

Off Site Movement of Pesticides Applied to Container Nurseries

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SUMMARY

Pesticide accumulation in ponds did not occur with the herbicides investigated. Larger amounts were consistently found following major applications. The greatest residues were detected following significant winter applications, when degradation reactions are inhibited. Smaller applications of herbicides spaced over the entire year would result in smaller amounts of herbicides detected in pond water and sediments. Ground or bed covers will continue to be utilized in container plant production because of the many benefits that these surfaces provide. It must be realized however, that water infiltration and pesticide infiltration are prevented by the materials, and the probability of pesticide movement in runoff water is enhanced. The formulation of a pesticide also affects amounts lost from application site. Gravel ground covers allowed less off site movement of granular formulations, and plastic or fabric bed covers resulted in smaller losses from sprayable products for the herbicides used in our research. Educated choices of formulation and ground cover material may reduce herbicide movement in runoff water. A further method to lessen the possibility of contamination of downstream waters is to install grassed filter strips or waterways contiguous to the ground covers. The grass functions as a bio-filter and reduces the total amounts of herbicides that leave application site in runoff water. Our studies indicate that pesticides do move from application site in runoff water generated during container plant production. Granular products appear to allow greater losses than spray formulations, and the more soluble pesticides have a higher potential for movement. Pesticide transport is greatest during the first runoff-generating event after application (from 5 to 10% of total losses), and the highest concentration of pesticides is consistently found in early runoff volumes. An alteration of management practices in which preemergence herbicides are activated with smaller amounts of irrigation would conceivably alleviate losses of large portions of the compounds. Reintroduction of pesticides at levels detected in recycled irrigation water should not have a detrimental effect on plant growth.

Introduction

The production of containerized plant materials usually requires the use of pesticides in order to provide marketable products of the highest quality as demanded by the consumer. But, what happens to the pesticides after application? It is difficult to open a newspaper or magazine and not be confronted with stories about the contamination of recreational or drinking waters by pesticides, or injury to wildlife as a result of misused pesticides. Pesticides in water sources can have subtle and dramatic effects on organisms and their environment.

Many studies have been conducted to determine the fate of pesticides applied to agricultural croplands, forests and golf courses. However, the container nursery industry uses production methods that are not common to other agricultural applications, and pesticides may not behave in the same way. A group of scientists at Clemson University in South Carolina, recognized the need for research which was specific to the plant nursery industry. Studies began in 1991, and have continued into the present.

This article will explore the characteristics by which pesticides may move from application site at a production nursery. Presented also will be methods by which losses can be minimized. Research projects have revealed a number of controllable and manageable factors that affect the loss of pesticides.

Fate of Pesticides

The fate of applied pesticides is a very complex issue, and is dependent upon the properties of the compound, environmental and climatic conditions, and application methods. Basically, the pesticide may be absorbed into the plants, diffused into the soil where it becomes bound (sorbed), volatilized into the atmosphere, dissolved in water, and/or undergo metabolic changes and degradation. The fate of a pesticide most likely includes all of the above, though, some methods of dissipation may be favored over others.

Pesticide Movement at Container Plant Nurseries

Certain management practices in the container nursery industry may enhance the movement of pesticides in runoff waters.

Ground covers of fabrics or plastics are used as a production base to facilitate handling of the potted plants and to reduce weeds, but water (and pesticide) penetration into the soil is prohibited. Excess water flows from the beds as runoff.

Overhead irrigation is typically only about 26% efficient meaning that if 100 gallons are applied, 26 gallons would enter the containers and be available to the plants, and 74 gallons would be lost in runoff or evaporation. An application of 1 in/hr would deliver 27,000 gal/A, and create a potential runoff volume of 20,000 gal/A. Natural precipitation would similarly generate runoff.

Granulated pesticide formulations are used at plant nurseries, particularly for herbicide applications, because of handling ease and applicator safety. Broadcast applications are most cost efficient, but a majority of the pesticide falls on the plastic cover where it is available for transport by runoff water into retention basins, ponds, streams and recreational waters.

