Agricultural Pollution of Surface Water and Groundwater in Forest Nurseries[1]

Thomas D. Landis, Sally Campbell, and Fred Zensen[2]

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Abstract. -- Potential water pollutants include pesticides and their degradates, nitrates, and phosphates which can be dissolved or carried as sediment in surface runoff or leach to groundwater. Nursery managers should assume that they have a problem, and become proactive by initiating testing and developing systematic water management plans. These plans must be specifically designed for each nursery, and should detail Best Management Practices that can reduce or even eliminate water discharges: source controls, cultural practices, control structures, and comprehensive measures.

INTRODUCTION

Clean, safe drinking water is justifiably considered to be a basic human right, and water quality will undoubtedly be one of the most important ecopolitical issues in the coming decade. As an indication of this trend, the cover of a recent issue of U.S. News and Word Report was entitled “Is your water safe? The dangerous state of drinking water in America”. The article discusses the many chemical and biological threats to drinking water, including nitrates and pesticides from agricultural sources (Carpenter and others 1991).

The agricultural industry, including forest nurseries, has previously been granted a special exemption from pollution control laws but this grace period has come to an end. Cultural activities, including fertilizer and pesticide applications, are now known to contribute to agricultural pollution of surface and groundwater (Russell and others 1987). The U.S. Environmental Protection Agency (EPA) recently completed a five-year survey of groundwater quality in which they sampled 1300 drinking water wells across the nation. The survey revealed that agricultural pollutants are reaching groundwater in some areas, albeit in minute concentrations (Brown 1991).

These and other water quality tests have confirmed many people’s fears, and this concern is being expressed in legislation at the federal, state, and even community level. These new laws and regulations will have a profound impact on the forest nursery industry.

This article will attempt to provide a general overview of the agricultural water pollution situation in forest nurseries, and has three objectives:

1. Provide basic information on the legal, political, and social aspects of agricultural water pollution.

2. Create an awareness of potential sources of agricultural pollution

3. Discuss practical alternatives for managing the problem.

Before we can discuss these issues, however, there are certain terms and concepts which should be clarified because many have legal as well as scientific implications.

Water quality

“Quality” means different things to different people because the definition depends on intended use. Water quality factors such as color, taste, turbidity, odor, and toxic ion concentrations are of paramount importance for domestic uses; on the contrary, the concentration of salt ions and the presence of pollutants or pathogens define quality for agricultural purposes (Landis and others 1989).

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[2]Thomas D. Landis and Fred Zensen are foresters and Sally J. Campbell is plant pathologist for the USDA Forest Service, Region 6, Regional Office, Portland, OR.

Obviously, anything that detracts from water quality could be considered a pollutant. The principal agricultural pollutants of concern to human health and the environment are pesticides and their degradates, nitrates, and phosphates. Because all of these potential pollutants are carried through the environment in water, a basic understanding of the hydrologic cycle is necessary.

Hydrologic Cycle

Water moves through the environment in a continuous cycle alternating between water vapor in the atmosphere, and liquid water on the earth's surface and in the ground (fig. 1). The solid phases of water (snow and ice) are of minor importance in the discussion of agricultural pollution. As soon as atmospheric water vapor condenses and falls as precipitation on the ground surface, the water begins to dissolve soluble materials including potential pollutants (CAST 1985) . Many fertilizers are specifically formulated to be water soluble, and pesticides are frequently applied as aqueous solutions. Therefore, fertilizers and pesticides, or their degradates, are highly susceptible to water transport.

Moving under the influence of gravity, water either travels overland as **surface water** or infiltrates into the soil. Once it penetrates the ground surface, water infiltrates through the relatively thin soil mantle and slowly leaches downward through the **vadose zone** (fig. 1). By definition, the vadose zone is only intermittently saturated as water fronts from irrigation or precipitation events move downward. When the leachate reaches the water table, it becomes part of the groundwater which is prevented from moving further downward by impermeable bedrock. The groundwater either remains trapped in an aquifer or moves very gradually down slope until it reaches a stream, lake, or the ocean (fig. 1).

Surface runoff and leaching to groundwater are the two principal pathways by which agricultural pollutants could leave the nursery and contaminate the surrounding environment.

Agricultural Pollutants

As mentioned earlier, the principal agricultural pollutants are pesticides and their degradates, nitrates, and phosphates. Pesticides and nitrates can adversely affect human health, and nitrates and phosphates pose a significant threat to general water quality through eutrophication.

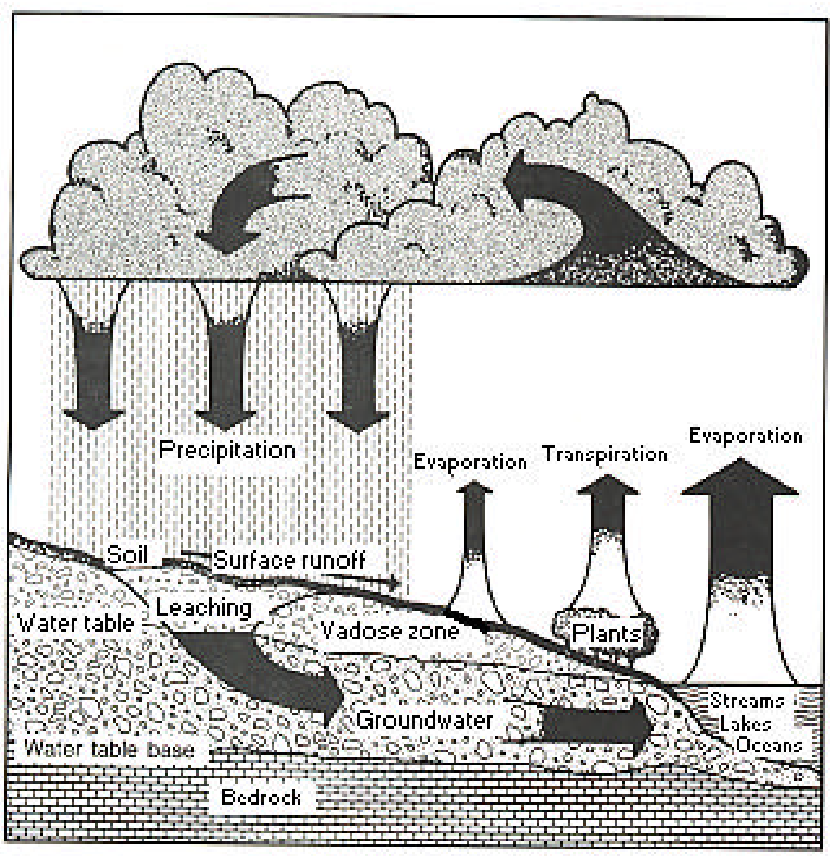

Figure 1.—-Water, either precipitation or irrigation, transports agricultural pollutants away from the nursery by two means: surface runoff, or leaching to groundwater (modified from CAST 1985; used with permission)

Agricultural pollutants are thought to endanger human heath by increasing the risk of cancer and contributing to other ailments. Several pesticides or their degradates are known to cause cancer in laboratory animals (CAST 1985). The actual threat to humans is unknown, but the popular concern about the link between man-made chemicals and cancer is very real. Even if they are only detected in very minute concentrations, people will not tolerate any level of a suspected carcinogen in their drinking water. Nitrates have also been linked to stomach cancer, although this relationship is tenuous. If nitrates are converted to nitrites, they can cause a disease celled methemoglobinemia in infants; this disorder does not affect adults, however (Newbould 1989). Phosphates are not known to pose any significant health risk.

