MITIGATING MOVEMENT OF SIMAZINE INTO GROUNDWATER IN CITRUS AND GRAPES

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ABSTRACT

Simazine is one of the herbicides widely used in grapes and citrus for weed controls in the eastern San Joaquin Valley of California. Leaching of simazine to groundwater and loss from soil to surface runoff water produce both a decrease in the effectiveness of the soil chemical treatment and a water quality hazard in receiving waters. Contamination of receiving water from herbicides could put important weed control tools at risk and potentially increase risks to human health. Simazine has been found in 30% of wells sampled in Fresno and Tulare counties, California and some contamination has been attributed to simazine use in citrus and grapes. In order to better understand the off-site movement of herbicides, a set of study was conducted in citrus orchards and a drip-irrigated vineyard.

Simazine was surface-applied to the entire floor in late fall and winter in citrus from 1996 to 1999. Surface runoff samples were then taken for simazine analysis after each rain-runoff event. Data showed that simazine concentrations could reach as high as over 1000 ug L^{-1} for an individual runoff events. The first and second storm runoff events following application of simazine produced peak concentrations if heavy rainfall occurred immediately after treatment of surface - applied simazine. Analysis of data also showed that mechanical incorporation, PAM application, and reduced rate of application (at 1.25 kg ai ha^{-1}) did not significantly reduce overall mean concentration of simazine in runoff water compared to standard rate applied at the rate of 2.0 kg ai ha^{-1}. Since most major rain events take place from December through March in the San Joaquin Valley of California, herbicide application made as late as possible into March should avoid most rainfall events and increase efficiency of weed control. However, determination of herbicide mass losses is needed.

Three field experiments were conducted to determine simazine movement and dissipation in a drip–irrigated grape vineyard with respect to 2 irrigation schedules (grower standard and current ET) and sampling time from 1997 to 1999 in a Hanford fine sandy loam, a soil type thought prone to leaching. In experiment 1, simazine was surface–applied in a 1.7 m swath down the vine row and chloride was applied as a tracer. Total recovery of simazine was below 1.0 % under emitters, 51 and 57 days after simazine application in 1997 and 1999, respectively. There were undetectable to trace amounts of simazine from 0–150 cm soil depth at 1.0 m from the emitter, perpendicular to the vine row. A chloride tracer moved to 90 cm soil depth but did not move deeper in the soil indicating limited leaching under low–volume drip irrigation. Chloride did move laterally under drip irrigation. In experiment 2, simazine moved to a 75 cm depth under emitter in 7 days but not move deeper into the soil. Under emitter, about 24 % to 34% of applied simazine remained at 0 – 45 cm soil depth and 3 % under 45 cm soil depth. In experiment 3, total recovery of simazine was only 10% to 14% with rain contrasted to 30% without rain at the same sampling date (day 63) . Rapid dissipation, most likely from

degradation, and proper irrigation scheduling, were key factors to prevention of deep percolation of simazine.

Simazine and diuron on weed control was studied in three citrus orchards from 1996 to 1999. The results showed that simazine and diuron applied at the rates of 1.0 kg ai ha^{-1} and 1.25 kg ai ha^{-1} were as effective as the standard rate at 2.0 kg ai ha^{-1}. Spotted spurge and common groundsel consisted of about 95 – 98 % total weeds found in the treated plots. A combination of a depleted seed bank from continuous use of herbicides and shading may have contributed to lower weed populations in older citrus.

Movement of herbicides to groundwater is an ongoing problem. Modifying how preemergent herbicides are used to control weeds is becoming increasingly important to protect both our environment and our ability to continue use of these important weed control tools. Increasing public concern about herbicides on environment and potential cost savings to growers requires changes of traditional use of preemergent herbicides.

Introduction

Simazine is an effective preemergent herbicide that controls several problem species in the San Joaquin Valley, including horseweed (*Conyza canadensis*), hairy fleabane *(Conyza bonariensis*), purple cudweed (*Gnaphalium purpureum*), and prickly lettuce (*Lactuca serriola*). Simazine is applied to approximately 73% of grapes planted in the San Joaquin Valley (California Pesticide Summary Database 1995). In citrus, simazine is one of widely used preemergent herbicides in fall and winter seasons to control germinating weeds. At least half of the annual preemergent herbicides are applied during the fall in order to maintain bare soil through the winter because vegetation cover during the winter is thought to lower tree canopy temperature (Spurlock et al., 1997). Clean citrus orchard middles often are compacted and have low water infiltration rates. Low infiltration rates and a smooth soil surface result in a greater potential for surface runoff. Simazine in groundwater has been documented by the California Environmental Protection Agency, Department of Pesticide Regulation. Simazine has been found in over 30% of wells sampled in Fresno and Tulare counties (Troiano et al. 1994). Dating of sampled water indicated a portion of the contaminated groundwater was less than 10 years old (Spurlock et al. 1998). Contamination of groundwater from herbicides puts important weed control tools at risk and potentially increases risks to human health.

One route of the mechanisms involved in pesticides movement is surface runoff (Braun and Hawkins, 1991). Surface water resources which receive drainage from intensively farmed agricultural production areas are likely to contain higher levels of pesticides, particularly at times related to recent use of pesticides (Barker and Mickelson, 1994; Goolsby et al., 1993). Larger amounts winter rain occur in the eastern San Joaquin Valley of California and there are believed to be associated with pesticide contamination of receiving waters (Lee, 1983; Pickett et al, 1990). Furthermore, the recharge of groundwater by surface runoff water is the vector for movement of herbicides to groundwater. Dry wells may be a direct route for surface water runoff carrying pesticides to move into groundwater (Holden, 1986).

Another route to groundwater contamination by herbicides occurs through leaching from soil profile to a groundwater aquifer (Wehtje et al. 1984; Freeze and Cherry, 1979). Recharge may result from both natural rainfall and irrigation (Bouwer, 1987). Drip irrigation is one of widely used irrigation methods in grapes. Drip irrigation applies water, typically through two emitters per vine in the vine row, and the water moves through herbicide–treated soil. Evaluating downward movement of herbicides is difficult under drip irrigation because water application is not uniform over the surface of the field and, as a result, both water and herbicide may move downward, laterally or both. In a previous study (Troiano et al. 1990), atrazine and tracer leaching were evaluated directly under the drip emitters. Very little atrazine or tracer was recovered in cores taken below the drip emitters, even at the lowest level of irrigation (irrigation depth ≈ 0.75 ET calculated over entire plot area). Troiano and coworkers (1990) concluded that more frequent and detailed sampling of soil located beneath and between drip emitters was needed to adequately describe solute movement in low volume systems where horizontal movement to non–irrigated areas could occur. Drip is a low–volume irrigation method that allows a high degree of control over water application and timing but, contrasted to furrow irrigation, enhanced herbicide transport may occur under the drip emitters because water directly contacts treated soil. The objectives of this project were (1) to determine simazine concentration in runoff water and evaluate if detectable levels of simazine were presented in surface runoff water from citrus following winter rain-runoff events, (2) to invegative simazine fate in a drip-irrigated vineyard, and (3) to evaluate effective weed controls in citrus orchard. The objectives were achieved through field research, extensive outreach and survey.

MATERIALS AND METHODS

I. Simazine levels in runoff water following winter rains from citrus

One study was conducted in a citrus near Ivanhoe of Tulare county in fall and winter seasons from 1996 to 1998. The citrus at the site, which had 0 – 2% slope, was a 8 years old grove of Valencia oranges. The soil contained 51% sand, 29% silt, and 20% clay. Soil infiltration rate was measured using cylinder infiltrometer in the field (Figure 1) (Bouwer, 1986). Treatments established were listed in Table 1. Effects of Polyacrylaminde (PAM) application, mechanical incorporation (MI), and reduced rate application of herbicide on concentration in runoff water were evaluated. The experimental design was a randomized complete block with 4 replications in 1996 - 1997 and 6 replications in 1997 – 1998. Simazine was surface-applied with a tractor-mounted sprayer over the entire orchard floor. In 1996 - 1997, applications were made on December 18, 1996 and February 20, 1997. However, no rainfall – runoff events occurred after the second application. In 1997 – 1998, simazine was applied on November 5, 1997 and February 13, 1998. PAM was applied at a rate of 10 kg ha^{-1} for treated plots before herbicide application. Mechanical incorporation was made by disking about 5 cm surface soil immediately after each herbicide application. The amount of precipitation related to each rainfall-runoff events was obtained from rain gauge installed at study site (Figure 2).

Another study was conducted in a mature citrus near Orange Cove in 1999. The soil at the site was mapped as a San Joaquin loam. The site had a 0 - 2% slope. Treatments established are listed in Table 2. The experimental design was a randomized complete block with 4 replications. Simazine and diuron were both surface-applied as preemergent herbicides over the entire orchard floor or were injected in the tree row. Herbicide application was made on February 2, 1999. Water pumps and buckets were set up for runoff collection at the end of treated plots.

Surface runoff water was sampled after each rainfall-runoff event, if applicable. The samples taken for simazine analysis were immediately frozen in dry ice and kept at -4^0C until submission to the laboratory. Simazine concentration was analyzed using an ELISA method (EnviroLogix Inc, 55 Industrial Way, Portland, ME 04103). Simazine concentration in surface runoff was logarithmic transformed before performing analysis of variance if needed. Statistical analyses were performed using the Statistical Analysis System (SAS, 1985). The general linear model (GLM) procedure was used to perform analyses of variance. All statistical tests were performed at $\alpha = 0.05$ level of significance. After analysis, data were transformed back to the original scale for presentation.

II. The Fate of Simazine In a Drip–Irrigated Grape (*Vitis vinifera*) Vineyard

General information

Studies were conducted in a drip–irrigated grape vineyard in Fresno County of California from 1997 to 1999. The site was chosen in an area with a high frequency of well contamination. The soil at the site was a Hanford fine sandy loam (SCS 1971). The soil profile was uniform and no other soil layers were found to 150 cm soil depth. The soil organic carbon content was 1.1% at 0 – 15 cm, dropping to 0.6% in 15-30 cm depth, and the pH was 7.3 at 0 – 15 cm soil depth. Organic carbon was determined using dichromate reduction with silver sulfate added (Rauschkolb, 1980). Soil pH was measured by 1:1 soil:water ratio. Soil texture averaged 49% sand, 45% silt and 6% clay as measured by Bouyoucos hydrometer method (Bouyoucos 1962). The diameter of the wetted zone under emitters averaged 0.8 m. This soil conducted water rapidly, so ponding under emitters did not occur.

