Aldicarb Transport in Drained Coastal Plain Soil

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Abstract: The pesticide aldicarb is extremely soluble in water, which causes it to be mobile in ground water. A field study was conducted to monitor the fate of aldicarb in a poorly drained soil in the North Carolina coastal plain. The research site consisted of three experimental plots with three water-table management treatments: conventional drainage, controlled drainage, and subirrigation. Surface and subsurface drainage rates were measured continuously and water-table elevations were monitored in each plot. A total of 651 soil and water samples were collected over a six-month period. Aldicarb degraded to nontoxic compounds with a half-life of approximately 7 days. The maximum aldicarb loss through drainage outflow and surface runoff was 0.02% and 0.05% of total applied aldicarb, respectively.

INTRODUCTION

The purpose of this paper is to present results of a field experiment to determine the effect of water-table control practices on the fate of the pesticide aldicarb in poorly drained soils in the coastal plain of North Carolina. The research site has subsurface drains that were maintained in conventional drainage, controlled drainage, and subirrigation. Aldicarb concentrations in the soil, ground water, tile drainage, and surface runoff were measured over a six-month period in nine sampling rounds. Surface and subsurface drainage was measured and total aldicarb losses in the tile outflow and surface runoff were determined. The half-life for aldicarb at this site was approximated.

Aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-methylcarbamoyloxime] was developed in 1962 by Union Carbide (now Rhone-Poulenc, Inc.) as a systemic insecticide, acaricide, and nematicide for use in agriculture and silviculture (Weiden et al. 1965). Aldicarb (temik) is typically formulated in granules containing 15% active ingredient (AI) and degrades rapidly and irreversibly (Lightfoot et al. 1987). Two of the metabolites, sulfoxide and sulfone, have properties similar to aldicarb (Table 1). All three compounds are extremely soluble in water, weakly sorbed to organic matter, and highly toxic (Hornsby et al. 1983). All aldicarb concentrations reported here are the sum of the aldicarb, sulfoxide, and sulfone concentrations.

Aldicarb is used widely throughout the world on fruits, vegetables, nuts, cotton, tobacco, and ornamentals. In 1979, aldicarb residues were detected in drinking-water wells on Long Island, New York (Zaki et al. 1982). To protect the public health, the U.S. Environmental Protection Agency (EPA) currently has a health advisory level of 3 parts per billion (ppb) for aldicarb, 2 ppb for sulfone, and 4 ppb for sulfoxide in drinking water.

Since 1979, over 88,000 soil and water samples have been collected in 35 states to study the fate of aldicarb (Jones 1989). The database for aldicarb movement and degradation in the unsaturated zone is larger than that for any other pesticide (Jones 1989). These intensive investigations of the fate of aldicarb have been conducted to assess the environmental impact that aldicarb will have on the many and varied locations where it is used.

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EXPERIMENTAL METHODS

The 13 ha research site, which was cleared for agriculture in 1975, is nearly flat. The soil is classified as a Portsmouth sandy loam (Typic Umbraquult; fine-loamy, siliceous, thermic). This is typically a very poorly drained soil that formed in loamy fluvial and marine sediments (Tant 1981). The surface horizon is a black fine sandy loam 0.30 m (12 in.) thick with an organic content in the 3% to 5% range. Various layers of fine sandy loam extend down to a sandy clay loam located at 0.50–0.90 m (23–35 in.). The sandy clay loam is underlain by a sandy loam, and then at 0.97–1.22 m (38–48 in.) by a grey sandy layer that contains thin layers of silt. A coarse sandy layer is found starting at 1.2–1.5 m and extending to 1.8–2.3 m, depending on location on the site. The coarse sand is underlain by a marine clay deposit that is approximately 6.1 m (20.0 ft) thick. The soil samples from 0 to 1.0 m.

The site, which is bounded on all four sides by drainage ditches, approximately 1.5–2.0 m deep, was subdivided into six, 1.7 ha, experimental plots. The aldicarb study was conducted on plots 1–3 (Fig. 1). These plots were delineated by the area drained by three adjacent subsurface drains. The two outside drains are referred to as guard drains. Measurements were conducted on the center drain. The function of the guard drains was to hydraulically isolate the area that was drained by the center drain from the influence of adjacent experimental plots.

Each experimental plot had an instrument house and underground vault (Fig. 2). Each underground vault intercepted the drainage outflow from the two guard drains, the center drain, and the surface runoff from two field runoff plots. The

TABLE 1. Aldicarb, Sulfoxide, and Sulfone Chemical Properties

Chemical (1)	Water solubility[a] (mg/L) (2)	Specific gravity[b] (3)	K_{oc}[a] (4)	LD_{50}[b] (mg/kg) (5)
1	6,000	1.195	29	0.93
2	330,000	—	0	—
3	8,000	—	11	—

[a]Hornsby et al. (1983).
[b]*Agrochemicals Handbook* (1990).

