.50
14	2900	Cf	8	4.0	1.5	1.50

[1] Soil types from MAG-ORSTOM (1980). "Cf" stands for Duriudoll-Eutrandept, "Dp" for Dystrandept and "Hf" for Eutrandept-Argiudoll.

[2] Amount of commercial formulation (Carbodan, Carbofuran 4f) applied during potato cycle.

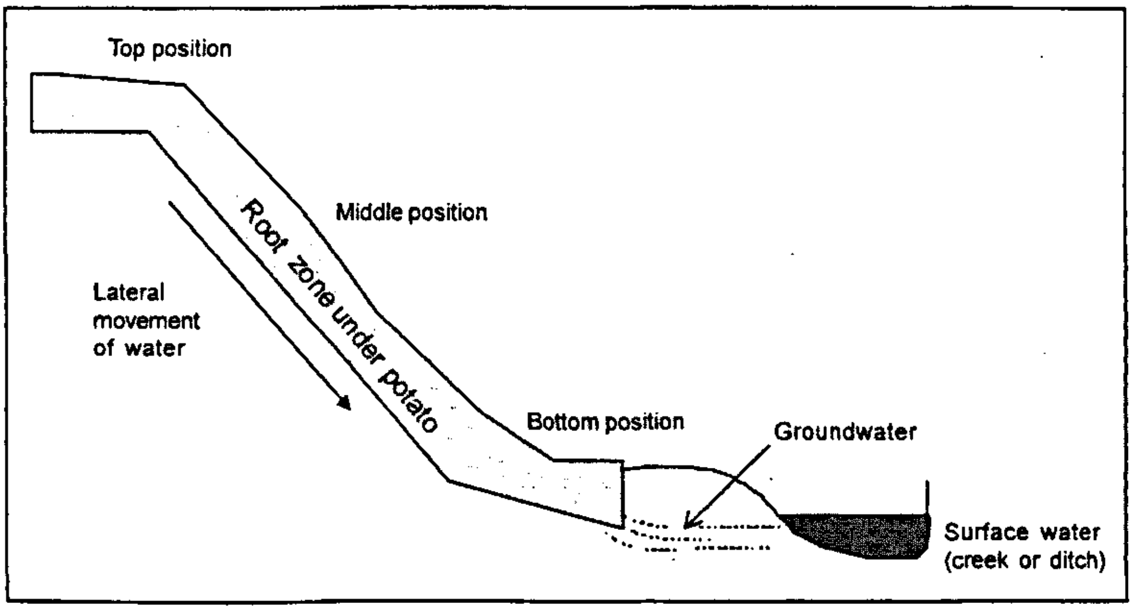

Figure 1. Representation of a sloping field and the relative positions (top, middle, and bottom) from which soil leachate, groundwater, and surface water samples were taken.

a depth of 80 cm just below potato roots. If a sandy or cemented layer was present at a shallower depth, the probes were placed above that layer. We were able to extract sufficient soil solution for carbofuran analysis during a 16-24 h period. Soil leachate samples were taken in this way from a total of 19 fields across all hydrologic units.

An attempt to collect groundwater samples was made once during the sampling period by boring a hole to a depth of 220 cm at the bottom portion of one field within each hydrologic unit. If groundwater was found, it was carefully pumped out using a syringe attached to a plastic pipe; in only 7 of the 14 units did we encounter groundwater at a depth of 220 cm or less. Surface water samples were taken usually at least twice, once near the beginning of the sampling period and again near the end, by scooping plastic bottles into water running through a creek or ditch at the bottom of each hydrologic unit.

Leachate and water samples were analyzed for the presence of carbofuran using the Carbofuran RaPID Assay® procedure (Strategic Diagnostic, Inc., http://www.sdix.com), which is based on the enzyme-linked immunosorbent assay (ELISA). The RaPID Assay allows detection at 0.1–5 parts per billion (ppb) carbofuran. When carbofuran concentration exceeds 5 ppb, dilutions can be made to measure the real amount.

