Department of Pesticide Regulation

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MEMORANDUM

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SUBJECT: STUDY 221–DEMONSTRATION STUDY ON CHEMIGATION OF SIMAZINE AND DIURON ON CITRUS ORCHARD IN TULARE COUNTY

SUMMARY

Chemigation is the application of pesticides through irrigation systems. Ground water protection regulations enacted by the Department of Pesticide Regulation (DPR) in May 2004 identify chemigation as an option for preventing the offsite movement of pesticides. However, many pesticide labels for atrazine, simazine, diuron, bromacil, and norflurazon, the known groundwater contaminants from the Title 3, California Code of Regulations (3CCR) section 6800(a), prohibit the application of these pesticides through irrigation systems. Beginning in 2003, DPR initiated collaborative investigations with Center of Irrigation and Technology at California State University, Fresno and pesticide registrants, Syngenta and Dow Chemical Companies, to facilitate the adoption of this mitigation measure. This collaboration focused on developing data that could be used to support removal of the chemigation prohibition from certain simazine and diuron pesticide labels. These pesticides were chosen because they represent herbicides that are commonly used on citrus. The initial collaboration was successful. In 2005, DPR approved two "Special Local Needs (SLNs)" labeling requests by Citrus Mutual, a grower organization, and added chemigation as an allowed method of application for Direx 4L (EPA Reg 1812-257) and Princep 4L (EPA Reg 100-526) for use on citrus in Fresno and Tulare counties.

This study was conducted in 2005/2006 on two commercial citrus groves, located in Tulare County to further assess and demonstrate the efficacy of this application method. From discussions with citrus growers, DPR staff learned that growers often split their broadcast herbicide applications in an effort to extend the period of efficacy. Some growers report achieving economical control through reduced application rates. To assess the effectiveness and transferability of these cultural practices to chemigation, Princep 4 L (simazine) and Direx 4 L (diuron) were split in two equal amounts and applied 90 days apart, with the first application occurring in the wintertime to control winter weed growth. One site received the maximum label rate while the second site received half of the maximum. Qualitative ratings were used to compare the efficacy on chemigated plots to the weed growth in control plots where no herbicides were applied.

Despite frequent and abundant winter rainfall in 2005/2006, the observed efficacy in both groves was good. Both cooperating growers were very satisfied with the performance of the chemigated pesticides. Splitting the application appeared to extend efficacy because qualitative ratings showed that the locations were free of weeds for a much longer period when compared to the single application applied on the previous year's trial (Basinal et al., 2005). One location was free of weeds from February 2006 through late August 2006, with only a few weeds noted after that. This study showed that chemigation can work well in orchards with cover cropped row middles because the grower can limit the application to the tree rows and not affect cover crop growth. Phytotoxicity was not observed; at present, this application method appears to be as safe as the common cultural practice of broadcasting these herbicides.

INTRODUCTION

Chemigation is the application of pesticides through irrigation systems. During development of the current regulations for ground water contaminants, DPR scientists identified chemigation as a potential method to mitigate ground water contamination, especially in areas where rainfall runoff of residues was the pathway of contamination (Braun and Hawkins, 1991; Troiano et al., 2000). The use of chemigation as a method of incorporation of pesticides into soil is listed in the 3CCR section 6487.4(b). Growers may find chemigation through micro-sprinklers advantageous because they can safely apply products at night or when fields are too wet for other equipment; their risks of handler exposure or pesticide drift to other crops or workers are reduced, and they can use the application time to do other farming activities.

In order to promote chemigation as an effective mitigation measure in vulnerable areas, DPR began, in 2003, sponsoring collaborative investigations with growers, Center of Irrigation and Technology at California State University, Fresno, Syngenta and Dow Chemical registrants to provide data to support expanding the pesticide labeling to allow this application method for simazine and diuron, two preemergent herbicides commonly used on citrus. These initial studies were conducted on small plots located within commercial citrus groves. California Citrus Mutual, a grower trade organization, used the data from these studies to support a request for a SLN labeling to allow the application of simazine and diuron through an irrigation system to citrus groves located in Fresno and Tulare counties (Basinal et al., 2005). DPR has issued a SLN. CA-050005 for Direx 4L, EPA Reg 1812-257 and SLN CA-050004 for Princep 4L, EPA Reg 100-526