Simazine was applied with a CO_2 powered backpack sprayer in a 1.7 m swath down the vine row to the soil surface for treated plots. Absorbent pads were placed on the soil surface during the application to measure actual herbicide deposition. Soil cores were taken in each plot using a hand-operated bucket auger. Soil samples taken for simazine analysis were immediately frozen in dry ice and kept at –4^0C until submission to the laboratory. Simazine concentration was analyzed using an ELISA method (EnviroLogix Inc, 55 Industrial Way, Portland, ME 04103).

Statistical analyses were performed using the Statistical Analysis System (SAS 1985). The general linear model (GLM) procedure was used to perform analyses of variance and the REG procedure was used to determine simazine half life. All statistical tests were performed at $\alpha = 0.05$.

Experiment 1: Simazine movement as influenced by irrigation scheduling

The experimental design was a randomized complete block with four replications in 1997 and three replications in 1999. Experimental variables consisted of two irrigation scheduling systems. The two irrigation schedules were grower standard (GS) and current evaporation/transpiration (CET) demand. For GS the amount of water was applied by the grower according to his experience. CET schedule was derived to relate the amount of water applied to crop requirements and climatic conditions (Synder et al. 1985; Peacock et al. 1999). Data for daily reference ET values were acquired from a CIMIS weather station located near the experiment site for the current ET schedule. Reference evapotranspiration (ET_0) was adjusted to the ET value by multiplying a crop coefficient value for current ET schedule. A water flow meter was installed for each irrigation schedule. Simazine was applied at the rate of 2.0 kg ai ha^{-1} on February 18, 1997 and 1.87 kg ai ha^{-1} on March 31, 1999. From simazine application to soil sampling, the amount of rainfall ranged from 0.03 cm to 1.04 cm per event for a total of 1.71 cm in 1997 and ranged from 0.1 cm to 1.17 cm per event for a total of a 3.37 cm in 1999. Soil samples were taken directly under the emitter on April 10, 1997 (51 days after simazine application) and at 1.0 m distance from the emitter, perpendicular to the vine row on April 17, 1997 (58 days after simazine application). In 1999, soil samples were taken directly under emitter and at 1.0 m distance from the emitter, perpendicular to the vine row on May 27, 199 (57 days after simazine application). Soil cores were taken and separated into samples from depths of 0 – 15, 15 – 30, 30 – 60, 60 – 90, and 90 – 150 cm.

Chloride was used as a tracer to follow the movement of soil water (Bowman 1984; Troiano et al. 1990; Schuh et al. 1997). Chloride was applied to the treated plots in a 1.7 m swath down the vine row on the soil surface as granular sodium chloride on March 21, 1997 and March 31, 1999. Rate of application was 168 kg ha^{-1} active ingredient. Soil cores were taken and separated into samples from depths of 0 – 15, 15 – 30, 30 – 60, 60 – 90, and 90 – 150 cm directly under the emitter, at 0.33 m and 0.66 m from the emitter, perpendicular to the vine row after chloride application and irrigation. Soil samples were placed in plastic bags and transported to the laboratory for drying, grinding, and analysis. Prior to analysis, samples were air–dried and ground to pass through a 2 mm stainless steel sieve. Soil chloride was extracted by 1:1 soil:water ratio. The solution was filtered through #40 Whatman filter paper and then measured with a digital chloridometer.

Experiment 2: Simazine movement during irrigation

The experimental design was a randomized complete block with three replications. Simazine was applied at the rate of 1.43 kg ai ha^{-1} on September 10, 1997 and 1.87 kg ai ha^{-1} on March 31, 1999**.** The treated plots were not influenced by rainfall. The first irrigation was made three days after simazine application and then weekly. Soil cores were taken under the emitter and at 0.33 m from the emitter, perpendicular to the vine row. Soil cores were removed 7 days, 14 days and 28 days after simazine application, respectively. Soil cores were taken and separated into samples from depths of 0 – 15, 15 – 45, 45 – 75, 75 – 115, and 115 – 150 cm for simazine analysis.

Experiment 3: Simazine dissipation over time

For this study, a randomized complete block was designed with three replications. Simazine was applied at the rate of 2.84 kg ai ha^{-1} on February 11, 1998 and 1.87 kg ai ha^{-1} on March 31, 1991. Soil samples were taken 7, 21, and 63 days after simazine application from plots which were covered to prevent rain from moving the simazine. Plots were not irrigated. Soil samples were also taken 63 days after application from plots subjected to rain effects. Soil cores were separated into depths of 0 – 15, 15 – 30 cm for the 7 and 21 day sampling, and 0 – 15, 15 – 30, 30 – 60, 60 – 90, and 90 – 150 cm for the 63–day sampling.

III. Changes to preemergent herbicide use maintains weed control in citrus

Three sites were established for weed control study. Site 1 and site 3 were in a mature grove of Navelencia oranges. Site 2 was in an 10 years old grove of Valencia oranges. The soil at the three sites were mapped as San Joaquin loam (SCS, 1971). The three sites were established on a 0 - 2% slope. Studies were conducted from 1996 to 1999. Treatments established in each grove are listed in Table 3. The experimental design was a randomized complete block with 4 replications. Simazine and diuron were surface-applied as preemergent herbicides with a tractor-mounted sprayer over the entire orchard floor. Total weeds by species were counted in April 1997, May 1998, and May 1999 by sampling the entire area of 4 trees for each plot at each site. Total weed numbers of each plot were logarithmically transformed before performing analysis of variance. Statistical analyses were performed using general linear model (GLM) procedure in the Statistical Analysis System (SAS, 1985). All statistical tests were performed at $\alpha = 0.05$ level of significance.

Table 1. Treatments selected for runoff study in citrus (Ivanhoe site).

Study Time	Treatment	Rate of Simazine	Others
1996 - 1997	Standard Rate	2.0 kg simazine ha^{-1} applied on Dec. 18, 1996	
		2.0 kg simazine ha^{-1} applied on Feb. 20, 1997	
	Standard Rate + PAM	2.0 kg simazine ha^{-1} applied on Dec. 18, 1996	PAM applied on soil surface
		2.0 kg simazine ha^{-1} applied on Feb. 20, 1997	PAM applied on soil surface
	Standard Rate + MI	2.0 kg simazine ha^{-1} applied on Dec. 18,1996	Mechanical incorporation
		2.0 kg simazine ha^{-1} applied on Feb. 20, 1997	Mechanical incorporation
1997 – 1998			
	Standard Rate	2.0 kg simazine ha^{-1} applied on Nov. 5, 1997	
		2.0 kg simazine ha^{-1} applied on Feb. 13,1998	
	Standard Rate + MI	2.0 kg simazine ha^{-1} applied on Nov. 5, 1997	Mechanical incorporation
		2.0 kg simazine ha^{-1} applied on Feb. 13, 1998	Mechanical incorporation
	Reduced Rate	1.25 kg simazine ha^{-1} applied on Nov. 5,1997	
		1.25 kg simazine ha^{-1} applied on Feb. 13,1998	

Table 2. Treatments selected for runoff study in citrus (Orange Cove site).

Trt #	Herbicide Applied	Application Methods	Application Rate
			------- kg ai ha^{-1}-------
1	Simazine, diuron	spray	2.0
2	Simazine, diuron	spray	1.25
3	Simazine, diuron	injection	1.25
4	Untreated	—	0.0

Table 3. Treatments selected for weed control study from 1996 - 1999.

Site	Trt #	Herbicide Applied	Rate 96 – 97	Rate 97 – 98	Rate 98 - 99	Season of application
			--------------- kg ai ha^{-1}	-------------------		
1	1	Simazine, diuron	2.0	2.0	—	Fall
			2.0	2.0	—	Winter
	2	Simazine, diuron	1.0	1.25	—	Fall
			1.0	1.25	—	Winter
	3	Glyphosate	1.0	1.0	—	Fall
		Simazine, diuron	1.0	1.0	—	Winter
	4	Untreated	0.0	0.0	—	
2	1	Simazine, diuron	2.0	2.0	—	Fall
			2.0	2.0	—	Winter
	2	Simazine, diuron	1.0	1.25	—	Fall
			1.0	1.25	—	Winter
	3	Glyphosate	1.0	1.0	—	Fall
		Simazine, diuron	1.0	1.0	—	Winter
	4	Untreated	0.0	0.0	—	
3	1	Simazine, diuron	—	—	2.0	Winter
	2	Simazine, diuron	—	—	1.25	Winter
	3	Untreated	—	—	0.0	

RESULTS AND DISCUSSION

I. Simazine levels in runoff water following winter rains from citrus

After simazine application in December 1996, three runoff events occurred and water samples were collected (Figure 3). Standard rate (2.0 kg simazine and diuron ha^{-1}) plus PAM application could produced as high as high as 700 ug simazine L^{-1} in runoff water. Simazine overall mean concentration of 3 runoff events showed that standard rate plus PAM application produced the highest concentration, where standard rate plus mechanical incorporation produced the least (Figure 4). Significant difference was found between treatments with PAM application and mechanical incorporation. However, PAM application and mechanical incorporation did not statistically reduce herbicide concentration in runoff water compared to standard rate application. No rainfall – runoff events occurred after application made on February 20, 1997.

In 1997 - 1998, three treatments – standard rate, standard rate plus MI, and reduced rate, were conducted. Runoff water samples were collected for six runoff events (Figure 5). Simazine concentration was much lower for reduced rate application compared to standard rate application in the first and the second runoff events. However, simazine overall mean concentration of six runoff events showed no significant difference was found among these three treatments (Figure 6). The same study was conducted in February 1998, simazine concentration in runoff events was presented with four runoff events (Figure 7). The overall mean concentration of four runoff events showed no significant differences in concentration was found among the three treatments (Figure 8).

No rainfall – runoff events occurred after herbicide application at Orange Cove site in 1999.

A high intensity storm did not take place during the study.

The data showed that after each simazine application, the first and second storm runoff events following application produced peak concentrations if heavy rainfall occurred immediately after treatment of surface - applied simazine. Then the concentrations in runoff water decreased rapidly. The amount of simazine available for runoff is greatest at the start of the runoff events. A fairly thin layer of surface soil called the “mixing zone,” often assumed to be about 10 mm thick, interacts with runoff release herbicide to rainfall and overland flow (Wallach et al., 1993; Baker and Mickelson , 1994). Reduction in the amount of herbicide in the mixing zone between the time of application and the first storm (and between storms) through degradation, volatilization, and /or movement by diffusion explains why herbicide concentrations is generally in the first two runoff events after application and decrease with time during the season (Wauchope, 1978).

The results form this study indicated PAM application, mechanical incorporation, and reduced rate application did not significantly reduce herbicide concentration in runoff water compared to standard rate application overall. As discussed above, high simazine concentration was detected in runoff water following herbicide application. One strategy to reduce significant herbicide runoff loss is to develop appropriate floor management, such as growing cover crop, to reduce runoff volume. Since most major rain events take place from December through March in the San Joaquin Valley of California (Figure 9), herbicide application made as late as possible into March should avoid most rainfall events and increase efficiency of weed control.