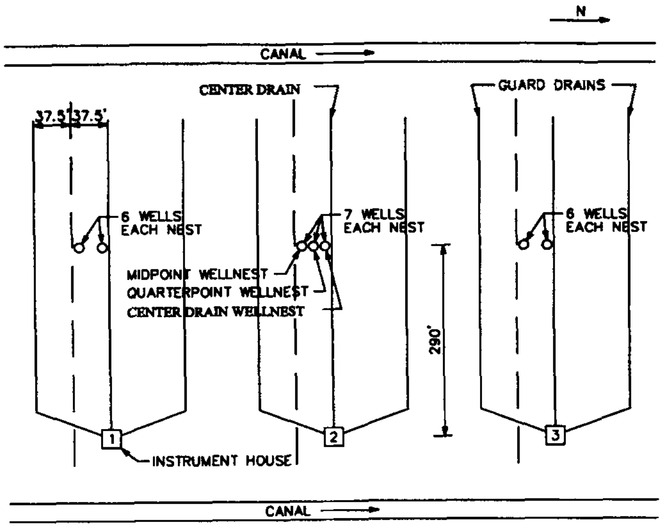

FIG. 1. Research-Site and Well-Nest Locations in Plots 1 (Subirrigation), 2 (Controlled Drainage), and 3 (Conventional Drainage)

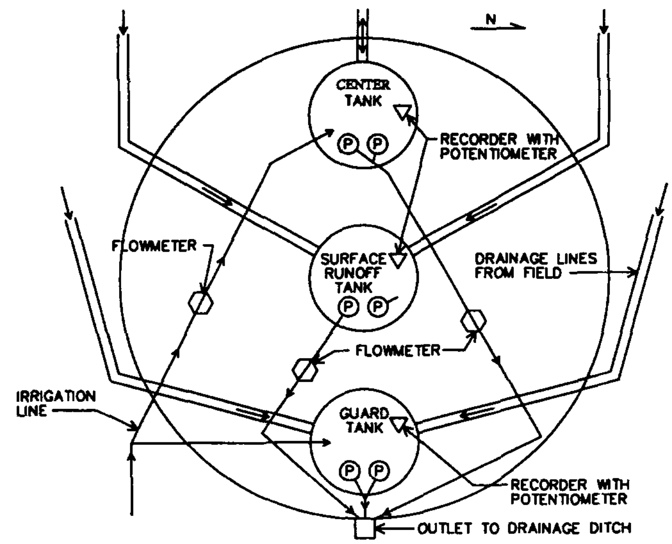

FIG. 3. Plan View of Underground Vault, Drainage Collection Tanks, and Instrumentation

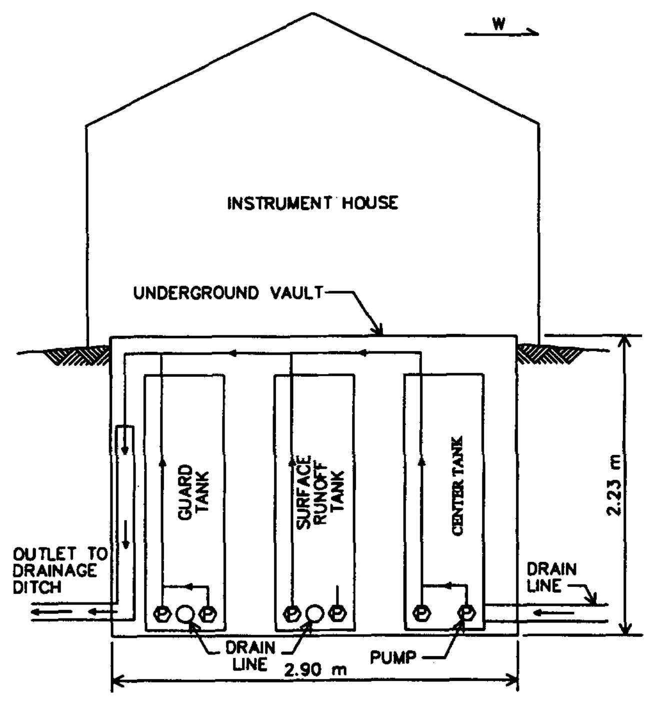

FIG. 2. Elevation View of Instrument House, Underground Vault, and Drainage Collection Tanks

field runoff plots were 6.1 m wide by 30.5 m long. They were isolated from the rest of the field by low berms (0.15 m high) and runoff was collected at the end in a stainless-steel collector and piped underground to the vault.

Each vault contained three cylindrical polyvinyl chloride (PVC) holding tanks that were 0.61 m in diameter and 1.83 m long. These holding tanks intercepted water from the field as follows. The center tank received the water from the center drain, the surface runoff tank received water from the two surface runoff collectors, and the guard tank received water from the two guard drains (Fig. 3). All three holding tanks were equipped with sump pumps, control floats, and metering devices that automatically pumped water from the holding tanks to the drainage-ditch outlet, controlled water levels, in the tanks and measured drainage rates. In addition, water from deep irrigation wells was available for subirrigation. Pumps, control floats, and metering devices were used to fill and measure the water supplied to the drain holding tanks for subirrigation. All drainage and subirrigation rates were continuously measured. These data were collected and processed by a personal computer located in a climate controlled room in equipment house two (Munster 1992).