Growers are more inclined to adopt environmental mitigation measures that are at least as effective as the current practices and economically and technically feasible. Based on the favorable results of the previous small plot studies conducted in 2003/2004 and 2004/2005, chemigation appeared to be promising alternative tool for applying herbicides in areas prone to winter rain runoff (Basinal et al., 2005). According to that report, the bulk of pesticide was held on the first six inches of the soil and the efficacy was not compromised. The positive results from that study provided impetus to further investigate chemigation as a commercially viable application method.

MATERIALS AND METHODS

This study was conducted on two citrus orchards in Tulare County. As in the previous small plot study, simazine and diuron were used for pre-emergent control of winter weeds, a common practice for citrus growers in California's Central Valley. Some growers have used split applications for broadcast sprays with the intent of extending the time period of weed control (Pickett et al, 1990). To test the efficacy of this practice under chemigation, the recommended maximum annual labeled rates was split in two applications made 90 days apart.

Study Site Description and Preparation: Site 1 was a single 9-acre citrus block located on a loamy soil. Site 2 was a 22-acre citrus orchard located on sandy clay loam to clay loam soil and it was divided into 4 blocks. The trees were 10 and 65 years old at Site 2 and Site 1, respectively. Canopy surface area was between 20 to 25% at Site 2 and 50 to 60% at Site 1. Consequently, the orchard floor was exposed to more sunlight at Site 2 than at Site 1. At Site 1, the cooperator typically grows vetch, a cover crop, in the row middles during the winter and then mows the middles later in the growing season. At this location, pre-emergent herbicides are broadcast on the tree rows and contact herbicides are applied whenever additional control is needed. At Site 2, the cooperator uses preemergent herbicides on the tree rows and contact herbicide on the row middles in lieu of a cover crop. It should be noted that before the end of study, the middle rows of control plots on Site 1 were mowed and the contact herbicide sprayed between the trees rows on both locations. These operations did not compromise the study outcome.

Both locations were under micro-sprinkler irrigation systems that used fanjet emitters with fixed heads. Fixed heads provide water in dedicated streams from the nozzle. The output of a single micro-sprinkler was approximately 30 to 36 L/hour at both locations. The distribution uniformity of the irrigation system at Site 2 was 88% and 97% at Site 1. The irrigation systems on both locations were evaluated and repaired prior to the injection of the pesticides. Back flow prevention valves were previously installed on both orchards in accordance with state and federal requirements to prevent ground water contamination. Prior to injection of pesticides, all five blocks were pre-irrigated for two hours.

As part of monitoring the amount of precipitation received by the plots during the study, was tracked from the California Irrigation Management Information System weather station located in Tulare County (Appendix, Table 5).

Application: The first injection was applied on November 18, 2005, on Site 1 and on February 2, 2006, on Site 2. The treated area per block was determined as the product of the area covered per single sprinkler emitter times the number of emitters per block. On Site 2, the intended rates used per application were 4.67 L and 3.74 L/ha/ per injection of simazine (Princep 4L, 41.9% active ingredient [A.I.]) and diuron (Direx 4L 40% A.I.), respectively. On Site 1, the rates per injection were halved and were 2.31 L/ha and 1.7 L/ha of simazine and diuron, respectively. At the first application, both pesticides were injected as a tank mix using a gas powered Honda motor running a diaphragm injection pump on Site 2 and a venturi injection system on Site 1. On Site 2, the calculated amount of simazine and diuron was diluted in a 30-gallon barrel and injected into the irrigation system. Each block was individually injected from the closest valve to the block. On Site 1, the products were pre-mixed and injected directly into the irrigation system. The speed of injection averaged two hours per block on both locations. Wind speed was not a factor during the injections.

For the second injection, 90 days after the first application, a 757-liter supply tank equipped with a mechanical agitator and diaphragm pump was used to inject the pesticides into the main irrigation line on Site 2. All four blocks were injected at the same time. On Site 1, 10-gallon container was used for pre-mixing. On Site 1, the pesticides were not diluted before being injected. The injection for the second application lasted two hours at each location.