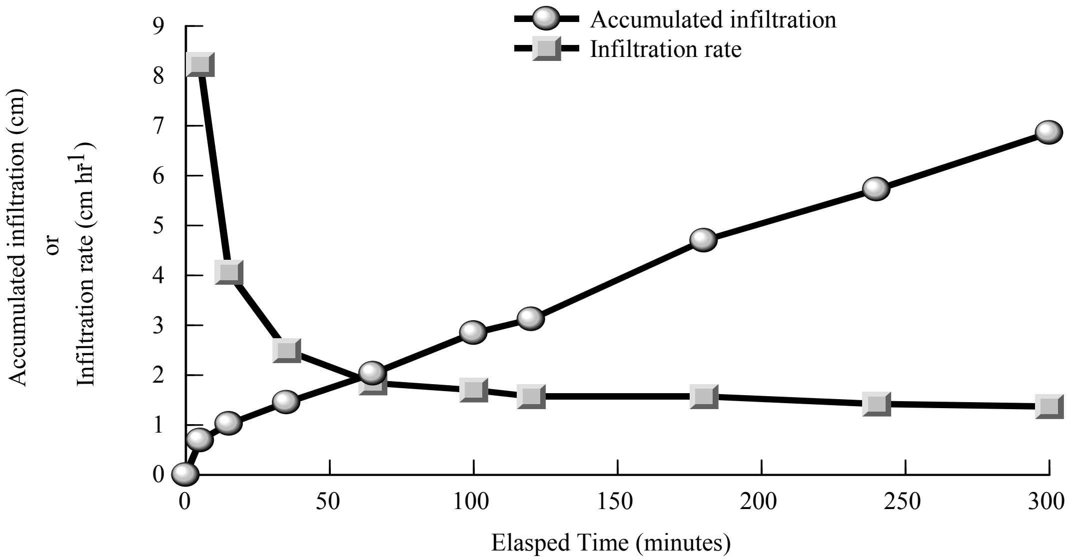

Figure 1. Soil infiltration rate.

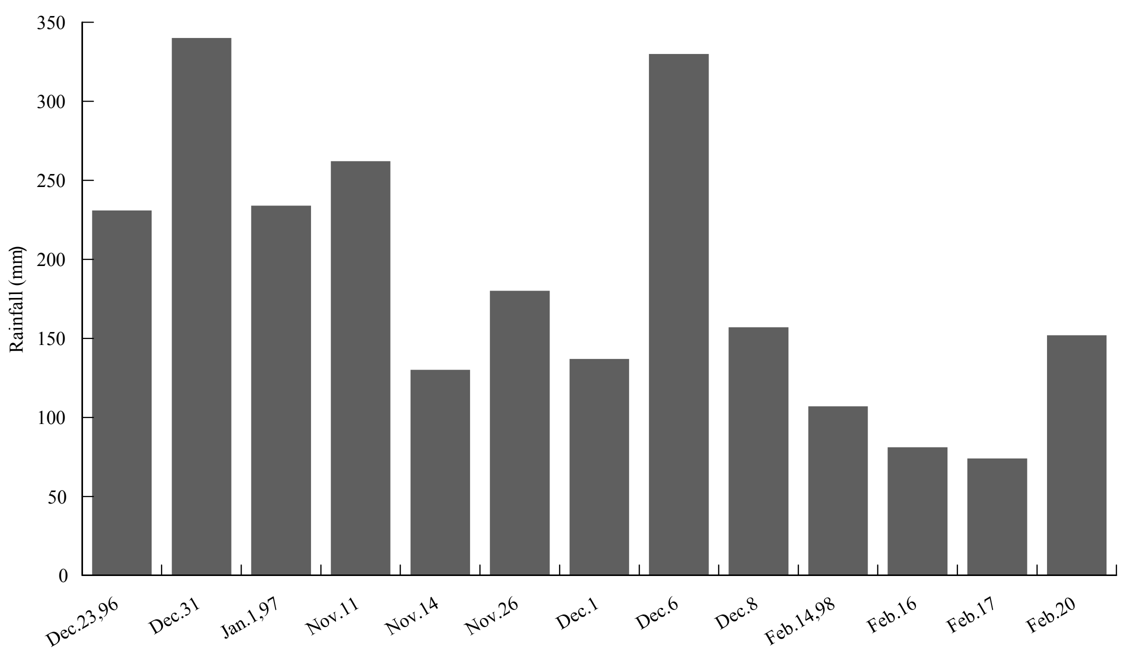

Figure 2. The amount of rainfall with respect to corresponding runoff events.

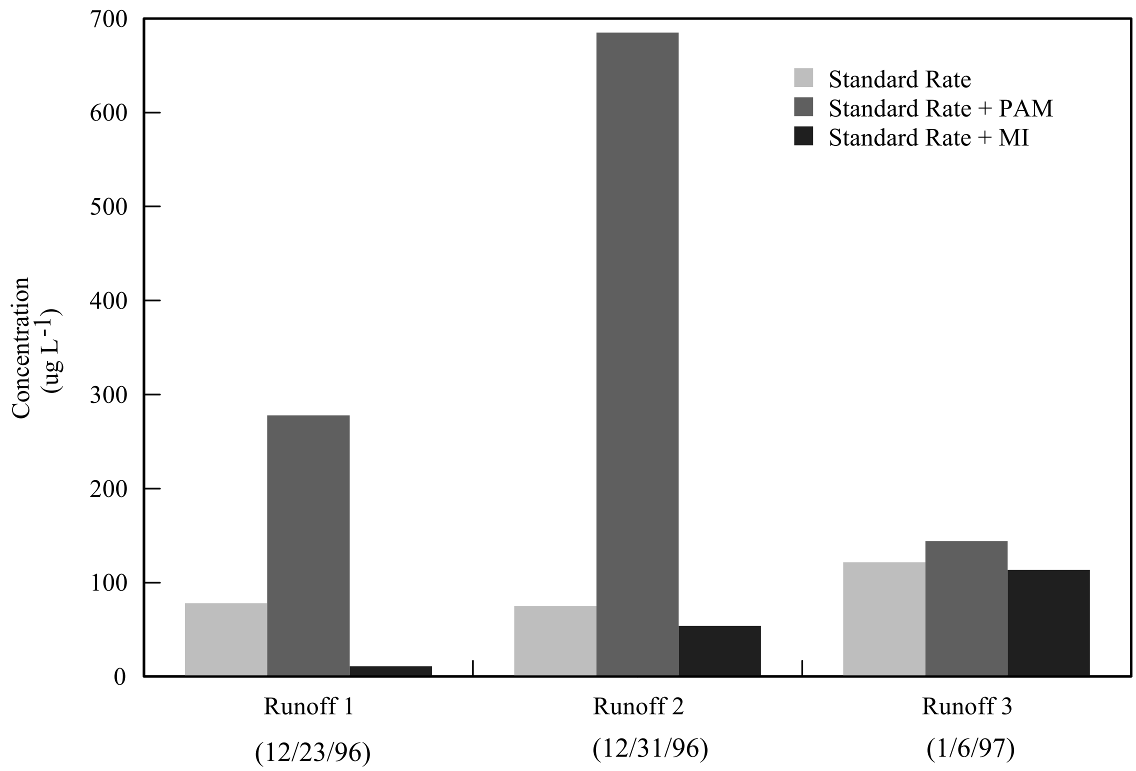

Figure 3. Simazine concentration in surface runoff water with individual runoff event. Simazine was applied on December 18, 1996.

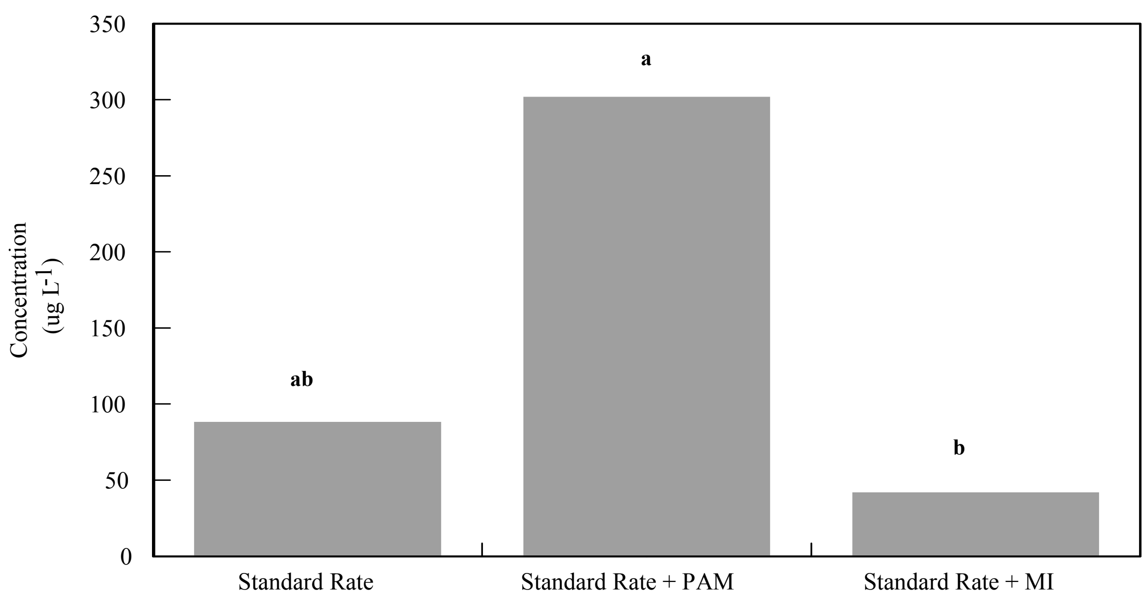

Figure 4. Simazine overall mean concentration of 3 surface runoff events following application made on December 18, 1996.. Means followed by the same letter are not significantly different according to an LSD test at the 0.05.

