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Analysis of Diazinon Agricultural use in Regions of Frequent Surface Water Detections in California, USA

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Abstract For five agricultural regions in California, USA, detection frequency of diazinon in surface water and several aspects of its use were determined from recent data (2005–2010): application method, product formulation and primary crops. Diazinon detection frequencies ranged from 10% to 91%. Application method and product formulations used were similar in all regions. The primary crops treated varied from lettuce (77%) in the regions with highest detections frequencies to tree crops (53%) in those with the lowest. The results suggest that the variation in diazinon detection frequencies likely was not due to the application method or formulation type.

Keywords Diazinon · Pesticide use · Runoff · Monitoring

Diazinon is a broad-spectrum organophosphorus insecticide currently used in California, mainly on vegetable crops during the irrigation season and dormant tree crops during wet season. Between 2005 and 2010, more than 274,000 lbs of diazinon active ingredient (AI) were used annually in California. Non-agricultural uses of diazinon were phased out during 2002–2004, after which detections of diazinon in urban areas have decreased significantly (Starner 2009). However, the pesticide is still frequently detected in streams in agricultural areas of California (Starner 2009; Ensminger et al. 2011). California Department of Pesticide Regulation (DPR) placed diazinon dormant spray products into re-evaluation in early 2003. The re-evaluation was further expanded in 2010 to include in-season agricultural uses. The expansion of the re-evaluation was based on analysis results from Starner (2009), which suggested that diazinon was frequently detected in areas with in-season agricultural use. Starner's analysis was based on surface water monitoring data between 2003 and 2008 (Starner 2009). Per requirement by the expanded re-evaluation, the registrant (Makhteshim-Agan of North America, Inc.) assembled and summarized diazinon water column monitoring data between 2005 and 2010. Their report indicated that diazinon was still frequently detected in agricultural areas of California with concentrations exceeding the target concentration of 100 ng/L. This target concentration is the Total Maximum Daily Load (TMDL) developed by California State Water Resources Control Board for the San Joaquin and Sacramento River Watershed (California State Water Resources Control Board 2008). It is the lowest water quality criteria for diazinon currently used in the United States. The objective of this analysis was to identify diazinon use scenarios that potentially contribute to its frequent detections in surface waters of California.

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Materials and Methods

This analysis targeted diazinon use scenarios in areas with frequent detections at high concentrations. First, monitoring sites with the most frequent exceedance of the 100 ng/L target concentration were identified using monitoring data from 2005 to 2010. Second, drainage areas contributing to these sites were identified using CalWater 2.2 watershed maps that were developed by the California Interagency Watershed Mapping Committee (IWMC, 2009). Finally, diazinon use data in the drainage areas was summarized to identify the top use scenarios.

Hall and Anderson (2011) reported diazinon monitoring data for 2005–2010 from the nine regions in California: Sacramento Valley, San Joaquin Valley, Pajaro, Salinas Valley, Tulare, Santa Maria Valley, Antelope, Ventura, and Imperial Valley. There were 282 sites from these nine use regions containing 3,732 measurements (Table 1). The highest concentration (24,465 ng/L) was reported in the Salinas Valley Region. Salinas Valley, Santa Maria Valley and Imperial Valley Region have the highest percentage of samples exceeding the target concentration of 100 ng/L (61.9%, 66.7% and 24.1%, respectively). In terms of sample numbers, Salinas Valley, San Joaquin Valley and Sacramento Valley Region have the largest number of samples exceeding the same target concentration (151, 60, and 44, respectively). Therefore, these five regions were selected as our study area (Fig. 1).

Diazinon use information between 2005 and 2010 was collected from DPR's Pesticide Use Reporting (PUR) database (DPR 2011). PUR data was mapped with the basic spatial unit of township/range/sections. Applications occurring within the contributing drainage area of a certain site were identified by overlaying the GIS maps of township/range/sections with CalWater2.2 watershed boundaries. Crops with top diazinon use (pounds of active ingredients (AI) were then identified in each drainage area.