Collection and recycling of runoff water, a practice which conserves water resources, may reintroduce pollutants onto the growing beds. Very small amounts of herbicides in irrigation water can be beneficial as the emergence of sensitive weeds will be reduced, but larger amounts may cause phytotoxicity problems.

Movement in Runoff Water

Not all pesticides will be transported in runoff water. The proclivity of a pesticide to move in water is determined by two factors: 1. how much of the compound will dissolve in water (solubility); and, 2. the attraction of the chemical to either water or soil (sorption) which is expressed numerically as the soil/water partition coefficient or K_{oc} . A low K_{oc} of 300 to 500 means that the chemical is more soluble in water and less attracted to soil particles.

Some compounds are strongly repelled by water and do not associate with aqueous solutions (dried peat moss, for example), while others readily suspend or dissolve in water. Many preemergence herbicides become bound to soils and are not available for off site movement. Pesticides may have a strong preference for the water or soil compartment, or may equally distribute between the phases. Pesticides that dissolve in water and are not bound to soil surfaces may potentially move from site in runoff waters.

Survey of Retention Basins for Pesticide Residues

The initial project undertaken by the Clemson researchers was to determine if herbicides were present in the retention ponds at container plant nurseries. Hypothesized was that because of the frequent broadcast applications of granular herbicides used in container plant production, and the large runoff amounts generated, herbicides would be transported from the growing beds, possibly accumulating in retention basins and irrigation ponds. Samples were collected over a two year period.

Two large wholesale container production nurseries in South Carolina were ideally suited for the research because they channeled, collected and recycled for irrigation purposes, all runoff water. One nursery encompassing almost 50 A was located in the piedmont section (north western corner) of the state. Runoff flowed from the growing beds, underlain with plastics and fabrics, through gravel ditches into a series of containment ponds. The other nursery had 150 A in production and was located in our state's coastal region. The production surface was packed coquina (shell) and gravel.

Granular applications of Ornamental Herbicide-2 (pendimethalin and oxyfluorfen), and Rout (oryzalin and oxyfluorfen) were applied to the growing beds, as needed for weed control, by nursery personnel who provided records on application timing and rates. The largest applications generally occurred in January or February for control of spring germinating cool season annual weeds. Overhead irrigation followed all herbicide applications.

Samples were collected from ponds on a monthly basis for the two year period from collection sites thought to have a high probability of pesticide residue. Samples were taken of pond water and of pond sediment.

What We Found

The herbicides were detected in both the water and sediments of ponds at low levels throughout the sampling period. Generally, the largest amounts were detected in the month of, or the month following the heaviest applications. The maximum levels detected, and the solubilities and K_{oc} 's of the herbicides are presented in Table 1. Amounts detected in pond sediments were much larger than amounts found in the pond water. The K_{oc} of pendimethalin and oxyfluorfen is quite large indicating a strong preference for the soil phase. Amounts detected for these two herbicides were 1000 and 300 times higher, respectively, in sediments than pond water. It appears that the herbicides which were transported in the runoff water adsorbed quickly to sediments in the pond.

However, the maximum amounts of all herbicides were found during winter months following applications to major sections of the nursery. Herbicides were not detected in sediments after summer weed control applications. Breakdown and degradation of the pesticides occurs at a more rapid pace in summer months due to increased temperature and light. Breakdown would not be as fast during winter months, resulting in a greater accumulation in sediments. Oryzalin has a smaller Koc and only four times as much was found in the sediment. There did appear to be a release from sediments of herbicides as residues were found in water samples the year following application. Amounts detected in pond water were well below the solubilities of the herbicides, though the higher the solubility, the greater the amount detected. Solubilities indicate the maximum amount of a compound which can be dissolved in water, and with all of the herbicides, saturation was not approached. Larger amounts of the herbicides could be accommodated by the runoff water, and potentially moved from site.

Table 1. Greatest quantities of herbicides detected (parts per million), in pond water and sediment, during the two year survey, and the solubilities and Koc of herbicides.