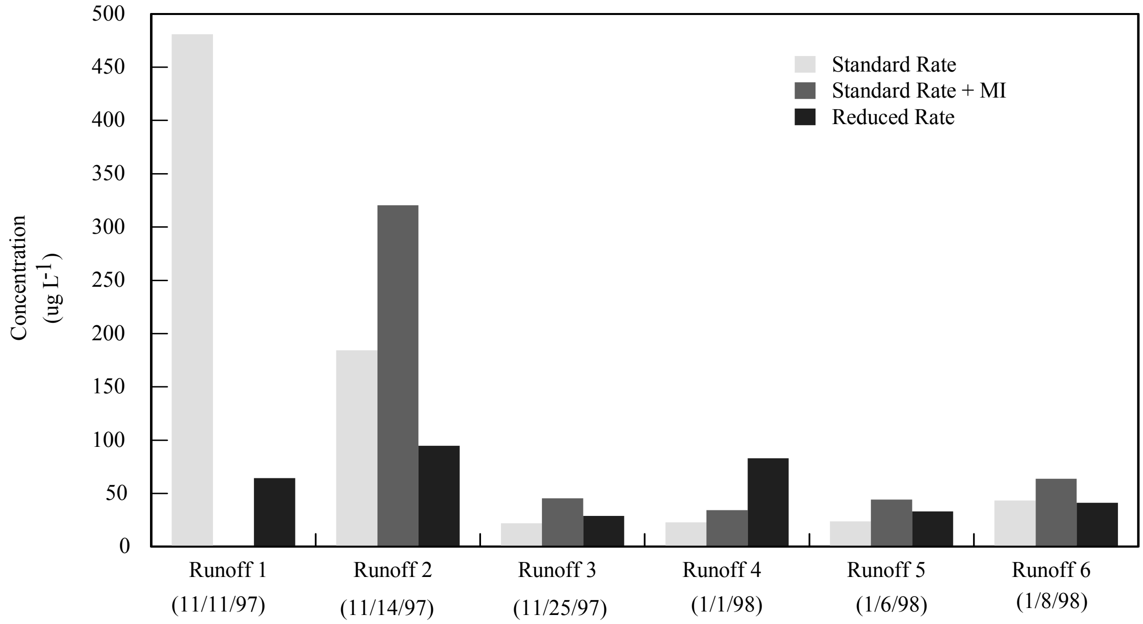

Figure 5. Simazine concentration in surface runoff water with individual runoff event. Simazine was applied on November 5, 1997.

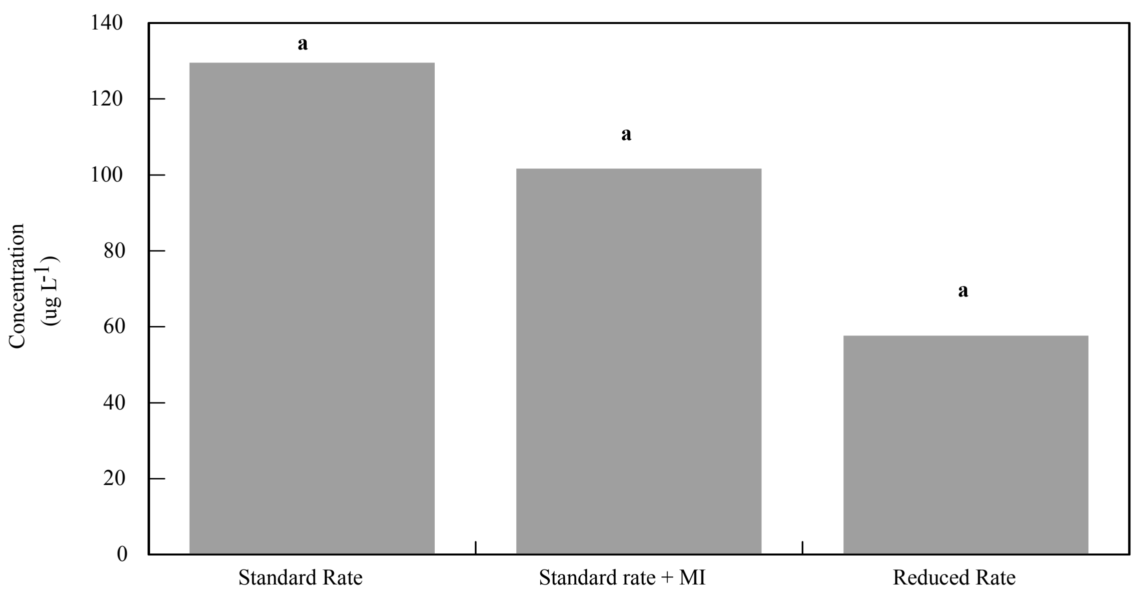

Figure 6. Simazine overall mean concentration of 6 surface runoff events following application made on November 5, 1997. Means followed by the same letter are not significantly different according to an LSD test at the 0.05.

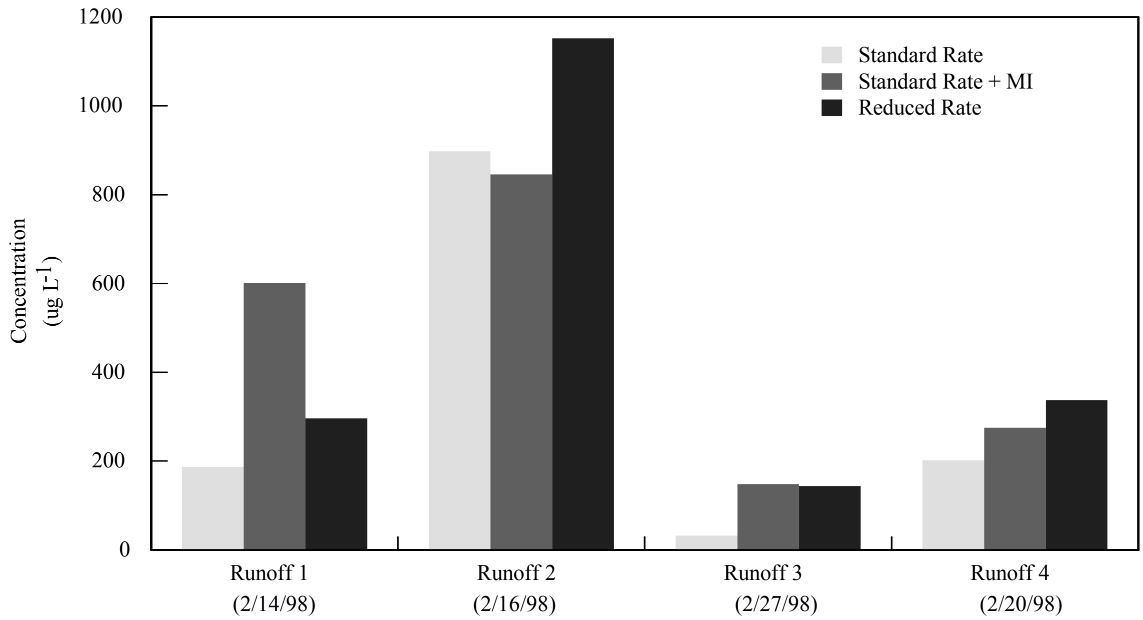

Figure 7. Simazine concentration in surface runoff water with individual runoff event. Simazine was applied on February 13, 1998.

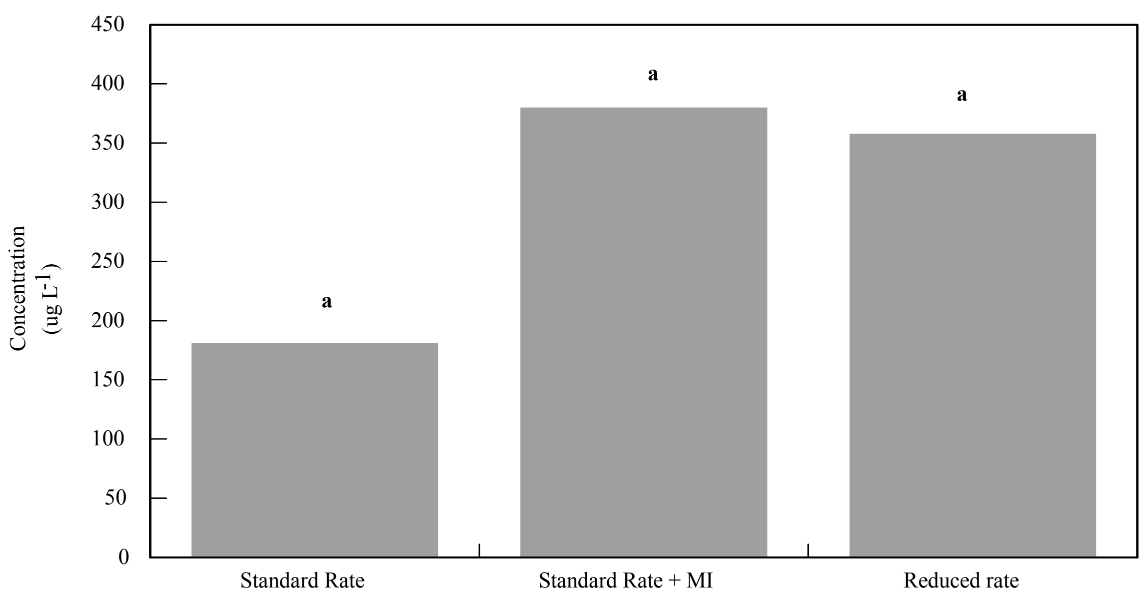

Figure 8. Simazine overall mean concentration in 4 surface runoff events following application made on February 13, 1998. Means followed by the same letter are not significantly different according to an LSD test at the 0.05.

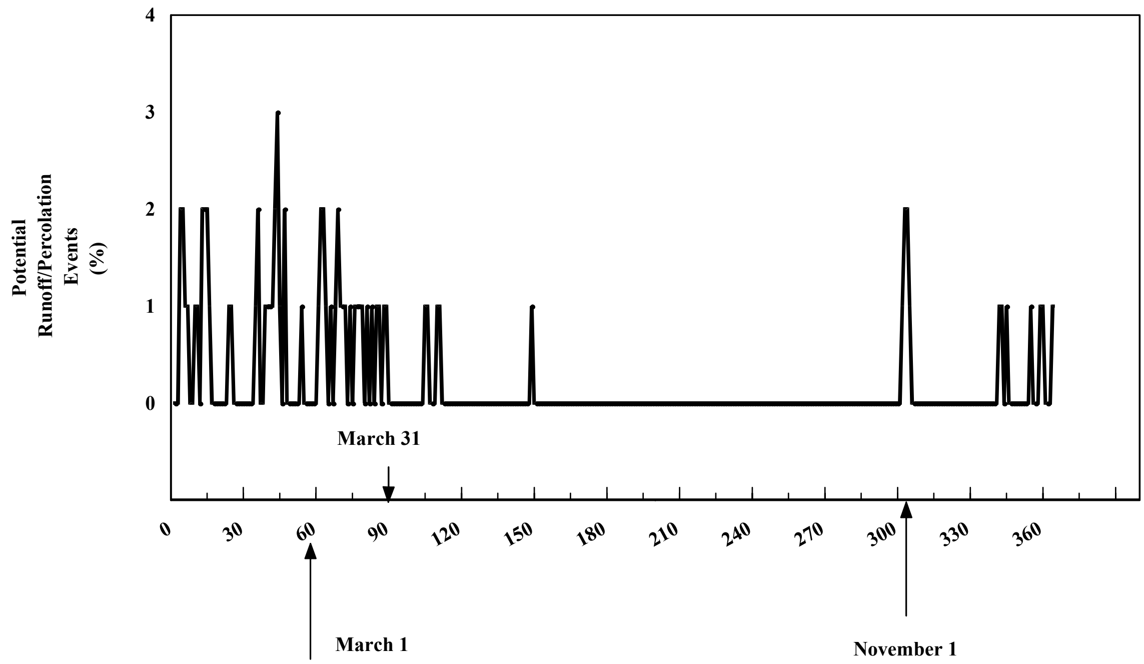

Figure 9. Frequency of rainfall event that were at least 3 cm in a 48 hour period from 1986-1996.

