Project Title: An integrated vegetated treatment system for mitigating imidacloprid and permethrin in agricultural irrigation runoff

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Abstract

Growers rely on applications of pyrethroid and neonicotinoid pesticides for the control of an array of insect pests in leafy greens. Concerns about the off-site movement of these chemicals in irrigation runoff and impacts to water quality may lead to stricter governmental regulations or the eventual loss of registration of these pesticides for leafy green production. Effective on-farm management practices are needed to eliminate aquatic toxicity of pyrethroid and neonicotinoid pesticides in irrigation run-off. The goal of this project was to evaluate the efficacy of using an integrated vegetated treatment system (VTS) to mitigate chemical loading and related toxicity of imidacloprid and the pyrethroid permethrin. The VTS incorporated a sediment trap area to remove coarse particles, a grass-lined ditch with compost swales to remove suspended sediment and insecticides, and a final treatment using activated carbon to remove residual chemicals not eliminated by the previous steps. Testing of the VTS was done at the USDA-ARS Spence Research farm using a 525-ft length of a ditch vegetated with red fescue between December 6, 2018 and May 20, 2019. Tests demonstrated that the VTS reduced the suspended sediment concentration by an average of 64% and removed an average of 90% of the sediment load carried in the runoff. Imidacloprid and permethrin concentration in the runoff was reduced by 91% and 96% respectively. However, despite dramatic reductions in pesticide concentration in the runoff the VTS did not consistently increase the survival of the aquatic test organisms *Chironomus dilutus* and *Hyalella azteca.*

Introduction and background

Research has demonstrated that integrated vegetative treatment systems (VTS) reduce pesticide loads and associated toxicity in agriculture tailwater runoff. Sedimentation ponds integrated in sequence with vegetated ditches within a VTS can reduce pyrethroid pesticides up to 100% (Anderson et al., 2011), and the addition of compost and granulated activated carbon (GAC) to a grass-lined ditch has been shown to reduce the load of the organophosphate pesticide chlorpyrifos by up to 98% (Phillips et al., 2017). Integrated systems have also been shown to reduce pesticide-associated toxicity to invertebrates in irrigation runoff. While these systems are effective at reducing organophosphate and pyrethroid pesticides, they have not been evaluated for treating more soluble insecticides, such as the neonicotinoid imidacloprid. Imidacloprid is used in conjunction with pyrethroids on most lettuce crops in the Salinas Valley and has recently been detected in irrigation runoff in the central coast region.

Because neonicotinoids are water-soluble, they can be transported from application sites via surface water runoff and groundwater (Bonmatin et al., 2015). Neonicotinoids are systemic pesticides, so some portion of the applied active ingredient is taken up by the plant (Sevigne-Itoiz et al., 2012; Stamm et al., 2016), and some portion will remain in the soil, where it will be broken down (Zhang et al., 2018). Plant uptake and soil degradation of imidacloprid are fairly well studied. To adequately study these topics further is beyond the scope and budget of the proposed study. Therefore, the focus of the current study is to mitigate imidacloprid, and the pyrethroid permethrin, in surface runoff.

The goal of this project is to evaluate the efficacy of using an integrated vegetated treatment system to mitigate chemical loading and related toxicity of imidacloprid and the pyrethroid permethrin. The VTS will incorporate a sediment trap area to remove coarse particulates, a grass-lined ditch with compost swales to remove suspended sediment and insecticides, and a final treatment using GAC to remove residual chemicals not eliminated by the previous steps**.**

Objectives:

The main objective of this project was to utilize an integrated vegetated treatment system (VTS) (sedimentation, vegetation, and GAC) to reduce imidacloprid and permethrin loading in agricultural run-off. The first objective is currently being accomplished as part of the Year 1 tasks. Objective 2 will be completed in the second year of the project (2019 season)

Objective 1. Evaluate the efficacy of the vegetated treatment system using simulated runoff.
Objective 2. Evaluate the efficacy of the treatment system with runoff from a lettuce crop.
Objective 3. Extend results to vegetable industry.