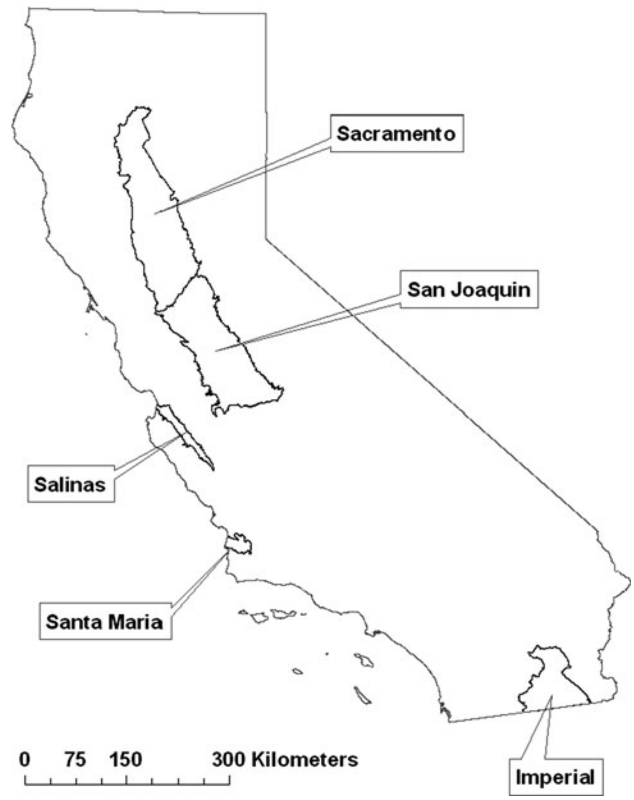

Fig. 1 Five study regions in California, USA

Results and Discussion

Statewide diazinon use decreased by 75% from 2005 to 2010 in both total pounds of AI and applied acreage (Fig. 2). Diazinon use in Salinas Valley was the highest among all the regions, accounting for 35% of the total pounds and 80% of the applied acreages (Fig. 2). Sacramento Valley ranked second accounting for 14% of the statewide use (Table 2). Use in San Joaquin Valley, Imperial Valley and Santa Maria Valley were relatively

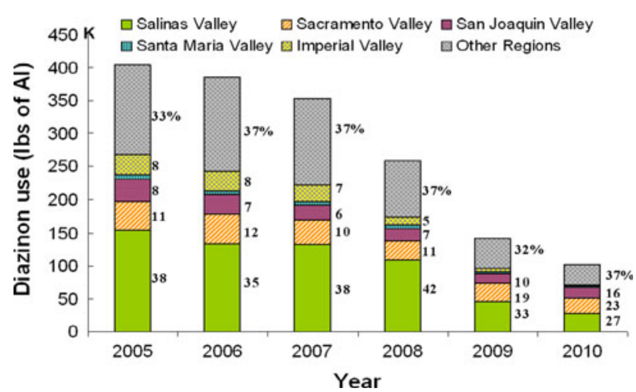

Fig. 2 Diazinon use in different regions of California by pounds of active ingredient. *Numbers* are the percentage of statewide use (pounds of AI) for each region. No percentage less than 5% was shown in the graph

lower, accounting for 9%, 6% and 2% of the statewide use, respectively.

In the Salinas Valley region, thirty-three sites were monitored for diazinon from 2005 to 2008. A total of 244 samples were taken, 61.9% of which exceeded the target concentration of 100 ng/L (Table 1). All the sites with exceedances were located in the Lower Salinas Valley basin. A total of 380,508 lbs of diazinon were used in the Lower Salinas Valley Region between 2005 and 2010 accounting for over 63% of the use in the entire valley.

Table 1 Summary of diazinon monitoring data (2005–2010)

Region	No. of sites	No. of samples	Max conc. (ng/L)	% of detection	No. of exceed	% of exceed
Sacramento	73	850	2,500	30.2	44	5.2
San Joaquin	121	2,465	1,200	10.0	60	2.4
Salinas	33	244	24,465	91.0	151	61.9
Santa Maria	12	21	977	90.5	14	66.7
Imperial	12	58	3,240	51.7	14	24.1

A target concentration of 100 ng/L was used to determine number of exceedances and percent exceedance