Using the sump pumps and control floats in the underground vaults, three water-table management treatments—free or conventional drainage, controlled drainage, and subirrigation—were implemented. Plot 1 was maintained in the subirrigration mode, plot 2 in the controlled drainage mode, and plot 3 in the conventional drainage mode during this study.

In conventional drainage, the pumps were set so that the water level in the holding tanks was always below the field drains. In controlled drainage, pump controls were set to remove water when the water level in the holding tanks exceeded the set point or control elevation, which was higher than the drain. The pumps were turned on when the water level exceeded the set point and off when the tank water level fell to the set point. No water was pumped in to maintain the control water level in controlled drainage. In subirrigation, the water level in the holding tank was maintained at a set point above the field drain outlet. Water from an irrigation well was pumped in to replace water lost from the holding tanks via subirrigation; when rainfall occurred, drainage water was pumped out of the tanks to maintain the subirrigation set point.

A refrigerator with a freezer compartment to preserve samples is located in each house. There were two large sample containers in each refrigerator to collect water from the center drain and surface runoff. Flexible 6-mm (ID) tubing is connected to the discharge pipes from the center-drain tank pump and the surface-runoff tank pump. The flexible tubing passes through the wall of the refrigerators and discharges into the sample containers. A portion of the discharge from the tank pump for the center drain and surface runoff was routed to the refrigerated sample containers.

A series of six to seven piezometers, referred to as a piezometer nest, were installed in lines parallel to the drainage tiles. Piezometers in each nest were spaced approximately 0.31 m horizontally and varied in depth from 0.40 to 2.25 m. Each well had a 152-mm-long well screen that was located in a distinct soil layer. A total of 45 piezometers were installed in seven well nests (Fig. 1).

The number, location, and depth of the piezometers were designed to provide the minimum number of sampling points that would permit a detailed analysis of the movement of the pesticide in the flow domain. Two well nests were located 11.40 m (37.5 ft) and 0.30 m (1.0 ft) from the center drain in experimental plots 1–3. These well nests were referred to as the midpoint well nest and the center-point well nest, respectively. An additional well nest was installed in plot 2, 5.70 m (18.8 ft) from the centerline. This well nest was named the quarter-point well nest. One well in each well nest, referred to as a water-table well, was screened the entire length.

EXPERIMENTAL PROCEDURE

Water samples for aldicarb analysis were obtained from the well nests, the drain outflow, the surface runoff collectors, the outlet ditch, and two irrigation wells on the site. The well-nest piezometers were purged and sampled using polyethylene bailers as described in Munster (1992).

Soil samples were obtained in 0.15-m increments in the unsaturated zone to the depth of the water table using an 83-mm-diameter bucket auger (Kirkland 1989). Soil samples from four random locations were sampled and composited within each experimental plot. A 1,000-g subsample for each increment was taken from the composite samples. All soil samples were refrigerated until the aldicarb extraction procedure as described by Hudson (1990) was performed. The soil water extract was then frozen until the analysis was performed.

Aldicarb was applied to a no-till soybean crop on June 27, 1990 (Julian day 178), at the time of planting. The granular aldicarb was incorporated into the soil, 25 mm deep, in 0.48-m rows at a formulated rate of 6.1 kg/ha (0.92 kg/ha active ingredient). Over a six-month period, nine sampling rounds were conducted starting on the day aldicarb was applied to the field. A total of 106 soil samples and 545 water samples were obtained. Included in the 545 water samples were 60 replicate samples that were used for split sample analysis by an independent laboratory. Because aldicarb had never been applied to the research site, no background sampling was performed.

Aldicarb concentrations were determined by a high-pressure liquid chromatography (HPLC) system with on-line postcolumn derivatization/fluorescence (Hudson 1989). This HPLC system is capable of simultaneously measuring the amount of aldicarb, sulfoxide, and sulfone in a sample. All aldicarb concentrations reported are the sum of aldicarb, sulfoxide, and sulfone concentrations.

EXPERIMENTAL RESULTS

Plot 3. Conventional Drainage

The water level in the drain outlet tank was always below the drain for the conventional drainage treatment (Fig. 4). Outflow from the center drain was measured at 21 mm along with 36 mm of surface runoff (Fig. 5). The midpoint water-table elevation remained at or above the drain (1.0 m) until 90 days after application, when an extended dry period occurred (Fig. 6).

As shown in Table 2, aldicarb persisted in the soil at the 0.00 to 0.15 m depth until day 225, 47 days after application. Aldicarb was not detected in the soil below the 0.46–0.61 m depth. However the initial concentration on day 1 was approximately four times the concentrations in the controlled drainage and subirrigation plots for unknown reasons. The high soil concentration (471 ng/g) in the 0.15–0.30 sample on day 178 (the day of application) may be due to cross contamination.