Model simulations

To simulate carbofuran movement in soil, we used the pesticide version (LEACHP) of the basic LEACHM model (Hutson and Wagenet, 1992). Simulation runs were made for each potato field sampled in the 14 hydrologic units. To run the model, weather data inputs (rainfall and temperature) were obtained from the INAMHI (Instituto Nacional de Meteorología e Hidrología) meteorological station in nearby San Gabriel, although for two of the units rainfall was measured on site. Soil data inputs (physical and chemical properties) were estimated in the field according to functional horizon relationships derived earlier by Kooistra and Meyles (1997). Carbofuran amounts and application dates for each field were obtained from farmer interviews.

Comparative simulation runs were made using two carbofuran degradation rates. One simulation used the average degradation rate of 0.0139/d (half-life = 50 d) cited in the literature (Wauchope et al., 1992); the other used the rate of 0.0495/d (half-life = 14 d) that was determined experimentally in a nearby field study (Stoorvogel et al., 2001). Although model runs were made on a per field basis, the results were averaged across the three main soil units for presentation.

Results and Discussion

Carbofuran measurements

Carbofuran was found in various concentrations throughout all hydrologic units except unit 10 (Table 2). The highest concentrations were found in soil leachate, with the amount being inversely related to soil OM content. Hydrologic units with Dp soils (10% OM) consistently had less carbofuran in soil leachate than units with Cf (8% OM) and Hf (6% OM) soils. Leachate from the Hf soils generally showed the greatest concentration of carbofuran. Hydrologic units with Hf soils also tended to have a greater concentration of carbofuran in groundwater samples, at least when compared to units where such samples were taken. In addition to containing less OM, the Hf soils tended to be more shallow, hence carbofuran concentrations would be expected to be somewhat higher in hydrologic units with these soils since the carbofuran could be more easily leached.

Carbofuran was even found in the two hydrologic units (3 and 7) where farmers indicated it was not applied to potato fields during the sampling period (Table 2). The relatively low concentrations in soil leachate in unit 3 may be due to applications made to an earlier crop. In unit 7, carbofuran was found only in the surface water on the second sampling date. In this case we are not sure of the source, although it may also come from earlier applications and the gradual movement of carbofuran over time. In general, more carbofuran was found in the second sample of surface water for most of the hydrologic units, which may have come from runoff as well as subsurface flow.

The United States Environmental Protection Agency has defined an enforceable

Table 2. Carbofuran concentrations (parts per billion (ppb)) found in soil leachate, ground water, and surface water in the fourteen hydrologic units.

Hydrologic unit number	Soil type	Carbofuran in soil leachate			Carbofuran in ground water[1] (ppb)	Carbofuran in surface water[1,2] (ppb)
		Mean (ppb)	Maximum (ppb)	Minimum (ppb)		
1	Cf	1.00	4.00	0.00	ns	0.10
2	Dp	0.00	0.00	0.00	0.00	0.19; 0.00
3	Dp	0.04	0.10	0.00	ns	0.12; 0.00
4	Dp	0.02	0.12	0.00	0.15	0.00
5	Dp	0.26	0.52	0.10	ns	0.00; 0.65
6	Dp	0.00	0.00	0.00	ns	0.00; 1.60
7	Dp	0.00	0.00	0.00	ns	0.00; 2.00
8	Dp	0.63	2.50	0.00	0.00	0.00; 0.07
9	Cf	0.05	0.20	0.00	ns	0.00; 0.95
10	Dp	0.00	0.00	0.00	0.00	ns
11	Hf	1.28	1.80	0.58	0.36	0.27; 0.80
12	Hf	1.82	6.20	0.40	0.32	0.29; 0.58
13	Hf	1.22	3.50	0.00	0.75	0.11; 0.26
14	Cf	1.23	3.60	0.00	ns	0.50; 0.46

[1] ns = no sample available.