Procedures

Field trials were conducted at the US Department of Agriculture-Agricultural Research Service (USDA-ARS) Spence Research Farm, located in Salinas, CA between November 2018 and May 2019. Field trials evaluated the efficacy of a vegetated treatment system to reduce the concentration of permethrin, imidacloprid, suspended sediments, turbidity and aquatic toxicity in simulated runoff from overhead sprinklers. Runoff simulations were conducted using a vegetated ditch with 525 ft (160 m) length, 12 ft (3 m) width, 3 ft (1 m) depth, and 2-3% slope (Figure 1). The ditch was vegetated with mature red fescue grass *(Festuca rubra)* originally seeded in 2007. Six compost mats were placed at the upper end of the ditch, spaced approximately at 36 ft (11 m) intervals (Figure 1). Compost mats were constructed with 5-ft (1.5 m) lengths of permeable geotextile sleeve (Filtrexx®, Grafton, OH, USA) filled with compost from a local supplier. The compost mats were oriented at the bottom of the vegetated ditch perpendicular to the direction of the flow.

Two types of carbon material (granular activated carbon and biochar) were tested as carbon filters during the trials. Three carbon filters were located at the lower end of the vegetated ditch at approximately 20 ft (6 m) intervals (Figure 1). The carbon filters were constructed using 2-ft (0.6 m) sections of Filtexx SafteySoxx® sleeves either filled with either granular activated carbon (GAC) or biochar. The carbon filled mats were placed along the upstream side of a wooden board inserted perpendicular the ditch (Figure 2).

Overhead sprinklers, consisting of 15 heads (20JH, Rainbird Inc., Tucson, AZ, USA) spaced on a 30 ft (9 m) grid, and located approximately 525 ft (160 m) upslope from the inlet of the vegetated ditch, were used to irrigate bare soil to create runoff with a high suspended sediment concentration. The sprinkler runoff was collected in a basin near the inlet of the vegetated treatment system. Simulated run-off water was created by combining well water with sprinkler runoff and pesticide in a 3-inch diameter manifold made of PVC pipe (Figure 3). The pressurized well water entered the manifold and runoff from the sprinklers was pumped from the basin into the manifold using a high-pressure centrifugal gas pump (WH20XT, American Honda Motor Co., Alpharetta GA, USA). Gate valves on the manifold were adjusted to proportion the flow rate of the well water and sprinkler runoff so that a final flow rate of 75 gallon (284 L) per minute and a turbidity between 200 to 300 NTU was achieved at the outlet. Concentrated solutions of imidacloprid and permethrin were prepared fresh for each trial by adding a stock solution to a known volume of Nanopure™ water. The pesticide solution was injected into the manifold at a flow rate of 50 mL/min using a metering pump (Model MD, Seepex GmbH, Bottrop, Germany). The simulated run-off water was applied to the inlet of the vegetated treatment system though a 6-foot (2-m) length of perforated 3-inch diameter layflat. Application of run-off water to the vegetated ditch lasted between 3 and 3.5 hours. The flow rate of water entering the ditch was monitored with a magnetic flowmeter (Ag2000, Seametrics, Kent, WA, USA) for determination of the total volume of runoff water entering the inlet of the ditch. The flowmeter was wired to a datalogger (CR300, Campbell Scientific, Logan, UT, USA) to record the flow rate at 5-min intervals. Water at the outlet of the ditch was collected behind a weir inserted across the ditch. The outflowing run-off was channeled into a 2-inch (5-cm) diameter PVC pipe and through a magnetic flowmeter (WMP101, Seametrics, Kent, WA, USA) to quantify the total volume exiting the ditch. The outlet flowmeter was interfaced with a data logger (CR1000, Campbell Scientific, Logan, UT, USA), which was programmed to record the flow rate at 5-minute intervals.

The same datalogger at the outlet was also used to activate three peristaltic pumps (Omegaflex FPU-122-12VDC, Omega Engineering, Stamford, CT, USA) that sampled the runoff throughout each trial. The pumping stations were actuated by the datalogger using an electronic relay and CAT5 telephone cable wire. The pumps were located at the inlet of the ditch (location A), before the carbon geotextile sleeves, (location B, 134 m [440 ft] from the inlet), and near the outlet

(Location C, 153 m [502 ft] from the inlet) (Figure 1). The pumps were activated at 5-minute intervals and sampled approximately a 400 ml volume for a duration of 2 minutes. The run-off was sampled through a stainless-steel tube suspended in the center of the ditch and drawn through silicone tubing into a 20 L stainless-steel container. Ten liters of composite sample from each sampling location were transferred into amber glass bottles at the end of a run-off simulation and brought back to laboratory for toxicity testing, chemical analysis, and measurement of turbidity and suspended solids concentration. *Chironomus dilutus* was used as the test organism for imidacloprid toxicity *Hyalella azteca* was used as the test organism for permethrin toxicity.