Very few of the samples from the piezometer nest near the center drain contained aldicarb (Table 3) and the concentrations seem to be without pattern. However, samples from the

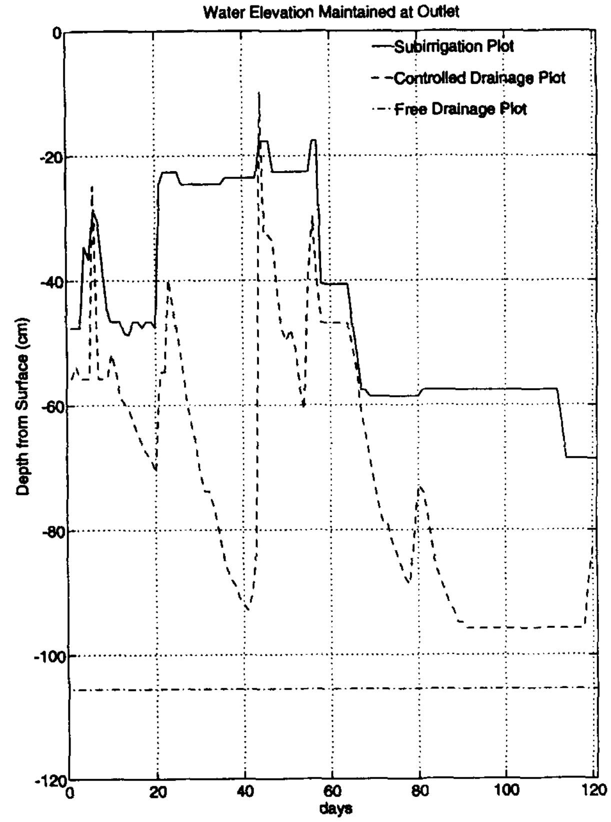

FIG. 4. Water Level Maintained at Drain Outlets

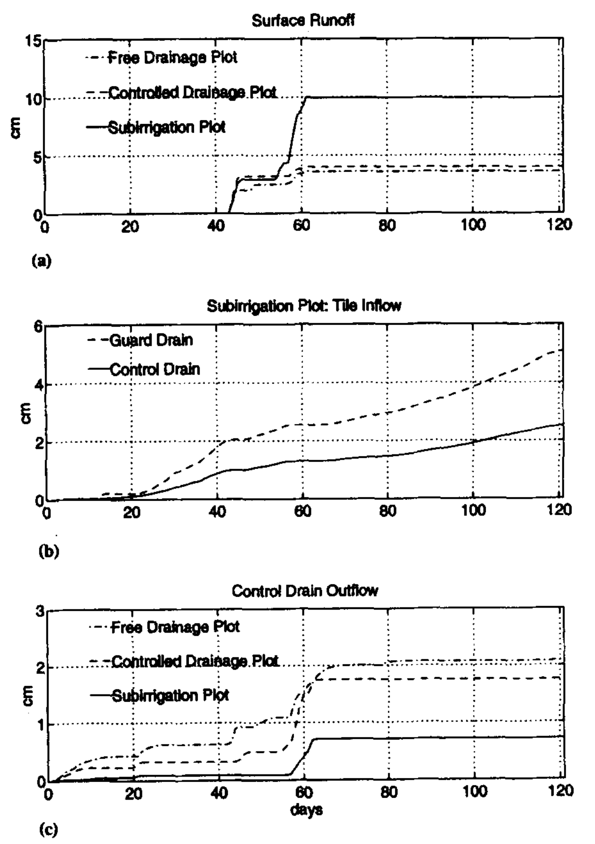

FIG. 5. Center Drain Outflow and Surface Runoff: (a) Subirrigation (Plot 1); (b) Controlled Drainage (Plot 2); (c) Free Drainage (Plot 3) with Subirrigation Inflow (Plot 1)

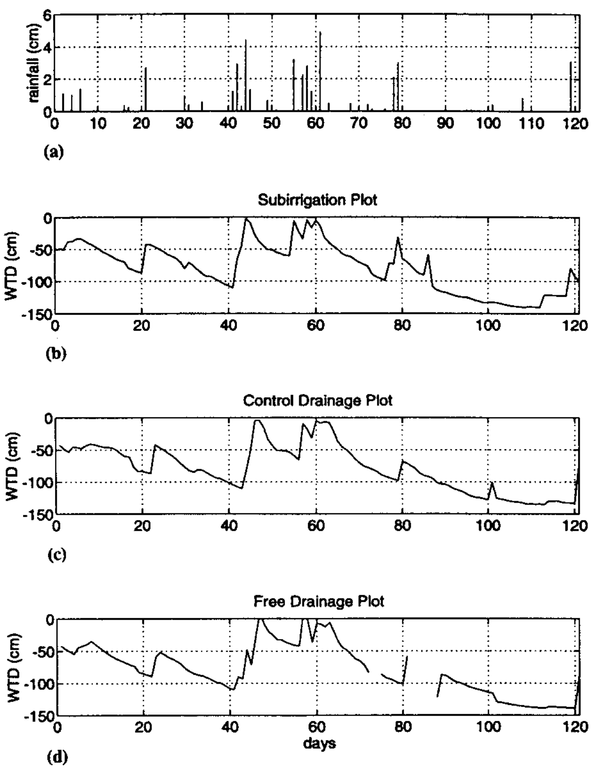

FIG. 6. Midpoint Water-Table Elevations: (a) Rainfall Record; (b) Subirrigation (Plot 1); (c) Controlled Drainage (Plot 2); (d) Free Drainage (Plot 3)