Eutrophication of surface waters is considered to be one of the most pervasive water quality problems around the world (Holland and others 1990). Eutrophication refers to the excessive nutrient enrichment of water, which results in nuisance production of algae and other water plants. Water quality progressively deteriorates as these plants decompose, creating taste and odor problems, and eventually killing fish and other aquatic organisms.

Although both nitrogen and phosphorus fertilizers contribute to eutrophication, phosphorus has more pollution potential. Phosphates are one of the most limiting nutrients in aquatic ecosystems, and so can rapidly cause eutrophication when added by excessive fertilization. As already discussed, nitrates are very mobile in water and can easily move from agricultural land to surface water. By contrast, phosphorus ions are essentially immobile in terrestrial ecosystems because they are either rapidly taken-up by plants or chemically immobilized in the soil (Rosen and others 1986). Therefore, surface runoff that carries suspended sediment is the only way that fertilizer phosphorus can become a agricultural pollutant.

The physical, chemical, and biological pathways by which potential pollutants move through the environment are different for each substance. The nitrogen (N) cycle (fig. 2) provides a good example of the extreme complexity of these movements. Nitrates have been moving in surface water and groundwater long before agriculture began because they have been found in very old groundwater and in fossil deposits (CAST 1985). The atmosphere, which is 78% nitrogen gas (N2) by volume, is the primary source of all N in the environment. Atmospheric N is chemically or biologically fixed into solid forms by several different mechanisms, including leguminous plants and free-living microbes (fig. 2).

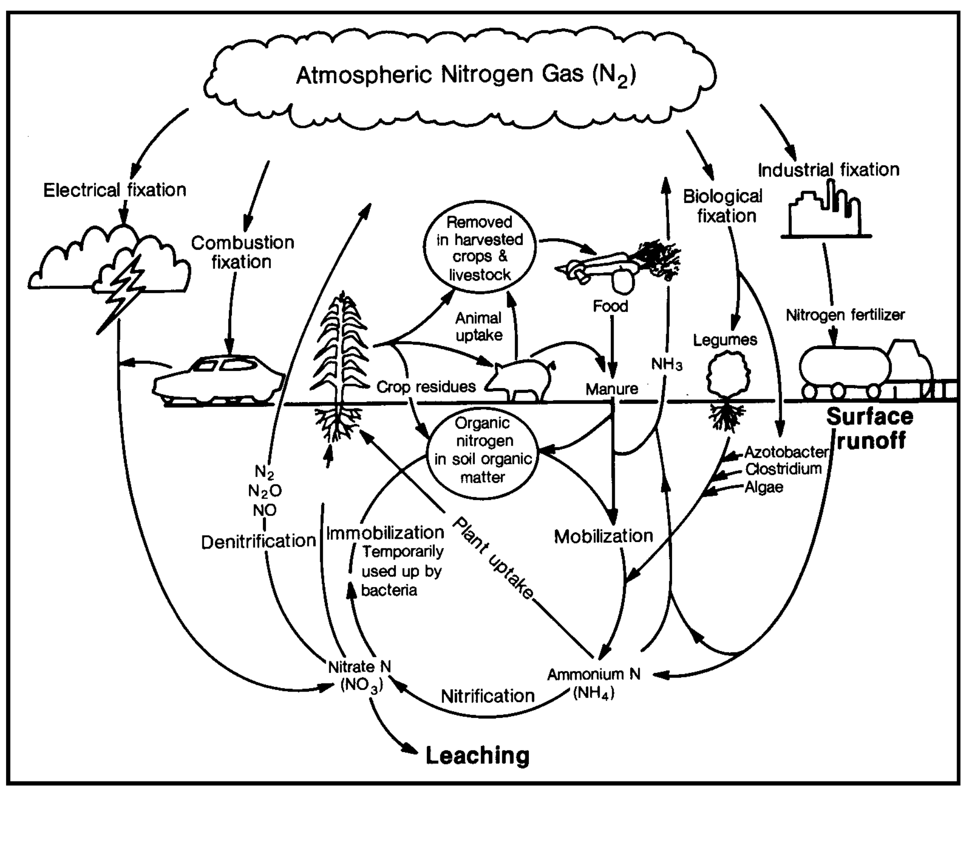

Figure 2.--Potential agricultural pollutants, such as nitrogen fertilizers, cycle through the environment by complex pathways and it is often difficult to determine their exact origin. For example, nitrates that leach from nursery soils can originate from natural sources as well as from fertilizers (modified from CAST 1985; used with permission).

One of the most significant sources of N in agricultural systems is N fertilization, and some fertilizer can be carried in surface runoff during heavy rain storms and could eventually reach streams or ponds (fig. 2). Inorganic fertilizers contain either nitrate or ammonium ions; although both can be used by plants, nitrate ions are taken up most readily. Decomposing organic matter and organic fertilizers release ammonium ions, which have a positive charge (NH_4^+) and are therefore adsorbed onto the negatively-charged soil particles. Once it enters the soil, ammonium is gradually converted to nitrate by soil microorganisms, as is the protein in decomposing organic matter. Nitrate has a much greater pollution potential than ammonium. Because of their negative charges (NO_3^-), nitrate ions are repelled by the soil particles, and some eventually leach out of the root zone and drain to groundwater (fig. 2). Urbano (1987) estimated that one-third to one-half of all the nitrates that are applied as fertilizers end up in groundwater.

The potential for pesticides and their chemical degradates to contribute to water pollution depends on their physical and chemical characteristics. Pesticides that remain soluble in water can be carried in surface runoff or leach to groundwater. Other pesticides become adsorbed onto soil particles, which could be carried by suspension in surface water (O'Hara 1991). These properties and their potential for agricultural pollution are discussed in more detail in the section on Best Management Practices For Forest Nurseries.

According to the legal definition, forest nurseries can generate either point source or nonpoint source pollution. As is often the case, however, the actual distinction between the two terms is quite fuzzy:

* **Point Source** - The Clean Water Act defines point source pollution as "any discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel ---- from which pollutants are or may be discharged" (Fentress 1989). As applied to forest nurseries, therefore, point source pollution would be most applicable to surface discharges because it is relatively easy to determine their source, especially from container nurseries with impermeable ground surfaces. Normal irrigation soaks into the ground in bareroot nurseries, but effluent from drain tiles or open drainage ditches could theoretically be defined as point source pollution.

* **Nonpoint source** - Although not specifically defined by The Clean Water Act, the EPA refers to nonpoint source pollution as that which is generated by diffuse land use activities, and which is conveyed to waterways through natural processes such as storm runoff or groundwater seepage. Furthermore, nonpoint pollution is not subject to "end of pipe" treatment, but is controlled by changes in land management activities (Fentress 1989). Both bareroot and container nurseries could be accused of nonpoint source pollution if tests of groundwater were found to be contaminated by nitrates or pesticides that are used at the nursery. Currently, however, it would be difficult to prove the exact source of the pollution because little is known about subsurface hydrology.

Water Management

Several technical terms are commonly encountered in water management discussions. As previously discussed, legal definitions will vary with the particular application. Definitions from the "Container Nursery Irrigation Water Management Plan" that was recently developed in Oregon will be discussed further in the section on Managing Agricultural Water Pollution.