Pesticide	Solubility	Koc	Amounts Detected			
			Coastal Nursery		Piedmont Nursery	
			Water	Sediment	Water	Sediment
	ppm		----- ppm -----			
Oryzalin	2.6	600	-----	-----	0.16	0.6
Pendimethalin	0.3	17000	0.008	14.3	0.012	11
Oxyfluorfen	0.1	100000	0.037	4	0.009	3

Herbicides were detected in irrigation water during two months. Pendimethalin was found at 2 ppb and oxyfluorfen at 5 ppb. Such small quantities are not likely to cause any problems with plant growth.

The movement of pendimethalin, oryzalin and oxyfluorfen in runoff water from granular applications appears to be minimal. The levels of herbicides found in pond water and sediments during the two year study were very small, and would not result in phytotoxicity to plants if waters were recycled for irrigation.

Results are explained by the solubility and Koc of the herbicides. Pendimethalin and oxyfluorfen are relatively insoluble in water. The Koc's are large indicating strong sorption to soils, and movement in runoff to ponds would be expected to be minimal. Greater amounts of oryzalin will dissolve in water, and a small Koc indicates that sorption to soil is not very strong. Predicted movement would be greater for oryzalin than for either pendimethalin or oxyfluorfen. Higher amounts of oryzalin were detected in the pond water.

Other herbicides may move in greater or smaller quantities than the investigated chemicals. Metolachlor, for example, has a solubility of 488 ppm and a Koc of only 200 ppm. Movement in runoff would be expected to be much greater than that of the investigated herbicides.

Accumulation in ponds did not occur with the herbicides investigated. Larger amounts were consistently found following major applications. The greatest residues were detected following significant winter applications, when degradation reactions are inhibited. Smaller applications of herbicides spaced over the entire year would result in smaller amounts of herbicides detected in pond water and sediments.

Ground Covers

Synthetic ground covers are often used in production areas in containerized nurseries to facilitate handling of plants, and to prevent weed infestations. The ground covers are typically either gravel, fabric or plastic, or a combination of the materials. Soil surfaces covered with gravel or fabric are often underlaid with plastic. The ground cover materials vary in permeability. Gravel allows greater infiltration of water than the synthetic fabrics, and plastics are impermeable to water. All of the materials deter the movement of water into the soil subsurface and therefore, affect the movement of pesticides which may be transported by the excess water.

A pesticide's formulation is the particular mixture of active and inert ingredients that allows the user to uniformly apply the active ingredient, thereby maximizing the effectiveness of the pesticide. Preemergence herbicides used in the nursery industry are available in granular, wettable powder (dry granule), emulsifiable concentrate, an aqueous solution, and water soluble bag formulations. Granular herbicides are applied as packaged (dry) using manual or powered spreaders. All other formulations of herbicides are mixed in water and applied as a spray.

The formulation of a herbicide affects the potential for movement from application site in runoff water. Researchers at N.C. State University reported greater losses from a broadcast spray application of herbicides than a granular broadcast or per pot application. Wauchope applied four differing formulations of atrazine to crop beds. Atrazine losses after a simulated rainfall (1 in) were 4 to 8% from emulsion and dispersible liquid applications, and 9 to 12% for wettable powder and dispersible granule formulations.

Our research group has conducted studies on the effects of various ground cover materials and herbicide formulations and the amount of herbicides in runoff water. Miniature nursery sites (1m²) were developed at the S.C. Botanical Gardens in Clemson, S.C., and were used for a majority of the research. The elevated plots were constructed of galvanized metal on a 5% slope, lined with sand and gravel, and covered with either plastic or landscape fabric, or left uncovered (gravel treatment). Landscape plants in one-gallon containers were spaced on 10 inch centers in each plot to simulate conditions at a nursery.

An additional study was conducted at a plant nursery in Northwestern S.C. in which runoff water from a large growing bed with a fabric covered plastic production surface was channeled into either a clay/gravel waterway or a grassed waterway. The purpose of the research was to investigate the potential of a grass waterway to reduce pesticide amounts which leave application site in runoff water.