II. The Fate of Simazine In a Drip–Irrigated Grape (*Vitis vinifera*) Vineyard

Simazine movement as influenced by irrigation scheduling

The total amount of irrigation water from the time of simazine application to the last sampling were 9.6 cm and 8.0 cm (calculated based on vine row area) for GS and CET in 1997 and 8.7 and 6.1 for GS and CET in 1999, respectively. The current ET schedule did apply less water than the grower standard. Concentration profiles and total recovery of simazine for the two irrigation schedules are presented in Table 4. In both 1997 and 1999, simazine was detected only in the soil surface (0–15 cm). Total recovery of simazine was below 1 % for both irrigation schedules. Such low recovery indicated a rapid dissipation of simazine. Deep percolation seemed unlikely since simazine was not detected below 15 cm soil depth. Lateral movement of simazine was examined by taking soil core samples at 1.0 m from the emitter, perpendicular to the vine row. No simazine was applied at the 1.0 m distance from the emitter. There were nondetectable to trace amounts of simazine throughout soil profile (data not shown) 1.0 m from the emitter. However, the diameter of the wetted zone under emitters averaged 0.8 m , making simazine movement to 1.0 m unlikely. Most of the simazine lost may be attributed to degradation. Organic carbon content was 1.1% in 0–15 cm soil depth and 0.6% in 15 – 30 cm soil depth. A positive correlation between organic carbon content of soil and biological degradation has been found (Morrill et al., 1982). With organic carbon content of the soil at the site, a higher rate of degradation would be expected near the surface at the 0–15 cm depth than for the 15–30 cm depth. If simazine had moved deeper into the profile, more of the simazine should have remained. Soil temperatures at 15 cm, during the period between simazine application to soil sampling, ranged from 10 C to 24 C in 1997 and ranged from 9 C to 27 C in 1999. The temperature range was favorable for microbial activity. The time between herbicide application and the first irrigation allowed for significant loss of simazine prior to the start of irrigation. Typically simazine is applied in November to February with irrigation beginning in mid April. Degradation and potentially lateral movement reduced the amount of simazine available to move downward.

Chloride is highly water soluble and has minimal adsorption or precipitation tendencies under normal field conditions, and microbial transformation are inconsequential. Chloride concentration in the surface soil (0 – 15 cm) increased as distance from the emitter increased (Table 4). Statistical analyses showed levels of chloride of two irrigation schedules were higher than background levels to a 90 cm soil depth, but not higher at levels below 90 cm, indicating limited leaching. No significant difference in chloride concentration was found between GS and CET irrigation schedules. Under the emitter, the maximum concentration of chloride was at the 15 to 30 cm depth. Chloride concentration and distribution was also studied by taking soil core samples at 0.33 m and at 0.66 m distance from the emitter, perpendicular to the vine row. Both distances received surface application of chloride but only the 0.33 m sampling distance was within the wetted zone under the emitter. Chloride mostly accumulated on the soil surface. Chloride recovery down to 150 cm soil depth was much less than 100% for both GS and CET irrigation scheduling sampling from the emitter, at 0.33 m and at 0.66 m from the emitter. The difference should have been partially due to the lateral movement.

Simazine movement during irrigation

In this study, irrigation started 3 days after simazine application and soil samples were taken at three sampling dates. The corresponding cumulative water inputs, based on vine row area, were 3.9, 8.6, and 15.4 cm for the three sampling dates in 1997, and 4.2, 8.3, and 15.6 cm in 1999, respectively. Analysis of the soil core data from 1997 and 1999 directly under emitters showed that no simazine was found below 75 cm in the soil even when drip irrigation was made remaining near the soil surface. On the second sampling date, total simazine recovered from the soil profile directly under the emitter dropped from 27 to 4 % in 1997 and from 37% to 10% in 1999. At the third sampling date, only 0.1% to 3% of applied simazine was detected directly under the emitter, 28 days after simazine application. Simazine dissipation rate with time since application is presented in Figure 10. The calculated half-life under the emitter was only about 6 days for the two studies. The short half-life was likely due to a combination of rapid degradation and lateral movement of simazine under drip irrigation. Simazine recovery was much higher at 0.33 m from emitters than under emitters at the three sampling dates (Table 5). The higher recovery could be due to slower degradation as well as lateral movement of simazine from other areas. The rate of simazine dissipation was slower at 0.33 m when contrasted to under emitter (Fig. 11). During this study, there was no rainfall so simazine moved into soil solution only by
irrigation water at 0.33 m from emitter. Statistical analysis showed that more simazine remained at 0 – 15 cm than moved to 15 – 45 cm soil depth. No simazine was detected below 45 cm soil depth.

Analyses of soil cores from three sampling dates indicated that a large amount of applied simazine did not move deeper into the soil by matrix water flow. Simazine appears to have been broken down rather than leached.

Simazine dissipation over time

Soil samples taken 7, 21, and 63 days in 1998 and 1999 after simazine application from plots which were covered to prevent rain showed that simazine concentration decreased in top soil at each sampling time. For the first and second sampling times, soil cores were taken to 30 cm depth because higher simazine concentration was unlikely under that depth. Soil samples taken 63 days after simazine application showed no simazine was found under 30 cm soil depth.

Total recovery of simazine decreased from 50 to 30 % in 1998 and from 58 to 30% in 1999 (Table 6). Significant recovery was found between 0 – 15 cm and 15 – 30 cm soil depth at each sampling date (Table 6). Total recovery of simazine was 10 to 14% with rain contrasted to 30% without rain 63 days after application (Table 6). The first-order model based on data from plots without rain was used to calculated a half-life of 39 days (Figure 12). Reported soil half-lives for simazine ranged from 56 (Troiano and Garretson, 1988) to 64 days (Rao et al., 1980).

Interpreting these results leads to several conclusions about simazine use in drip-irrigated vineyards of the San Joaquin Valley. Leaching of simazine was minimally affected by method of irrigation scheduling since most simazine was gone by the time irrigation began. No deep percolation of simazine was observed under drip irrigation for either irrigation method, GS or CET scheduling. Some lateral movement of herbicides did occur under drip irrigation. Since simazine did not move down through the soil profile, most of it must have broken down rapidly in the continually moist drip irrigated soil. The rapid degradation of simazine and proper irrigation scheduling using low volume of drip irrigation minimized the potential for simazine to move out of the vineyard root zone to groundwater.

Table 4. Leaching of simazine and chloride as influenced by irrigation schedule.

	Simazine				Chloride‡					
	Under emitter		1 m from emitter		Under emitter		0.33 m from emitter		0.66 m from emitter	
Depth	GS	CET	GS	CET	GS	CET	GS	CET	GS	CET
----- cm ----	------------------- ug kg^{-1} (%)† ---------------------				------------------------------ mg kg^{-1} (%) ---------------------------------					
					1997					
0 – 15	3.2 (0.14)	2.4 (0.11)	0.0	0.0	13.5	15.0	18.5	27.2	45.0	39.2
15 – 30	0.0	0.0	0.0	0.0	15.4	16.8	10.3	11.3	11.0	10.1
30 – 60	0.0	0.0	0.0	0.0	10.0	12.0	8.6	9.7	14.7	10.3
60 – 90	0.0	0.0	0.0	0.0	12.0	10.0	8.1	8.8	9.5	10.3
90 – 150	0.0	0.0	0.0	0.0	9.4	8.2	7.4	7.5	9.0	9..3
					(67)	(64)	(42)	(61)	(79)	(76)
					1999					
0 – 15	5.1(0.3)	6.0 (0.3)	0.0	0.0	16.4	17.9	27.3	26.7	42.6	45.3
15 – 30	0.0	0.0	0.0	0.0	20.1	19.8	18.7	17.6	16.5	14.1
30 – 60	0.0	0.0	0.0	0.0	13.2	12.7	13.4	12.1	11.4	10.7
60 – 90	0.0	0.0	0.0	0.0	9.7	10.5	8.4	9.8	8.7	9.2
90 – 150	0.0	0.0	0.0	0.0	7.8	7.2	7.2	6.9	7.2	7.7

	(67)	(65)	(71)	(69)	(75)	(76)

† Percent of amount applied

‡ Chloride concentrations are not significantly different between GS and CET at each depth under the emitter, at 0.33 m and at 0.66 m from the emitter

Table 5. Simazine recovery from plots under drip irrigation †

Days a simazine application	Soil depth 0 – 15	15 – 45	45 - 75
------------- d -------------	-- cm	-------------------------	
		Under emitter (97)	
7	16.9a‡	7.2a	3.0a
14	4.3a	0.1a	0.1a
28	0.1a	0.1a	0.1a
		At 0.33 m from emitter (97)	
7	59.7a	6.8b	0.0b
14	68.5a	4.2b	0.0b
28	24.8a	0.8b	0.0b
		Under emitter (99)	
7	22.6a	10.9b	3.1b
14	8.0a	1.9b	0.7b
28	2.7a	1.0b	0.0b
		At 0.33 m from emitter (99)	
7	57.7a	6.4b	0.0b
14	38.4a	0.6b	0.0b
28	25.0a	0.2b	0.0b

† Percent of amount applied

‡ Means in each row with the same letter are not significantly different using Fisher's Protected LSD, $\alpha = 0.05$.

Table 6. Simazine recovery from plots without irrigation and with/without rain effect†

Days after simazine application	Soil depth 0 – 15	15 – 30	>30
------------- d -------------	-- cm -------------------------		
		1998	
7 (no rain)	47.3a‡	2.6b	—
21(no rain)	35.3a	1.5b	—
63 (no rain)	26.7a	3.8b	0.0b
63 (with rain)	7.0	3.0	0.0
		1999	
7(no rain)	54.6a	4.0b	—
21(no rain)	33.2a	1.7b	—
63(no rain)	28.7a	1.1b	0.0b
63(with rain)	11.5	2.3	0.0

† Percent of amount applied

‡ Means in each row with the same letter are not significantly different using Fisher's Protected LSD, $\alpha = 0.05$.

