Why Aquatic Herbicides Affect Aquatic Plants and Not You!

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Slide Presentation Transcript

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Slides

Slide 1
Why Aquatic Herbicides Affect Aquatic Plants and Not You! Dr. Carole Lembi, Botany and Plant Pathology, Purdue University.

Slide 2
Welcome to a presentation on why aquatic herbicides affect aquatic plants and not you.

Slide 3
Does your pond or lake look like this? Are there portions of your body of water that are as weedy as this one is? If so, you have undoubtedly wondered how all or most of this weed growth can be controlled. As a part of that thinking process you have probably thought about the possibility of using chemicals, either aquatic herbicides or algicides, to control the weeds. But how do you know whether the use of chemicals in your body of water will be safe to you and safe to the environment? That is a legitimate concern that all of us should have before we apply any chemical to control some pest. How toxic is the chemical to humans and other mammals? How persistent is it in the environment? Will it cause cancer? The purpose of this presentation is to provide you with enough information about the characteristics of aquatic herbicides and algicides so that you can base your decision on fact and not on fear. It is not my goal to convince you to use chemicals, but I do want you to understand that we have sound scientific evidence that should alleviate some of your concerns.

Slide 4
This talk will cover some aspects of botany or plant science and some of the principles of pesticide chemistry and toxicology. This may sound like pretty heavy stuff, but be assured, you will understand it! The main thing is that what happens when we apply chemicals to a body of water is not a bunch of mumbo jumbo. We can predict what will happen in terms of human health and the environment.

Slide 5
But before we can go forward we have to go back a step. We must realize that aquatic plants play very important roles in a body of water. The phytoplankton, or microscopic algae, produce oxygen through photosynthesis, oxygen that is essential for the life of fish and other organisms in a body of water. The phytoplankton also provide the base of the aquatic food chain. The macrophytes or larger plants in a body of water also produce oxygen. They provide habitat and shelter for fish and other organisms, and they stabilize the sediments that would otherwise be erodible.

Slide 6
Unfortunately there are situations in which invasive species of aquatic plants can gain a foothold in a body of water. This photo shows two or three stems of Eurasian watermilfoil, which is attached to the bottom sediments by roots. These plants are growing up through a body of water and are beginning to form a canopy over the surface of the water. This canopy of vegetation will continue to grow and extend and eventually shade out and kill the native species that are growing below it.

Slide 7
Eventually the Eurasian watermilfoil will completely take over the body of water, making it

impossible to swim or fish or conduct just about any other recreational activity.
Slide 8
Excessive growths of microscopic algae, often called blooms or algal blooms, will cause water to turn an unsightly green.
Slide 9
Once such algal blooms occur and subsequently die off or "crash", they can deplete the water of its oxygen and cause a fish kill. The best remedy for algal blooms is a good watershed management program.
Slide 10
When is it appropriate to manage aquatic plants? Invasive species such as Eurasian watermilfoil or hydrilla should be controlled when new patches of growth appear in the water. Established infestations should also be managed in order to prevent the invasive species from completely taking over a lake or pond. Sometimes even native species have to be controlled, particularly in shallow water where the plants come to the surface and prevent recreational and other activities. Keep in mind, though, that the ideal situation is to maintain some vegetation to provide habitat, shelter, and oxygen for fish and other organisms. Typically 20 to as much as 40 percent of the shallow area should be left in native vegetation.
Slide 11
Well, let's get into a little botany now. What are the kinds of plants that grow in a body of water? They range all the way from the very simple algae to the more complex kinds of plants such as the horsetails, ferns, and flowering plants. Actually, the most common kinds of plants that cause weedy problems in ponds and lakes are the algae and the flowering plants.
Slide 12
The aquatic flowering plants are found in different zones of a body of water according to how they grow. Emergent plants include such plants as cattails, bulrushes, and various brushy species. They are rooted into sediments, but most of their foliage is above the water surface. The rooted floaters such as water lilies and spatterdock are also rooted in the sediment but they have leaves and flowers that float on the surface of the water. The submersed species, or the truly underwater aquatic plants, are also rooted in the sediments and grow up through the water. Examples include plants such as elodea, pondweeds, naiads, and some of the invasive species such as Eurasian watermilfoil and hydrilla. The free-floating plants, of course, are not rooted, and they include species such as duckweed, water meal, and in the southern part of the United States, water hyacinth.
Slide 13
Let's talk a little more botany. All flowering plants are divided into two groups, the monocots and the dicots. You are very familiar with both of these groups. The monocots on land include such plants as the grasses, lilies, orchids, and palm trees. You would recognize them as monocots very easily because they tend to have long narrow leaves. Think about grasses, or the turf in your lawn. The dicots, on the other hand, tend to have broader leaves. Think about terrestrial plants such as soybeans or tomato plants or the roses that are in your garden or the broad leaves that maples produce. Just like land plants, aquatic flowering plants are also divided into either monocots or dicots. Most of our native species such as the pondweeds, the naiads, elodea, and eelgrass are monocots. Other plants such as the invasive Eurasian watermilfoil, other native milfoils, and coontail are actually dicots. It turns out that most aquatic plants are monocots. Fewer are dicots. Interestingly, this is in contrast to the terrestrial situation where more species of plants are dicots than they are monocots.
Slide 14
I'm sure you are aware that plants are quite different organisms from animals. Let's ask the question, what is it that plants can do that we as humans and animals cannot do? One of the things that plants can do is make their own food by the process known as photosynthesis. Animals cannot make their own food. They have to obtain their food by eating either other animals or plants. The reason that plants photosynthesize is because they contain a green pigment called chlorophyll. Chlorophyll, of course, is the reason why plants, or the leaves of plants, are green in color. Plants also contain another group of pigments called the carotenoids. These pigments are orange in color. You generally don't see them during the summer because the chlorophyll is in such abundance that the green color