Run-off simulation trials lasted approximately 3 to 3.5 hours. Trials compared the efficacy biochar and granular activated carbon to remove pesticides from run-off by conducting 3 sets of runoff simulations beginning on March 25 that were randomly assigned with either a GAC or biochar carbon treatment.

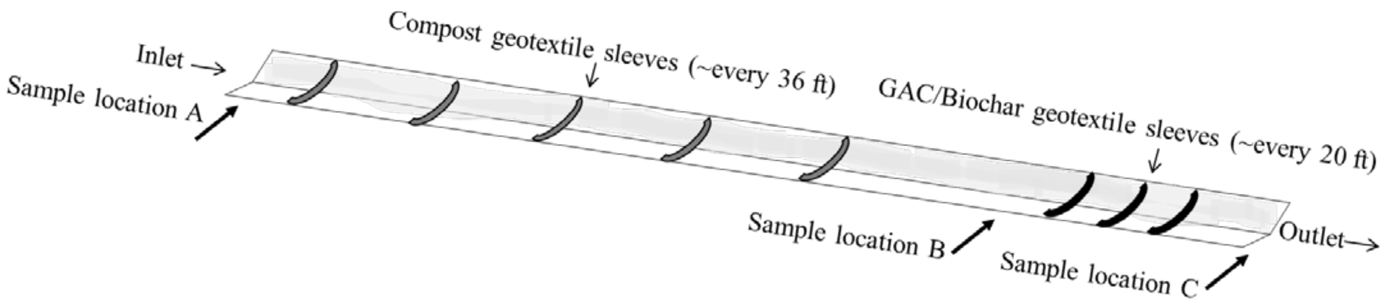

Figure 1. Diagram of vegetated treatment system showing run-off sampling locations A, B, and C.

Figure 2. Carbon filters located at the lower end of the vegetated ditch.

Figure 3. Manifold used to mix well water, sprinkler runoff and pesticide in the simulation trials.

Results and Discussion

A total of 7 run-off simulations were conducted in the vegetated treatment system between Dec. 6, 2018 and May 20, 2019 (Table 1). Heavy and frequent rain events delayed trials in 2019 until late March.

Flow data was collected at the inlet to the ditch for all dates, but outflow data was not collected for the trial on December 6 due to a malfunction in the flowmeter (Table 2). Total run-off entering the ditch averaged 14,634 gallons during the simulation trials and outflow averaged 4465 gallons at the lower end. An average of 70% of the run-off infiltrated along the length of the 525 ft vegetated ditch. Infiltration rates varied from 48% to 77% among the different simulation trials (Table 2) and may be related to the saturation of the ditch before conducting the tests. The lowest infiltration measurements occurred when significant rainfall events occurred within 15 days of the simulation tests. Apart from the first simulation test, suspended sediment concentration and turbidity of the runoff water entering the VTS averaged 180 mg/L and 242 NTU, respectively. These relatively low concentrations of suspended at the inlet were intended to simulate a pretreatment of the irrigation water with polyacrylamide which has been shown to reduce suspended sediment concentration in sprinkler runoff by 90%. Turbidity of the runoff was reduced by an average of a 54% between the inlet and outlet of the ditch and the suspended sediment concentration was reduced by an average of 64% (Table 2). During several simulations the reduction in suspended sediment concentration was as high as 86% (Table 2). Sediment concentration and turbidity frequently increased between sample locations B and C, presumably due to disturbance to the soil at the bottom of the ditch caused by the installation of the carbon filters (Table 2). The load reduction in sediment was calculated from the flow data and sediment concentration at the inlet and outlet of the VTS. The average load reduction in suspended sediment was 90% and ranged from 71% to 98% among runoff events.