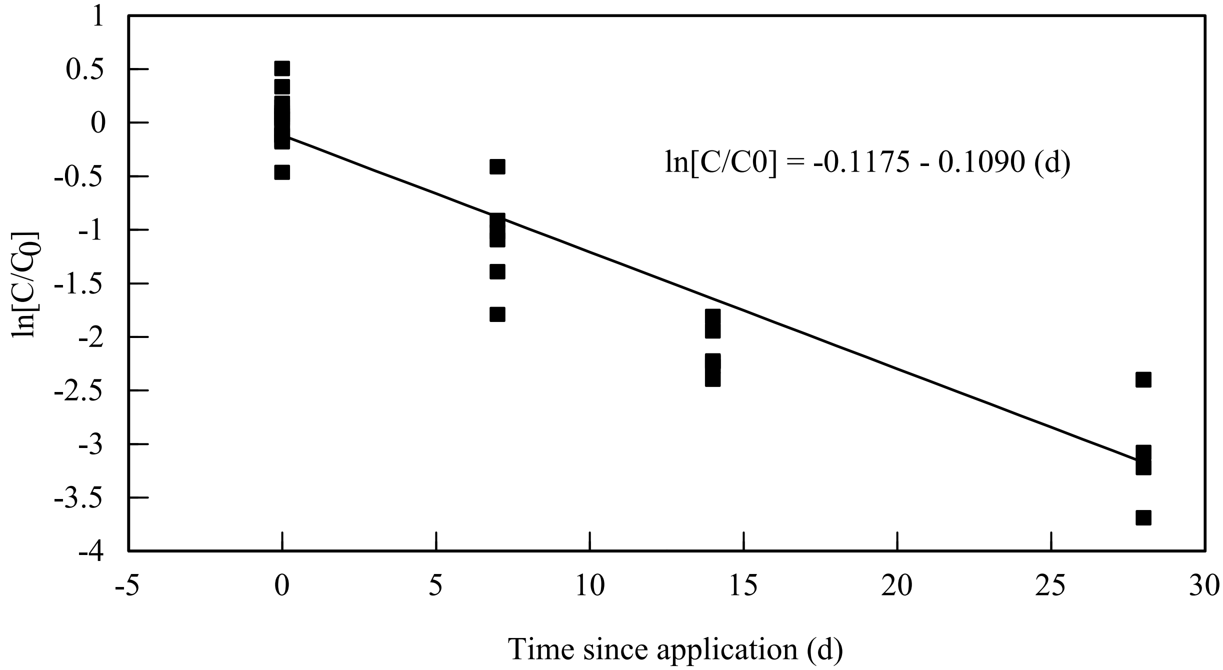

Figure 10. Simazine dissipation rate under the emitter. This figure represents combined data for 1997 and 1999 since no significant differeence of recovred simazine is found between the tars years.

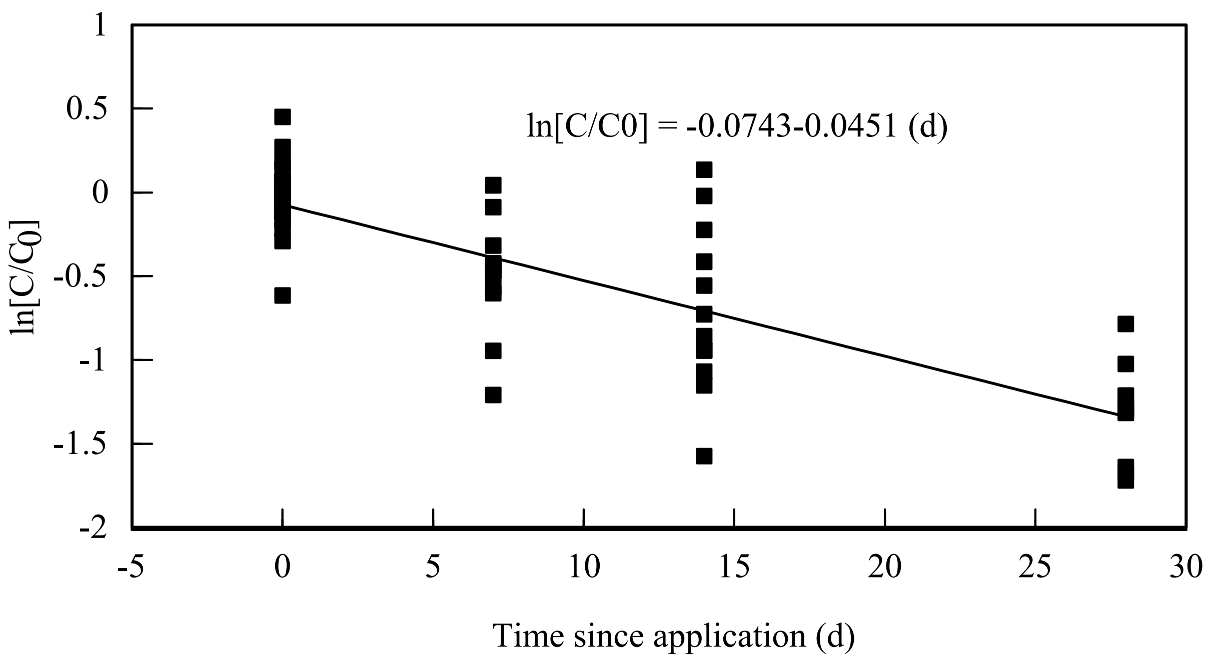

Figure 11. Simazine dissipation rate at 0.33 m from the emitter. This figure represents combined data for 1997 and 1999 since no significant differeence of recovered simazine is found between the two years.

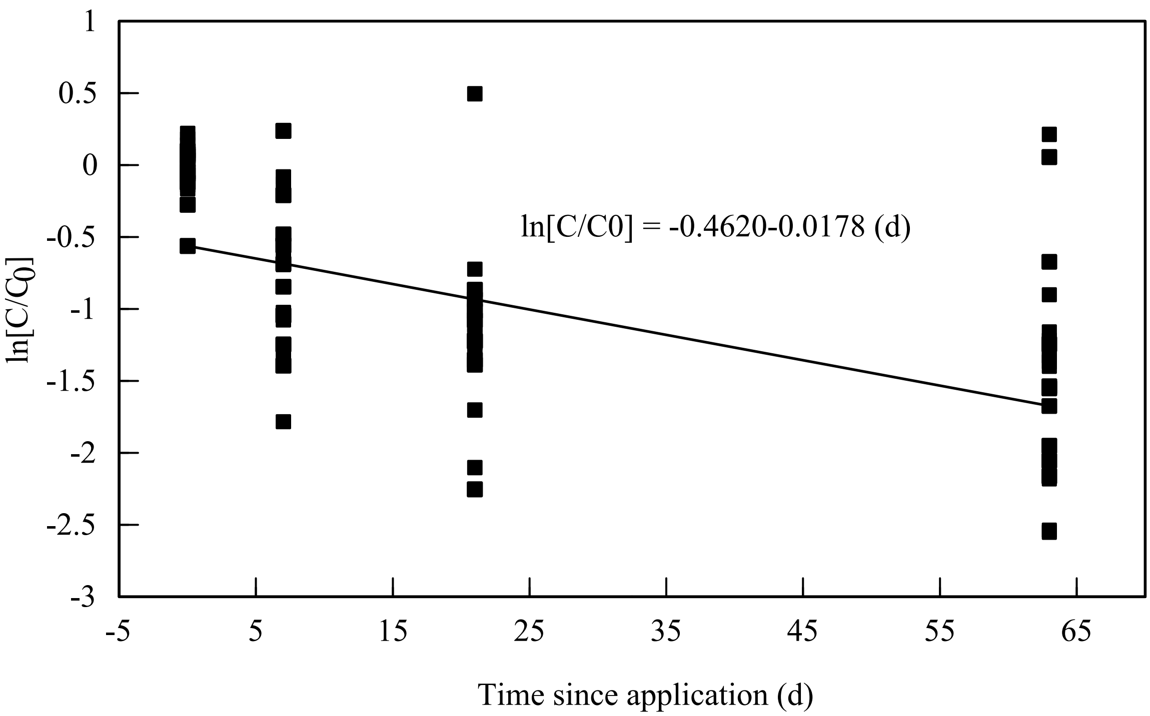

Figure 12. Simazine dissipation rate from plots protected from rain. This figure represents combined data for 1998 and 1999 since no significant differeence of recovered simazine is found between the two years.

II. Changes to preemergent herbicide use maintains weed control in citrus

In 1996 – 1997, weed species and density data recorded in April illustrated the effective control achieved with all treatments at site 1 (Figure 13). Plots with herbicide treatments had significantly fewer weeds than the untreated control. Weed species included: spotted spurge, common groundsel, redstem filaree, burr medic, horseweed, annual sowthistle, and purple cudweed. Data at site 2 showed that postemergent herbicide use in the fall, followed by preemergent herbicides in late winter were not significantly different from the untreated control (Figure 14). Weed species at site 2 included: spotted spurge, common groundsel, horseweed, annual sowthistle and purple cudweed. Spotted spurge and common groundsel, however, consisted of about 95% total weeds found in the treated plots at both the sites.

The result obtained in 1997 - 1998 showed that no significant difference in weed density was found between herbicide treatments at site 1 (Figure 13). Plots at site 2 had similar results (Figure 14). All herbicide treatments significantly differed from untreated plots. Weed species, like found in 1996 – 1997, included spotted spurge, common groundsel, annual sowthistle, horseweed and hairy fleabane at both sites. Spotted spurge and common groundsel consisted of about 98% total weeds found in the treated plots. In 1998 – 1999, a field study was conducted in another mature citrus orchard at site 3. Plots with herbicide application had significantly fewer weeds than the untreated control (Figure 15). However, no significant difference in total weeds was found between the rates applied at 1.25 kg ai ha^{-1} and 2.0 kg ai ha^{-1}. The result was consistent with the study conducted in 1997 and 1998.

The results showed that preemergent herbicides applied at reduced rates (1.0 kg ha^{-1} or 1.25 kg ha^{-1}) were as effective as the standard rate at 2.0 kg ha^{-1} for weed controls by using spray application in entire orchard floor. Data from site 1 and site 2 also showed that weed density in 1997 – 1998 was larger than in 1996 – 1997, especially for the younger grove at site 2. Increased weed density most likely resulted from high rainfall in 1997-1998. For example, significant rainfall-runoff events occurred after winter application of herbicide in 1998. However, in 1996- 1997 study, no rain occurred after herbicide application in winter 1997. Rainfall – runoff events could result in herbicide loss and reduce its efficiency on weed control. Site 1 and site 3 had much lower weed populations in both untreated controls and herbicide treated plots compared to the younger grove at site 2. A combination of a depleted seed bank from continuous use of herbicides and shading may have contributed to lower weed populations at site 1 and site 3.