* **Discharge** - In the broadest sense, a discharge is any water (irrigation or precipitation) which leaves the nursery. Although both surface runoff and water which leaches to groundwater can be considered discharges, some definitions state that that normal seepage is not classified as a discharge. Note that some water flows, such as surface runoff from a sudden thunderstorm, could be considered discharges even though they are beyond the control of the nursery manager.

* **Best Management Practices** (**BMP'S**) - Nursery managers can prevent or even eliminate water discharges by a variety of activities. As will be discussed in the section on Best Management Practices For Forest Nurseries, BMP's can be used throughout the nursery system.

* **Water Management Plan** - These are documents that detail the specific BMP'S to be undertaken by a nursery to control agricultural contamination of surface or groundwater. They are legal transactions that are reviewed and filed with government pollution monitoring agencies.

DO YOU HAVE A PROBLEM?

Problems are extremely subjective, but a workable definition is the difference between "what is" and "what should be" - what constitutes a serious problem to one person may be inconsequential to another. Defining problems always involves value judgments, and so the values or objectives of an individual or organization will define the nature of its problems (Landis 1984). In the context of agricultural pollution, the mere presence of minute concentrations of a pesticide in a water sample may be deemed unacceptable, even though the levels are below known toxicity levels. Because of this subjectivity, problems can be divided into "real" or "perceived" problems for nursery management purposes.

Unfortunately, it can be technically difficult, time consuming, and costly to determine if your nursery is discharging waterborne pollutants into the environment. Agriculture in general does have a problem, however. Industry estimates show that over two-thirds of the pesticides used in the U.S.

are applied to agricultural land (fig. 3); in 1983, this equated to over three-quarters of a billion pounds of pesticide (Storck 1984). Use of nitrogen fertilizers has also increased by 10 million tons since 1955 (McWilliams and others 1991). Not surprisingly, water quality agencies in 34 states have identified agricultural nonpoint source pollution as a major problem (Bjerke 1989).

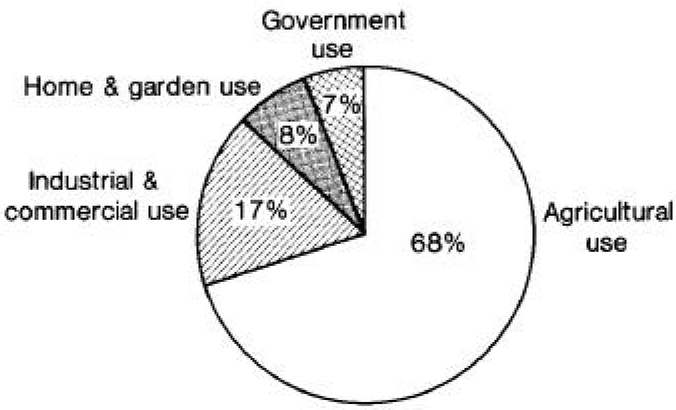

Figure 3.--Agriculture is the major user of pesticides in the United States, and so forest nurseries are potential polluters by implication (Storck 1984).

Granted, forest nurseries are only a very small percentage of total agricultural production but, the very fact that nurseries apply potential pollutants, means they are guilty by association. Perhaps the most prudent philosophy is to assume that all forest nurseries have at least a perceived problem with agricultural pollution. This is particularly true where landowners living around the nursery routinely see fertilizers and pesticides being applied - to these nursery neighbors, this use may very likely constitute a problem (Scholtes 1991a).

MANAGING AGRICULTURAL WATER POLLUTION

There are a variety of different management approaches to any situation, and problem solving is routinely required. Unfortunately, one traditional technique is the "ostrich approach", which involves merely ignoring the problem. After all, there's no real reason to panic until you get a call from the Environmental Protection Agency, or the "60 Minutes" truck pulls up outside the nursery!

Obviously, we recommend a more realistic approach and assume that you have, or soon will have, either a real or perceived problem with agricultural pollution. And, rather than wait for a problem to develop, nursery managers should become proactive and learn how to prevent or at and Department of Environmental Quality to iron-out the specific language. This is an excellent example of how nurseries can control their own fate and help influence water quality regulations (Grey 1991).

Inquire about legislation

There are several federal laws that regulate agricultural pollution of surface or groundwater in the United States, including the Clean Water Act, FIFRA - the Federal Insecticide, Fungicide, and Rodenticide Act, The Safe Water Drinking Act, and The Food Security Act (Logan 1990). Several states have also passed laws, such as the California Safe Drinking Water and Toxic Enforcement Act, which is better known as "Proposition 65". This act has some unique elements which will be of concern to nursery managers. A "bounty hunter" clause stipulates that any citizen can bring suit to enforce the regulations, and that the claimant is entitled to 25% of any fines that are levied (Brouwer 1990). The U.S. Supreme Court recently ruled that even local governments, such as city and counties, can establish their own pesticide use laws that supercede federal regulations (Nursery Manager 1991).

Even within a state, you need to know which agencies actually regulate water quality. In Oregon, the "Container Nursery Irrigation Water Management Plan" was established through a Memorandum of Understanding between the Oregon Department of Agriculture and the Department of Environmental Quality, but the Department of Agriculture was assigned the responsibility for implementing and monitoring the Plan (Grey 1991).

The type of pollution also affects the applicable legislation. Most laws are aimed at point source pollutants because they are easier to identify, and control measures are relatively straight-forward. Nonpoint source pollution has not been widely addressed, however, because it is primarily caused by general land use activities and the exact source is often difficult to identify.

Each piece of legislation or regulation can have different definitions, so you have to read each one carefully. For example, the following are from the "Container Nursery Irrigation Water Management Plan" (Oregon Department of Agriculture 1991):

The Plan defines "discharge" as "a release of irrigation return flows to surface waters, or a significant release of such water to groundwater". Note that, although it mentions groundwater, the definition continues: "Normal seepage resulting from standard irrigation practices is NOT classified as a discharge" (emphasis added). Also, note that surface runoff caused by precipitation is not specifically mentioned.

The Plan states that Water Management Plans must be developed by individual container nurseries and gives two options: 1) eliminate all irrigation runoff discharges, or 2) obtain runoff discharge permits, which are not only expensive, but will require monitoring and perhaps further water treatment (Grey 1991).

Monitor surface runoff and groundwater

It would be prudent to have surface and groundwaters tested to determine if any agricultural pollutants are actually leaving the nursery. Most forest nurseries have never analyzed their water discharges for possible pollutants, but it would be wise to establish some baseline data as soon as possible. If nothing else, this would provide some measure of legal protection as it would show that you are at least aware of a potential problem. The next step would be to initiate a regular testing program to show changes over time. It. is extremely important to document test results so that they will be readily available in case you ever need them.

What to sample

Surface water, water moving through the vadose zone, or groundwater can all be sampled for pollutants. Sampling of surface runoff should be relatively easy. Some facilities, like Monrovia Nursery in Dayton, OR, were laid out with graded and sloped beds to collect surface runoff. Most forest nurseries can monitor surface runoff or sediment from collection ponds, adjacent streams or rivers, drainage ditches, or simply water flowing off seedbeds following irrigation or rainfall.

Determining if pollutants are leaching can be particularly difficult because of the extreme variability that can occur in subsurface hydrology. A fairly sophisticated sampling grid in both the vertical and horizontal dimensions may be required to positively establish the pattern of leachate movement. Bareroot nurseries with drain tiles could sample the discharge at several different locations to get a rough idea of the leaching situation.