TABLE 2. Aldicarb Concentrations (ng/g dry soil) in Free Drainage Plot in Soil Samples

Sample round number (1)	Sample date (Julian day) (2)	Sample Depth (m) 0.00–0.15 (3)	0.15–0.30 (4)	0.30–0.46 (5)	0.46–0.61 (6)	0.61–0.76 (7)
1	178	2018.0	471.0	—	—	—
2	184	461.0	41.0	17.0	—	—
3	198	140.0	4.0	7.0	—	—
4	215	29.0	0.0	3.0	5.0	—
5	225	7.0	0.0	0.0	0.0	—
6	239	0.0	0.0	0.0	0.0	0.0
7	256	0.0	0.0	0.0	0.0	0.0
8	297	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0

TABLE 3. Aldicarb Concentrations (μg/L) in Free Drainage Plot in Center Drain Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m) 0.61 (3)	0.85 (4)	1.30 (5)	0–1.2 (6)	1.77 (7)	2.42 (8)
1	178	0.0	0.0	0.0	0.0	0.0	0.0
2	184	—	8.0	0.0	19.0	0.0	0.0
3	198	42.0	0.0	0.0	0.0	0.0	0.0
4	215	—	—	0.0	—	0.0	0.0
5	225	5.0	0.0	0.0	36.0	0.0	0.0
6	239	0.0	0.0	0.0	0.0	0.0	0.0
7	256	—	0.0	0.0	0.0	0.0	0.0
8	297	—	—	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 4. Aldicarb Concentrations (μg/L) in Free Drainage Plot in Midpoint Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m) 0.59 (3)	0.90 (4)	1.22 (5)	0–1.0 (6)	1.74 (7)	2.22 (8)
1	178	0.0	0.0	0.0	0.0	0.0	0.0
2	184	0.0	7.0	2.0	14.0	10.0	0.0
3	198	0.0	0.0	0.0	8.0	0.0	0.0
4	215	—	—	1.0	—	0.0	0.0
5	225	6.0	0.0	0.0	2.0	0.0	0.0
6	239	0.0	0.0	0.0	1.0	0.0	0.0
7	256	—	0.0	0.0	0.0	0.0	0.0
8	297	—	—	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 5. Aldicarb Concentrations (μg/L) in Free Drainage Plot in Tile Outflow

Sample round number (1)	Sample date (Julian day) (2)	Center tank (3)	Guard tank (4)	SRO tank (5)
1	178	0	0	0
2	184	16	9	—
3	198	35	32	—
4	215	0	0	—
5	225	4	4	15
6	239	0	0	2
7	256	0	0	—
8	297	0	0	—
9	4	0	0	0

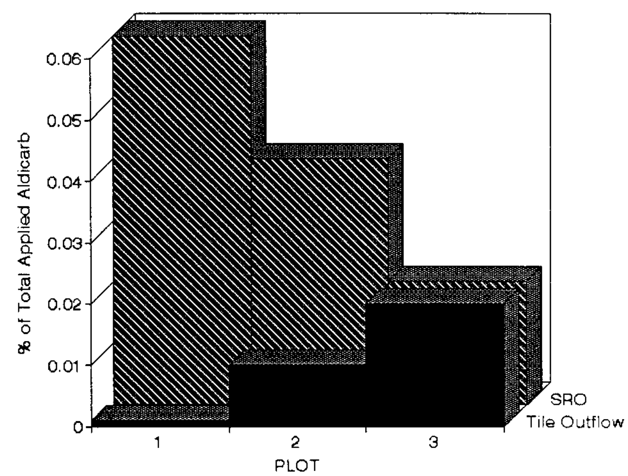

FIG. 7. Total Aldicarb Lost as Percentage of Amount Applied in Tile Outflow and Surface Runoff (SRO) from Subirrigation (Plot 1), Controlled Drainage (Plot 2), and Free Drainage (Plot 3)

midpoint piezometer nest (Table 4) exhibited a consistent decline in aldicarb concentrations with depth and time. The erratic pattern in the piezometer nest near the drain was due to temporal variation in the water-table and water movement near the drains. In the conventional drainage mode, the water table near the drain was lowered to the drains. The shallow piezometers became dry and a soil-water sample could not be obtained to determine aldicarb concentrations (Table 3, Julian days 184 and 215). The next large rainfall event caused the water table to rise to the shallow piezometers (Table 3, Julian days 198 and 225) so that aldicarb concentrations could be determined. These concentrations indicated that aldicarb retained in the soil may be quickly transported vertically downward near the drains in the conventional drainage mode during infiltration events.