masks the orange color. The importance of this fact, that plants can photosynthesize and that we do not, will be made more apparent later in the presentation.

Slide 15

What else can plants do that we cannot do? Plants can make certain amino acids and vitamins. Plants, for example, can take the compound shikimate-3-phosphate and convert it to a compound that is abbreviated EPSP. The enzyme that catalyzes this reaction is called EPSP synthase. This series of reactions results in the production of three amino acids, tryptophan, phenylalanine, and tyrosine. Now you might ask, of what importance is it that plants can make amino acids? Well, it turns out that all organisms are made up of three major constituents: fats, carbohydrates, and proteins. And it turns out that the building blocks for proteins are amino acids. We have to have amino acids in order to make proteins, and without proteins we couldn't make muscles and other vital bodily constituents. We generally get our amino acids either by eating plants or by making them ourselves. There are some amino acids that we cannot make, however. We can only get tryptophan, phenylalanine, and tyrosine by eating plants. So that means that plants alone have the enzyme EPSP synthase. They alone can make tryptophan, phenylalanine, and tyrosine. Again the importance of this fact, that plants can make certain amino acids and we cannot, will become more apparent later in the presentation.

Slide 16

Let's shift gears for a moment and talk a little bit about pesticides. There are many different kinds of pesticides. Insecticides, for example, are intended to kill insects, rodenticides to kill rodents, and so on. A herbicide is intended to kill plants, and algicides are intended to kill algae. Each one of these kinds of pesticides differs in terms of the organism that it targets and in many of its other properties. Unfortunately, when we hear the term pesticides, we often think they are all the same. Nothing could be further from the truth. Each group of pesticide is intended to kill a different organism or group of organisms.

Slide 17

So again, what is a herbicide? A herbicide is a type of pesticide that is intended specifically to kill unwanted plants.

Slide 18

What are some of the algicides and herbicides that are used to control algae and aquatic flowering plants? The algae are primarily controlled using copper compounds, particularly copper sulfate, which is probably the most widely used of the algicides or herbicides in bodies of water. The submersed flowering plants can be controlled with compounds such as Aquathol, Reward, Sonar, or 2,4-D (Navigate or Aquakleen). The free-floating plants can also be controlled with Reward, Sonar, or 2,4-D depending on the species. The emergent plants are primarily controlled using the product that is called Rodeo. We are going to talk about each of these herbicides and algaecides. I will start first with Sonar, then move to Rodeo, and then to 2,4-D. I will end the presentation with a discussion of the copper compounds, Aquathol, and Reward.

Slide 19

Think back to our botany lesson. Remember that one of the things that plants can do that we cannot do is to photosynthesize, and that in order to photosynthesize, plants have to be able to make chlorophyll and carotenoid pigments.

Slide 20

Here is another fact: Sonar, very specifically, inhibits the synthesis of carotenoids.