Chemical analysis for permethrin and imidacloprid in the run-off samples were only partially completed at the submission of this report (Table 3). For 4 of the 7 run-off simulation events, the average imidacloprid concentration was 4550 ng/L and the average permethrin concentration was 290 ng/L in the runoff entering the VTS. Average reduction in pesticide concentration between the inlet and outlet of the VTS was 91% and 96% for imidacloprid and permethrin, respectively (Table 3). Based on the data analyzed to date, the effectiveness of GAC and biochar to treat these pesticides appeared to be equal. In several simulations the VTS removed 99% or more of the permethrin in the runoff. Load reduction of these pesticides will be finalized in an updated report when the chemical concentrations for missing dates become available. Preliminary calculations would suggest that the load reductions from the VTS under the conditions of these simulations for imidacloprid and permethrin were close to 97% and 99%, respectively.

Despite the effectiveness of the VTS to remove imidacloprid and permethrin, toxicity testing demonstrated mixed results. The VTS treatment improved the survival of *Chironomus* to as high as 99% for five dates (Table 1). The VTS only improved survival of *Hyalella* on 2 dates. *Chironomus dilutus* is susceptible to imidacloprid and *Hyalella azteca* is more susceptible to toxicity from permethrin. It is possible that another pesticide, not intended to be in the run-off, was present in the ditch or in the sediment trap at the time of testing. Significant volumes of storm run-off from adjacent fields flowed through the sediment trap and through the ditch less than 15 days before the two dates that *Chironomus* survival at location C was low (Dec. 6, 2018 and May 20, 2019 in Table 1). Additionally, survival of *Hyalella* at the outlet of the VTS for these dates was 0% despite reducing the permethrin concentration by more than 95%. A more in-depth chemical analysis of the runoff samples may be able to identify if other pesticides besides imidacloprid and permethrin were present.

Conclusions

Preliminary results of these simulation trials showed that the combination of using vegetation, compost mats, and carbon treatment as an integrated treatment system was effective in reducing the concentration of imidacloprid and permethrin pesticides in runoff by more than 90%. Suspended sediment concentration and turbidity of the runoff was reduced by more than 50% by the VTS and an average of 70% of the runoff infiltrated into the ditch, resulting in high reductions in loads of sediment and pesticides. However, toxicity was not consistently reduced at the outflow of the VTS, possibly due to contamination from an additional pesticide. Objective 2 of the project will completed during the 2^{nd} year of the project (2019 season). An updated report will be submitted when the missing chemistry results become available.

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Table 1. Toxicity tests of runoff sampled from locations A,B, and C using test organisms *Chironomus and Hyalella.*

Date	Carbon Treatment	Replication	Rainfall during prior 15 days (inches)	Toxcity test	Toxicity Test Sample location A	B	C
12/6/2018	GAC	--[x]	2.4	*Hyalella* Survival (%)	0	0	0
				Chironomus Survival (%)	0	0	13
				Chironomus Growth (mg)	NA	NA	0.03
3/25/2019	GAC	1	0.6	*Hyalella* Survival (%)	0	0	0
				Chironomus Survival (%)	40	85	94
				Chironomus Growth (mg)	0.03	0.81	5.35
4/8/2019	Biochar	1	0.2	*Hyalella* Survival (%)	2	2	48
				Chironomus Survival (%)	6	77	83
				Chironomus Growth (mg)	0.10	2.74	2.93
4/15/2019	Biochar	2	0.2	*Hyalella* Survival (%)	0	0	0
				Chironomus Survival (%)	4	96	93
				Chironomus Growth (mg)	0.10	1.71	5.79
4/22/2019	GAC	2	0.1	*Hyalella* Survival (%)	0	2	8
				Chironomus Survival (%)	38	96	98
				Chironomus Growth (mg)	0.02	4.07	5.43
5/14/2019	GAC	3	0.1	*Hyalella* Survival (%)	0	48	96
				Chironomus Survival (%)	0	90	99
				Chironomus Growth (mg)			
5/20/2019	Biochar	3	1.2	*Hyalella* Survival (%)	0	0	0
				Chironomus Survival (%)	0	0	0
				Chironomus Growth (mg)	NA	NA	NA
Average	Overall			*Hyalella* Survival (%)	0	7	22
				Chironomus Survival (%)	13	63	69
Average	GAC			*Hyalella* Survival (%)	0	17	35
				Chironomus Survival (%)	26	90	97
Average	Biochar			*Hyalella* Survival (%)	1	1	16
				Chironomus Survival (%)	3	58	59

[x] not paired with a biochar evaluation

NA not applicable

Table 2. Volume, turbidity, sediment concentration and sediment load of run-off from seven tests of the vegetated treatment system.