The herbicides were incorporated as expected and no runoff occurred during the process. This is probably due to the fact that in both sites the soil infiltration rate is equal or greater than irrigation rate. Adjusting irrigation rate to the soil infiltration rate is a good irrigation management.

Water and Soil Sampling: Soil and water samples were taken prior to chemigation injections to measure background levels of the herbicides (Appendix, Tables 1 and 2). On Site 2, two 1-liter bottle samples of water were taken from the emitters and eight randomly collected soil samples were taken down to the 4-inch soil depth. On Site 1, three water samples were collected and the results of the final soil sampling from a study conducted in the previous year at his ranch were used as background data. Soil sampling methodology conformed to specification in SOP FSSO002.00 (Garretson, 1999).

Soil and water samples were randomly collected to measure the concentration in soil after application (Appendix, Tables 3 and 4). On Site 2, 6 water samples and 10 randomly collected soil samples were taken down to the 4-inch soil depth. On Site 1, 5 water samples and 8 randomly collected soil samples were taken down to the four-inch soil depth. The water samples were collected in 1-liter amber bottles and they were obtained from the micro-sprinklers during the chemigation. At the end of injection, all blocks were irrigated for 1-1/2 hours. The purpose of this post irrigation was to purge out all pesticide from the irrigation system. Samples were analyzed for the presence of simazine and diuron.

Chemical Analysis: The Center of Analytical Chemistry of the California Department of Food and Agriculture analyzed both soil and water samples for simazine and diuron using high performance liquid chromatography with a UV detector. The reporting limit for the water method is 0.1 ppb for both simazine and diuron. The reporting limit for soil is 30 ppb for both simazine and diuron.

Procedures for both analytical methods followed established SOP QAQC001.00 for Chemistry Laboratory Quality Control (Segawa 1995). Specific methodology and procedures are available upon request.

Efficacy and Phytotoxicity: Qualitative evaluations for efficacy and phytotoxicity were conducted several times at each location by a team composed of study staff members, growers and registrant's representative. Each qualitative rating was always a result of consensus from the team. The efficacy rating reflected the overall performance of chemigated plots compared to the control plots where pesticides were not applied. Weed control was visually rated on a 0–100 scale in which the score was a subjective evaluation of the weed population on a block. The density and the distribution of the weed population on the control block were used as reference point to rate the treated blocks. The ratings were as follow:

- 0%: Total lack of control
- 5–30%: Insignificant to poor weed control; little or no control on the plot
- 40–60%: Inadequate weed control
- 70%: Adequate weed control
- 80%: Good weed control; few weeds present
- 90%: Excellent weed control; very few weeds present
- 100%: Complete control; no weeds

In addition to the scale described, digital pictures were taken to reinforce the visual ratings.

Data Analysis: For calculating the amount of active ingredient applied, the area of soil treated by an emitter was determined as the mean radius of the wetted circle measured from five randomly selected emitters. Since the area was circular in pattern, the formula for using the radius to determine the area of a circle was used: πR2. The mean wetted area of emitters at Site 2 was 186,698 sq cm and at Site 1 was 236,290 sq cm. The expected amount of active ingredient applied per emitter was calculated from the applied rate of simazine and diuron. This calculated amount was also used to determine the expected soil concentration on first 4 inches as shown on Table 1. These expected amounts were compared to the actual amount applied through the emitter. The actual amount delivered was determined as the product of the concentration measured in emitter samples and the length of chemigation. The amount recovered in soil was the product of the measured concentration, the bulk density of the soil, and the volume of the soil sample.

RESULTS

Water and Soil Samples: All water samples collected prior to injection were negative for both simazine and diuron. Diuron and simazine residues were found on background soil samples on Site 2 but none on Site 1 (Appendix, Tables 1 and 2). As expected, all post injection samples showed the presence of applied pesticides in the water as well as in the soil samples (Appendix, Tables 3 and 4).