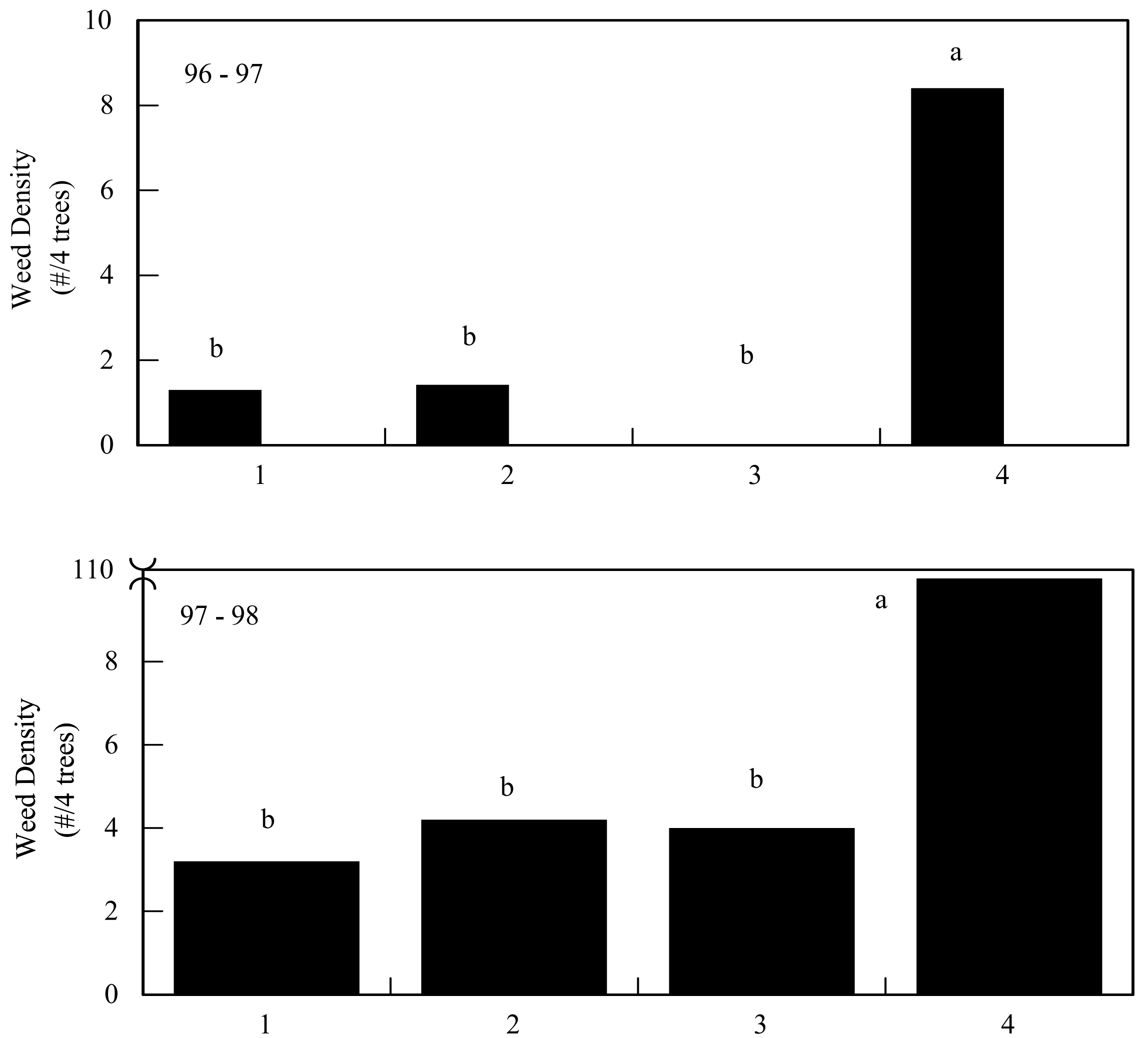

Figure 13. Total weed density of each treatment at Site 1. Treatment numbers along the x-axis refer to the treatments listed in Table 3. Means with the same letter are not significantly different to an LSD test at the 0.05 level.

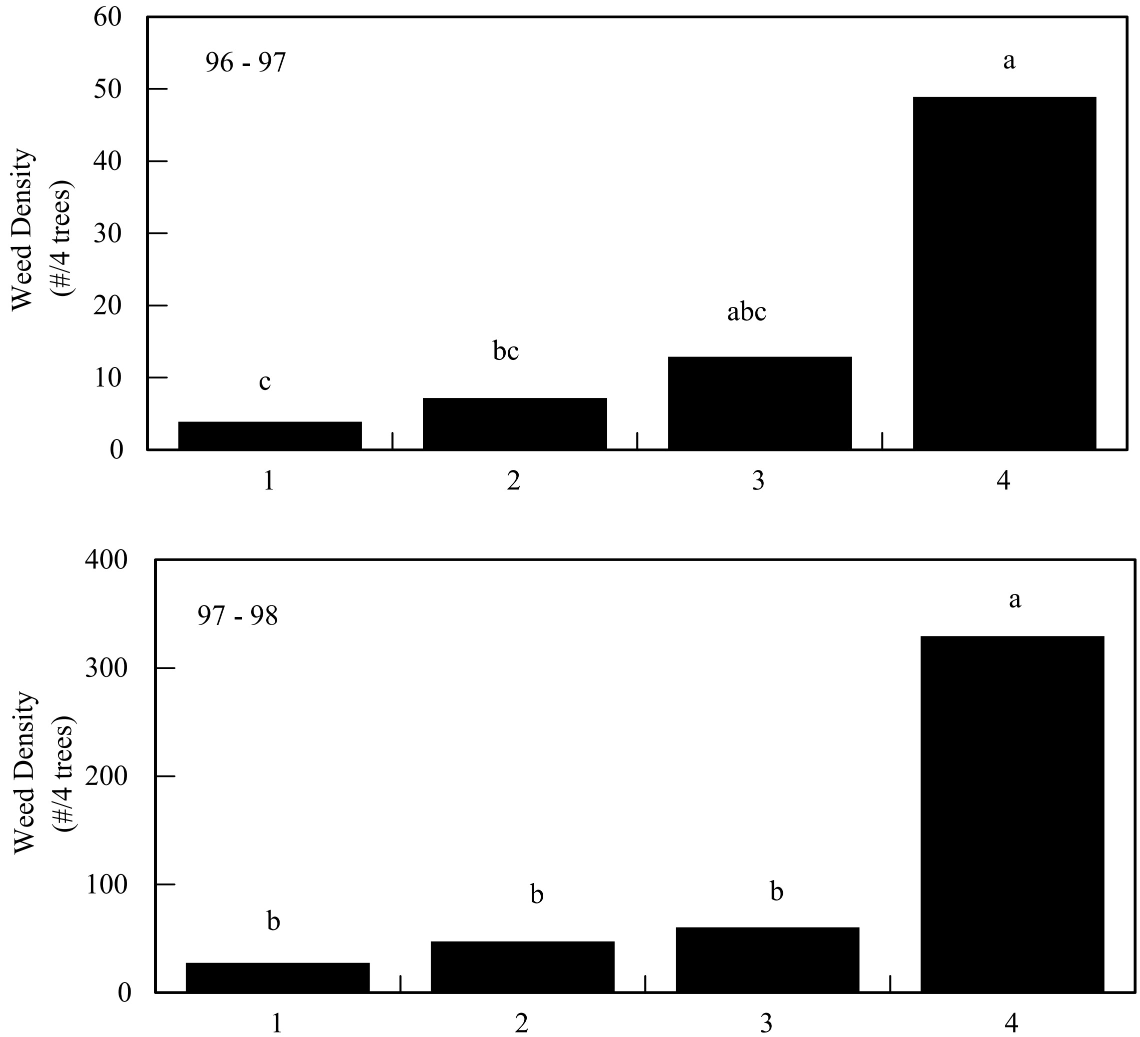

Figure 14. Total weed density of each treatment at Site 2. Treatment numbers along the x-axis refer to the treatments listed in Table 3. Means with the same letter are not significantly different to an LSD test at the 0.05 level.

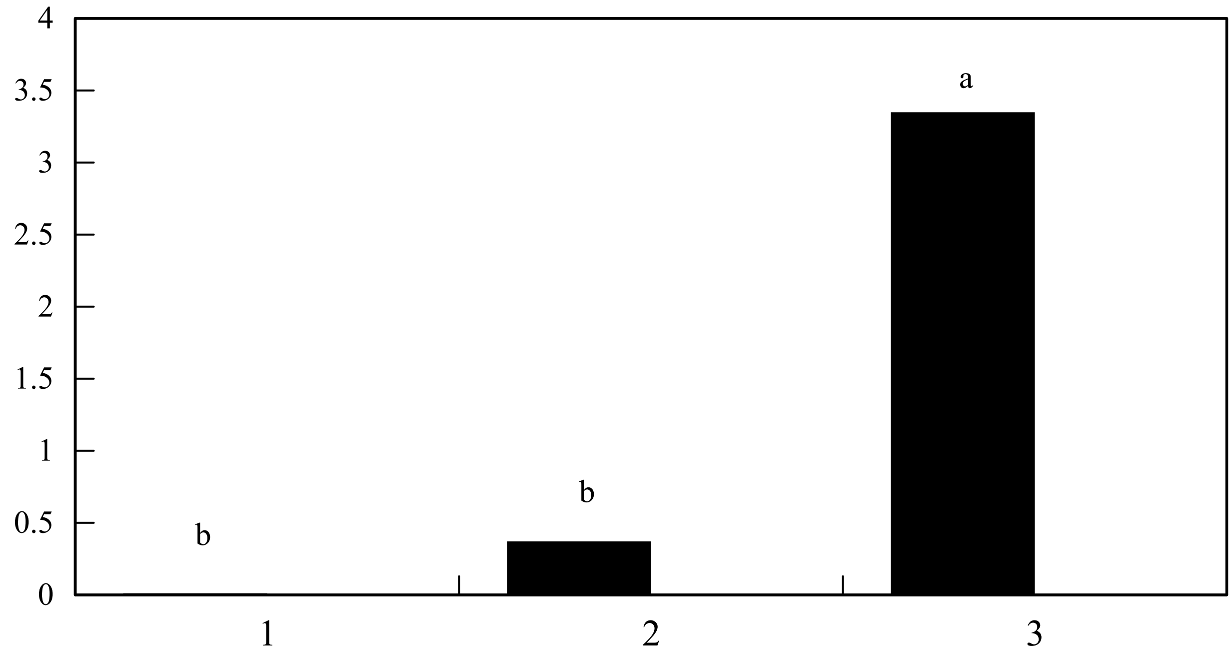

Figure 15. Total weed density of each treatment at Site 3. Treatment numbers along the x-axis refer to the treatments listed in Table 3. Means with the same letter are not significantly different to an LSD test at the 0.05 level.