In a study of movement of herbicides in runoff water from differing ground cover materials, the microplot tray surfaces were treated with granular formulations of Ornamental Herbicide 2 (oxyfluorfen and pendimethalin), or Rout (oxyfluorfen and oryzalin), at recommended rates. Applications were broadcast with a hand-held shaker. Overhead irrigation was applied daily (1 inch), and runoff was collected on the day of application and on various days through 19 days after treatment.

The research project indicated that the composition of the ground cover affects the amount of herbicide in runoff water. Smallest losses of all granulated herbicides were detected from the gravel beds, with greater amounts lost from the plastic and fabric lined plots (Table 1). The gravel bed cover retained herbicides to a greater degree (smaller losses), possibly by allowing granules to be washed from the surface into cracks and crevices where it remains trapped. The plastic and fabric covers allow decreased water and pesticide infiltration and, thus, promote the movement of herbicides from site.

Table 1. Cumulative herbicide loss in runoff water from plastic, fabric and gravel bedcovers in microplot study. Means followed by the same letter are not different (P=0.05).

Ground cover Material	Oryzalin	Oxyfluorfen	Pendimethalin
	µg		
Plastic	1000 a	160 a	115 a
Fabric	820 a	150 b	115 a
Gravel	500 b	120 c	80 b

In the second study, the movement of two different formulations of herbicides containing the same active ingredient isoxaben was investigated from various ground covers. Snapshot TG (a granular formulation of isoxaben and trifluralin), and Snapshot DF (a sprayable formulation of isoxaben and oryzalin), were applied to the microplots at recommended rates. These herbicide formulations are commonly used during container plant production for preemergence weed control. Overhead irrigation (1 inch) was applied to the plots daily for 30 days. All runoff water was collected and measured, and samples from various days after application were analyzed for herbicide residues.

Total isoxaben losses (as a percent of applied) were less from the sprayable formulation (Snapshot DF) than from the granular product (Snapshot TG). Similarly, oryzalin losses from the spray formulation were less than for granulated trifluralin.

Losses from the ground cover treatments were affected by the formulation of the herbicides (Table 2). Both spray applied herbicides had larger losses from gravel beds than plastic or fabric covered plots, while greater losses of granulated herbicides were noted from the plastic and fabric ground covers. Speculated is that the spray applied herbicides were bound to the fabric and plastic surfaces more strongly than to the gravel because of the increased availability of binding sites. While the gravel ground cover may be more structurally interactive with the herbicides, the plastic and fabric covers appear to provide more chemically active sorption sites.

Table 2. Cumulative losses of herbicides from granular and spray formulations (percent of total amount applied) for the ground cover treatments. Treatments followed by the same letter are not significantly different at $P = 0.05$.

Formulation	Granular		Spray	
	Isoxaben	Trifluralin	Isoxaben	Oryzalin
Ground Cover Treatment	% of Total Applied			
Gravel	21 a	1 a	15 b	16 c
Plastic	28 b	4 b	10 a	9 a
Fabric	25 ab	4 b	11 a	12 b

An application of Snapshot TG (granulated trifluralin and isoxaben) was applied at the recommended rate to a 4 acre growing bed at a plant production nursery. Overhead irrigation followed application and runoff water from half of the area was channeled into a clay waterway, and runoff from the other half flowed into a bermudagrass (*Cynodon transvaalensis* x *C. dactylon*) waterway. Runoff samples were collected from the lower ends of the waterways and analyzed for herbicide content.

Isoxaben amounts in runoff water were lower from the grass than the clay waterway. This reduction was largest on the day of application (15%). Cumulative amounts of isoxaben recouped were 11% and 13% of total applied from the grass and clay waterway, respectively. Trifluralin amounts were not reduced by the grass waterway, but recovered amounts in runoff water were very small. Trifluralin is highly volatile and expected is that only minute quantities would be associated with runoff water.