						Total Suspended Solids				Turbidity				Sediment load		
						Sample location				Sample location						
Date	Replication	Carbon Treatment	Inflow volume	Outflow volume	Infiltration of Runoff	A	B	C	Reduction in Concentration	A	B	C	Reduction in Turbidity	Inlet	Outlet	Reduction in sediment load
			----- gallons ------		%	---------- mg/L ------			%	-------- NTU --------			%	lbs	lbs	%
12/6/2018	--	GAC	13790	M	M	887	394	386	56	>1000	>1000	998	NA	101.9	13.6	87
3/25/2019	1	GAC	14550	7624	48	107	60	75	30	131	121	147	NA	13.0	3.8	71
4/8/2019	1	Biochar	17000	4310	75	295	29	47	84	373	101	112	70	41.8	1.0	98
4/15/2019	2	Biochar	13890	3233	77	189	32	29	85	285	90	76	73	21.9	0.9	96
4/22/2019	2	GAC	13990	3381	76	194	30	61	68	326	95	135	59	22.6	0.8	96
5/14/2019	3	GAC	15460	3931	75	158	22	28	83	122	44	51	58	20.3	0.7	97
5/20/2019	3	Biochar	13760	4310	69	139	54	84	40	214	116	153	29	15.9	1.9	88
Average		Overall	14634	4465	70	281	89	101	64	242	94	112	54	33.9	3.3	90
Average		Biochar	14883	3951	73	208	38	53	69	291	102	114	57	26.5	1.3	94
Average		GAC	14667	4979	66	153	37	54	60	193	86	111	58	18.6	1.8	88

GAC Granular Activated Carbon
M missing
NTU Nephelometric Turbidity Unit
NA Not Applicable

Table 3. Concentration of imidacloprid and permethrin sampled from simulated run-off at three locations in vegetated treatment system.

			Imidacloprid concentration				Permethrin concentration					Imidacloprid toxicity units			Permethrin toxcity units		
			Sample location				Sample location					Sample location			Sample location		
Date	Treatment	Replication	A	B	C	Reduction	A	B	C	Reduction	Test Organism	A	B	C	A	B	C
			-------- ng/L --------			%	--------- ng/L ---------			%							
12/6/2018	GAC	--	6670	1590	528	92	505	50.4	27.5	95	*Hyalella*	0.10	0.02	0.01	23.93	2.39	1.30
											Chironomus	1.16	0.28	0.09	5.10	0.51	0.28
3/25/2019	GAC	1	3220	935	392	88	164	2.45	0	100	*Hyalella*	0.05	0.01	0.01	7.77	0.12	0.00
											Chironomus	0.56	0.16	0.07	1.66	0.02	0.00
4/8/2019	Biochar	1	4790	1510	270	94	P	P	P	P	*Hyalella*	0.07	0.02	0.00	P	P	P
											Chironomus	0.83	0.26	0.05	P	P	P
4/15/2019	Biochar	2	3520	1530	370	89	271	34.9	3.26	99	*Hyalella*	0.05	0.02	0.01	12.84	1.65	0.15
											Chironomus	0.61	0.27	0.06	2.74	0.35	0.03
4/22/2019	GAC	2	P	P	P	P	218	28.7	18.7	91	*Hyalella*	P	P	P	10.33	1.36	0.89
											Chironomus	P	P	P	2.20	0.29	0.19
Average	Overall		4550	1391	390	91	290	29	12	96	*Hyalella*	0.07	0.02	0.01	13.72	1.38	0.59
											Chironomus	0.79	0.24	0.07	2.92	0.29	0.12
Average	GAC		4945	1263	460	90	296	27	15	95	*Hyalella*	0.08	0.02	0.01	14.01	1.29	0.73
											Chironomus	0.86	0.22	0.08	2.99	0.27	0.16
Average	Biochar		4155	1520	320	92	271	35	3	99	*Hyalella*	0.06	0.02	0.00	12.84	1.65	0.15
											Chironomus	0.72	0.26	0.06	2.74	0.35	0.03

P pending analyses from the California Department of Pesticide laboratory