EXTENSION OUTREACH

Extension activities included meetings, field days and development of a water quality curriculum for grapes on the central coast. Reducing preemergent herbicide use and emphasizing cultivation and postemergent herbicide use were topics of two Biologically Intensive Vineyard Systems (BIVS) meeting (45 approximate attendance at each meeting) held in Fresno County on 12/1/98 and 1/5/99 Vineyard floor management during grape establishment and timing of applications were discussed in the Tulare County UCCE winter meeting (150 approximate attendance) held 12/15/99. In April, a field day was held to discuss reducing preemergent herbicide use and the use of cover crops to reduce runoff from citrus groves on 4/8/99 (60 approximate attendance). Prior to the field day, and interview with Channel 24 Fresno was conducted for use on the morning agriculture program. A groundwater protection short course (40 approximate attendance) was held in Paso Robles where prevention of surface runoff was the topic. The short course is part of a larger project to develop a water quality – groundwater protection curriculum and site-specific management program for grapes on the central coast. This program is patterned after the rangeland water quality short course. Recommendations and curriculum will be built, in large part, from our research conducted from this grant.

SURVEY RESULTS - Citrus Farmers in the San Joaquin Valley

A mail survey was conducted among citrus farmers in Fresno and Tulare counties in 1997. The response rate was 38% with 220 completed surveys. In order to assess the if the population of those who responded is representative, a follow up effort to determine characteristics of non-respondents will be conducted.

One quarter of respondents have 1 to 10 acres of citrus and another third have 11 to 40 acres. A second third have citrus farms with 41 to 500 acres and the remaining farms have 501 acres or more. The average number of citrus acres is 256 (sd = 1209) (Table 1). Ninety-six percent of respondents have at least one acre of Navel whereas only about half of respondents have at least one acre of Valencia. The average number of Navel acres among respondents is163 (sd=969) and for Valencia it is 62 acres (sd=321) (Table 2).

The vast majority of the respondents both own and manage their citrus acreage (795) and the average number of years respondents have worked with citrus is 24 years (sd=14). Just over half of respondents have worked in citrus for more than 20 years (Tables 3-4). When asked who has primary responsibility for decisions to apply herbicides, 64% indicated that the owner or manager does. Thirty-one percent indicated that it was a joint decision between the owner or manager and the PCA and only 5 percent indicated that the responsibility was primarily the PCA's (Table 5).

While most farmers were satisfied with their herbicide program, 41% have modified or were considering modifying their program within the last three years (fall 1993 through summer 1996). Among those making or considering modifications, two reasons were selected by a majority: to save money (61%) and weed species not controlled (56%). The effects of weed management on soil, trees, and water quality were each selected as reasons for modification by 24%, 20% and 16% respectively. Only 7% selected restriction on future land use as a reason for modification (Table 6).

The respondents' likelihood to modify their herbicide program was looked at in relationship to farm size, years in citrus, and primary decision maker on herbicide applications. Overall as farm size increases so does the likelihood of modifying the herbicide program. Specifically 30% of farms with 10 acres or less compared to 73% of farms with more than 500 acres were likely to modify their herbicide program.

About half of those who have worked in citrus 10 years or less were likely to modify their herbicide program compared to only one third of those who have worked in citrus 40 years or more. Among the other groups, 36% of those in citrus who have worked 11-20 years, 45% of those in citrus 21-30 years, and 38% of those in citrus 31-30 years were likely to modify their herbicide program.

Finally, 44% of those farms where herbicide decisions were made jointly by the owner/manager and the PCA indicated a likelihood to modify their herbicide program, followed by 40% of farms where the owner/manager made the primary decision. Only one third of farms where the PCA made the primary herbicide decisions were likely to modify their herbicide program.

The survey measured farmers' attitudes toward two weed management practices: maintaining clean orchard floors and shallow incorporation of preemergent herbicides in orchard middles. Farmers were asked to rate their level of agreement or disagreement with a set of positive and negative statements about each of the practices. Overall, there was a more favorable assessment by respondents of maintaining a clean orchard floor than the practice of shallow incorporation of preemergent herbicides in orchard middles.

There was overwhelming agreement with three of the four positive statements about maintaining a clean orchard floor. Over two-thirds of respondents agreed either strongly or somewhat that a clean orchard floor reduces competition with crop (90%), reduces frost risks (87%), and allows for better movement of equipment (82%). Sixty-five percent agreed either strongly or somewhat that a clean orchard floor prevents the growth of insect pests. There was overall disagreement with two of the three negative statements about maintaining a clean orchard floor. Sixty-three percent disagreed, either strongly or somewhat, with the statement that maintaining a clean orchard floor inhibits nutrition and 58% disagreed that a clean orchard floor reduces water penetration in the soil. In contrast, 66% agreed either strongly or somewhat, that a clean orchard floor inhibits the growth of beneficial insects (Table 7).

With regard to shallow incorporation of preemergent herbicides, a majority agreed either strongly or somewhat that shallow incorporation allows better movement of herbicides into the soil (69%) and less movement of herbicides out of the orchard (53%). Similarly, there was majority agreement with each of the negative statements about shallow incorporation including it is too expensive, too time consuming, and disturbs the soil making harvest more difficult; 72%, 71% and 68% respectively (Table 8). Furthermore, three-quarters of the respondents indicated they are somewhat to very unfavorable towards the practice of shallow incorporation (Table 9).

While about one third of respondents applied preemergent herbicides in both the fall and spring, another third applied them in the fall to early spring. Eighteen percent applied preemergent herbicides in the late winter to spring only. The remaining 13% did not apply preemergent herbicides at all (Table 10). Two-thirds of respondents indicated that none of their citrus acres had a slope greater than 4%. Less than 10% indicated that a majority of their acreage had greater than a 4% slope (Table 11).

Finally, respondents represent a slightly older, well-educated group. The average age of the respondents is 55 years (sd=14) and the majority are over 50 years of age while about one third are over 60 years of age. Half of the respondents have a college degree or higher. Ninety-four percent of respondents are male (Table 12).

TABLE 1. Total Citrus Acres (including all citrus): N=217

Acres	*Percent*
1 to 10	25
10 to 20	18
21 to 30	9
31 to 40	9
41 to 70	10
71 to 100	6
101 to 250	11
250 to 500	6
501 to 1000	3
1001 or more	4
Mean acres =	256
SD =	1209

TABLE 2. Number of Acres Citrus: Navel and Valencia

Acres	*Navel Percent (n=218)*	*Valencia Percent (n=217)*
None	4	49
1 to 10	31	16
11 to 20	17	10
21 to 30	9	6
31 to 60	15	9
61 to 100	7	5
101 to 250	7	2
251 or more	10	4
Mean acres =	163	62
SD =	696	321

TABLE 3. Years Working in Citrus

Years in Citrus (N= 214)	*Percent*
Ten years or less	23
11 to 20 years	26
21 to 30 years	20
31 to 40 years	18
40 years or more	13
Mean years =	24
SD =	14

TABLE 4. Position in Citrus Management

Position (N= 203)	*Percent*
Owner and Manager	79
Manager Only	11
Owner Only	4
PCA	3
Other	1

TABLE 5. Weed Management Decision Making

Position (N= 203)	*Percent*
Mostly Owner or Manager	64
Mostly PCA	5
Jointly with PCA and Owner/Manager	31

TABLE 6. Modifications in Citrus Weed Management. Respondents (41%) indicated they have modified or have considered modifying their citrus weed management program within the last three years, fall 1993-summer 1996.

Reasons for Modifications (N=82) *(multiple response)*	*Percent* *Favoring*
To save money	61
Weed species not controlled	56
Effects of weed management on soil	24
Effects of weed management on trees	21
Effects of weed management on water quality	16
Restrictions on future land use	7
Other reason	10

TABLE 7. Respondent Attitudes Toward Maintaining a Clean Orchard Floor as a Citrus Management Practice.

Statements about the Practice (N = 179-184)	*Strongly Agree*	*Somewhat Agree*	*Somewhat Disagree*	*Strongly Disagree*
Advantages of the practice				
Reduces competition with crop	48	42	7	3
Reduces frost risks	65	22	8	4
Prevents growth of insect pests	23	42	27	8
Allows for better equipment movement	49	33	14	4
Disadvantages of the practice				
Reduces water penetration in soil	10	32	32	26
Inhibits growth of beneficial insects	16	50	28	6
Inhibits nutrition	9	28	41	22

TABLE 8. Respondent Attitudes Toward Shallow Incorporation of Preemergent Herbicides in Orchard Middles as a Citrus Management Practice.

Statements about the Practice (N = 121-129)	*Strongly Agree*	*Somewhat Agree*	*Somewhat Disagree*	*Strongly Disagree*
Advantages of the practice				
Better movement of herbicide into soil	14	45	28	13
Less movement of herbicide out of orchard	12	41	36	11
Disadvantages of the practice				
Too time consuming	31	40	22	6
Damages the roots	14	46	26	13
Causes soil erosion	13	38	31	17
Too expensive	27	45	19	9
Disturbs soil which makes harvest difficult	40	28	19	13

TABLE 9. Favorability Toward Shallow Incorporation of Preemergent Herbicides

Level of Favorability (N= 145)	*Percent*
Very favorable	6
Somewhat favorable	18
Somewhat unfavorable	39
Very unfavorable	37

TABLE 10. Timing of Preemergent Applications, Fall 1993 – Summer 1996

Usually applied (N=185)	*Percent*
Both fall and spring	35
Fall to early winter only	35
Late winter to spring only	18
Did not use preemergents	*13*

TABLE 11. Slope of Citrus Acreage

Percent of Acres (N=212)	*Flat Ground (0% -4%)*	*Gully or Hill Sides (> 4%)*
None	5	67
1 to 20% of acreage	6	11
21 to 40% of acreage	6	5
41 to 60% of acreage	7	7
61 to 80% of acreage	5	4
81 to 99% of acreage	8	1
100% of acreage	63	4

TABLE 12. Social Demographic Characteristics

Level of Education (N= 207)	*Percent*
Less than High School	3
High School	17
Some College	27
Vocational Degree	3
College Degree	32
Some Graduate Work	5
Graduate Degree	13

Age (N= 205)	*Percent*
Less than 40 years	14
41 to 50 years	26
51 to 60 years	21
61 to 70 years	23
71 years or more	14
Mean years =	55
SD =	14

Sex of Respondent (N=209)	*Percent*
Male	94
Female	6

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