A current study is investigating the remediation effect of grassed waterways and cyclic irrigation on pesticide amounts which leave application site in runoff water. Cyclic irrigation involves the application of water for shorter periods of time on a more frequent basis. Preliminary results indicate that the combination of the two practices will result in smaller losses than traditional irrigation methods.

Summary of Ground Cover Research

Ground or bed covers will continue to be utilized in container plant production because of the many benefits which the surfaces provide. It must be realized however, that water infiltration and pesticide infiltration are prevented by the materials, and the probability of pesticide movement in runoff water is enhanced. The formulation of a pesticide also affects amounts lost from application site. Gravel ground covers allowed less off site movement of granular formulations, and plastic or fabric bed covers resulted in smaller losses from sprayable products for the herbicides used in our research. Educated choices of formulation and ground cover material may reduce herbicide movement in runoff water. A further method to lessen the possibility of contamination of downstream waters is to install grassed

filter strips or waterways contiguous to the ground covers. The grass functions as a bio-filter and reduces the total amounts of herbicides which leave application site in runoff water.

Amounts and Effects of Pesticides in Runoff Water from a Container Nursery

The transport of pesticides from application site by runoff water is a particular concern in containerized plant production because of the use of broadcast applications of granular pesticides in which a majority of the product may fall on the ground cover production surface. The ground- covers reduce or prevent infiltration of water and pesticides. Excess water resulting from overhead irrigation, applied to activate preemergence herbicides, creates runoff which may move the pesticides into off site waters.

Conditions and management practices at a container plant nursery appear to encourage the loss of pesticides in runoff water. But, is this what actually occurs? And what effect would reintroducing this level of contamination (irrigation water recycling) have on the growth of the nursery crop? Addressing these questions were a series of research studies conducted at a wholesale container plant production facility in SC, and in the greenhouse at Clemson. The plant nursery was ideally suited for the research because of an isolated 4 acre growing area which sloped in one direction. Runoff water from the beds flowed through a gravel and clay drainage ditch into a storm drain which emptied into a containment pond.

The field nursery studies were conducted with pesticides frequently used in container plant production applied to the growing beds at recommended rates. The areas were irrigated generating runoff water, and samples were collected.

The initial research project measured the movement of oryzalin and oxyfluorfen, from the granular formulation of Rout, in runoff water on the day of application. The highest concentration of oryzalin (4 ppm) was found in early runoff samples. Detected concentrations of oxyfluorfen were less than 1 ppm. Oryzalin losses totaled 5% of amount applied (Table 1), and oxyfluorfen losses were less than 0.5%. The lower oxyfluorfen amounts in runoff water can be attributed to the very low water solubility of the compound.

Table 1: Pesticide solubilities and amounts lost on the day of application, expressed as a percent of amount applied for the first nursery study.

Pesticide	Solubility in Water (25 °C)	Day of Application
	mg/L	% of total applied
Oryzalin	2.5	5
Oxyfluorfen	0.1	< 0.5

Movement of isoxaben and trifluralin from the granular formulation of Snapshot TG was monitored through five days after application (Table 2) in a study spanning two years. The greatest total isoxaben loss was 12% of the total applied, with most of the loss occurring on the days of application (8% of total applied). Cumulative trifluralin losses were < 0.3% of applied with again, the majority of the loss occurring on the day of application (0.2%). The highest concentrations detected were < 1 ppm isoxaben and < 0.1 ppm trifluralin. As in the first study, highest concentrations were detected in the early runoff samples of each sampling day. Isoxaben and trifluralin have similar solubilities in water, and the differences in amounts lost cannot be explained by this characteristic. Trifluralin is, however, much more volatile and more strongly absorbed to soils than isoxaben, and smaller amounts lost may be expected.

Table 2. Pesticide solubilities and amounts lost on the day of application and cumulative totals, expressed as a percent of amount applied, for the second nursery study.