Slide 21

Why does it make any difference whether a plant is able to synthesize carotenoids or not? Let's consider chlorophyll spread out in a very thin layer, much as it is in a blade of a leaf. Chlorophyll is actually very sensitive to sunlight; in fact if it is unprotected, it will start to bleach and in a very short period of time, start to die. The carotenoids function as a sunscreen, sort of like an umbrella for the chlorophyll, protecting it from excessive light rays from the sun. The chlorophyll molecule on the right without a carotenoid umbrella obviously is very unhappy and is about to bleach and die. Sonar does not affect chlorophyll synthesis. It only effects carotenoid synthesis. We cannot manufacture carotenoids. Consequently, humans and other animals are not affected by Sonar.

Slide 22

The effects of Sonar on treated plants are very obvious. The pondweed plants on the left are bleached and are starting to die. The untreated plants on the right are still healthy and green. Remember, Sonar blocks carotenoid synthesis, which in turn causes chlorophyll to bleach and the plant to die.

Slide 23

The effects of Sonar can also be seen on some non-target species of plants such as these cattails, which also are showing some whitening and bleaching, although cattails generally will survive the treatment.

Slide 24

Let us move on to another fact. Remember that we said that plants can synthesize certain amino acids and we cannot.

Slide 25

The herbicide Rodeo inhibits the synthesis of those three amino acids that we talked about, tryptophan, phenylalanine, and tyrosine and it does this by very specifically inhibiting the enzyme EPSP synthase that catalyzes the reaction that leads to the formation of these three amino acids. Animals do not make EPSP synthase, only plants. Consequently, Rodeo affects plants and not animals.

Slide 26

What does it mean if the plants can't make these amino acids? It means that it cannot make proteins and without proteins a plant cannot grow and will eventually die.

Slide 27

Rodeo is used primarily for the control of emergent plants such as these cattails that are being treated.

Slide 28

Because these cattail plants can no longer make protein, they stop growing and eventually will die.

Slide 29

As I said before, Rodeo is used primarily to control emergent plants, so we could ask the question "why does Rodeo only work on plants above the water line"? The reason demonstrates an important scientific principle and illustrates that we know a lot about what happens to pesticides in the environment. Consider a very tiny soil particle in a body of water. Even though a body of water may look clear, most lakes and ponds do have suspended sediment in them. Suspended sediment particles consist primarily of clay, and clay tends to have negative charges. Remember that opposites attract, and that negatives will attract positives. Surrounding that negatively-charged clay particle will be molecules with positive charges such as aluminum and iron (the Al and Fe molecules shown here).

Slide 30

The Rodeo molecule, on the other hand, has a negative charge. The Rodeo molecule is illustrated on the left hand side of this photo. Notice the negative charge associated with the oxygen on the right hand side of the molecule. That negative charge is going to be attracted to the positive charges that are surrounding the clay particle. Consequently, the Rodeo molecule is going to be very tightly bound to the clay particle.

Slide 31

Once the Rodeo molecule is attached to the positive charges associated with the clay particles, it is effectively bound and can no longer affect plants. It also becomes very susceptible to decomposition by the microbes that are in the water. In fact, Rodeo is a very simple molecule and consequently the microbes have a very easy time of breaking it down to obtain the carbon, nitrogen, and hydrogen that they need for their own metabolism. This is one of the reasons why Rodeo has a very short persistance time in water and in the environment generally.

Slide 32

Again, let's go back to one of our first botany lessons when we said that most aquatic flowering plants are monocots, not dicots.

Slide 33

Added to that, let's talk about something else that plants do that we cannot do. Plants can make certain kinds of hormones. One of the groups of hormones that they make are the auxin hormones.

If a plant cell is exposed to auxin, that plant cell is then stimulated to grow and become larger. An animal cell, on the other hand, is not affected when exposed to auxin and will stay the same size. The reason that the animal cell is not affected by auxin is because it does not have receptors on its outer cell membrane that recognize the auxin. The third herbicide that we're going to talk about is 2,4-D. 2,4-D is a type of auxin hormone.

Slide 34

Here are some more facts. 2,4-D acts like an auxin hormone; in other words, it stimulates growth in plant cells. However, it turns out that 2,4-D is primarily effective on dicots or on broadleaved plants. This tomato plant has been treated with 2,4-D and the cells along the upper surface of the stem have been stimulated to grow causing the very symptomatic curvature that 2,4-D causes on dicots or broadleaved plants.

Slide 35

Since 2,4-D works primarily on dicot plants and since most of our native species are monocots, and since Eurasian watermilfoil is a dicot, 2,4-D can be used selectively to remove Eurasian watermilfoil from stands of native aquatic plant species.