The aldicarb concentrations in the drain outflow (Table 5) support the previous hypothesis. Aldicarb concentrations as high as 35 ppb were detected in the tile outflow soon after the large rainfall event on day 198.

Aldicarb concentrations were detected in two surface-runoff samples from days 225 and 239 (Table 5). However, total aldicarb losses in the tile outflow and surface runoff (Fig. 7) were 0.02% and 0.02% of the aldicarb applied, respectively, for the conventional drainage mode.

Plot 2. Controlled Drainage

Controls were set on the outlet tanks such that drainage water was not pumped from the outlet until it exceeded a set point. The water level in the outlet is shown in Fig. 4. No additional water was pumped into the outlet in this controlled-drainage treatment. Total measured outflow from the center drain was 18 mm with 40 mm of surface runoff (Fig. 5). The measured water table midway between the drains is shown in Fig. 6.

TABLE 6. Aldicarb Concentrations (ng/g Dry Soil) in Controlled Drainage Plot in Soil Samples

Sample round number (1)	Sample date (Julian day) (2)	Sample Depth (m)				
		0.00–0.15 (3)	0.15–0.30 (4)	0.30–0.46 (5)	0.46–0.61 (6)	0.61–0.76 (7)
1	178	544.0	21.0	—	—	—
2	184	234.0	17.0	16.0	—	—
3	198	38.0	3.0	3.0	—	—
4	215	8.0	0.0	0.0	0.0	—
5	225	0.0	0.0	0.0	0.0	—
6	239	0.0	0.0	0.0	0.0	—
7	256	0.0	0.0	0.0	0.0	0.0
8	297	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0

TABLE 7. Aldicarb Concentrations (μg/L) in Controlled Drainage Plot in Midpoint Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m)						
		0.60 (3)	0.82 (4)	1.06 (5)	0–1.2 (6)	1.40 (7)	1.78 (8)	2.37 (9)
1	178	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	184	6.0	12.0	0.0	3.0	11.0	0.0	0.0
3	198	0.0	11.0	0.0	6.0	0.0	0.0	0.0
4	215	—	—	0.0	0.0	0.0	0.0	0.0
5	225	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	239	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	256	0.0	1.0	0.0	0.0	0.0	0.0	0.0
8	297	—	0.0	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 8. Aldicarb Concentrations (μg/L) in Controlled Drainage Plot in Quarter Point Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m)						
		0.56 (3)	0.79 (4)	1.03 (5)	0–1.1 (6)	1.55 (7)	1.85 (8)	2.34 (9)
1	178	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	184	0.0	8.0	0.0	3.0	11.0	0.0	2.0
3	198	2.0	13.0	0.0	0.0	6.0	0.0	23.0
4	215	—	—	0.0	0.0	0.0	0.0	0.0
5	225	0.0	2.0	0.0	0.0	0.0	2.0	0.0
6	239	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	256	0.0	1.0	0.0	0.0	0.0	5.0	0.0
8	297	—	0.0	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 9. Aldicarb Concentrations (μg/L) in Controlled Drainage Plot in Center Drain Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m)						
		0.55 (3)	0.80 (4)	1.09 (5)	0–1.1 (6)	1.36 (7)	1.80 (8)	2.31 (9)
1	178	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	184	1.0	0.0	0.0	0.0	0.0	0.0	2.0
3	198	4.0	7.0	0.0	0.0	0.0	0.0	3.0
4	215	—	—	0.0	0.0	0.0	0.0	0.0
5	225	0.0	2.0	0.0	0.0	0.0	0.0	0.0
6	239	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	256	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	297	—	0.0	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 10. Aldicarb Concentrations (μg/L) in Controlled Drainage Plot in Tile Outflow

Sample round number (1)	Sample date (Julian day) (2)	Center tank (3)	Guard tank (4)	SRO tank (5)
1	178	0	0	0
2	184	14	9	—
3	198	14	7	0
4	215	23	0	—
5	225	6	6	27
6	239	0	0	0
7	256	0	0	0
8	297	0	0	—
9	4	0	0	—

Aldicarb concentrations in the soil in plot two (Table 6) completely dissipated by day 225, 47 days after application. Aldicarb was not detected in the soil deeper than the 0.30–0.46 m samples.

Aldicarb was not consistently detected after day 198, 20 days after application, in the piezometer nests (Tables 7–9). The drainage outflow from both the center and guard drains consistently had aldicarb concentrations from 6 to 23 ppb (Table 10). Aldicarb in the soil water near the drain, as indicated by concentrations in the piezometer nest, was lost in the drainage outflow.

Only one surface-runoff sample contained aldicarb (Table 10). Surface runoff from the rainfall event that occurred 47 days after application (Julian day 225) had an aldicarb concentration of 25 ppb. Aldicarb losses in the tile outflow and surface runoff (Fig. 7) were 0.01% and 0.04% of total aldicarb applied, respectively.