Another option is to use lysimeters - sampling instruments that are specifically designed to monitor water in the unsaturated vadose zone (fig. 4). Each lysimeter is permanently installed at a certain depth in the soil. Soil moisture is drawn into the lysimeter when a vacuum is applied; the water is removed with application of another vacuum to the sample recovery line (fig. 5). Since lysimeters are expensive and difficult to move and re-install, their placement is important. They should be located where there is a high probability of obtaining polluted water or where water quality documentation is needed: beneath high permeability soils, under sedimentation ponds, or adjacent to sensitive surface waters,

The USDA Forest Service initiated a lysimeter study in 1989 in which four to six lysimeters were installed at each of the 11 Forest Service

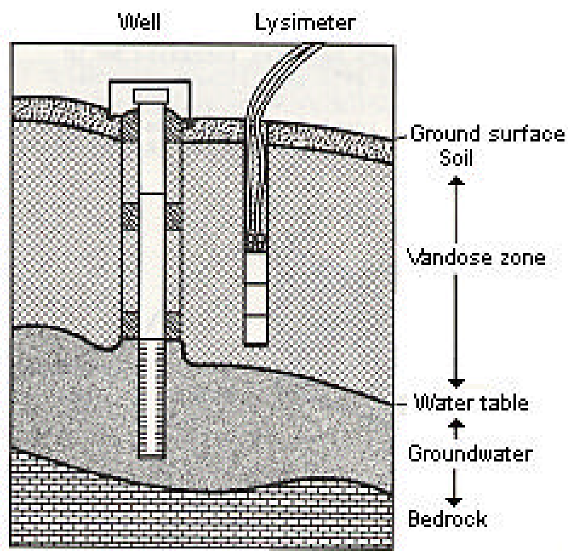

Figure 4.--Although both lysimeters and wells can be sampled to determine if agricultural pollutants are leaching to groundwater, they sample different hydrologic zones - lysimeters sample the vadose zone, whereas wells can be used to test groundwater (modified from Timco 1987; used with permission).

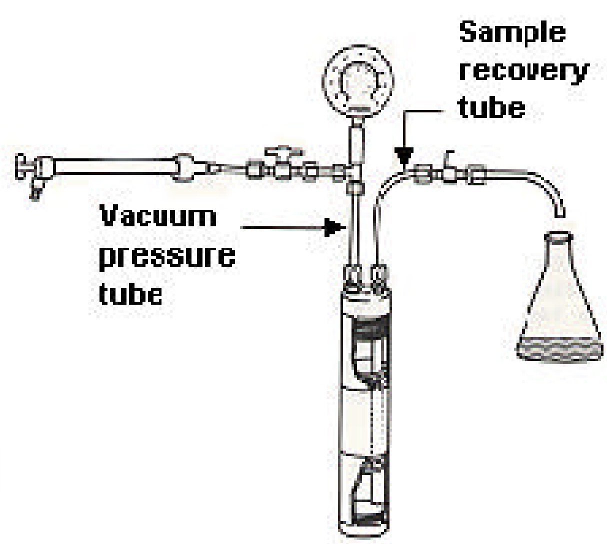

Figure 5.--Lysimeters can be used to collect a sample of water from the vadose zone by creating a vacuum with a hand pump (modified from Timco 1987; used with permission).

nurseries across the United States. All are bareroot operations except one which also has container seedling facilities. Water samples from each lysimeter were drawn quarterly over a 2-year period and sent to laboratories for analyses of nitrate content and six pesticides (benomyl, chlorothalonil, dacthal, diazinon, and diphenamide) or their degradates.

Interim test results show a wide range of nitrate levels (0 to 242 ppm) with the majority of samples falling between 0 and 50 ppm. These levels are slightly higher than normal: Brouwer (1990) reported that nitrate levels in the vadose zone typically range from 5 to 100 ppm, with frequent detections in the 20 to 40 ppm range. These Forest Service lysimeter tests indicate that forest nurseries may indeed have a problem with nitrate leaching, as the maximum limit for drinking water is 10 ppm (CAST 1985).

The interim results for pesticides show a little over 10% of samples with detectable pesticide residues although the detection limits for these tests are in parts per billion (ppb). The reported test values were extremely low, ranging from 0.01 ppb to 1.00 ppb, and so the testing laboratory wants to re-analyze the samples by a second procedure to make certain that the detections are not the result of contamination or other operational flaws.

Additional lysimeter monitoring is planned and will give managers of the Forest Service nurseries ongoing information about the amount of nitrate and pesticide that is leaching from their soils.

Measuring the groundwater itself is more straight-forward, as samples can easily be taken from existing irrigation wells (fig. 4). Special "observation wells" could also be established and sampled for possible pollutants. But again, it may be difficult to establish the exact source of the pollution.

Sampling Procedures

A well thought-out monitoring plan should be drawn up before any actual sampling begins. Plans should describe when to sample, where to sample, how to sample, as well as what to sample, and should be reviewed at least yearly to ensure that they are current and appropriate. Monitoring plans may very likely need to be revised as new sampling methods are developed or conditions at the nursery change.

Water samples can either be taken on a periodic set schedule or after certain events, such as when pesticide or fertilizer applications are followed by heavy irrigation or rainfall. The chances of detecting potential pollutants in surface or groundwater are maximized in the latter case and represent a worst-case situation. A calendar-based sampling schedule might consist of sampling surface and below-ground water every 2 weeks or every month, for example. Ideally, a combination of the two sampling schedules should be used. For example, routine samples could be scheduled at periodic intervals, and special samples could be collected after heavy irrigation and precipitation.

Prior to beginning a monitoring program, it is helpful to analyze the nursery site and try to map natural water flow, drainage patterns, soil types, and underground hydrology. Monitoring water quality vertically, from surface to vadose to groundwater, as well as horizontally from seedbed to sedimentation pond to stream, can provide additional information on water flow patterns at the nursery site. For most locations, however, there is little or no information on underground hydrology.

Special equipment and handling techniques are required when collecting water quality samples (Taylor and others 1988). Many potential pollutants are volatile or can otherwise change before they can be analyzed, and so special sampling bottles must be used. The analytical laboratory can provide bottles and recommend the proper handling and storage procedures. Munch (1991) explained the sophisticated sampling methods used during the national EPA groundwater survey.

The cost of water sampling varies depending on the chemicals to be analyzed; some analyses are more complex and therefore more costly. Costs can be reduced by taking composite samples when the monitoring program is started. Samples from a number of locations in the nursery are combined and submitted to the lab as a single sample; if a suspect chemical is detected, then single samples can be taken to determine the exact location of the positive sample. To date, very few pesticides have been detected in vadose zone or groundwater samples from both forest nursery and other agricultural sites so composite samples are a logical way to proceed. Costs can also be reduced by monitoring select chemicals. If it is not economically feasible to monitor all chemicals used at the nursery, those which pose the greatest hazard to water resources or human health or those which are controversial should be given first priority.

Inform neighbors, local authorities and the media

One of the best ways to avoid future problems is to let people know that you are aware of the pollution potential at your nursery, and how you are planning to deal with it. You might want to begin with the people living around your nursery. As previously discussed, even if a pollution problem is discovered, it is often difficult to determine exactly where it is coming from. Your neighbors are only too aware that you use fertilizers and pesticides on your nursery, and so you will be judged guilty if they discover any chemical pollutants in their well water. It would be prudent to let them know that you have instituted a testing program and that you are considering other pollution management practices (Scholtes 1991a).