	Solubility in Water (25 °C)	Day of Application	Cumulative
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		Total	Total
	mg/L	% of total applied	
Isoxaben	1 - 2	8	12
Trifluralin	< 1	0.22	0.28

The behavior of an insecticide and a fungicide were investigated in addition to herbicides. Prior to the application of granular Snapshot TG (isoxaben and trifluralin), Dursban, an insecticide containing chlorpyrifos, and Cleary's 3336, a systemic fungicide with thiophanate-methyl as the active ingredient, were spray applied to the growing beds. Overhead irrigation followed the herbicide application and runoff was sampled through 22 days after treatment.

Concentrations of all of the pesticides were highest within the first 40 minutes of runoff for all sampling days. Isoxaben was detected through 15 days after application and cumulative losses were 23 to 32% of the total amount applied (Table 3). On the day of application, 13 to 15% of isoxaben applied was detected as being transported in runoff water. Trifluralin losses were much smaller, as in earlier research. Less than 1% of applied was noted in the fall study and less than 0.01% in the project conducted in the summer months. Total losses were 8 to 13% for thiophanate-methyl and 0.01 to 6% for chlorpyrifos. Highest detected concentrations of the pesticides were > 5 ppm thiophanate-methyl, > 3 ppm isoxaben, > 4 ppm chlorpyrifos and < 0.3 ppm trifluralin. With the exception of the fungicide, losses of the pesticides were greatest in the early study which was conducted during cooler temperatures when volatilization was not as rapid.

Table 3. Pesticide solubilities and amounts lost on the day of application and cumulative totals, expressed as a percent of amount applied, for the third nursery study.

Pesticide	Solubility in Water (25 C)	Day of Application Total	Cumulative Total
	mg/L	% of total applied	
<u>Fall Study</u>			
Isoxaben	1-2	15	32
Trifluralin	< 1	0.7	0.9
Chlorpyrifos	2	5	6
Thiophanate-methyl	27	8	8
<u>Spring Study</u>			
Isoxaben		13	23
Trifluralin		< 0.1	< 0.1
Chlorpyrifos		< 0.1	< 0.1
Thiophanate-methyl		13	13

Effects of Pesticides in Irrigation Water on Plant Growth

Research studies indicate that pesticides are transported in runoff water generated during containerized plant production. Pesticides were detected in the runoff water from nurseries in South Carolina, and herbicides were found in the water and sediments of containment ponds. The collection and recycling of runoff water is an encouraged practice as water resources are conserved. But, will the pesticides which are moved from application site have a detrimental effect on plant materials? Do the pollutants need to be removed from the waters?

Woody and herbaceous plant species were irrigated with herbicide laden water. Roots and shoots were evaluated and growth index was determined. The herbicides used were oryzalin, oxyfluorfen and isoxaben which are components of common nursery industry preemergence herbicide formulations.

Fountain grass and daylily, herbaceous plant species, were more sensitive to herbicides in irrigation water than any of the woody species evaluated. Oryzalin and oxyfluorfen applied to fountain grass at 10 ppm for 6 weeks, reduced growth index, and similarly, oryzalin (10 ppm) applied to daylily for 11 weeks, decreased growth index. The only effect noticed in the woody species tested was that root weights of Hellers holly were reduced by irrigating with 10 ppm isoxaben. All of the concentrations of herbicides which affected growth are much greater than amounts which have been detected in either runoff water or irrigation containment ponds. It would appear that irrigation with collected runoff water containing small concentrations of herbicides would not have a detrimental effect on plant growth.

Our studies indicate that pesticides do move from application site in runoff water generated during container plant production. Granular products appear to allow greater losses than spray formulations, and the more soluble pesticides have a higher potential for movement. Pesticide transport is greatest during the first runoff generating event after application (from 5 to 10% of total losses), and the highest concentration of pesticides is consistently found in early runoff volumes. An alteration of management practices in which preemergence herbicides are activated with smaller amounts of irrigation would conceivably alleviate losses of large portions of the compounds. Reintroduction of pesticides at levels detected in recycled irrigation water should not have a detrimental effect on plant growth.