Table 2 Diazinon use by application method. 2005–2010

	Crop	Total (lbs)	Ground (%)	Aerial (%)	Other (%)
Salinas Valley	Lettuce, leaf	156,921	96	4	0
	Lettuce, head	137,234	96	4	0
	Broccoli	41,408	99	1	0
	Cauliflower	18,220	99	1	0
	Spinach	17,607	100	0	0
	All crops (Total)	380,508	97	3	0
Sacramento Valley	Prune	52,850	99	1	0
	Processing tomatoes	36,426	100	0	0
	Peach	35,885	100	0	0
	Walnut	12,062	68	32	0
	All crops (Total)	152,557	96	4	0
San Joaquin Valley	Cherry	11,776	99	1	0
	Peach	6,756	100	0	0
	Almond	6,067	97	3	0
	Corn	5,249	1	99	0
	All crops (Total)	46,272	86	14	0
Imperial Valley	Sugarbeet	30,070	11	89	0
	Lettuce, head	24,416	50	19	31
	Broccoli	13,623	55	26	19
	Lettuce, leaf	12,291	54	12	34
	All crops (Total)	105,761	44	37	18
Santa Maria Valley	Lettuce, head	8,993	86	13	1
	Broccoli	8,775	82	18	0
	Lettuce, leaf	2,187	87	13	0
	Cauliflower	1,795	99	1	0
	All crops (Total)	27,700	88	12	0

Only major crops in areas with frequent detections and exceedances are listed

Diazinon was mainly used on lettuce (head and leaf), broccoli, cauliflower and spinach (Tables 2 and 3). Use of diazinon on lettuce alone accounted for about 77% of the total diazinon use in the area between 2005 and 2010. Diazinon was used throughout the year with the majority of applications occurring during the irrigation season between March and September (Fig. 3). Almost all the applications were by ground spray (Table 2). On lettuce, more than half of the applied diazinon was formulated as emulsifiable concentrate (EC) and over 20% was formulated as wettable powder (WP) (Table 3). On broccoli, cauliflower and spinach, EC products accounted for over 95% of the applied amount (Table 3). The frequent detection of diazinon in Salinas Valley likely resulted from the large

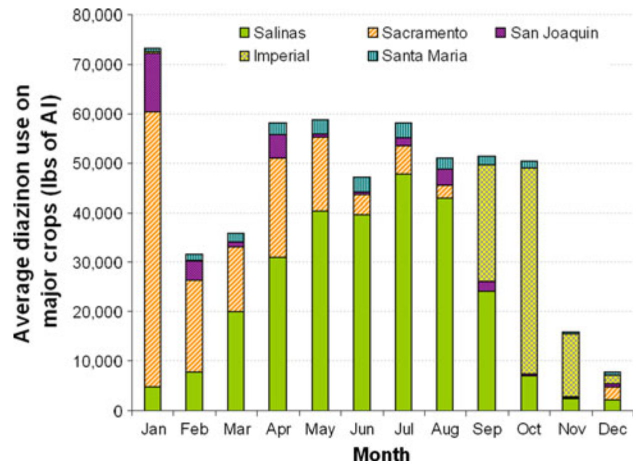

Fig. 3 Monthly average use of diazinon on major crops of five regions. 2005–2010

amount of use on a relatively small watershed. Since pesticide application method and product formulation are similar to other regions with few detections, it is unlikely that these two factors contribute significantly to offsite movement of diazinon.

In the Sacramento Valley region, 73 sites were monitored for diazinon from 2005 to 2010. A total of 850 samples were taken, 5.2% of which exceeded the target concentration of 100 ng/L (Table 1). Sites with exceedances were located at 10 drainage basins spread throughout in the entire valley. Between 2005 and 2010, a total of 152,702 lbs of diazinon were used in these drainage basins accounting for 75% of the use in the entire valley. Diazinon was mainly used on tree crops (prune, peach, walnut, almond and cherry) and processing tomatoes (Table 2). Applications occurred mostly in January through May with very few applications after August (Fig. 3). Almost all the applications were implemented through ground application using EC formulated products except for walnut, on which 32% of the applications were aerial and 20% of used products were WP (Tables 2 and 3). Compared to Salinas Valley, Sacramento Valley had less frequent detections and exceedances. This could be due to the lower amount of pesticide use and relatively larger watershed area. Other factors such as irrigation method, soil and slope may also play a role. However, application method and product formulation likely did not.

In the San Joaquin Valley region, a total of 121 sites were monitored for diazinon from 2005 to 2010. Among the 2,465 samples taken, 2.4% exceeded the target concentration of 100 ng/L (Table 1). Sites with exceedances were located at four drainage basins. A total of 28,295 lbs of diazinon were used in these four basins between 2005 and 2010 accounting for 21% of the use in the entire valley. Diazinon was mainly used on tree crops (cherry, peach,