Plot 1. Subirrigation

Subirrigation was applied to plot 1 by maintaining the water level above the drain outlets as shown in Fig. 4. The center drain subirrigated 25 mm while draining 7 mm during wet periods (Fig. 5). During the 120-day field study, 100 mm of surface runoff was measured in plot 1 (Fig. 5). The midpoint water-table elevation is shown in Fig. 6.

As shown in Table 11, aldicarb persisted in the soil at the 0.00–0.15 m depth until day 225, 47 days after application. Aldicarb was not detected in the soil below the 0.30–0.46 m depth.

Aldicarb was never detected below the 1.3-m depth in the piezometer-nest samples (Tables 12 and 13). The concentrations in the midpoint nest were approximately twice the values in the samples taken from the nest near the drain. This is due

TABLE 11. Aldicarb Concentrations (ng/g Dry Soil) in Subirrigation Plot in Soil Samples

Sample round number (1)	Sample date (Julian day) (2)	Sample Depth (m)				
		0.00–0.15 (3)	0.15–0.30 (4)	0.30–0.46 (5)	0.46–0.61 (6)	0.61–0.76 (7)
1	178	553.0	5.0	—	—	—
2	184	163.0	9.0	52.0	—	—
3	198	57.0	1.0	6.0	—	—
4	215	30.0	0.0	4.0	1.0	—
5	225	19.0	0.0	0.0	0.0	—
6	239	0.0	0.0	0.0	0.0	—
7	256	0.0	0.0	0.0	0.0	0.0
8	297	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0

TABLE 12. Aldicarb Concentrations (μg/L) in Subirrigation Plot in Midpoint Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m)					
		0.56 (3)	0.76 (4)	1.17 (5)	0–1.3 (6)	1.87 (7)	2.54 (8)
1	178	0.0	0.0	0.0	0.0	0.0	0.0
2	184	15.0	0.0	0.0	2.0	0.0	0.0
3	198	8.0	0.0	0.0	9.0	0.0	0.0
4	215	—	—	0.0	5.0	0.0	0.0
5	225	0.0	0.0	0.0	15.0	0.0	0.0
6	239	0.0	0.0	0.0	3.0	0.0	0.0
7	256	—	0.0	0.0	0.0	0.0	0.0
8	297	—	—	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 13. Aldicarb Concentrations (μg/L) in Subirrigation Plot in Center Drain Wells

Sample round number (1)	Sample date (Julian day) (2)	Screen Depth (m)					
		0.59 (3)	0.87 (4)	1.17 (5)	0–1.3 (6)	2.00 (7)	2.37 (8)
1	178	0.0	0.0	0.0	0.0	0.0	0.0
2	184	0.0	1.0	0.0	0.0	0.0	0.0
3	198	5.0	5.0	0.0	8.0	0.0	0.0
4	215	—	—	0.0	0.0	0.0	0.0
5	225	0.0	0.0	0.0	2.0	0.0	0.0
6	239	0.0	0.0	0.0	0.0	0.0	0.0
7	256	—	0.0	0.0	0.0	0.0	0.0
8	297	—	0.0	0.0	0.0	0.0	0.0
9	4	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 14. Aldicarb Concentrations (μg/L) in Subirrigation Plot in Tile Drainage

Sample round number (1)	Sample date (Julian day) (2)	Center tank (3)	Guard tank (4)	SRO tank (5)
1	178	0.0	0.0	0.0
2	184	0.0	2.0	—
3	198	0.0	0.0	0.0
4	215	—	—	—
5	225	—	—	26.0
6	239	0.0	0.0	2.0
7	256	0.0	0.0	—
8	297	—	—	—
9	4	0.0	0.0	—

TABLE 15. Aldicarb Concentrations (μg/L) in Drainage Ditch and Irrigation Wells

Sample round number (1)	Sample date (Julian day) (2)	Ditch (3)	Shallow irrigation well (4)	Deep irrigation well (5)
1	178	0.0	0.0	0.0
2	184	2.0	0.0	0.0
3	198	0.0	0.0	0.0
4	215	0.0	0.0	0.0
5	225	7.0	0.0	0.0
6	239	0.0	0.0	0.0
7	256	0.0	0.0	0.0
8	297	0.0	0.0	0.0
9	4	0.0	0.0	0.0

TABLE 16. Percentage of Aldicarb and Metabolites Sulfoxide and Sulfone Detected in All Soil Samples Taken 1, 6, 20, and 37 days after Application

Days after application (1)	Aldicarb (%) (2)	Sulfoxide (%) (3)	Sulfone (%) (4)
1	14	86	0
6	0	81	19
20	0	39	61
37	0	18	82

to the effects of subirrigation. The center-drain nest was located 0.30 m from the center drain, and the aldicarb concentrations were diluted by subirrigation water. However, due to high head losses near the drain, subirrigation water was not uniformly distributed across the plot and the midpoint piezometers, which were 11.4 m from the center drain, were less affected by subirrigation.

Aldicarb occurred in the drain outflow once at a level of 2 ppb (Table 14). The quantity of aldicarb in the drain outflow was less than 0.001% of total applied aldicarb (Fig. 7).