[2] Surface water samples were taken once or twice. Where two samples were taken, the first number is the first sample result; the second number is the second sample result.

standard for the presence of chemicals in drinking water; it is called the maximum contaminant level (MCL). For carbofuran, the MCL has been set at 40 ppb (EPA, 1998). Nevertheless, if carbofuran is found at levels above 0.9 ppb, the water supplier must set up a continuous monitoring system to track carbofuran levels (EPA, 1998). The levels of carbofuran found in the Carchi hydrologic units were all much less than 40 ppb, although in a few cases carbofuran was found at levels considerably higher than the monitoring trigger of 0.9 ppb.

In addition to its negative impact on human health, carbofuran and other pesticides can also have adverse effects on aquatic life. For that reason, performance goals that set the upper limit on daily concentrations of pesticides permitted in freshwater environments have been implemented by many state water quality control boards in the United States, which is distinct from standards set for drinking water. For example, the performance goal for carbofuran in California freshwater environments has been set at only 0.4 ppb (Crepeau and Kuivila, 2000). Some of the surface water samples taken from the Carchi hydrologic units showed that carbofuran concentrations often exceeded this performance goal (Table 2).

Model simulations

The simulation of carbofuran movement with LEACHM showed the model to be extremely sensitive to the degradation rate, or half-life used for carbofuran. When the more conservative estimate of pesticide persistence was used (half-life = 50 d), the model predictions of carbofuran in soil leachate greatly exceeded the amount measured (Figure 2). Nevertheless, the simulations did capture the inverse relationship between soil OM content and the amount of carbofuran leached. When the simulation used the half-life of 14 d that was obtained from the experiment conducted locally by Stoorvogel et al. (2001), model predictions were closer to the observed values, particularly for Dp soils, although they now underestimated the amount of carbofuran in soil leachate for Hf and Cf soils (Figure 2).

These results show that even though the model did not accurately predict the amount of carbofuran in soil leachate, it could still be useful for describing the relative importance of factors such as soil OM in controlling pesticide fate. Perhaps, too, the model results can be improved with (1) further understanding of carbofuran degradation in volcanic ash soils in the high Andes, and (2) on-site measurement of soil and weather data needed as model inputs.

Conclusions

Carbofuran was found in soil leachate, groundwater, and surface water samples taken from sites within 14 hydrologic units in Carchi. Analysis confirmed a low degree of pollution for the area that is below the MCL of 40 ppb, but often above a level of 0.4 ppb known to adversely affect some aquatic life forms. Despite the high OM content of the soils, and evidence for the fairly rapid degradation of carbofuran in these environments, leaching of carbofuran does occur and it can make its way into groundwater.

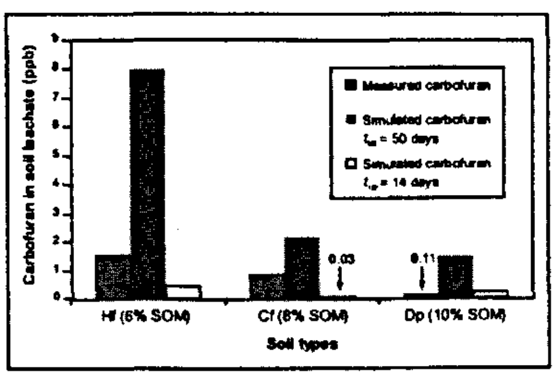

Figure 2. Measured and simulated concentrations of carbofuran in soil leachate averaged by soil unit and soil organic matter (OM) content (Hf: Eutrandept-Argiudoll; Cf: Duriudoll-Eutrandept; Dp: Dystrandept). One simulation assumed a half-life of 50 days, the other assumed a half-life of 14 days.

Likewise, carbofuran occurs in surface waters, getting there probably through runoff. LEACHM can be a valuable tool for evaluating carbofuran fate since it was shown to correctly identify soil types with the greatest risk for leaching.

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