It is also a good idea to contact local water management authorities regarding your concerns about agricultural pollution, and your intention to begin monitoring. It is possible that they can let you know if other people in your area have testing programs, and perhaps you can even participate in a existing program. Federal (Soil Conservation Service 1991) and state (DeLuca and Johnson 1990) agencies have even developed computer models that help evaluate the likelihood of groundwater pollution at a particular site.

The University of Idaho Forest Research Nursery recently developed a small wetland to store and treat the surface runoff water from their container nursery (Dumroese and others 1991). Because the fate of natural wetlands is currently newsworthy, the nursery staff worked with the University newsletter on an article that details their program (Lyons 1991). If presented in a positive manner, these small efforts can turn a potentially volatile topic into a one that will reflect favorably on you and your nursery.

Develop a systematic water management plan

Before you start working on the details of a water management plan it is helpful to step back and look at the entire situation. The flow of potential pollutants through a nursery can be viewed as a simple input-output system (fig. 6). The inputs are nitrates or phosphates from fertilizers, any pesticides that are applied, and the water that acts as the carrier. The outputs are the two types of discharge: surface runoff or leaching to groundwater. This systematic approach is invaluable when deciding which pollution control measures are warranted, and when they will be most effective.

A comprehensive water management plan should consist of the following (Grey 1991):

1. Base maps that show the nursery and the location of relevant topographical and cultural features.

2. A narrative section that provides general information about the nursery operation and the type of irrigation system.

3. A monitoring program which discusses which water quality tests were used, and itemizes test results.

4. Supporting documentation which should include engineering plans, photos, and other technical information.

5. A list of Best Management Practices that will be employed.

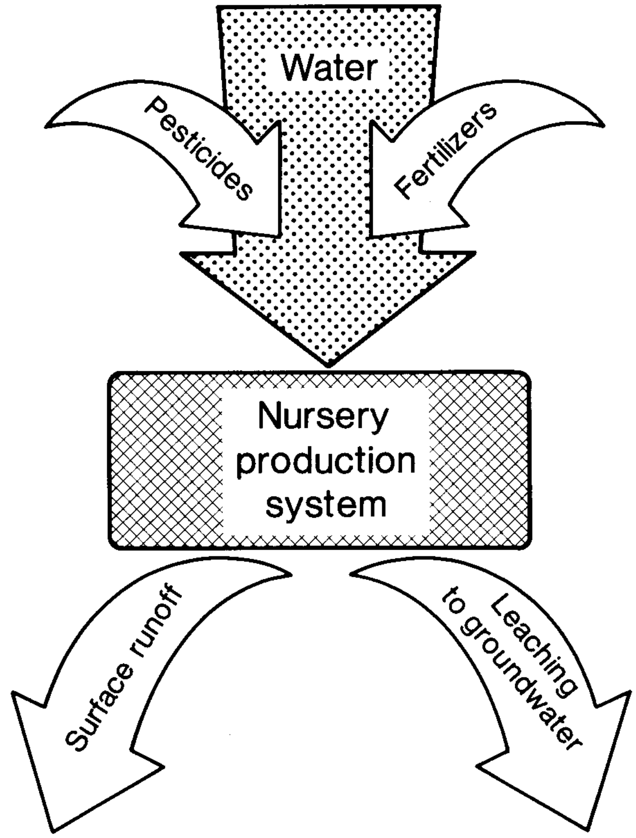

Figure 6.--The agricultural pollution process in forest nurseries can be viewed as an input-output system: pesticides and fertilizers are carried into the nursery system in water and can leave the nursery in surface runoff or as leachate.

BEST MANAGEMENT PRACTICES FOR FOREST NURSERIES

Every nursery is different, and so each should develop a systematic water management plan that addresses its own specific situation. Using the model, nursery managers should consider all four types of Best Management Practices (BMP's): **source controls, cultural practices, control structures,** and **comprehensive measures**. Each type of BMP affects a different part of the nursery system (fig. 7). Source controls limit the input of fertilizers and pesticides into the nursery system, cultural practices can be used within the nursery system itself, and control structures reduce or even eliminate the discharge of pollutants from the nursery. Comprehensive measures contain elements of several of the other three BMP categories. For example, integrated pest management (IPM) includes source controls (limiting the types and amounts of pesticides that are applied), as well as cultural practices that can reduce the need for pesticides.

The most appropriate BMP will depend on the kind of nursery (container or bareroot), the chemical characteristics of the target pollutants, and the types of discharge that need to be managed (table 1). Most BMP’s are oriented at one particular pollutant or one type of discharge. For example,

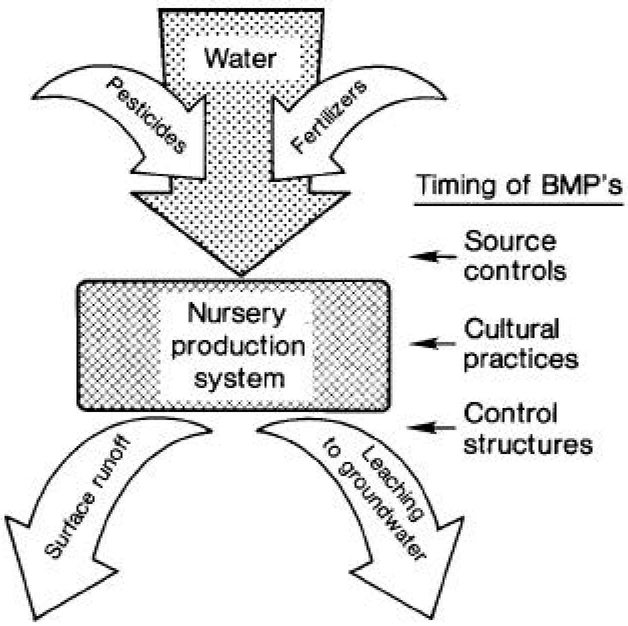

Figure 7.—Individual Best Management Practices (BMP'S) are only effective at certain times during the nursery system. Comprehensive BMP's include parts of the other three types, and so are useful throughout the system.

a sediment basin may work well for trapping pesticides that may be carried on soil particles, but it is ineffective for soluble nitrates and pesticides. Unlined sediment basins are intended to control surface water discharge, but may even encourage the leaching of soluble pollutants that can leach to groundwater. Nurseries should evaluate all potential effects and consequences before adopting a specific BMP

Source controls

These are the easiest type of BMP to implement and are by far the most effective (Logan 1990). They include determining the pollution potential of fertilizers and pesticides, and coordinating irrigation to insure that these materials are carried into the root zone but do not leave the nursery in surface runoff or leach to groundwater.

Determining the pollution potential of fertilizers

Most nurseries overfertilize because it is cheaper and easier to waste a little fertilizer than take the risk of reducing seedling growth. Now, however, an additional expense must be considered - the cost of potential water pollution. More efficient use of fertilizer is both economically and ecologically sound (Newbould 1989).