For water, the amount of active ingredient delivered per emitter was similar between the expected amount and the actual amount delivered, except for diuron on Site 2 (Table 1). For Site 2, the calculated amount of diuron was 50% less than the expected amount. For soil, the agreement between expected and measured soil concentration for diuron was good at both locations. For simazine, values are bolded and they did not appear to agree. But if the values were exchanged between locations, then the agreement would have been very good. It is possible that there was an error with the labeling at some point in the collection, transfer, or analysis of these samples. This could not be confirmed, however.

Table 1. Comparison of the expected and actual amount of simazine and diuron delivered through the emitters and measured in soil.

Location	Product	Rate Product / Application (Kg/ha)	Expected per Emitter (g)	In Water During Injection			In Soil (0 – 4 inches)	
				Average Concentration (ug/L)	Amount Water (L / Emitter)	Calculated per Emitter (g)	Average Concentration (ug/kg)	Expected Concentration (ug/kg)
Site 1	Simazine	1.12	2.64	46000	60	2.76	2127	801
		1.01	2.38	40600	60	2.43	684	721
Site 2	Simazine	2.24	4.18	88200	60	5.29	807	1602
		1.79	3.34	29000	60	1.74	1144	1282

Diuron

Table 2. Coefficient of Variation (%) for soil and water samples

Diuron Locations	Water Concentration		Soil Concentration	
	Simazine	Diuron	Simazine	Diuron
Site 1	8.2	3.4	108	126
Site 2	3.4	2.8	92l	73

Table 3: Efficacy and Phytotoxicity at Site 2 and Site 1

Grower	Date	Efficacy Rating In % controlled	Crop Phytotoxicity In % injured
Site 1	12/15/2005	90	0
	04/19/2006	85	0
Site 2	04/06/2006	98	0
	05/16/2006	98	0
	06/02/2006	98	0
	07/05/2006	90	0
	08/14/2006	90	0

The coefficient of variation (CV) was low for water samples collected from the emitters during the injection, (Table 2). The low CV for water samples showed consistency in concentration of pesticide delivered in the water through the emitters. In contrast, the CV for soil concentration was high at both locations, which could have been influenced by several factors. First, the micro-sprinkler heads provided a fixed stream of water, potentially concentrating the pesticide in the swath of the fixed streams. Use of rotating micro-sprinkler heads could provide improvement in the distribution of pesticides throughout the wetted circle. Second, micro-topography of an area such as small changes in slope could have provided areas in which the irrigation water would have collected. Figure 1 illustrates how the debris in soil may have affected the distribution of the pesticide applied through the emitters. The debris would have altered the distribution by intercepting the residues prior to their contact with the soil surface. Lastly, although the wind was light, this could have been a factor in shifting the direction of the spray from the sprinkler emitters thereby reducing the uniformity of the application. Again, use of a rotating micro-sprinkler head would tend to minimize this effect.

Figure 1: Debris on the soil during chemigation would have intercepted residues thereby affecting distribution and soil concentration.

Efficacy and Phytotoxicity: Efficacy measurements were based on a qualitative rating system that reflected the overall performance of the treatment. The rating did not segregate between grasses and broadleaves or between species on treated blocks. As seen in the digital pictures taken of the control plots from Site 1, plant growth was profuse, confirming a high potential for weed infestation in the fields (Figure 2). Foxtail, crabgrass, feather finger grass, common purslane, hairy vetch, Persian speedwell were the predominant weeds on control plots on Site 1. On Site 2, the predominant weed species in the control plots were chickweed, groundsel, fleabane, malva weed, pigweed, and prickly lettuce (Figure 3). The weed vegetations are unique for each Location because of soil texture and cultural practices. On Site 1 the cover crop is practiced and the soil is lighter. On Site 2 the texture is heavier and contact herbicide is used on row middles to control the weeds.

Figure 2. View of weed growth in the control block at Site 1. The view was from South to North in middle row of one of three rows reserved for control. The middles exhibited a profuse mixture of grasses and broadleaf weeds. The middles were mowed later on and the rows, around the sprinklers, sprayed with contact herbicide.

Figure 3. View of the control plot at Site 2. Chickweed, groundsel, fleabane, malva weed, pigweed, and prickly lettuce were the most predominant weed species. This picture was taken approximately four months after the first application. Contact herbicide was used later on to burn the vegetation and destroy the seeds.