Two rainfall events produced high concentrations of aldicarb in the surface-runoff samples obtained 47 and 61 days (Julian days 225 and 239) after application (Table 14). The aldicarb concentration of 26 ppb in the surface-runoff sample from day 225 was very similar to the concentration found in the surface runoff sample from plot 2 (25 ppb) on the same day. The amount of aldicarb in the surface runoff was approximately 0.06% of total applied aldicarb (Fig. 7).

Ditch, Shallow Irrigation Well, and Deep Irrigation Well

Water samples were taken from the drainage ditch and the shallow and deep irrigation wells each sampling round. Aldicarb was never detected in either of the irrigation wells (Table 15). The drainage ditch contained aldicarb concentrations of 2 ppb on day 184 (6 days after application) and 7 ppb on day 225 (47 days after application).

ALDICARB DEGRADATION

A summary of the degradation of aldicarb to the sulfoxide and sulfone metabolites detected in soil samples is shown in Table 16. The soil samples taken on the day of application (day 1) were obtained approximately 2 h after application. As shown in Table 16, 86% of the aldicarb detected had degraded to the metabolite sulfoxide. The sulfoxide then degraded to the metabolite sulfone.

The half-life for aldicarb (aldicarb, sulfoxide, and sulfone) was estimated using analysis data from the drain outflow and soil and water samples taken six days after application in the controlled-drainage plot. The center-drain outflow contained an aldicarb concentration of 14 ng/mL (Table 10). This concentration was assumed to exist in the saturated zone from the water table (0.60 m) to the maximum depth at which aldicarb was detected (1.40 m) as shown in Table 7. The average soil concentration detected in the soil samples was 89 ng/g (Table 6). This concentration was assumed to exist from the soil surface to the water table.

Using these soil and water concentrations and the average porosity of the soil layers from 0.60 to 1.40 m, and the average bulk density of the soil from 0.60 m to the surface, the total mass of aldicarb within a unit width (0.01 m) cross section of the soil profile was determined. The amount of aldicarb lost from the plot was also determined using tile-outflow data.

The cross section extended from the center drain to the midpoint between the adjacent guard drain and the center drain. When the calculated mass of aldicarb was compared to the mass applied to this unit cross section, 70% of the applied aldicarb was remaining on the sixth day after application.

A decay constant (k) of 0.06 was calculated by solving the radioactive decay equation:

$$A = A_0 e^{-kt} \tag{1}$$

where t = time (days) = 6; A_0 = initial concentration = 1; and A = concentration at time t = 0.70. The half-life for aldicarb was calculated to be 11.5 days using the radioactive decay equation where k = decay constant = 0.06; A_0 = initial concentration = 1; and A = concentration at time t = 0.50.

SUMMARY

Aldicarb dissipated from the soil in all three plots by 61 days after application. Most of the aldicarb detected in the soil was found in the 0.00–0.15 m samples. Aldicarb was detected in the soil at a maximum depth of 0.46 m.

In each plot, the aldicarb concentrations in the midpoint well samples were consistently higher than those at the piezometer nest near the drain. For the subirrigation plot, this is due to a combination of dilution due to subirrigation water and aldicarb transport from near the drain with tile outflow when there was drainage. For the controlled-drainage and conventional-drainage plots, aldicarb transport in the vicinity of the drain with tile outflow is the sole cause. Aldicarb was not consistently detected in the well-water samples after Julian day 239, 61 days after application.

The conventional-drainage plot produced the largest volume of tile outflow with the highest aldicarb concentrations. This combination resulted in conventional drainage having the highest percentage of aldicarb lost from tile outflow, followed by controlled drainage, and then subirrigation (Fig. 7). However, the amount of aldicarb lost through the subsurface drains for all three management modes is extremely small when compared to the total amount of aldicarb applied (Fig. 7). Aldicarb was not detected in the tile outflow after Julian day 225, 47 days after application.

Aldicarb concentrations in the surface runoff were similar in all three plots. However the volume of surface runoff was highest for the subirrigation plot and lowest for the conventional-drainage plot. The subirrigation plot maintained the highest water table and the conventional drainage plot had the lowest water table. Therefore, the soil profile in subirrigation had the least amount of storage for infiltration and the soil profile in conventional drainage had the most storage. Accordingly, more surface runoff and aldicarb was lost in the subirrigation mode than in the controlled drainage or conventional drainage modes (Fig. 7). Although the amount of aldicarb lost through surface runoff was higher than tile outflow, the total percentage of aldicarb lost through surface runoff is extremely low when compared to the total percentage applied (Fig. 7). Aldicarb was not detected in the surface runoff after Julian day 239, 61 days after application.

Aldicarb degraded quickly in each plot. Calculations based on a mass balance for aldicarb resulted in an estimated half-life of 11.5 days.

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APPENDIX II. NOTATION

The following symbols are used in this paper:

A = concentration; and
e = base of natural logarithm.

Subscripts

0 = initial value.

Superscripts

k = decay constant; and
t = time (days).