The total amount of fertilizer that is applied per season should be examined. We know that increased fertilization stimulates seedling growth so that

Table 1.—The effectiveness of different Best Management Practices (BMP'S) varies with kind of nursery, the target pollutant, and the type of discharge

		Target Pollutant		Type of Discharge	
Type of BMP	Nursery System	Pesticides	Nitrates	Surface Runoff	Leaching
Source Controls	Bareroot & Container	High	High	Positive	Positive
Cultural Practices					
Cover Cropping	Bareroot	High	Medium	Positive	Positive
Subsoiling	Bareroot	Low	Low	Positive	Negative
Control Structures					
Tile Drains	Bareroot	Low	Medium	Variable	Positive
Sediment Basins (Unlined)	Bareroot & Container	Medium	Low	Positive	Negative
Comprehensive Measures					
Integrated Pest Management (IPM)	Bareroot & Container	Medium	None	Positive	Positive

we can produce a shippable crop on a shorter rotation. If fertilization rates must be decreased to stop pollution, then crop rotation timing will also have to be adjusted. Many nurseries apply fertilizer as a matter of tradition, and have never actually done any fertilizer response trials to determine the proper application rate for their species, cultural regime, and climate. Nurseries can empirically determine the proper amount of fertilizer to apply by correlating application rates to yield. Note that even different species of the same genus vary in their response to fertilization (fig. 8).

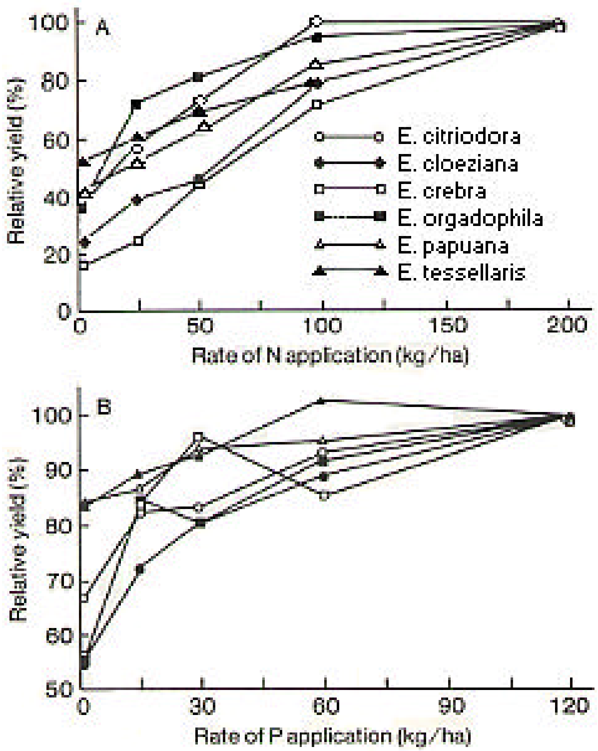

Figure 8.--Five species of Eucalyptus (Eucalyptus spp.) seedlings had different growth responses to both nitrogen (N) or phosphorus (P) fertilization (Olsen and Bell 1990; used with permission).

The timing of fertilizer applications is also important (McWilliams and others 1991). Rather than apply nitrogen fertilizer in one or two large applications, it is more effective to apply a number of small applications based on seedling phenology (fig. 9). Large applications of nitrogen late in the growing season are not only less effective, but are also wasteful. Experience has shown that phosphorus applications have a greater impact when scheduled very early in the growing season.

The method of fertilization affects the pollution potential. In bareroot nurseries, fertilizers should be incorporated into the root zone if at all possible because surface applications can easily wash off the seedbed, especially on soil types that develop surface crusts. Soil incorporation is particularly important with phosphorus fertilizers because phosphate ions are quickly immobilized and will move only a few centimeters from the fertilizer granule (McWilliams and others 1991). Progressive nurseries are experimenting with banding fertilizers at the time of sowing or between rows of established seedlings later in the growing season. In container nurseries, slow-release fertilizers incorporated into the growing medium have been shown to produce less fertilizer leachate than liquid fertilizer applications (Whitcomb 1988).

Determining the pollution potential of pesticides

Using agricultural chemicals to control pests is an accepted part of nursery culture, but there is increasing pressure to limit or even eliminate pesticide use. Prudent use of pesticides can be an integral part of an IPM program, however. If the proper chemical is applied in the proper manner, at the proper application rate, and at the proper time, the risk of adverse environmental effects is reduced.

The pollution potential for a given pesticide is a function of the characteristics of the pesticide, the nursery soil, irrigation practices, and precipitation events (fig. 10). Pesticide characteristics including solubility in water, soil adsorption, and persistence in soil are all important and vary considerably between the herbicides, insecticides, and fungicides that are commonly used in forest nurseries. When integrated together, these characteristics can provide an estimate of the pollution potential by surface runoff or leaching to groundwater (table 2). Some pesticides, metalaxyl for example, have a high leaching potential because they are very soluble in water but are not held by the soil. Others, such as oxyfluorfen, have a high soil adsorption index and so have a high probability of moving with soil particles in surface runoff. A complete listing of water solubility, soil adsorption indices, persistance in soil and pollution potential ratings can be found in Becker and others (1989). Computer models are available that will calculate pollution potential by collectively integrating pesticide characteristics and environmental conditions at a particular site (e.g. DeLuca and Johnson 1990; Soil Conservation Service 1991).

Environmental conditions, species tolerances, and cultural practices are different in every nursery, and so growers should conduct actual field trials with pesticides to determine the proper rate and timing of applications. New pesticide application techniques are continually being developed. In Finland, researchers have developed a sprayer that applies the pesticide from the side so that the

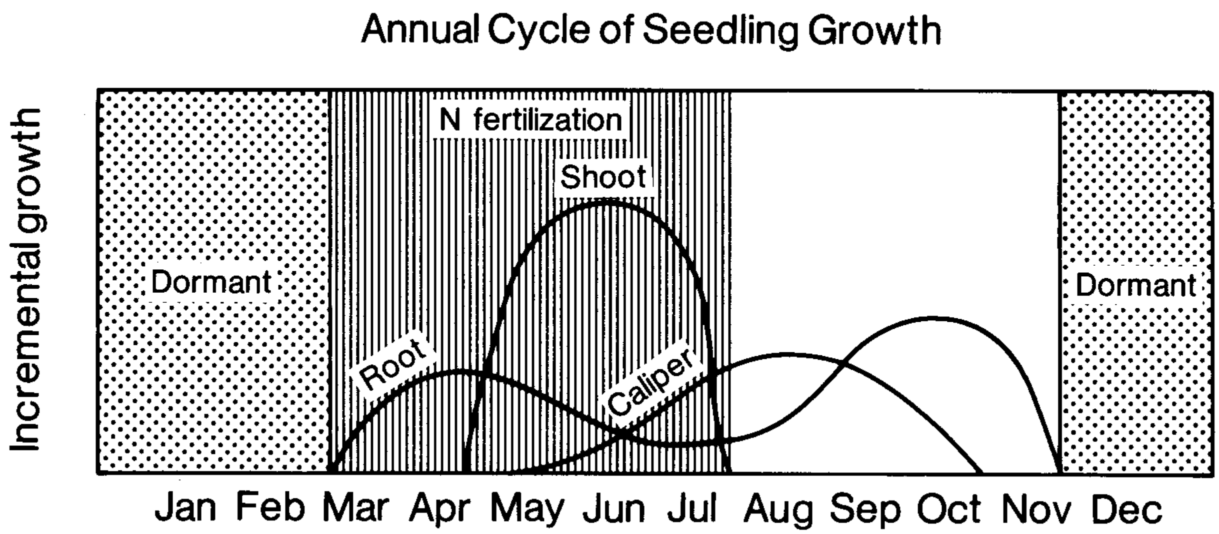

Figure 9.—-Applying several small applications of nitrogen (N) fertilizer early in the growing season is more effective than one or two large applications and also minimizes the pollution potential.