On Site 1, two ratings were taken, one at approximately 30 days after the first application and the second at 2 months after the second split application (Table 3). During that period, the observed efficacy of herbicide treatments was very good with values observed ranging from 85% to 90%. At 60 days after treatment, lack of plant growth was evident throughout Site 1 (Figure 4). By 90 days after treatment, a high level of regrowth is apparent in the row middles with very little growth in the treated area (Figure 5). Re-growth of plants in row middles after mowing is normal.

At Site 2, five ratings were taken at five consecutive months commencing in April 2006 (Table 3). These measurements provided data on weed control after the first split treatment application and then for another three months after the second split application. Throughout that period, the efficacy measures for herbicide treatment were between 90 and 98%, indicating that the plots were essentially weed free for 6 months. The picture in Figure 6 was taken five months after the first application, where a high level of control was evident throughout the location.

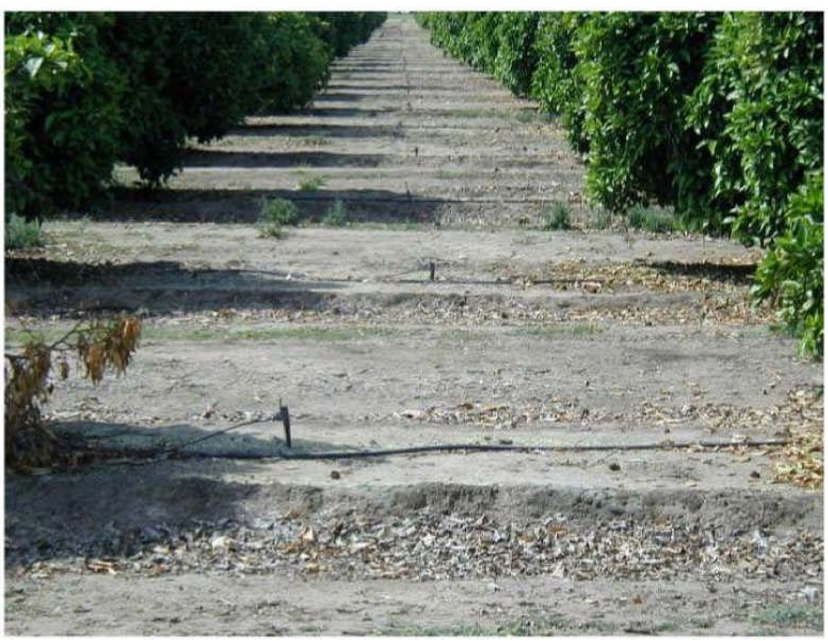
The differences in cultivation of the row middles may have affected control in Site 1. There would have been a higher and more constant pressure for volunteer weed growth from seeds produced in the row middles. Another reason for a slightly better weed control on Site 2 maybe due in part to residue levels of simazine and diuron found in background soil samples and to the higher theoretical application rate. Site 1 received only 1/2 of rate applied on Site 2.

Figure 4. This picture taken two months after application at Site 1 clearly illustrates the effect of herbicide treatment in controlling weeds in the tree rows. The picture was a cross section, east to west, of the treated block.

Figure 5. This picture was taken at four months after application at Site 1 where growth is evident in the row middles where no herbicide was applied but growth is still controlled in the area treated by the emitters located in the tree rows.

Figure 6. This picture was taken at Site 2, one month after the second split application. Weed control was excellent in the area of the emitters.

Figure 7. At five months after first application, the usual circular rings of plant growth around the emitters were not observed at Site 2 .



Despite frequent and excessive rainfall in March and April, the observed efficacy was very good 60 days after the second application (Figure 7). The average rainfall for Tulare County is around 20 cm per year but in 2005–2006, the County received 31 cm of rainfall. Usually, the control of plant growth for pre-emerge herbicides is longer than for contact herbicides such as Roundup. This difference in length of control is usually evident around the emitters where rings of growth surround the pre-emergent. treated area. This pattern is not evident in Figure 7 and may be due to lateral movement of pre-emergence residues caused by the larger amount of rain runoff experienced in this growing season.