Slide 36

This selectivity can be illustrated by a study that was conducted with triclopyr. Triclopyr is a compound that is very similar to 2,4-D and acts just like 2,4-D. In this study, the control or untreated plots before treatment contained over 290 grams of dry weight per square meter of Eurasian watermilfoil. After 52 weeks, that stand had almost doubled to 498 grams of dry weight per square meter. The native species, on the other hand, suffered greatly. They did not grow at all during the period when the Eurasian watermilfoil was growing. Look at the treated data. Eurasian watermilfoil pre-treatment was at 254 grams dry weight per square meter. After 52 weeks the Eurasian watermilfoil stand had been reduced to 72 grams of dry weight per square meter. The native species, on the other hand, being monocots and not being sensitive to compounds like triclopyr or 2,4-D increased over the 52 week period to almost 433 grams dry weight per square meter. This is why we say that Eurasian watermilfoil can be removed selectively, leaving the native species to function in their normal roles as producers of habitat, shelter, and oxygen.

Slide 37

Very clearly then, compounds like 2,4-D, Rodeo, and Sonar have very specific sites of action. They affect processes that occur in plants and not in humans or other animals. This is why the toxicity of these herbicides is very low. Toxicity in mammals is measured as an oral LD50. The LD50 is the dose of the compound in milligrams per kilogram of body weight that will cause mortality to 50% of the test population, in this case, rats. The LD50s of 2,4-D and Sonar range from 800 to greater than 10,000 milligrams per kilogram of body weight of rat. In other words, it would take anywhere from an ounce to as much as a quart of these products to cause death to humans and other organisms. This is if we were to drink the herbicide straight out of the jug. Fortunately, if anyone were to try to drink an ounce, much less a quart of one of these products, they would certainly gag before they could get very much down. Now let's look at the other compounds. I've put sodium arsenite in the table just for reference purpose. Fortunately, sodium arsenite is not used as an aquatic herbicide. It is a very toxic compound, and it only takes from a taste to a teaspoon of arsenite to kill a human being. We haven't talked yet about three compounds, Aquathol, Reward, and copper sulfate. In looking at these data, one would assume they are very toxic since it takes only a teaspoonful to cause human toxicity.

Slide 38

Let's talk a little about these compounds. All three are what are called contact herbicides. That means they kill plant tissue very quickly. For example, Reward destroys the outer cell membranes, actually of both plants and animals.

Slide 39

If aquatic herbicides like Reward, Aquathol, or copper are so toxic and if they can affect both plant and animal systems, why don't they kill us when they are used to treat our bodies of water? There are three reasons why these compounds, when used correctly, are not nearly as toxic as one would think. These reasons involve aspects of dose, persistence in the environment, and fate in animal tissues. Let's discuss each of these aspects one at a time.

Slide 40

Before we get to these aspects, it is very important that we understand that all pesticides must undergo a thorough screening and analysis before they can be registered for use by the EPA or the Environmental Protection Agency. Each pesticide undergoes up to 140 different kinds of tests and analyses. These tests include acute toxicity (how much of the compound causes immediate death to the test animal) and chronic toxicity (how much of the compound causes death over a longer period of time). Pesticides are tested for their carcinogenicity (their ability to cause cancer) and for their mutagenicity (their ability to cause genetic defects). They are also screened for their persistence in the environment, and many other kinds of tests are conducted.

Slide 41

Based on these tests we know the mammalian toxicity of each herbicide, as we saw on a previous slide. However, these toxicities apply if we were to drink the herbicide straight out of the jug. When someone applies a herbicide to a body of water, the herbicide is going to be greatly diluted. In other words, the actual amount of herbicide in the treated body of water would be extremely low. Based on this very low concentration in the water, and using Reward as an example, a 150 lb. person would have to drink over a 1000 gallons of Reward-treated water every day over a lifetime to get an adverse effect. The phrase "the poison is in the dose" is very, very true. Aquatic herbicides are diluted to extremely low concentrations, such that they have very little toxic effect once they have been applied to the water.