Table 2.—-Properties of some common nursery pesticides that determine their pollution potential

Trade Name	Common Name	Water Solubility (ppm)	Soil Adsorption Index# (K_{oc})	Persistence In Soil * (days)	Pollution Potential: Surface Runoff	Pollution Potential: Leaching
Herbicides						
Dacthal	DCPA	0.5	5,000	100	Large	Small
Goal	oxyfluorfen	0.1	100,000	35	Large	Small
Princep	simazine	6.2	138	75	Medium	Large
Roundup	glyphosate	900,000	24,000	47	Large	Small
Tordon	picloram	200,000	16	90	Small	Large
Insecticides						
Cygon	dimethoate	25,000	8	7	Small	Medium
Diazinon	diazinon	40	500	40	Medium	Medium
Malathion	malathion	145	1,800	1	Small	Small
Orthene	acephate	818,000	2	3	Small	Small
Thiodan	endosulfan	32	2,040	120	Large	Small
Fungicides						
Benlate	benomyl	2	190	240	Large	Large
Botran	dicloran	7	5,000	10	Large	Small
Captan	captan	4	100	3	Small	Small
Daconil	chlorothalonil	0.6	1,380	30	Large	Small
Ridomil	matalaxyl	7,100	16	21	Small	Large

= An index of the tendency of pesticides to adsorb to soil particles

* = The time required for pesticides to degrade to one-half their previous concentration (“half-life”)

Source: Becker and others (1989)

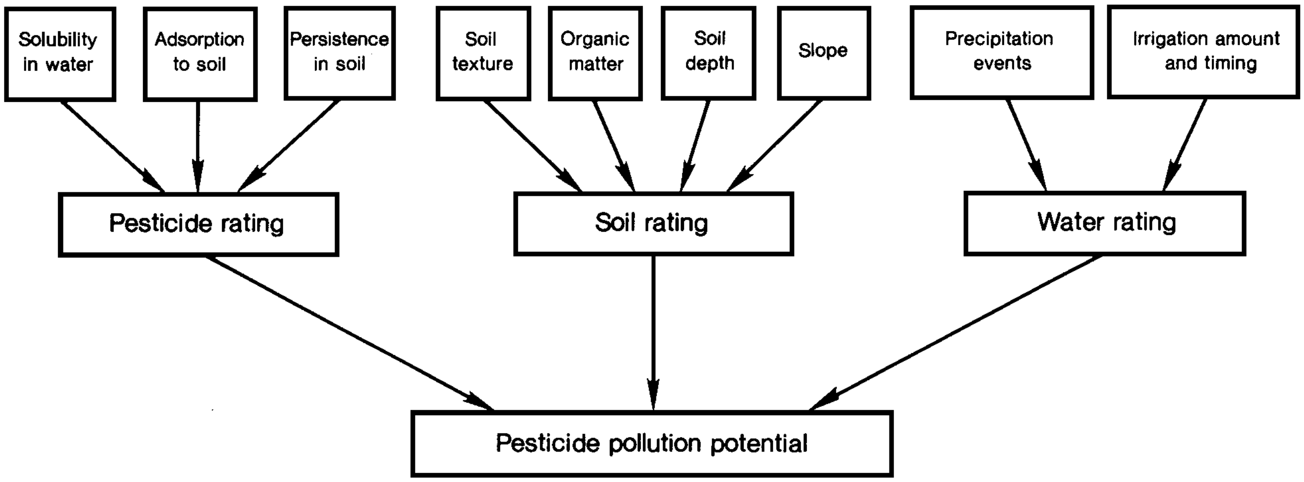

Figure 10.--The pollution potential of any pesticide is a function of its chemical characteristics, soil properties, and the timing and amount of water applications (modified from Becker and others 1989).

excess chemical can be captured by a vacuum and recycled (Tervo and Others 1991).

Most pesticide pollution problems can be traced back to improper storage, transportation, and mixing rather than application to crops. Nurseries should store their pesticides in specially designed facilities that have been constructed to contain spills. Pesticides should only be mixed at special paved loading areas that have catchment basins in case of spills. The worst place to mix agricultural chemicals is near an irrigation well with an unsealed casing, although this often happens because this is where the sprayer tank is filled with water.

Coordinating irrigation with fertilizer and pesticide applications

Water is necessary to dissolve fertilizers or pesticides that are applied as top dressings and carry them into the root zone. However, excessive irrigation causes undesirable leaching or surface runoff, which can be just as damaging as over application of the fertilizers or pesticides themselves. Irrigation and precipitation factors also affect the pollution potential rating of pesticides and fertilizers (fig. 10). Some water-related factors like irrigation practices can be managed but severe precipitation events, such as thunderstorms, cannot be controlled. Heavy rainfall can quickly exceed the soil infiltration rate and can cause agricultural pollution through surface runoff. In climates with frequent heavy rains, growers may want to consider pesticides with a lower surface runoff potential (table 2).

Cultural Best Management Practices

Nursery managers can control potential agricultural pollution with careful selection and timing of cultural operations. For example, in bareroot nurseries, between-the-row cultivation immediately before application of a fertilizer top dressing will increase the water infiltration rate and reduce surface runoff. Container growers should consider regulating irrigation timing and amount by monitoring block weights; using a calendar to schedule irrigation results in overwatering and subsequent runoff of soluble fertilizers and pesticides.

Structural Best Management Practices

Once the potential pollutants are in the nursery system, there are basically two management options: 1) eliminate all discharge, which means catchment ponds and recycling, or 2) install treatment systems to make discharges meet water quality standards.

Collection and recycling systems

These involve catching and collecting all water discharges, from both irrigation and precipitation, and so would be very difficult to implement in an existing nursery. Newly-constructed container facilities, however, should be designed with an impermeable ground surface and catchment basins. This is less practical for bareroot nurseries, although new technology is continually being developed. For instance, a dual pipe irrigation system has been developed that uses the top pipe for subirrigation and any leachate is captured by a lower pipe and returned to the irrigation reservoir for reuse (fig. 11).

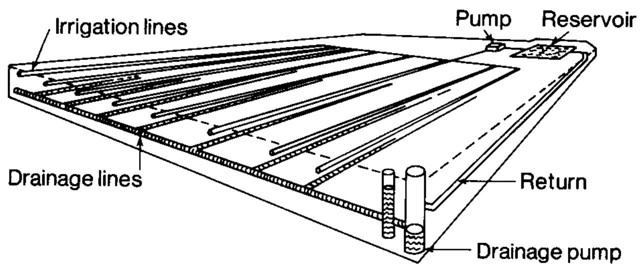

Figure ll.--New technology, such as this dual pipe irrigation system, will help reduce the potential for pollutants to leach from bareroot nurseries to groundwater (Subsurface Irrigation Systems 1991; used with permission).