CONCLUSIONS

1. Chemigation of pre-emergence herbicides in citrus orchards is efficacious as evidenced by qualitative ratings.
2. Chemigation systems can be set up to deliver consistent amounts of pesticides to emitter. Use of rotating heads instead of dedicated stream emitters could produce better distribution uniformity during application.
3. Common grower practices, such as split applications, can be made through chemigation system with no apparent reduction in efficacy.
4. Chemigation does not increase the risk of phytotoxicity. No symptoms of herbicide injury were observed on the orange trees at any of the two locations
5. Demonstration studies are an effective way to increase interest in innovation in the grower community. Both cooperating growers were very satisfied with the performance of the chemigated herbicides and would continue to use chemigation as a method of application. Also, both growers agreed that the split application positively affected the performance of simazine and diuron by extending the coverage.

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APPENDIX

Table 1: Pre-injection samples at Site 1

Samples Media	Laboratory Samples Number	Results in ppb	
		Simazine	Diuron
Water	1	ND	ND
	2	ND	ND
	3	ND	ND
Soil	Background from previous season.	ND	ND
		ND	ND
		ND	ND
		ND	ND
		ND	ND
		ND	ND
		ND	ND
		ND	ND

Table 2: Pre-injection samples at Site 2

	Laboratory Samples Number	Results in ppb	
		Simazine	Diuron
Water	3008	ND	ND
	3009	ND	ND
Soil	3000	67.7	376
	3001	54.4	709
	3002	ND	333
	3003	261	748
	3004	183	384
	3005	ND	80
	3006	ND	156
	3007	149	287

Table 3: Post-injection samples at Site 1

Samples Media	Laboratory Samples Number	Results in ppb	
		Simazine	Diuron
Water	4	76000	28000
	5	94000	30000
	6	93000	30000
	7	88000	28000
	8	90000	29000
	Average	**88200**	**29000**
Soil	300	1515	212
	301	1819	534
	302	671	227
	303	7604	2710
	304	2385	1002
	305	763	263
	306	660	142
	307	1596	378
	Average	**2127**	**684**

Table 4: Post-injection samples at Site 2

Samples Media	Laboratory Samples Number	Results in ppb	
		Simazine	Diuron
Water	3010	47000	41000
	3011	48000	42000
	3012	45000	41000
	3013	46000	40000
	3014	44000	39000
	Average	**46000**	**40600**
Soil	3021	2304	2643
	3022	1699	2069
	3023	506	934
	3024	395	478
	3025	262	198
	3026	240	641
	3027	129	148
	3028	1443	1745
	3029	479	962
	3030	612	1626
	Average	**807**	**1144**

Table 5: Precipitation from November 2005 to August 2006

DATE	Precipitation Inches	DATE	Precipitation Inches
11-11-2005	0.11	03-21-2006	0.31
11-26-2005	0.02	03-22-2006	0.01
12-02-2005	0.47	03-27-2006	0.17
12-03-2005	0.08	03-28-2006	0.53
12-20-2005	0.13	03-29-2006	0.38
12-25-2005	0.01	03-31-2006	0.30
12-28-2005	0.59	04-01-2006	0.32
12-31-2005	0.12	04-03-2006	0.08
01-01-2006	0.33	04-04-2006	1.21
01-02-2006	2.02	04-05-2006	1.22
01-18-2006	0.04	04-06-2006	0.45
01-19-2006	0.10	04-10-2006	0.08
02-18-2006	0.06	04-11-2006	0.03
02-19-2006	0.08	04-12-2006	0.01
02-28-2006	0.50	04-15-2006	0.24
03-03-2006	0.37	04-17-2006	0.03
03-04-2006	0.01	04-22-2006	0.30
03-06-2006	0.20	04-23-2006	0.12
03-07-2006	0.08	04-24-2006	0.80
03-08-2006	0.15	04-26-2006	0.06
03-10-2006	0.11	04-27-2006	0.01
03-11-2006	0.13	05-21-2006	0.04
03-12-2006	0.09	05-22-2006	0.37
03-15-2006	0.16	05-23-2006	0.01
03-18-2006	0.45		
Total for the Period			**13.49 inches**