Slide 42

Let's now consider the persistence of these herbicides in the environment. Herbicides can be removed from the water through three primary mechanisms. The copper compounds, Reward, and Rodeo are very quickly adsorbed to soil particles. The soil particles then drop to the bottom, effectively removing these compounds from the water. Rodeo, of course, is very soon degraded by microbes. Aquathol and 2,4-D are also very susceptible to microbial degradation. In fact, Aquathol is degraded to the innocuous compounds carbon dioxide and water within 10 - 14 days. Sonar is removed from the water by photodegradation. In other words, it is very sensitive to light and breaks down in the light. Its half-life is only 20 days. So all of these compounds have a very short persistence in the water. Consequently, even if you were able to drink 1000 gallons of treated water a day, the compound would not even be there after, at most, 30 days (for 2,4-D, for example).

Slide 43

Lastly, let's consider the fate of these herbicides in animal tissues. The way that we can do this is to look at the solubility of these compounds. Let's look at DDT as an example. As you know, DDT was banned some years ago because of its propensity to persist in the environment and to build up in the fatty tissues of animals and cause birth defects. The solubility of DDT in water is extremely low at 0.0012 parts per million. On the other hand, DDT is extremely soluble in fats. For example, you can get something like 78 grams of DDT to dissolve in 100 grams of fat. This is why DDT built up in fatty tissues. Now let's look at the three aquatic herbicides: copper sulfate, Aquathol, and Reward. All three of these are extremely soluble in water. In fact, Reward is soluble to the tune of 72 grams of Reward for every 100 grams of water. That is extremely water soluble! On the other hand, these compounds are not soluble in fats. In fact, copper sulfate and Reward are considered to be insoluble in fats. Consequently, these compounds do not dissolve in our fatty tissues and do not accumulate in our fatty tissues. When we swim in herbicide-treated water, we take these compounds in through our mouth. They stay in the water part of our body and exit through the urine. They do not build up in our fatty tissues and consequently do not cause major problems in terms of birth defects and other sorts of health hazards.

Slide 44

So, now I know that these aquatic herbicides are not going to kill me outright, but what about their potential to cause cancer? All pesticides are currently undergoing a reregistration process through the Environmental Protection Agency. What this means is that all of the gaps in the data that relate to carcinogenicity and other adverse effects have to be filled. The EPA uses an alphabetical system of A to E in how they categorize the cancer potential of a pesticide. "A" compounds have been shown through tests to cause human cancer. "E" compounds have been shown through tests to be non-carcinogenic. Aquatic herbicides are either category D, in the case of 2,4-D, in which the evidence to date suggests that it is non-carcinogenic, or E in the case of Aquathol, Reward, Sonar, and Rodeo, in which case animal tests have shown that these compounds are non-carcinogenic. That covers 5 of the 6 aquatic herbicides that we have been talking about. But what about copper sulfate, one of the most widely used pesticides in bodies of water? Will copper sulfate cause cancer?

Slide 45

The answer is no and the reason is this. Humans require trace amounts of copper in their diets for normal health. A vitamin pill with mineral supplements contains 2 mg of copper. Now, if you were to treat a body of water at the standard use rate for copper sulfate or any of the copper chelated products, you would have to drink 8 liters, or more than 2 gallons, of treated water to get the amount of copper that is present in just one vitamin pill. And remember, even if you could drink 2 gallons of water every day, copper is gone from the water in 7 days. Consequently, there is no long-term exposure to the copper compounds. The vast amount of literature and scientific studies on the use of copper as a mineral nutrient indicates no evidence of a potential to cause cancer.

Slide 46

I don't want you to think that herbicides get off with a completely clean bill of health. Herbicides must be used wisely in the environment. Aquatic herbicides can, if they are misused, destroy valuable habitat for animals. They can cause the release of nutrients into the water, which in turn can stimulate the growth of algal blooms, although this condition is usually temporary. The major problem with the use of herbicides is when too much vegetation is killed off at once. This can result in an oxygen depletion situation and subsequent fish kill. Herbicides must be used wisely in the environment to prevent adverse effects to the organisms that live in it.

Slide 47

This concludes our presentation on why aquatic herbicides affect aquatic plants and not you. What I hope that you have gotten out of this talk is that when we apply an aquatic herbicide to the environment, we are not doing something mysterious. We can predict what a pesticide will do in the aquatic environment. On that basis we can then make wise use of these chemicals.

Slide 48

Do you remember that weedy lake that I showed you at the very beginning of this presentation? That was the situation about 15 years ago. Using aquatic herbicides, the lake now looks clean and clear. The lake association uses a combination of mechanical harvesting in the deeper areas and aquatic herbicides in the shallow areas to maintain this lake in a pristine condition. Aquatic herbicides can be used effectively and they can do so with a minimum of adverse environmental and health effects.

Slide 49

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