Constructed wetlands

Manmade wetlands are a relatively new way of biologically treating wastewaters by creating a habitat which encourages aerobic and anaerobic microorganisms to remove pollutants from discharge water (fig. 12A). Although originally developed for municipal wastewater, constructed wetlands have been used to treat water that is contaminated with a wide variety of pollutants, including mining and agricultural wastes. Constructed wetlands can remove potential pollutants from water is several different ways:

1. Nutrients, such as P and N, are taken up and organically fixed by wetland plants, such as cattails and reeds (fig. 12A), and are therefore temporarily removed from the discharge water. Harvesting these plants and removing them from the site will make room for more nutrient immobilization as new growth occurs.
2. Wetland plants create an aerobic environment (fig. 12B) that is favorable for denitrification bacteria, which can convert nitrates into harmless N gas.
3. Some anaerobic microorganisms that live in wetlands can even decompose organic pollutants, including pesticides. Microbiologists have recently discovered an anaerobic bacteria that can breakdown pollutants from coal tar waste that had leached into groundwater (American Nurseryman 1991). Someday, it may even be possible to custom-design a constructed wetland with the proper mix of microorganisms that can degrade specific pollutants.
4. Constructed wetlands provide a place for pesticides to physically degrade by sunlight and oxidation. If water has a short residence period in the wetland, then this would only be applicable to pesticides that have a short half-life.

Although natural wetlands are effective for treating wastewater, it would be unwise, if not downright illegal, to use a natural wetland for disposing of wastewater. The classification of wetlands is a very hot political topic at the present time and there is even disagreement as to what constitutes a wetland.

Several forest nurseries have begun to consider the use of constructed wetlands for treating their irrigation discharges. The staff at the Lone Peak Conservation Center Nursery, with help from the Soil Conservation Service, is developing a constructed wetland to handle the wastewater from their greenhouse near Salt Lake City, UT. One of the exciting innovations of this particular design is that they are planning to grow riparian species in the treatment ponds.

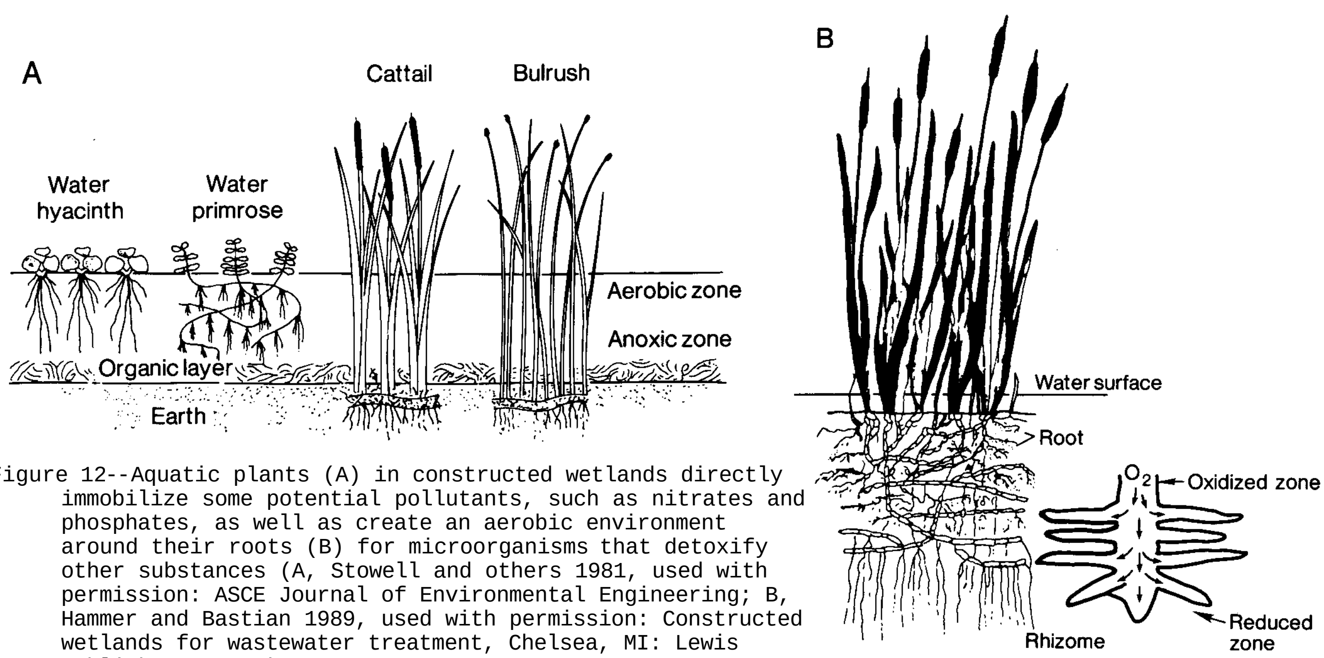

Figure 12--Aquatic plants (A) in constructed wetlands directly immobilize some potential pollutants, such as nitrates and phosphates, as well as create an aerobic environment around their roots (B) for microorganisms that detoxify other substances (A, Stowell and others 1981, used with permission: ASCE Journal of Environmental Engineering; B, Hammer and Bastian 1989, used with permission: Constructed wetlands for wastewater treatment, Chelsea, MI: Lewis Publishers, Inc.).

Comprehensive Best Management Practices

Certain programs, such as IPM, affect several different aspects of the nursery system (fig. 7). Although it has been around for years nursery managers should reconsider IPM, which combines the use of pesticides with a battery of other non-chemical pest control measures. Decisions for selecting a pest control method should be reached by comparing the pros and cons of each practice - pollution potential should be considered along with cost, ease of application, and effectiveness. Operational studies have shown that, if biological and cultural control methods are emphasized and pesticides are applied only when really necessary, total use of pesticides will decrease significantly in both container (Dumroese and others 1990) and bareroot nurseries (Scholtes 1991b)

CONCLUSIONS AND RECOMMENDATIONS

The first step is to become more knowledgeable about agricultural pollution and the following publications are highly recommended:

Agriculture and Groundwater Quality. Publication No. 103. Can be purchased for $5.00 from:

Council for Agricultural Science and Technology
137 Lynn Ave. Ames, IA 50010-7197

PHONE: 515-292-2125

Rural Groundwater Quality Management - Emerging Issues and Public Policies for the 1990's. Journal of Soil and Water Conservation, Volume 45, No. 2. Available for $12.00 from:

Soil and Water Conservation Society
7515 N.E. Ankeny Road
Ankeny, IA 50021-9764

PHONE: 515-289-2331

Pesticides: Surface Runoff, Leaching, and Exposure Concerns. Bulletin No. Ag-BU-3911. Send $2.00 to:

Minnesota Extension Service
Distribution Center, Room 3, Coffey Hall
1420 Eckles Ave.
University of Minnesota
St. Paul, MN 55108-6064

PHONE: 612-625-8173

Each nursery should develop a systematic water management plan, which consists of a base map, a narrative section, best management practices, and details of a monitoring program. These plans will vary with the type of nursery, soil type, climate, and cultural practices. Start a water sampling program immediately and take a hard look at your use of fertilizers and pesticides. Management decisions will have to be made in the face of scientific uncertainty and ambiguity, so don't wait for the perfect wastewater treatment system to be developed. It is prudent to show that you are aware of a potential agricultural pollution problem, and that you are taking positive actions to minimize any adverse effects.

This article is just the first of a series of papers that were presented in the special focus session on agricultural water pollution. Additional information can be found in the following 8 articles in this Proceedings.

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