Table 3 Diazinon use by formulation. 2005–2010

	Crop	Total (lbs)	EC* (%)	WP* (%)	Other (%)
Salinas Valley	Lettuce, leaf	156,921	62	23	15
	Lettuce, head	137,234	58	22	20
	Broccoli	41,408	97	1	2
	Cauliflower	18,220	96	1	3
	Spinach	17,607	100	0	0
	All crops (Total)	380,508	68	18	14
Sacramento Valley	Prune	52,850	95	3	1
	Processing tomatoes	36,426	97	0	3
	Peach	35,885	100	0	0
	Walnut	12,062	79	20	0
	All crops (Total)	152,557	95	3	2
San Joaquin Valley	Cherry	11,776	3	97	0
	Peach	6,756	98	2	0
	Almond	6,067	96	4	0
	Corn	5,249	100	0	0
	All crops (Total)	46,272	57	43	0
Imperial Valley	Sugarbeet	30,070	71	20	9
	Lettuce, head	24,416	54	1	45
	Broccoli	13,623	49	0	51
	Lettuce, leaf	12,291	48	4	48
	All crops (Total)	105,761	65	7	28
Santa Maria Valley	Lettuce, head	8,993	100	0	0
	Broccoli	8,775	100	0	0
	Lettuce, leaf	2,187	98	2	0
	Cauliflower	1,795	100	0	0
	All crops (Total)	27,700	99	1	0

*EC: emulsifiable concentrates, *WP: wettable powder

Only major crops in areas with frequent detections and exceedances are listed

almond, apple and prune) and corn (Table 2). Applications occurred in almost every month from January to September with fewer in October, November and December (Fig. 3). Almost all the applications were implemented through ground application using EC formulated products except for corn and apple. Applications on corn were mainly aerial using EC products. All the diazinon products used on apples were WP by ground application (Tables 2 and 3).

In the Imperial Valley region, 12 sites were monitored for Diazinon from 2005 to 2008. A total of 58 samples were taken, 24.1% of which exceeded the target concentration of 100 ng/L (Table 1). Exceedances occurred in 8 of the 12 sites. Between 2005 and 2010, a total of 105,761 lbs of diazinon were used in this valley. Diazinon was mainly used on sugarbeet, lettuce, broccoli, carrots and onion, accounting for 90% of the use in the entire valley (Table 2). Applications occurred mostly in winter months from September to December (Fig. 3). Ground application and EC products still being the majority but to a lesser degree compared to other regions (Table 2). For sugarbeet, 89% of the diazinon was applied aerially using mostly EC products (Tables 2 and 3).

In the Santa Maria Valley region, 12 sites were monitored for Diazinon with data available from 2005 to 2009. Most of the sites were sampled only once except for one site that was sampled 10 times. However, the detected concentrations were high with the majority of them exceeding the target concentration (Table 1). Eight of the 12 sites exceeded the target concentration. Crop use of diazinon in Santa Maria Valley was much less compared to the other four regions with over 27,700 lbs of diazinon AI, composing 2% of the statewide use between 2005 and 2010.

Major diazinon use crops include lettuce (head, leaf), broccoli and cauliflower accounting for over 81% of the total use in the region (Table 2). The majority of the applications occurred during the irrigation season between March and September (Fig. 3). Like other regions, diazinon was applied mainly through ground applications using EC products (Tables 2 and 3). Tables 2 and 3 showed that application method and product formulation did not differ significantly among different regions. Most of the applications were made through ground application using EC formulated products (Tables 2 and 3). Although Salinas Valley has more frequent detections and more exceedances compared to other regions, application method and product formulation were similar in all regions. Therefore, diazinon detections in surface water likely did not occur primarily due to the application method or formulation type.

The differences in detection frequencies between regions are likely due partially to the use amount and intensity. For example, the higher detection frequency in Salinas Valley compared to other regions is likely at least partially due to higher use in a relatively small watershed. As a water soluble pesticide, diazinon has high potential for moving off-site in runoff that is induced by either rain or irrigation. In general, factors that affect pesticide transport in runoff include climate (rainfall amount, intensity and timing relative to pesticide applications), soil characteristics, field slope, agricultural management practices (irrigation, soil erosion control efforts, pesticide formulation, application method and application rate), and the physiochemical properties of pesticides (Larson et al. 1991). This study suggests that diazinon detections in surface water likely did not result primarily due to application method or formulation type. Besides use amount and intensity, other factors such as irrigation method, rainfall, timing of application, soil characteristics and field management practices are likely more relevant to the off-site movement of diazinon into surface water. Therefore, further investigation into the effects of these factors may provide additional insights into this matter. Several of these factors are crop-specific; as such, investigation into the relevance of those factors might best be focused on crops with high use in regions with frequent detections of diazinon in surface water.

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